# VIEWPOINT

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# Opportunity agriculture

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**ABSTRACT**

Rental values for farmland in the United Kingdom seem to bear little relation to the land's productive capacity. One of the culprits is short-termism, encouraged by shorter and shorter durations of the standard instrument, the Farm Business Tenancy. Following on from his report, *Opportunity Agriculture*, to the 2014 Oxford Farming Conference, the author argues for alternative models of land tenancy, especially those based on shared ventures.

**KEYWORDS:** land; tenancy; share-farming; rent; United Kingdom

Most readers of this journal will know that rental values for arable land in the UK – at least those for land offered on Farm Business Tenancies – have experienced a good deal of upward pressure in recent years, driven partly by competition for a limited resource but also reflecting several profitable years for arable farming.

Tender rents – even for Grade 3, cereals-and-oilseeds land – have frequently been offered at £500 per hectare and more[2], even though these levels begin to look increasingly questionable as commodities value slump back to 2010 levels. The determination to win land, even with the ambition of spreading costs and working assets harder, seems untempered by prudence or a medium- or long-term view.

It is this absence of a longer-term view which interests me. Land which is paid for 'through the nose' will inevitably attract less care, attention to detail, or investment than that which is owned or where greater margins can be achieved. As I discussed with a client of mine recently, considering tendering for one of the better farms in the district: "do you really want to commit a quarter of a million pounds in rent, working capital and interest before you've even harvested anything, with the prospect of making only twenty or even thirty thousand pounds net profit?". As it transpired, we were not among those casting bids. But I can imagine the outcome – a clutch of bids in excess of £500/ha, and the landlord has the option to take the highest one. What can go wrong? If the tenant gets into difficulties in a year, so what? There will be plenty of frustrated underbidders who will welcome another bite of the cherry, and will be prepared to put their hands in their pockets to do so.

The downside of this, it seems to be, is that it is so catastrophically short-term in nature. Land that is not looked after will take years to put right, and, despite the continued growth in capital values, I cannot believe most landlords don't consider the longer-term state of their asset.

All this leads me to question whether there are better alternatives to the 'standard model' – short-term Farm Business Tenancies (FBTs) – which have become shorter and shorter in length. When they were introduced in 1995 at a time of critical reform for the tenanted sector, twenty or thirty-year FBTs were expected. Now most are offered on three- or five-year terms and it is not unusual to find one- or two-year arrangements. There's not much profit in there, if it takes you three seasons to put right the soil structure, nutrient status and drainage mess left by your predecessor.

So the question at the centre of this remains: what alternatives may be out there? What other arrangements could be developed for the occupation of land, the sharing of risk and reward between parties, where interests are more closely aligned? This was one of the central points in a paper published at the Oxford Farming Conference in January. Working with the University of Reading and a leading agricultural research firm, I was asked by the conference directors to explore the opportunities which British agriculture might face in the coming decade, and suggest changes in farm structure or priorities for investment which may become necessary, if UK farming was to be 'sustainably competitive', ten years in the future.

The issue of land occupation and tenure models might seem small; irrelevant, when one considers the 'bigger picture'. Most of those who work in agriculture know that, with a world population which has already eclipsed seven billion, and with another two billion people expected by mid-century, food production is going to have to increase output - and fast. For instance, average UK cereal yields grew by one tonne per hectare every decade from 1980 to the end of the century. But yields have now begun to plateau: although varieties are continually being developed with better disease resistance or more desirable food characteristics, the best wheat growers struggle to achieve more than 12 tonnes per hectare and the UK average is 8.5. And yet we know that wheat, as it stands today (i.e. with no genetic manipulation) has a theoretical potential yield of nearly 20 tonnes per hectare.

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[2] In mid-September 2014, £1 was approximately equivalent to €1.26 and $US1.63 (www.xe.com)

Thirty years ago, Britain had an enviable network of government-backed research stations which generated and distributed new knowledge in most sectors of agriculture. Nowadays, most research has to be funded by the private sector and therefore, companies focus on developing products on which they can recoup their investment within a relatively short timescale. In the field of crop protection this has become the norm – it takes seven years to get a new pesticide product from development to full market approval, allowing perhaps another seven years of sales before the product is possibly revoked, superseded or replaced by a competitor's.

In the last few years, government has acknowledged that the dismantling of the research-and-development structure in the late 1980s had to be addressed, and has launched the Agri-Tech Strategy and its Catalyst Fund, to pump-prime fresh research and development in food production. This followed an influential report called Feeding the Future, published in 2012, which was the industry's own effort to determine research-and-development priorities for primary food production.

So the big challenges truly are huge, and there is hope to be found in the science. But there will also be opportunities for farmers as the world looks to them to produce more food and green energy, and it is not unreasonable to expect that we might see these opportunities within the next decade. But what might they look like? And how could you predict them?

The reality is that new investors continue to be attracted to agricultural land as an asset class. Investors want returns from operation (farming) plus the capital growth they have come to expect, particularly in the UK. Our study found that a growing divergence could emerge between those who own land and those who operate it. Investors don't want necessarily to outsource management and operation - they want to see some return from this too.

So we come back to the central problem. What models are out there to achieve this? Why should standard tenancies or contract-farming be (more or less) the only ways?

Consider this as one possible outcome: there will be more opportunities as contractors for investors who run their own operations. And opportunities in contract-farming for those who adopt the tried and tested model. But those who want to retain ownership of the operating entity, and at the same time want their 'manager' totally involved, on-side and motivated in the same way they are, may consider alternative structures where interests are better aligned.

Many readers will know how popular share-farming, or share-milking, has become in New Zealand over the last twenty or so years. In a share-milking example, one farmer typically provides the land, buildings and some of the fixed equipment, while the share-milker provides the cows, some working capital, and the management, labour and skill. But here's the crucial difference. Instead of simply getting a basic payment for services, plus a share of profits (like a contract farming agreement) the share-milker is invested in the business himself. And over time that investment grows, as the business (hopefully) makes more money and appreciates in value.

One of the reasons why this has been so popular in New Zealand is that it has created a way for new people (not necessarily farmers' sons and daughters, although they might be) to enter farming and own some or, eventually, all of their own business. I'm not suggesting this model will simply be rolled out here, although it's not unknown, mainly in the dairy sector. What this report suggests is that there is potential to develop new business models and structures, which align interests more effectively than, say, a two-year Farm Business Tenancy.

And 'investors' needn't necessarily exclude family farming businesses or trusts - in fact there is no reason why family farming businesses should not be at the heart of UK agriculture in ten years' time as they are today. But with an increase in average farm sizes, an upscaling in technology and machinery, and growing interest from 'outside' investors in land and farming, it seems likely that these businesses may be bigger - perhaps have a board rather than just family partners - and be working in new ways. With the changes in population growth and demand for food, farming is once again being called on to innovate. There seems no reason why that shouldn't apply to methods of land occupation and management, too.

## About the author

**Ian Ashbridge** is a farm business consultant and advisor with property firm Bidwells, managing arable farms and providing strategic advice for UK and overseas clients. He has practical experience of a range of farming systems and is involved with agribusiness development projects in Africa and south-east Asia. A former Business and Economics Editor for the journal Farmers Weekly, Ian sits on the national council of the Institute of Agricultural Management. He is a Visiting Lecturer in Farm Business Management at the Royal Agricultural University.

Ian is the main author of *Opportunity Agriculture*, a report commissioned by the Oxford Farming Conference with the brief to look at what needs to change in UK agriculture in the next decade to make it sustainably competitive. The project team started by trying to establish a definitive picture of the industry today, and where the immediate 'direction of travel' might be taking it. This involved studying every sector of UK agriculture, the food chain, and the UK's relative position in the world, and trying to set down what was already known.

In some cases this was quite straightforward – the deal agreed in Brussels last year on the replacement to the Single Payment Scheme will run until 2019. Other aspects of the future are harder to predict, and the Oxford Farming conference wanted a 'better than guess' assessment. So the team turned to the industry – 100 farmers and 50 other professional like grain traders, agronomists, banks – and said: "This is where it looks like we're going today - where do you believe this 'direction of travel' will take us?" Analysing the transcripts of those interviews resulted in a series of statements – more than 40 – which were put in front of a panel of ten expert witnesses, to test whether they were genuine probabilities, or commonly-believed myths. Those that survived, that stood up to scrutiny, went on to shape the report's conclusions.

A free copy of the report can be downloaded from the Oxford Farming Conference website at www.ofc.org.uk.

 

# REFEREED ARTICLE

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# The well-being benefits of sensory-rich farm visits

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**ABSTRACT**

There is increasing evidence to show that exposure to nature positively affects health and well-being of individuals in society. This paper is based on the evaluation of Let Nature Feed Your Senses (LNFYS), an English project to encourage people with disabilities, from areas of high social deprivation, and older people to access and enjoy the natural environment through sensory-rich farm visits. The evidence of positive health and well-being impacts from the project is assessed, and the wider implications for policy and practice are discussed. Qualitative data from 38 follow-up interviews conducted with group leaders one to six months after a visit; testimonies and quotes from visit evaluation forms and letters and comments received by host farmers; and a focus group with 10 group leaders were analysed. The results revealed that enhanced mental well-being and social inclusion were consistently reported as a benefit of the farm visit. Participants particularly referred to the calming impact of the farm environment; an increase in self-esteem and independence; improvements in memory function and reminiscence ability; and increased communication. The paper concludes that whilst there is a clear benefit and demand for such on-farm experiences, in order to secure future funding evidence of their economic impacts and longitudinal follow-up studies of benefits are required.

**KEYWORDS:** health benefits; farm visits; well-being; social inclusion; sensory engagement

## 1. Introduction

The last decade has witnessed increasing recognition of the multifunctional potential of farming to produce not only food, but many diverse environmental and recreational services. Furthermore, there is a growing realisation that rural areas, including farmland, are also able to provide health services. In the UK, recent publications, such as the UK National Ecosystem Assessment (NEA, 2011), acknowledge the importance of health services from the countryside. Also public bodies and third sector organisations in European countries are actively promoting the health benefits of natural landscapes, and the need for initiatives which strengthen the connection between people and nature (Defra, 2011; Hine *et al.*, 2008; Di Iacovo *et al.*, 2009).

This paper is based on the evaluation of Let Nature Feed Your Senses (LNFYS), an English project[5] to encourage people with disabilities, from areas of high social deprivation and older people, to understand, access and enjoy the natural environment. The project has been run since May 2009 in partnership by two UK charities, LEAF (Linking Environment And Farming) and the Sensory Trust. As of January 2013, the project had organised 670 sensory farm visits for over 11,800 visitors on 75 farms across England. The majority of the farms are commercial holdings, with farm sizes ranging from one to over 1,000 hectares. Whilst educational visits to farms for children in many mainstream schools are relatively well established, the LNFYS initiative is different because it provides opportunities for groups of people who are often unable to access the countryside. Project visits have been highly variable, lasting from one to five hours, involving three to 80 persons, with activities varying from pond dipping and bark rubbing to assisting with practical farm tasks, such as sorting lambs for market or digging potatoes. Host farmers are encouraged to engage all visitors' senses, including taste by cooking farm produce during a visit (e.g. making pancakes or bread after milling wheat and collecting eggs). Host farmers are also encouraged to communicate the links between food, farming and nature in novel and engaging ways, using approaches developed by the Sensory Trust, a UK charity dedicated to enriching outdoor experiences and learning through sensory engagement.

Whilst a growing evidence base demonstrates that contact with nature can have health and well-being benefits for the general population (Sempik *et al.*, 2010), less is known about these benefits for vulnerable groups who often have fewer opportunities than others to access the countryside. Some evidence exists of the health and well-being impacts of one-off visits to farms

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[5] The project is majority funded by 'Access to Nature', a £28 million Lottery-funded grants programme run by Natural England

by the general public (Hine and Pretty, 2008); of repeated visits on farms by school groups (Dillon *et al.*, 2005); and the therapeutic value particularly of longer-term, structured 'care farm' experiences (Sempik *et al.*, 2010). LYNFS has sought to test and understand the impacts of individual farm visits (predominantly one-off but also including some repeat visits) upon the mental and physical wellbeing of the groups mentioned above, including the disabled and older residents in care. In this paper, we assess the evidence of positive health and well-being impacts from the project, and discuss its wider implications for policy and practice.

## 2. Literature Review

There is increasing evidence to show that exposure to nature and green space positively affects health and well-being of individuals in society. Exposure to nature can reduce stress levels, improve mood and self-esteem, decrease mental fatigue and restore mental clarity and concentration, and increase a sense of well-being (Hartig *et al.*, 1991; Kaplan and Kaplan, 1989; Bird, 2007; Barton and Pretty, 2010; Emmett *et al.*, 2011; Wilson, 1984; Ulrich, 1981). For example, research has shown that children with a high number of stressful life events were less stressed and had a higher global self-worth with increasing opportunities to experience nature (Bingley and Milligan, 2004; Wells and Evans, 2003). Furthermore, children undertaking outdoor activities in nature exhibit 30% lower levels of the symptoms of ADHD compared to those undertaking urban outdoor activities, and a threefold reduction compared to those whose activities are confined to an indoor environment (Taylor *et al.*, 2001; Kuo and Taylor, 2004).

Three key theories offer explanations of these phenomena, related to human interaction with nature. All focus on the restorative effects of the natural environment, suggesting that some level of contact with nature contributes to enhanced well-being, mental development and personal fulfilment (Barton *et al.*, 2009). One such theory is the Biophilia hypothesis, which suggests there is an innate evolutionary basis to the positive relationship between humans and nature derived from peoples' fundamental dependence on nature and conscious and unconscious desire to connect with it (Wilson, 1984; Kellert and Wilson, 1995; White and Heerwagen, 1998). An alternative theory is Attention Restoration Theory (ART), which focuses on the cognitive changes associated with restoration. According to Kaplan and Kaplan (1989), contact with the natural environment contributes to a restoration of attention from attention fatigue, by providing an opportunity for people to take a physical and temporal break from routine tasks and thoughts ('being away') and to focus attention on something different, without thinking about it ('soft fascination'), thus giving the neural mechanisms underlying 'directed' attention a chance to rest and replenish. In addition, Psycho-Evolutionary Theory (PET) of stress reduction argues that the restorative effects of nature are derived from a reduction of stress (blood pressure, muscle tension and pulse rate) associated with views of nature, which are the result of an inherent reflex shaped by what proved an adaptive benefit during human evolution. It posits that throughout human evolution, individuals that possessed this capacity for immediate recovery in response to nature had a greater chance of survival by remaining mentally alert after stressful situations (Ulrich, 1981; Ulrich *et al.*, 1991). In all these theoretical perspectives, an enduring interdependence between people and nature is reflected.

Other empirical research has identified health benefits from farm visits. One example is repeated educational visits to farms, which Dillon *et al* (2005) showed benefited students not only cognitively, in learning about farming practices and gaining an appreciation of nature, but also in learning about themselves and working with others, which then led to an increase in confidence and improved social skills. Hine and Pretty (2008) conducted a study to observe changes in (*inter alia*) visitor well-being and connectedness to nature during LEAF's 'Open Farm Sunday' campaign, in which the public is encouraged to visit a farm on the second Sunday in June each year. The study used three methods of assessment: an adapted form of the 'connectedness to nature' psychological scale to assess whether visiting a farm increased an individual's sense of being connected to nature, a Profile of Mood States (POMS) questionnaire to enable any changes in health parameters to be evaluated, and a Total Mood Disturbance (TMD) score to make an overall assessment of emotional state change from a visit. The majority of participants (91%) reported improvements in their overall mood after visiting the farm and the authors concluded that spending time on a farm is effective in enhancing mood.

Not all farm visits are of this one-off kind. Some individuals experience longer-term, structured 'care farm' contact. Care farming (also called 'social farming' or 'green care farming') can be defined as the therapeutic use of farming practices[6]. There is much variety in care farms, with differences in the type and extent of farming and care activities that they offer, the biophysical and social context, the client group and the type of farm involved (Sempik *et al.*, 2010). Care farms can provide services for diverse groups, including people with learning difficulties, people with psychological problems, older people with dementia and young people with behavioural problems. While each group requires a different sort of care, activities and guidance (Elings, 2012), there is growing empirical evidence that care farming has the potential to increase health and well-being for a wide range of individuals. Hine *et al* (2008) undertook a survey before and after 72 participants spent time on care farms and found an increase in participants' self-esteem after spending time on the farm, with the majority (88%) also reporting improvements in their overall mood. Elings cites a study by Hassink (2011), which researched the effects of a combined study-work programme on farms for troubled young people between the ages of 16 and 20. The farm programme was found to have had a positive effect on behavioural problems and self-respect, effects that remained visible a year after finishing the farm programme.

These studies suggest that a programme of one-off or repeat farm visits, that provide close contact with

[6] http://www.carefarminguk.org/

 

nature, could have restorative or therapeutic value. However, it is not possible to identify from existing research whether single visits have lasting benefits; Hine and Pretty (2008) relied upon questionnaires conducted on the day of a visit, whilst the other studies measured impacts from longer-term repeat visits. Secondly, none of these studies focused attention upon the type of interaction with nature encouraged by the various approaches and its relationship to perceived benefits. Thirdly, we are unaware of studies which have examined the potential for visits to farms by older people in care homes to enhance residents' well-being. The LNFYS project, therefore, offered a valuable opportunity to learn more about the well-being potential of farm visits, as discussed in this paper.

## 3. Methodology

There are methodological challenges in seeking to isolate the important variables in the causal chain between farm visits and health and well-being benefits. The evaluation of LNFYS visits between 2010 and 2012 attempted to capture both impacts and their causal influences through a mixed-methods approach combining quantified indicators with qualitative feedback from group leaders and individual visitors. Quantitative scores of well-being were self-reported in 'before' and 'after' visitor questionnaires developed by University of Essex, providing a 'snapshot' indicator of impact upon visitors' own positivity or happiness status immediately before and after a visit. Whilst such evaluative research traditionally uses quantitative approaches to collect data there are recognised difficulties of trying to gather such ex-post quantitative data from vulnerable groups (Curry *et al.*, 2009). There were some practical difficulties encountered with the completion of the questionnaire upon arrival and before departure, which for a typical 2 hour visit took a disproportionate amount of time to administer and was often filled out in haste, which limited their capacity to provide a detailed understanding of outcomes. Also the original set of questionnaires included questions measuring changes in mood which were inappropriate for some of the vulnerable visitors. Thus a growing sense of the limitations of this kind of quantitative assessment led the LNFYS project team to undertake further, separate data collection exercises in the weeks and months after a visit, to capture longer-term and more contextualised narratives of impact which could provide insights into how and why certain types of benefit might arise, and in what temporal patterns. This richer, qualitative data was used to help identify where and how LNFYS visits had been successful in affecting well-being and to provide lessons of wider relevance to future work of this kind. Although it is acknowledged by adopting such methods it was only possible to gather secondary data (the views of group organisers) instead of primary feedback from the beneficiaries themselves.

Qualitative data was gathered through 38 follow-up interviews conducted by the LNFYS team with group leaders, from one to six months after a visit, selected at random from lists collated by LNFYS staff. Testimonies and quotes were also gathered from visit evaluation forms and letters and comments received by host farmers. Furthermore, a focus group was held with 10 group leaders and facilitated by the authors in January 2012. Such a method is useful to gain an understanding of a group's views and experiences and has effectively been used in the past to explore the experiences of carers of people with learning disabilities (Thornton, 1999) and to elicit views on generic mental health services (Powell *et al.*, 1996). Table 1 provides details of the participants attending the focus group and the groups of people that they accompanied on the farm visits.

The 10 participants to the focus group came from six different groups that had participated in LNFYS visits within the West Midlands region in 2010 or 2011. Four of the groups represented worked with vulnerable children, one supported adults with special needs and one worked in a care home for older people. Discussions in the focus group aimed to provide an in-depth analysis of LNFYS visit experiences for groups and individuals within those groups, as recalled by the qualified group leaders, including impacts in the days and weeks following a visit. A semi-structured approach to facilitation was adopted, ensuring discussion focused around the broad themes of: the overall LNFYS visit experience; the contrasting impact upon visitors initially and over a longer time period; and the perceived relationship between the quality of experience and the actions and conduct of the visit host(s). The semi-structured format also allowed respondents to raise additional, unplanned themes in respect of their groups' experience, its therapeutic value and its links to the wider context of the LNFYS approach.

The focus group discussion was tape-recorded and transcribed in full. The transcription was then analysed following an iterative and reflexive process using, Nvivo, a qualitative data analysis software package as suggested by Bryman (2008) and Bazeley and Jackson (2013). Using a priori deductive codes, the data was first coded into four broad categories for analysis: visitor characteristics, host characteristics, positive visitor experiences, barriers' to visits. The second stage of the analysis took an inductive approach to further coding, capturing different patterns and themes within the broad categories. A theme represented 'a pattern in the information that at minimum describes and organises the possible observations and at maximum interprets aspects of the phenomenon' (Boyatzis, 1998, p.161).

It was possible to triangulate the findings from the focus group with follow-up interviews conducted with group leaders and the visitor interviews to identify the main health and well-being benefits of the farm visits.

## 4. Results

The interpretive analysis of the interview and focus group data suggested that the LNFYS visits had delivered a number of different health and well-being benefits due to the particular characteristics of the visits. Rather than any singular characteristic contributing to the health and well-being benefits, it was a combination of different factors that led to these benefits. These characteristics are summarised in the table below and focus on the nature of the host, event structure, activities and environment (Table 2).

**Table 1:** Details of focus group and farm visit participants

| Focus group participants | Details of farm visit participants |
|---|---|
| Youth Service and Targeted Support Programme | Children (11–16 years) who have been permanently excluded from school, missing education or recently moved into the area and identified as requiring alternative education. |
| Special School | Children on the autism spectrum with specific needs or unrecognized specific needs or un-met specific needs. |
| Residential home for elderly | Mainly 80 to 90 year old residents, many with dementia. |
| Special school | School for children ages 4 to 18 year with learning difficulties |
| Voluntary support group for children with disabilities | Children with range of disabilities from profoundly disabled children to those with moderate disabilities and those in the autistic spectrum. |
| Centre for people experiencing depression and other Mental Health problems | Group of adults experiencing depression and other mental health problems aged between mid-30s and 70 years. |

Making connections across the different categories it was possible to identify different benefits of the visits, such as physical and educational benefits. However, two benefits were particularly consistently reported as benefitting health and wellbeing and thus will be explored in the next section in more detail; enhanced mental well-being; and social inclusion.

## Mental well-being

Three themes emerged from the data, representing positive mental well-being outcomes from a LNFYS visit;

- A calming impact of the farm environment, which was seen as relaxing and stress-reducing
- An increase in self-esteem and independence
- Improvements in memory function and reminiscence ability

Group leaders and visitors reported a calming influence upon children from being in the open air, from the sense of space and freedom of the farm environment and from a lack of noise. As one carer reflected:

*"We always find it a very calm environment. It just automatically makes you calm down. It is amazing. Some of our kids admit to anger issues, they both said how much calmer they felt. It's just walking around in the fresh air with not a lot of noise." (Carer, young people with learning difficulties and/or disabilities).*

Visitors experience the farm as an environment with different stimulations to the urban areas where many of them live. Elements of the farm visits added to a calming effect, especially the care, sensitivity and personalised attention given to visitors from host farmers combined with fewer distractions, for example, from the shops and cafes that are often found on farms which are managed principally as commercial visitor attractions.

*"I think it changes attitudes about what the countryside has to offer you. I think people think it is boring, especially children and young people and I think it really does change your attitude. I think because everyone is so patient there and so calm. I think living in the city, you are rushing and thinking about everything and when you are there you are so much calmer that you can open yourself up to learn something." (Carer, young people with learning difficulties and/or disabilities).*

*"Every time it is a positive experience. For the children who find it difficult and find it hard to relate to anybody socially. There was one child who was "I hate everything, I hate, I hate, I hate," but in that environment it was "I don't really want to go back", "can't we stop a bit longer", so we stopped a bit longer, and then "please can we stop a bit longer!" Then coming home and seeing that rosy look about them, that healthy look and carefree, sort of like a rag doll - that the tension had gone." (Carer, young people with learning difficulties and/or disabilities).*

It was not just children that benefitted from the calming effect of a farm visit, but also older visitors with dementia, as one carer related;

*"The farm visits had an extremely calming and therapeutic effect on the residents. People with dementia can often be withdrawn, distressed or confused, but you really notice the difference it makes when you visit a farm. The huge variety of things to see, touch, smell and hear really helped engage the residents. For many it helped evoke childhood memories." (Carer, dementia specialist care home).*

These observations in relation to the calming effect of the farm environment may relate to the theory based theme discussed earlier of the restorative properties of nature allowing recovery from mental fatigue.

Participants also reported the benefits of a relaxing and stress-reducing environment. The absence of other people who may judge visitors that look or behave differently was noted. Also the fact that visits were designed for a group's specific needs meant that visits were not only less stressful for the group participants, but also for the group leaders. One clear advantage voiced was the lack of expectations for visitors to behave in a particular way. The socially determined expectations of what people with disabilities are and how they should be treated have been shown to have a

**Table 2:** Identification of specific characteristics of LNFYS visits

| Host | Event | Activities | Environment |
|---|---|---|---|
| Personal connection<br>Respectfulness<br>Patience<br>Non-judgmental | Flexible timings<br>Informal structure<br>Exclusive event<br>Tailored event | Interaction with animals<br>Freedom to explore<br>Excitement of tractor rides<br>Risks of pond dipping | Calming environment<br>Sense of space<br>Lack of noise |

 

great effect on the lives of people with disabilities (Smith, 2005). The farm visits offered an opportunity for both the visitors and their carers of freedom from often reported stigmatism or prejudices towards their disabilities (Olney and Kim, 2001).

*"Our children are very slow and when they walk with their walkers they take ages. They walk very methodically and slowly and we found that it didn't matter. So with the calm they felt like they weren't being hurried. It wasn't like 'you've had your turn, now get lost,' it didn't matter about anything." (Staff member, special needs school).*

*"We found the children with high autism when we took them to another farm [managed as a visitor attraction] they would see the sweet shop and be running around. It was really hard and then you don't get much of an experience out of it because it is hard to manage it. We found out about these [LNFYS] farms and when we did go there was nobody else there, it was just our group. For them to have fresh air and get really close to the animals and the activities set for them to be outside. They were really calm. When you are there we don't really have to hold onto them and if they wanted to run they could have, but they were really calm..." (Carer, support group for disabled children).*

Visits were designed so that individuals could choose the extent to which they participated in activities and were able to experience them at their own pace.

*"It is really accessible because there are some people who want the full hands-on experience and some from a distance. It is all there and everyone can have their own individual access. There are no set boundaries. It is up to them how close they get." (Carer, support group for disabled children).*

*"Well organised, everything worked. It was relaxed. The farmer that was there let us go at our own pace, the students could lead the day in their own time. Our students can take a long time to settle and feel comfortable, which they had. Not rushing from one thing to another." (Staff member, visually impaired students).*

A further benefit of the visits reported by group leaders was a noticeable increase in self-esteem and independence of usually shy or aggressive individuals. For some disaffected children the activities on the farm provided an opportunity to let down their guard and express themselves.

*"The one week [farmer] actually suggested pond dipping and I wasn't sure how it was going to go and they absolutely loved it, they were like kids again. I couldn't catch my breath. I was amazed how well it had gone, it was wonderful to see them be like that and let their guard down and actually enjoy themselves and learn at the same time. It's an opportunity for them to forget their reputation and just be children and do what children do best." (Carer, working with disaffected youth).*

The visits also provided an opportunity to encounter new experiences and to confront fears which can boost self-confidence.

*"They have talked about everything and remember a lot. Particularly the young man who had been frightened, he felt proud of himself, really boosted his confidence and self-esteem." (Staff member, visually impaired students).*

An important quality is the attitude of the host farmer. The LNFYS initiative encourages farmers to approach visitors as normal people, rather than as patients and they therefore experience respect with no prejudice.

*"We found at these farms were that they were slow in how they approached and spoke to them [visitors] and they actually treated them as human beings. That was something all of them came back and said. It wasn't like raising your voice as if they had a hearing aid, it was in a normal voice which is what we enjoyed." (Group leader, care home for people with dementia).*

There was also evidence that the visits had a positive impact on memory function and reminiscence ability. The experience of being on the farm stimulated reminiscence in some older visitors, giving some the opportunity to recall their experiences of living and working on farms. Sensory visits seem to have had a particular effect on older visitors with dementia, reconnecting them to their memories of past experiences with nature, helping them to reminisce and increasing communication with other group members and staff.

*"They have [talked about the visit since], which is incredible. They have dementia and usually don't remember anything, so it's amazing that the visit stimulated them like it did." (Group leader, care home for people with dementia).*

*"The reminiscence by the group. One gentleman had been a pig farmer and he was in his element when seeing the pigs." (Group leader, care home for people with dementia).*

## Social inclusion

Analysis of the data indicated that visitors not only bonded with each other, group leaders and farm staff during their visit, but also experienced increased communication with friends and family or with other people in a care setting since the LNFYS visit(s). All of this goes some way to reducing social isolation and to increasing feelings of belonging, both of which are essential elements of well-being.

A number of carers report improved communication amongst visitors during the visit;

*"We are always very concerned that K may run off when we take him out of [residential home]; he doesn't speak to many of the other residents and can be very unpredictable and aggressive. During the visit to the farm, however, he was very relaxed and friendly; he held hands with another resident whom he usually doesn't speak to! When we had afternoon tea he sat down for the entire duration, which is not in his character as he is usually restless and anxious." (Activities co-ordinator, residential home for people with dementia).*

*"It wasn't about learning as much as the experience. We saw deer running in a big field - one boy still talks about it now. One child is autistic, he doesn't talk, but he got close to a cow and said 'cow'." (Staff member, children and family centre).*

*"Eileen, a lady with late stage dementia, who finds it very difficult to communicate, and who has a very short attention span, was fully engaged throughout the day. Eileen stayed with the group throughout the trip and loved seeing the cows and lambs. She was talking lots to a member of staff's little boy who came along with us. She also enjoyed looking through the reminiscence objects over afternoon tea; it was lovely to see Eileen so happy and content in herself." (Activities Co-ordinator, residential home for people with dementia).*

Two of the quotes reflect findings from other studies (Mallon, 1994; Berget *et al.*, 2008) of the importance of interaction with farm animals for both children and adults in producing psychological and well-being benefits, including improved communication.

There was also evidence of improved communication during the time following a farm visit. The quote below highlights how the farm visit had enhanced one visitor's confidence, trust and social capability to communicate within her group, which afterwards helped her treatment and well-being.

> *"It wasn't just going to the farm, it is what it brought back into the home that I found beneficial. One of my ladies wasn't very well at the time and her health just went way up because of the interest when she came. She wasn't a lady that gave a lot and … she could actually say 'I did this and I did that' and it was, you know what they say, that you see light and I got a lump in my throat because she so wanted to give. That to me, it was just worth it. She has got so much more confidence now, to come and say her views because she had been there [farm]." (Group leader, care home for people with dementia).*

For some visitors the farm visit also increased feelings of belonging;

> *"Made them feel part of the community again. Their opinion was appreciated. Boosted morale and self-worth." (Group leader, residential care home).*

For this group the visit seemed to overcome the reported evidence that people with disabilities can feel marginalised and excluded from the community (Sayce, 1998). The non-judgemental and respectful attitude of the hosts and the sense of a personal connection in particular was reported to help improve the participants feelings of self-worth and belonging.

## 5. Discussion

In this paper we describe the experiences in England of a particular initiative, LNFYS, that aims to provide sensory-rich experiences on farms for groups of people who are often not readily able to access farm visits. The evidence from case studies, testimonials and a focus group highlights not only the well-being benefits from a LNFYS farm visit on the day of the visit, but also the more enduring benefits in the weeks and months after a visit takes place. For some visitors a farm visit led to an increase in self-esteem and independence beyond the visit. Visits seem to have had a particular beneficial effect on older visitors with dementia, often reconnecting them to their memories of past experiences with nature, helping them to reminisce and increasing their communication with other group members and staff.

This finding is consistent with literature indicating that involvement in nature, animals, and outdoor activities provides opportunities for reminiscence (Filan and Llewellyn-Jones, 2006; Gibson *et al.*, 2007), of reality orientation by reminding patients with dementia of facts about themselves and their environments (Douglas *et al.*, 2004) and providing a source for multi-sensory stimulation (Bossen, 2010; Chalfont, 2008)). It is suggested that green care may evoke memories, stimulate the senses, and help retain the link with reality (Bruin *et al.*, 2009). However, not all empirical evidence on this topic is positive: although one study found that older people with dementia at care farms showed fewer behavioural problems, on average used fewer psychotropic drugs, and were more actively involved in normal daily activities than their counterparts participating in nursing home day care (Schols and van der Schriek-van Meel, 2006); another study (de Bruin *et al.*, 2012) found no significant change over time in functional performance, and disease and medication incidences between patients with dementia attending day care at care farms and regular residential day care facilities. This suggests that further in-depth work on this particular topic is required.

The findings also identified other benefits of the visits related to the calming effect of the environment on the participants. As indicated earlier multiple studies provide strong indications that the natural environment improves people's mood. Feelings of fear and anger are reduced while positive feelings are enhanced (Hartig *et al.*, 1991; Ulrich *et al.*, 1991). The LNFYS results also indicated that the helpful, accommodating and respectful attitude of the host farmers, with a lack of expectations or prejudice, added to the calming effect of the farm visit. This attitude, along with the interaction with farm animals was shown to improve communication and made some participants feel less socially excluded.

The success of LNFYS has depended upon active engagement by willing host farmers. Many farms are looking to broaden their economic base through pluriactivity and on-farm diversification. Sensory farm visits could provide a new source of income for the farms and nature reserves involved. The LNFYS project is majority-funded by the National Lottery and the payments received by each host contribute towards the costs of running a visit (between £100 to £150 per visit[7], depending on the size of the group). However, many host farmers are highly motivated by the social benefits they are able to offer, and indeed host farmer motivation was a criterion used in the project's host selection process. Projects such as LNFYS are also able to offer farmers support and advice in carrying out such visits successfully, including safety management information. This is a valued element, as there is evidence that some farmers are deterred from hosting farm visits due to concerns relating to the safety of visitors and the fear of being sued in a case of personal injury on the visit (Dillon *et al.*, 2005).

The views expressed by the group leaders involved in farm visits demonstrate that there is a clear demand for such experiences. In part, this is because such visits are able to provide services better tailored to the specific needs of visitors, compared to mainstream welfare systems which are under increasing financial pressure (O'Conner *et al*, 2010). There is also strong qualitative evidence of the mental well-being benefits of such visits. However, crucial for the further development of such initiatives is the need for appropriate policy and institutional developments as regards health care funding, ensuring that financial resources are available. In England, there are now opportunities in some parts of the country for consortia of host farmers to bid for contracts with the new GP-led Clinical Commissioning Groups (which arose from the 2012 Health and Social Care Act) although commissioning priorities vary greatly across the country.

In England, the type of social or care faming offered by LNFYS hosts is yet to be recognised as a system in social care, as in some EU countries, such as Belgium,

[7] At the time of writing (May 2014) £1.00 was equivalent to approximately €1.21, $US1.68 and $AUS1.83.

 

the Netherlands, Norway and Italy (see Di Iacovo *et al.*, 2009). In these situations, financial support for such activity is available from public health budgets. In Britain, the move to patient-led personalised health budgets has provided some scope for established care farms to tap into this kind of funding, but it is not yet available for farm visits of the type discussed here. Many farms thus still face difficulties in sourcing such funding through social and health networks. For example, one of the current challenges in England for consortia of hosts wanting to secure funding from some of the new Clinical Commissioning Groups is a requirement to gather robust impact evidence and monetise the benefits of farm visits. This would entail a new form of quantification of the types of benefit discussed in this paper; which is not a simple task, given the sensitive nature of the beneficiary base. As well as capturing benefit during and soon after each visit, there would also be a need for well-designed longitudinal follow-up studies (Social Return on Investment or similar) to provide more evidence of positive visitor outcomes in the longer term. The resources and skills to undertake such analysis will generally be beyond the scope of individual farmers.

Despite various policy frameworks and financing schemes across Europe (Di Iacovo and O'Connor, 2009; Hine *et al.*, 2008; Dessein, 2008; and Gallis, 2007), historically care or social farms have existed largely in spite of government policy, rather than because of it (Hine *et al.*, 2007, p.134). In the present context of particular public financial stringency, it is likely that new business models will need to be developed to enable the economic continuity of the services provided by initiatives like LNFYS, for the well-being of society. Potential may exist for the use of alternative business models through, for example, private sector contributions in the form of Corporate Social Responsibility (CSR) and Creating Shared Value (CSV) initiatives. But perhaps the biggest obstacle to making these things happen is the lack of sustained resourcing for the co-ordination and evaluation functions which projects like LNFYS only provide for their limited lifespan. LNFYS was initially funded for only three and a half years, the first of which was devoted largely to establishing the network, leaving relatively little time from which to learn and reflect upon the value of the visits achieved. The evidence discussed here suggests that investing more time and effort to help projects such as this to demonstrate the monetised benefits of their actions over a longer timespan than has previously been recognised could help to sustain these actions through longer-term health funding, for the benefit of society as a whole.

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# REFEREED ARTICLE

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# Do farmers act like perfectly rational profit maximisers? Results of an extra-laboratory experiment

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**ABSTRACT**

Many economic studies are based on the theory of the *homo oeconomicus*, frequently put simply and described as a perfectly rational, profit-maximising decision-maker. However, there are often considerable differences between the theoretical decisions based on this theory and the behaviour of farmers observed in reality. The specific magnitude and the influencing factors of this discrepancy are hardly analysed due to the lack of a benchmark in reality. Therefore, on the basis of realistic decisions made by farmers in an extra laboratory experiment, the present study investigates if farmers act as perfectly rational profit maximisers. Furthermore, factors shall be identified that influence deviations from relative economic performance. The results show that farmers are not perfectly rational profit-maximising decision-makers. The decision-making behaviour is rather influenced by the farmers' socio-demographic and socio-economic characteristics, such as the gender or the leading position of the farmer.

**KEYWORDS:** multiple goal decision making; bounded rationality; business simulation games; experimental economics

## 1. Introduction

Most studies, models, and forecasts dealing with the economic management of agricultural businesses are based on the underlying assumption of the *homo oeconomicus* (Camerer and Fehr, 2006; Fehr and Gächter, 2001; Gintis, 2000). Often the *homo oeconomicus* is simplified as an actor who maximises the profit as a proxy for the utility in a perfectly rational way. Hence, the actors are often assumed as perfectly rational profit maximisers (Camerer and Fehr, 2006; Happe *et al.*, 2007; Roth *et al.*, 1991). If, however, the theoretically expected behaviour is compared with the real decisions of entrepreneurs, it becomes clear that a considerable discrepancy exists (Camerer, 2001; Camerer and Fehr, 2006; Fehr and Gächter, 2001; Gintis, 2000; Roth *et al.*, 1991). This also becomes apparent regarding the central question about the corporate success. Hence, decision-makers in general and farmers in particular reach less profit than what would be possible using theoretically optimal decision behaviour assuming perfectly rational profit maximising (Nuthall, 2009). Frequently mentioned explanatory approaches for the discrepancy are the existence of multiple objectives (Benz, 2009) and bounded rationality (Kahneman, 2002; Selten, 1990; Simon, 1956).

However, the magnitude of the discrepancy between theoretically expected behaviour and real decisions, as well as which factors influence the magnitude, still remain unknown. With this in mind, the present study aims to investigate if farmers act as perfectly rational profit maximisers and if not, which factors significantly influence a deviation. Answering these questions is especially relevant for advising individual enterprises as well as for policy impact analysis. The analysis of the influence of individual characteristics on deviations from profit-maximizing behaviour can be used to improve the results of farm modelling approaches and, therefore, forecasts of farm developments.

In order to do so, it is difficult to use real operating data because in reality the individual benchmark for each farm cannot be clearly derived (Pasour, 1981). Therefore, an experimental approach is necessary to control the framework conditions. Two methods seem to be particularly suitable: laboratory experiments and business simulation games. In contrast to laboratory experiments, business simulation games allow a realistic design and setting of the decision situations that is an important advantage (Levitt and List, 2007). In our business simulation game farmers lead a virtual farm and are asked to make decisions about the production programmes in consecutive production periods. These production programmes will then be analysed with regard to their relative economic performance, meaning the ratio between the achieved expected profit and the theoretically possible expected profit assuming perfectly rational profit maximising.

To our knowledge, we are the first who analyse the specific magnitude and the influencing factors of the

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discrepancy between theoretically expected behaviour assuming perfectly rational profit maximising and real decisions using a business simulation game applied to German farmers. Furthermore, many scientists work on studies about bounded rational behaviour (Selten, 1990, Simon, 1959). This study, however, focuses on different explanatory approaches that have not been examined as extensively. We analyse the influence of individual characteristics in order to improve the results of theoretic modelling. Also forecasts can be improved with knowledge about factors influencing deviations from profit-maximising behaviour.

The present study is structured as follows: In section 2, hypotheses are derived from the literature. In section 3, the design of the business simulation game will be described and will then lead over to methodology selection (section 4). The sample description in section 5 will be followed by the presentation of results and discussion (section 6) before the study will end with conclusions and future research prospects (section 7).

## 2. Hypotheses

Many studies have focused on the decision-making behaviour of entrepreneurs (Fehr and Gächter, 2001; Gintis, 2000). It is described that there often exist considerable discrepancies between the theoretically expected actions of profit-maximising actors and the decisions of real persons (Camerer and Fehr, 2006; Fehr and Gächter, 2001; Gintis, 2000; Nuthall, 2009; Roth *et al.*, 1991). Many of these deviations from the theoretic economic optimum are explained by Simon (1956) as consequences of bounded rational behaviour what often can be observed in practice (Selten, 1990). Furthermore, decision-makers rely on judgmental heuristics (Tversky and Kahneman, 1974). We examine whether differences can be observed between the theory of pure profit maximisation and experimentally observed decisions of the farmers. Our hypothesis is:

*H1: Farmers do not act as perfectly rational profit maximisers.*

Benz (2009) found that decision-makers often pursue several objectives, such as generating profit, striving for security, tradition, leisure activities, or social acknowledgment. The theory of the perfectly rational profit maximiser ignores all of these multiple objectives. Agriculture is especially confronted with risk. For example, volumetric risks caused by weather fluctuations and diseases are an important issue. Therefore, risk reduction may be an entrepreneurial objective of major importance (Hardaker *et al.*, 1997). It can be assumed that risk reduction is a utility-providing factor that competes with the profit-maximising intention of the farmers. With this background, we formulate the following hypothesis:

*H2: Farmers choose production programmes with reduced income risk and accept less expected income than what would be possible.*

Besides bounded rationality and risk reduction, further socio-demographic and socio-economic characteristics of farmers might influence the relative economic performance. Even the bounded rationality described by Simon (1956) and the judgemental heuristics revealed by Tversky and Kahneman (1974) are based on the individual-specific characteristics of the decision-makers. These are often latent variables which cannot be measured directly and objectively. Therefore, they can only be included in a (mathematical) model by using indicator variables (Hausman and Taylor, 1981). The collected socio-demographic and socio-economic parameters of the farmers illustrate their living conditions and thus are suitable to describe the subject-specific latent variables. Hence, investigating the extent of the socio-demographic and socio-economic characteristics of farmers may explain the degree of relative economic performance. This leads to our final hypothesis:

*H3: Differences in the relative economic performance can be explained by socio-demographic and socio-economic characteristics.*

## 3. Study Design

The experiment is divided into three sections. In the first section, a multi-period one-person business simulation game is carried out. Subsequently, a Holt-and-Laury lottery (HLL) (Holt and Laury, 2002) is performed to investigate the participants' risk attitude. In the third section of the experiment, socio-demographic and socio-economic information about the participants is collected. The computer based experiment is carried out with farmers who know that they are participating in an experiment and that their decision-making behaviour is documented and analysed. Furthermore, the experiment was conducted on an agricultural trade fair and not in a laboratory setting. Hence, the business simulation game can be classified as an 'extra-laboratory experiment' according to Charness *et al.* (2013).

### Design of the business simulation game

In the first section of the experiment - the business simulation game - participants are asked to manage a virtual 100-hectare arable farm over six production periods. Each production period depicts one year of farming and equals to one round of the business simulation game. At the beginning of the experiment, the participants are introduced to the farming situation. Each participant receives an initial capital of play money €100,000[3]. In each production period, living costs in the amount of €30,000 play money are deducted. After each completed period, every participant receives a premium of €300 per hectare. The periods in the game build on one another and, at the beginning of each period, the participants are informed about the results of the previous one. A production period is completed as soon as the participant has made the following decisions:

1. Production programme decision: Design of the production programme for using the total farmland available to cultivate wheat, silage maize, sorghum, and flowering cover crops.
2. Contract decision: Conclusion of a substrate supply contract of 0 t, 1,500 t, 3,000 t, or 4,500 t of fresh mass for a neighbouring biogas plant. For fulfilling the obligation to deliver, silage maize, sorghum, and flowering cover crops are under deliberation.

[3] In mid-September, €1 was approximately equivalent to £0.80 and $US1.29 (www.xe.com)

For the production programme decision, further rules are given. One crop rotation includes at least two crops. This restriction is implemented by setting a minimum requirement of 5 ha of cultivation for wheat and silage maize. For all production methods, a maximum cultivation extent of 70 hectares of farmland can be used. All cultivation extents have to be integers, apart from this limitation, no specific field sizes were given. The completed substrate quantity delivered is paid with €35 per ton independently of whether the fresh weight consists of silage maize, sorghum, or flowering cover crops.

However, the decisions are additionally affected by various stochastic parameters which make the decision situation more realistic (Harrison and List, 2004). Hence, the yields as well as the prices are depicted as uncertain factors in the business simulation game. They change randomly from period to period and, thus, vary between the participants. Starting from an initial value that is equal for all farmers in the game, the market prices follow an arithmetic Brownian motion (Dixit and Pindyck, 1994:59) as shown in Figure 1.

The occurring market prices fall or rise in each period by €20 per ton for wheat and €1.50 per ton for silage maize with a probability of 50% starting from the price in the previous period (Figure 1). Also, the weather conditions influence the gross margins of the production alternatives. We distinguish between above-average, average and below-average weather conditions expecting above-average and below-average weather with a probability of 20% each and average weather with a probability of 60%. Above-average weather means that the yields per hectare of all crops reach their maximum, whereas, for below-average weather, the yields fall to a minimum as described in Table 1. The three weather conditions with their probabilities of occurrence as well as the corresponding yields per hectare are announced in each round.

Despite the uncertain yields per hectare, the chosen supply contract must be fulfilled by 100%. If this is not possible on the basis of the own harvest, the lacking amount of substrate must be purchased on the market for the double of the current market price of silage maize. If the harvest of biomass exceeds the contract, the surplus is sold for the market price of silage maize.

As there are not any storage facilities available for the crops harvested, all goods are sold for the current prices at the end of each period. The prices and the occurred weather conditions of the previous period are announced at the beginning of each new production period. Furthermore, participants receive additional information about the profit achieved as well as the cultivation and contract decisions of the previous periods. The earned assets sum up until the end of the game.

## Holt-and-Laury lottery

After the business simulation game, the second part of the experiment focuses on the participants' risk attitude using a Holt-and-Laury lottery (HLL) (Holt and Laury, 2002). This procedure is already established in agricultural economics (Brick *et al.*, 2012) and, therefore, is not explained in more detail here. Participants have to decide between the lotteries A and B. In lottery A, it is possible to win either €200 or €160 and €385 or €10 in the more risky lottery B. The probabilities to win one of the two aforementioned possible lottery outcomes are systematically varied in steps of 10% resulting in ten different decision-making situations. The change of the decision for lottery A to the more risky lottery B provides the HLL-value and reflects the participants' risk attitude. HLL-values (number of safe choices) from 1 to 3 indicate a risk-seeking behaviour, an HLL-value of 4 means that the participant is risk neutral and HLL-values from 5 to 10 denote risk-averse participants. The amounts of money used in the HLL are comparable to the possible prize money that can be won by the participants.

## Expense allowance and incentive compatibility

In order to attract farmers to participate in the experiment, an expense allowance in the amount of €10 per participant is paid. With a planned duration of the game of 30 minutes, the expense allowance corresponds to an hourly wage of €20, while the average hourly wage in the German agricultural sector is €9.92 (DESTATIS, 2010). This should cover the opportunity costs of participants.

For ensuring incentive compatibility, additional monetary incentives are set for 'good' decisions. The

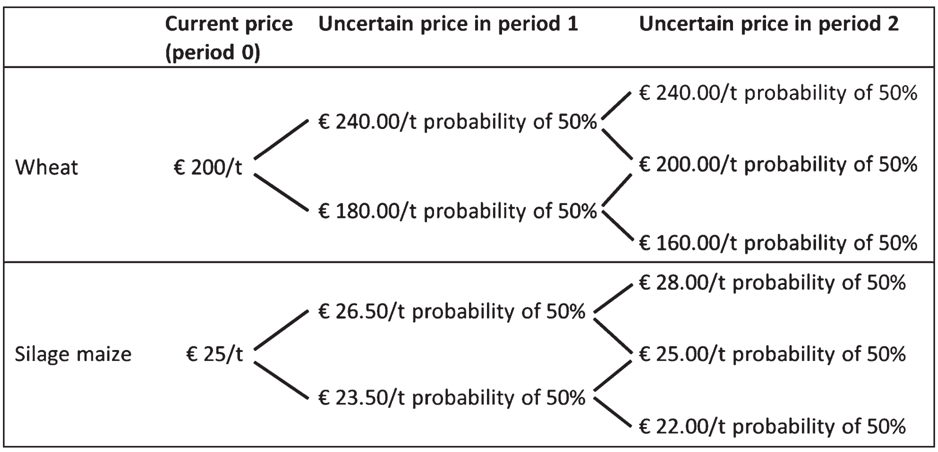


**Figure 1:** Potential price developments for the first two production periods for wheat and silage maize

**Table 1:** Possible production alternatives to cultivate the farmland

| | Wheat | Silage maize | Sorghum | Flowering cover crops | |
|---|---|---|---|---|---|
| Marketing option (market price) | Spot market (volatile price) | Substrate input for Biogas plant (€35/t) Spot market (volatile price) | Substrate input for Biogas plant (€35/t) | Substrate input for Biogas plant (€35/t) | Nature conservation (€640/ha) |
| Costs of cultivation | € 970/ha | € 832/ha | € 800/ha | € 880/ha | € 340/ha |
| Minimum extent | 5 ha | 5 ha | 0 ha | 0 ha | |
| Maximum extent | 70 ha | 70 ha | 70 ha | 70 ha | |
| Yield for | | | | | |
| above-average weather (20%) | 9.6 t/ha | 60.5 t/ha | 53.5 t/ha | 46.0 t/ha | No yield measured, biodiversity |
| average weather (60%) | 8.0 t/ha | 55.0 t/ha | 48.0 t/ha | 40.0 t/ha | |
| below average weather (20%) | 6.4 t/ha | 49.5 t/ha | 42.5 t/ha | 34.0 t/ha | |

experiment is planned for 120 participants, with tolerance of 5%. In total €2,005 of prize money is offered, so that the expected prize per participant is €16.71. As the length of the game of 30 minutes is already compensated by an expense allowance of €10, the chance to win additional prize money should motivate the participants to make well-considered decisions.

Previous studies revealed that incentives influence the behaviour of participants in experiments. They are considering their decisions longer and more intense if the amount of incentives depends on their own decisions (Camerer and Hogarth, 1999; Duersch *et al.*, 2009). Furthermore, Camerer and Hogarth (1999) point out that participants overestimate the probability of being selected if only few participants receive an incentive. Due to this reason, we decided to pay a higher incentive to only few participants. Out of the planned 120 participants of the business simulation game, four farmers will be randomly selected for a cash prize. The amount of each cash prize for the first three winners depends on the success in the business simulation game. They receive the share of €540 that corresponds to their relative economic performance. For the fourth cash prize, one participant is randomly selected for whom the Holt and Laury lottery is carried out. The participant receives between €10 and €385 according to his/her risk attitude.

## 4. Deviation of the Benchmark and Data Analysis

Assuming a pure profit-maximising decision-maker, an optimal production programme provides the maximum expected gross margin for one period of the business simulation game. Due to assuming a stochastic process for the market price developments, changes of the prices deliver new information for the expected prices of the following periods (Figure 1). Therefore, for each period and each participant an individual optimal production programme has to be calculated. Hence, for the analysis, all optimal production programmes are calculated applying the procedure described in Table 2.

The calculation of the profit-maximising production programme applies full enumeration, i.e. all possible proportions of the production activities and all contract decisions are systematically combined (Table 2). For each of the 5.8 billon possible combinations the expected total gross margin is calculated. Finally, the production programme with the highest expected total gross margin represents the optimal solution for this production period.

Furthermore, the expected total gross margins of the production programmes chosen by the participants are calculated (Table 2, first column). The quotient of the realized and the maximum expected total gross margin of each period of the business simulation game and each participant describes the relative economic performance of the decisions made by the participants. The lower this value is the more the farmer's decision differs from the decision of a perfectly rational profit maximiser.

In order to answer our hypotheses, we have to analyse the relative economic performance. It must be noted that the data generated by the business simulation game cannot be considered as independent as it includes several observations of each individual (relative economic performance for each farmer in each of the six production periods). Thus, the data structure can be described as a panel. That has to be taken into account when analysing the data as otherwise the statistic methods do not provide efficient and consistent results (Hausman and Taylor, 1981). The main focus of the following investigations is on the inter-subjective differences between the farmers. In order to efficiently depict the latter in a regression model, we apply a Between Regression on the mean of the relative economic performance:

$$\bar{y}_i = a + \bar{x}_i^l \cdot \boldsymbol{\beta}_i + z_i^l \cdot \gamma_i + u_i \quad (1)$$

The individual time variant variable (here: mean of relative economic performance of individual $i$ during the six production periods) is expressed by $\bar{y}_i$. Parameter $a$ is a constant. $\boldsymbol{\beta}_i$ indicates the estimated coefficients for the independent variables which are time variant. In this case, the mean of the independent variable ($\bar{x}_i^l$) has to be fit in. $\gamma_i$ indicates the estimated coefficients for the independent variables which are time constant. They can be directly included ($z_i^l$) in the regression. $u_i$ forms the error term. The results of the Between Regression can be interpreted more intuitively than the results of a Random Effects Regression, which would provide identical values for the estimators (Hausman and Taylor, 1981).

 

**Table 2:** Calculation of the profit-maximizing production programs and the relative economic performance of each participant in each period

| Observed decisions of the participant in the experiment | Derivation of the benchmark for a profit-maximizing decision-maker |
|---|---|
| Chosen production program: | About 5.8 bn. possible production programs: |
| Chosen amount of wheat | 5, 6, …, or 70 ha wheat |
| Chosen amount of silage maize | 5, 6, …, or 70 ha silage maize |
| Chosen amount of sorghum | 0, 1, …, or 70 ha sorghum |
| Chosen amount of flowering cover crops used as biogas substrate | 0, 1, …, or 70 ha flowering cover crops used as biogas substrate |
| Chosen amount of flowering cover crops for nature conservation | 0, 1, …, or 70 ha flowering cover crops for nature conservation |
| Contract decision: | Four possible contract decisions: |
| Chosen supply contract | Supply contracts: 0 t; 1,500 t; 3,000 t; 4,500 t |
| Calculation of expected total gross margin for the chosen production program: | Calculation of expected total gross margin for the optimized production program: |
| Calculation of the 12 potential total gross margins[(a)] | Calculation of the 12 potential total gross margins[(a)] for each theoretically feasible production program |
| Weighted mean of 12 possible outcomes | Weighted mean of 12 possible outcomes for each of the production programs is calculated |
| | Production program with highest expected total gross margin is the benchmark |

$$\text{Relative economic performance} = \frac{\text{Achieved expected total gross margin}}{\text{Highest expected total gross margin}}$$

**Note:**
(a)3 weather conditions · 2 price developments of silage maize · 2 price developments of wheat.

## 5. Sample Characteristics

The data set used was collected with an experiment carried out at the trade fair 'EuroTier' that took place in Hanover, Germany, from November 13–16, 2012. For the experiment, 946 visitors of the trade exhibition were directly asked to participate. In total, 123 farmers participated. The first section of the experiment, the business simulation game, took 23.1 min, whereby 11.2 min were used to read the instructions, and processing the business simulation game took 11.8 min. Another 2.9 min were used for the second section, the HLL, and 4.3 min for the questionnaire in the last section of the experiment. On average, the participants needed 30.2 min to complete the experiment. Table 3 displays some socio-demographic and socio-economic characteristics of the participating farmers.

When the experiment was carried out, participants were on average 29 years old, including the youngest participant with 16 years and the oldest in the age of 62 years. The farmland used in real business by each farmer has an average size of 245 ha. The participants assess the performance of their farm to be slightly higher than average. The average HLL-value of 4.4 indicates that the participants are risk neutral. Concerning the HLL, it is striking that 37 participants (30%) change more than once between lottery A and B. From a theoretical perspective, there is no reason to switch between the two lotteries offered several times (Holt and Laury, 2002). Approximately 30% of the participants are managers of a farm, while 40% consider themselves as farm successors. In total, 63% of the participants have completed an agricultural training, while 51% hold a university degree, and 41% of them even studied agricultural sciences. All in all, 37% of the participants focused on economics during their studies. In addition, about half of the participants indicate that they have already applied extensive farming methods when it was not economically advantageous due to environmental protection aspects. Moreover, 63% consider the cultivation of flowering cover crops as useful due to environmental protection reasons, whereas only 31% would support it even from an economic perspective.

As we look at six production periods of 123 virtual farms in the business simulation game, the sample size will comprise 738 observed production programme decisions. Table 4 gives an overview of the chosen production programmes of the farmers.

## 6. Results and Discussion

Hypothesis 1 assumes that farmers are perfectly rational profit maximisers. If this is the case, farmers decide for the production programmes with the highest expected profit and reach a relative economic performance of 100%. When comparing the theoretically possible expected gross margins with the expectation values of the decisions made by farmers in the business simulation game, however, differences in the relative economic performance become apparent. Figure 2 depicts the average of the relative economic performance of farmers over the six periods observed.

In the conducted business simulation game, no farmer made always perfectly profit-maximising decisions. Nevertheless, 28.5% of the farmers reached a relative economic performance higher than 90%, whereby only 8.9% of the participants reached less than 70%. A normal distribution for the relative economic performance depicted in Figure 2 cannot be rejected according to a Kolmogorov-Smirnov test (p-value=0.783). Furthermore, a single sided t-test for independent samples confirms that the mean of the reached relative economic performance of 83.7% differs significantly from the maximum (p-value<0.001). This can be interpreted as a first

**Table 3:** Socio-demographic and socio-economic characteristics of the participants (N=123 farmers)

| Characteristic | Mean | Standard deviation |
|---|---|---|
| Age (in years) | 29.2 | 10.9 |
| Share of female participants | 12.2% | - |
| Years of education | 13.4 | 2.6 |
| Agricultural training (a) | 62.6% | - |
| Economic study focus (b) | 36.6% | - |
| Manager/successor (c) | 69.9% | - |
| HLL-value (d) | 4.4 | 2.6 |
| Consistency of lottery decisions (e) | 69.9% | - |
| Evaluation of supply contracts (f) | 2.9 | 1.0 |
| Evaluation of agri-environmental measures (g) | 2.7 | 0.9 |
| Subjective estimation of farm success (h) | 57.2 | 25.4 |
| Farm is main source of income | 86.2% | - |
| Farmland in ha | 245.0 | 440.2 |
| Share of arable farms (i) | 30.9% | - |
| Time needed to complete the business simulation game (in minutes) | 30.2 | 22.4 |

**Notes:**
(a) 1=completed an agricultural training; 0=no completed agricultural training.
(b) 1=economic study focus; 0=other study focus or no study degree.
(c) 1=farm manager or farm successor; 0=other position.
(d) 1–3=risk seeking; 4=risk neutral; 5–9=risk averse.
(e) 1=without multiple switches between the lotteries in the Holt-and-Laury lottery; 0=with multiple switches between the lotteries.
(f) What is your opinion about the conclusion of supply contracts? 1=completely against to 5=completely in favour.
(g) What is your opinion about agri-environmental measures? 1=completely against to 5=completely in favour.
(h) How do you evaluate your farm success in comparison to other farms? 0=very under-average to 100=very above-average.
(i) 1=arable farm; 0=processing/forage/others.

indication that farmers' decisions are based on approximations instead of exact calculations.

**Hypothesis H1, stating that farmers do not act as perfectly rational profit maximisers, cannot be rejected. The majority of the farmers make decisions that differ significantly from those of a perfectly profit-maximising decision-maker.**

It needs to be tested whether farmers differ systematically from profit maximisation. If random effects are the reason for the observed non-optimal behaviour, the deviations from the profit-maximising areas of cultivation are normally distributed and no underlying decision-making pattern can be identified. However, if these deviations cannot be considered as random, it must be investigated which factors that have not yet been considered that may be the reason for the differences. Figure 3 shows the deviations of the amounts of different production activities from the amounts in the profit-maximising cultivation programmes.

In each period, the profit-maximum cultivation area for each production activity is subtracted from the cultivation area selected by the farmers. Compared to profit-maximising decision-makers, farmers decide to cultivate on average 19.2 ha too much wheat and 8.7 ha too many flowering cover crops. Although the cultivation of flowering cover crops was economically not optimal in any period of the business simulation game, it was realized in 51% of all periods. The production areas for silage maize and sorghum are 23.3 ha and 4.7 ha too small to attain the maximal expected total gross margins. While a too large-scale contract was chosen in 2.7% of all periods, farmers decided for too small-scale supply contracts in 69.4% of all periods. The described differences from an economically optimal solution are highly significant for each production activity and for the contract size ($p$-value$<0.01$). This provides evidence that systematic deviations in the cultivation programmes are the reason for the diminished relative economic performance. Thus, further factors, which farmers consider for their decisions that therefore deviate from the profit-maximising behaviour, need to be identified.

A possible factor that makes the farmers deviate from the aim of profit-maximising might be the reduction of profit risk. In order to reduce the profit risk, a lower average relative economic performance could be accepted. In a first step, we investigate how the selection of the production programme influences the standard deviation of the possible results of a period. On average, however, the standard deviation of the profits calculated from the production programmes chosen by the farmers is higher than that of the profit-maximising production

**Table 4:** Overview of production programmes chosen by the participants (N=738 production programme decisions)

| Characteristic | Mean | Standard deviation |
|---|---|---|
| Amount of wheat in ha | 33.8 | 20.2 |
| Amount of silage maize in ha | 44.7 | 20.0 |
| Amount of sorghum in ha | 12.7 | 15.6 |
| Amount of flowering cover crops for use in Biogas plant in ha | 4.4 | 8.0 |
| Amount of flowering cover crops for ecological purposes in ha | 4.4 | 8.8 |
| Contracted amount of biomass in tonnes | 2,774.4 | 1,310.2 |

 

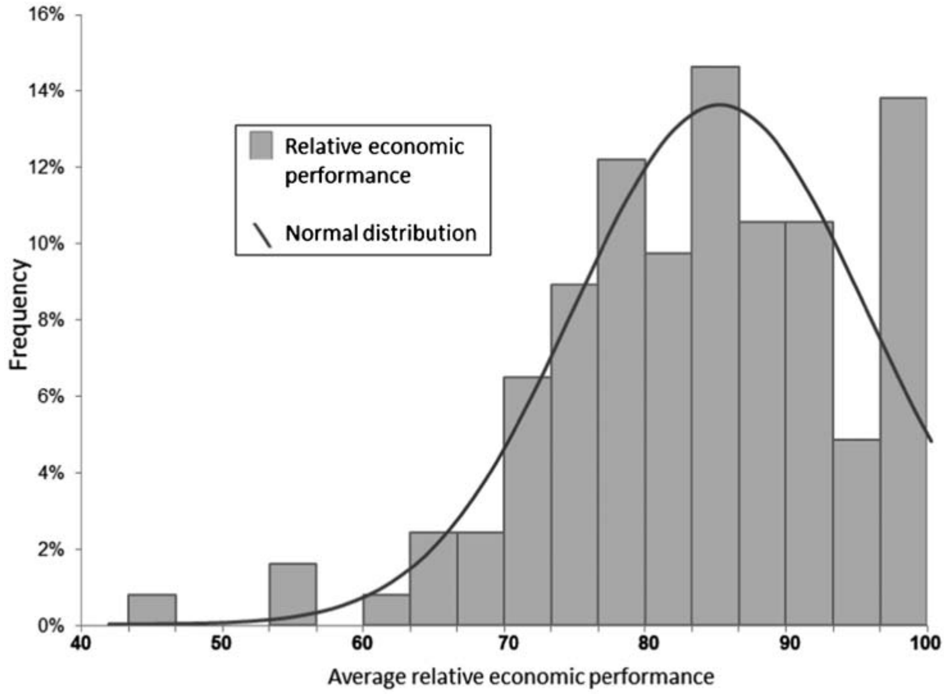


Figure 2: Average relative economic performance of farmers over six production periods (N=123 farmers)

programmes. Thus, the possible entrepreneurial objective of risk reduction is not reached by the participants.

In a second step, we analyse the impact of the risk attitude (HLL-value) on the relative economic performance using a between regression. Besides the HLL-value, other subject-specific characteristics are included in the regression model. The results are depicted in Table 5.

The Between Regression shows that the risk attitude, expressed in the HLL-value has no significant influence on the relative economic performance of a participant. Consequently, the aim of risk reduction cannot be

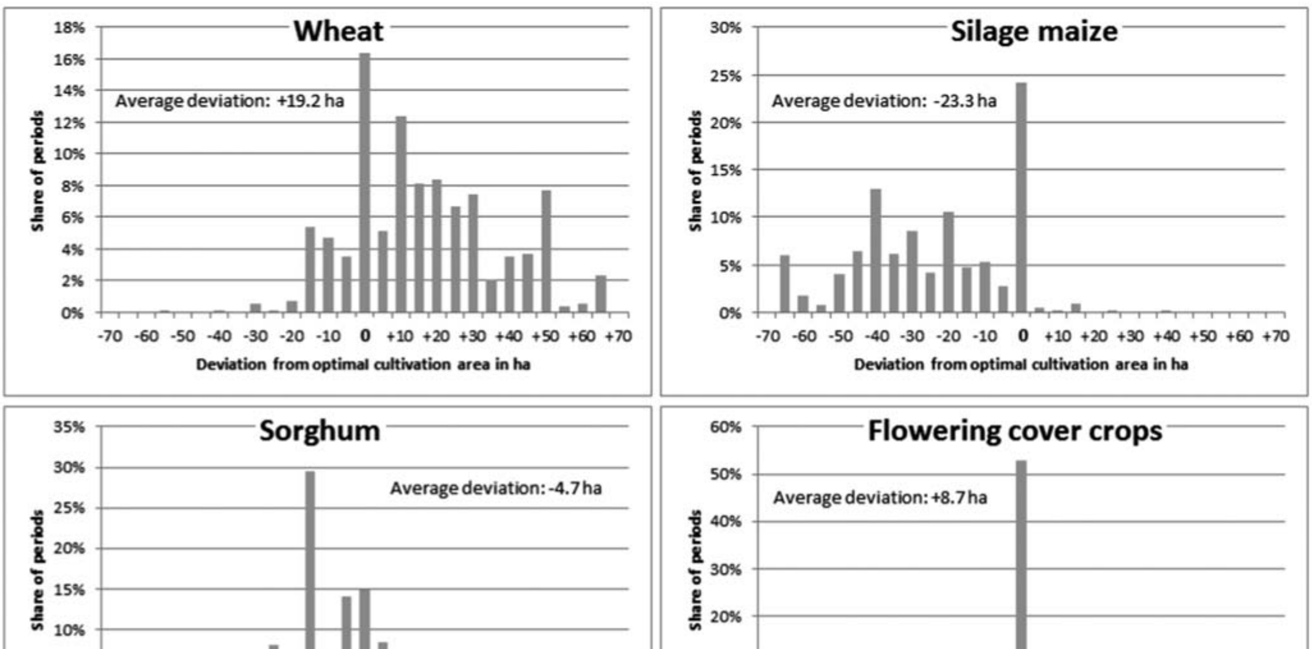


Figure 3: Deviations from the optimal cultivation areas (N=738 production program decisions)


 

**Table 5:** Between Regression of the subject-specific variables on the reached relative economic performance (N=123 farmers)

| | Coefficient | t-statistics [(a)] |
|---|---|---|
| Constant | 77.858 | 11.610*** |
| Age (in years) | 0.093 | 1.158 |
| Gender | −5.951 | −2.177** |
| Years of education | −0.214 | −0,631 |
| Agricultural education [(b)] | 2.238 | 1.185 |
| Economic study focus [(c)] | 4.582 | 2.440** |
| Manager/successor [(d)] | 5.508 | 2.841*** |
| HLL-value [(e)] | −0.148 | −0.350 |
| Consistency of lottery decisions [(f)] | 7.927 | 3.323*** |
| Evaluation of supply contracts [(g)] | −1.601 | −1.767* |
| Evaluation of agri-environmental measures [(h)] | −0.210 | −0.218 |
| Subjective farm comparison [(i)] | −0,008 | −0.231 |
| Farm is main source of income | 0.402 | 0.152 |
| Farmland in ha | 0,000 | 0.184 |
| Farm type [(j)] | −1.398 | −0.684 |
| Time needed to complete the business simulation game (in minutes) | 0.021 | 0.515 |
| F-value | 3.975*** | |
| $R^2$ | 0.358 | |

**Notes:**
(a) *=p-value<0.10; **=p-value<0.05; ***=p-value<0.01.
(b) 1=completed an agricultural training; 0=no completed agricultural training.
(c) 1=economic study focus; 0=other study focus or no study degree.
(d) 1=farm manager or farm successor; 0=other position.
(e) 1–3=risk seeking; 4=risk neutral; 5–9=risk averse.
(f) 1=without multiple switches between the lotteries in the Holt-and-Laury lottery; 0=with multiple switches between the lotteries.
(g) What is your opinion about the conclusion of supply contracts? 1=completely against to 5=completely in favour.
(h) What is your opinion about agri-environmental measures? 1=completely against to 5=completely in favour.
(i) How do you evaluate your farm in comparison to other farms? 0=very under-average to 100=very above-average.
(j) 1=arable farm; 0=processing/forage/others.

identified as a reason for the deviation of the profit-maximising cultivation programmes.

**Thus, Hypothesis H2 cannot be supported: Farmers do not choose production programmes with reduced income risk and accept less expected income than what would be possible.**

Reasons for the differences in the relative economic performance reached may possibly be based on personal characteristics of the participants different from risk attitude. In the following, these inter-subjective differences will be investigated in more detail.

The high significance of the factor ‘gender’ in the regression shows that male participants reached a result that is on average 6.0 percentage points higher than the result of female participants. This fact is in contrast to the findings of Johnson and Powell (1994) who stated that male and female managers make decisions of similar quality. A gender-specific analysis of the production programme decisions shows that the tendencies of the deviations from the optimal cultivation areas described in Figure 3 imply that the underlying decision-making patterns are similar for both male and female participants. Nevertheless, women induce significantly higher absolute values of the deviation from optimal cultivation areas than men. Participants with an economic focus in their study degree reached a result that is on average 4.6 percentage points higher than that of farmers who did not hold a university degree or whose degree did not focus on economics. Therefore, it can be assumed that their capacities to process economic information were trained. Farmers who were in a leading position at the time of survey conduction or who expected to take over such a position (manager/successor) reached a relative economic performance that was on average 5.5 percentage points higher than agricultural employees. Also the variable ‘consistency of lottery decisions’ indicates that relative economic performance of farmers, who switched several times between the lottery A and B during the HLL, was significantly on average 7.9 percentage points less optimal. From a theoretical perspective, there is no reason to switch between the two lotteries offered several times (Holt and Laury, 2002). Therefore, this behaviour leads to the thesis of either insufficient capacities to process information or indicates the participants as not willing to use these capacities to generate optimal solutions. A positive evaluation of the supply contracts diminishes the relative economic performance by 1.6 percentage points per step on a five-step Likert scale. This positive effect of a more pronounced aversion to supply contracts may be a result from the fact that some participants already have had experiences. These farmers possibly better understand the planning problem and, therefore, reach higher values of relative economic performance.

**Hypothesis 3 cannot be rejected. That is, differences in the relative economic performance can be explained by socio-demographic and socio-economic characteristics.**

## 7. Conclusions and Future Research Prospects

Many economic models are based on the theory of the *homo oeconomicus* that is often put simple and described as a perfectly rational, profit-maximising decision-maker.

 

However, considerable differences exist between the theoretical model results based on this theory and the behaviour of farmers observed in reality. In a realistically designed business simulation game, participants are faced with realistic decision-making situations. On the basis of the results of the game, the present study investigates if farmers act like pure profit maximisers and if they do not, which factors influence their deviation from the highest relative economic performance.

The results show that the behaviour of the participating farmers differs significantly from that of perfectly rational profit-maximising decision-makers. Moreover, risk reducing is not a significant factor but the extent of deviations between the economic performance of individual decisions and highest possible economic performance differs individually. It is true that the socio-demographic and socio-economic factors identified significantly influence the degree of relative economic performance. There are strong indications that, on one hand, bounded rational behaviour plays a role. On the other hand - and this aspect deserves special consideration and requires further research - there are indications to not reduce the model of the *homo oeconomicus* to profit-maximising decision-makers, but also to take into account other useful factors. The deviations between the observed behaviour and the benchmark are not random but systematic. Next to general factors, such as the recreational value or prejudiced thinking, even the possible particularities of the agricultural sector (e.g. the importance of sustainability and environmental protection) need to be revealed and taken into account.

Due to the system of premises and results of models, two different explanatory approaches for the discrepancy between model results and reality derive. On one hand, decisions of the farmers could be assumed as individually optimal and that leads to the existence of multiple, partially unconsidered objectives. On the other hand, the basic assumptions of a model may be accepted as axioms, and bounded rationality of the decision-makers is responsible for deviating results. In order to improve the understanding of decision-making in the agricultural sector and therefore also to improve modelling for policy impact assessment, both explanatory approaches have to be isolated. This may contribute to a more realistic design of models and, thus, of forecasts and policy measures that are based on it. In addition, it may lead to a better understanding of the decision-making behaviour of farmers.

In reference to the planning and implementation of future experiments, some aspects should find special attention. First, the question arises to what extent the experimentally conducted behaviour reflects the situation in practice. Do farmers act similarly in reality and deviate from the aim of profit maximization in order to pursue other activities that are also useful for them? In this context, incentive compatibility plays an important role. Second, business simulation games with economic actors from different sectors carried out under controlled conditions may reveal further general determinants for decision-making as well as the particularities of the agricultural sector. Third, the reasons for certain behaviour or a general 'tactic' in the game should be addressed. It is true that the evaluation of such statements takes up a lot of time. However, appropriate heuristic analysis can help to avoid speculations about the aims of participants and to identify new approaches that have not been considered before.

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REFEREED ARTICLE

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# Estimating whole farm costs of conducting on-farm research on midwestern US corn and soybean farms: A linear programming approach

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**ABSTRACT**

Precision agricultural technologies such as GPS-enabled automated guidance, yield monitors, and controller-driven variable rate applicators have reduced but not eliminated the costs of conducting on-farm trials. Farm decision makers often contemplate the benefit side of the profitability equation when considering on-farm trials. However, the cost portion of the equation must be considered to make informed decisions. This study estimates the whole-farm costs of conducting on-farm trials using a modification of the classic down-time model in a linear programming framework with comparisons to previously estimated potential benefits. Results indicate that after accounting for the whole farm costs there are still benefits to on-farm trials. Whole farm costs vary significantly dependent upon the type of on-farm trial undertaken. When on-farm trials cause planting and harvesting field operations to be conducted outside the optimal time, crop yields may be adversely affected. Therefore, farm decision makers should consider research questions that do not necessitate adversely impacting these windows until experience has been gained.

**KEYWORDS:** precision agriculture; yield monitor; GPS; down-time model; on-farm research

## 1. Introduction

Culminating from recent advancements in agricultural technology and shifts in price/cost structures, farmers are motivated to conduct their own on-farm[5] trials. However, on-farm trials are not costless. Reasons farmers often cite for not conducting on-farm trials include: (1) interference with other farming operations, (2) reduced yield and/or increased costs of inferior inputs or non-optimal rates (rates that are too high or too low), (3) increased probability of implementing an experiment based on a faulty experimental design or inappropriate analysis, and (4) inaccessibility to appropriate software, computation, and/or human resources. This study addresses the first point regarding on-farm trials interfering with other farming operations.

The commercialization of instantaneous yield monitors reduced the time commitment of harvesting on-farm trials, motivating some farmers to re-examine field-scale on-farm planned comparisons (Taylor *et al.*, 2011). In addition to increased numbers of farmers conducting on-farm trials, some farmers are implementing more trials on their farms (Griffin *et al.*, 2008). Similar to yield monitors reducing data collection time requirements during harvest, time requirements during other times have decreased for on-farm trial implementation with the adoption of automated controllers and automated guidance. According to most recent estimates by Schimmelpfennig and Ebel (2011), yield monitor adoption is between 35 and 45 percent of planted acres of corn, soybeans, and winter wheat based on the United States Department of Agriculture Agricultural Resource Management Survey (ARMS). Also based on ARMS, Griffin (2009b) reported that conducting on-farm experiments is the most common use of yield monitors in cotton and third most common in corn and soybean production.

Some farmers have been reluctant to devote efforts necessary to properly conduct on-farm trials because they recognize the potential interference with other farming operations during both the implementation and data collection phases. Implementation of on-farm trials is best discussed relative to before, during, or after planting. For instance, tillage comparisons may occur prior to planting, cultivar trials or seed treatments

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[5] Throughout the manuscript, on-farm will be used to describe farmer managed trials being conducted on their farms. These trials are conducted at a landscape or field scales rather than small plot scale.

implemented during planting, and foliar fungicide treatment comparisons implemented after planting. Field equipment and human capital may have to be diverted away from other farming operations so that the experiment can be implemented. When an experiment implemented during planting period causes other fields to be planted too soon before or in particular too late after the optimal period, then yield potential is adversely impacted (Nafziger, 2014). Even though precision agriculture technologies such as automated controllers and yield monitors have reduced field operation time requirements, it has not been eliminated. Calibration of yield monitors per manufacturers' recommendations occurs during harvest. If weigh scales are available in the field, it is anticipated that calibration takes two hours although a portion of this time crop is being harvested (Griffin, 2010).

With most yield monitor manufacturers, corn harvest is associated with two calibrations, one for wet corn and one for dry corn; additional calibrations are suggested when harvesting different corn hybrids (Doerge *et al.*, 2006). Therefore, a cultivar trial may require multiple calibrations such as one for each treatment whereas other types of on-farm trials with a single cultivar such as tillage comparisons, seeding rates or seed treatment may have a single calibration for the whole experiment.

Estimating the benefits of on-farm trials is more difficult than estimating the costs. The rational decision maker should be cognizant of initial cash outlays as well as expected yield penalties incurred due to implementing the field experiment. Using mathematical programming, the cost of conducting on-farm trials from a whole-farm[6] profitability perspective is estimated for a representative U.S. Midwestern corn and soybean farm. Specifically, the model set forth will allow for the investigation of how the initiation of these experiments impact timeliness of other operations that must be conducted across the operation.

## 2. Methods

A linear programming (LP) model was used to determine optimal solutions to maximize contribution margins. LP is a mathematical tool for optimizing an objective function (Dantzig 1949) such as maximizing contribution margins with respect to a set of whole-farm constraints on land, labour, and capital under a given weather regime (Doster *et al.*, 2010). Contribution margins are total crop sales revenue minus total direct costs, and can be considered returns to resources or fixed costs such as land, unpaid labour, and machinery. The base for comparison was a representative sized U.S. Midwestern corn and soybean farm with single equipment set with one corn planter, one soybean planter and one harvester. The base was modified in a series of LP runs. The scenario was modelled as a classic down-time problem and specified as a linear programming model in the standard summation notation and written as in Boehlje and Eidman (1984) as:

$$Max\ \Pi = \sum_{j=1}^{n} c_j X_j \tag{1}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \text{ for } i = 1 \ldots m \tag{2}$$

$$X_j \geq 0 \text{ for } j = 1 \ldots n \tag{3}$$

where:

$X_j =$ the level of the $j$th production process or activity,

$c_j =$ the per unit return to the unpaid resources ($b_i's$) for the $j$th activity,

$a_{ij} =$ the amount of the $i$th resource required per unit of the $j$th activity,

$b_i =$ the amount of the $i$th resource available.

The $j$ production processes or activities include corn and soybean grown in rotation. The $i$ resources include the (1) amount of land available for crop production, (2) amount of available labour expressed as combination of number of people, number of hours per day, and number of days suitable for fieldwork per period, and (3) the availability of your machinery based on number of machines of each type, number of hours per day that the machine is available, and working rates in acres per hour for each crop production task. The remaining variables $X$, $c$, $a$, and $b$ are the activity levels, per unit returns, production resource requirement, and resource constraints, respectively. Griffin *et al.* (2005) and Griffin (2009a) iterated over a range of working rates of specific field machinery ($b_i$) to model the economics of adding higher accuracy guidance systems to existing field equipment. Nistor and Lowengberg-DeBoer (2006) changed hours per day constraint to model increased labour availability for controlled drainage. Robertson (2006) evaluated the long-term profitability of continuous corn by altering the $X_j$ matrix of cropping systems. Several other studies have performed analyses by changing given resource availability and activities in specific ways including machinery (Danok *et al.*, 1980), cropping systems and rotations (Bender *et al.*, 1984; Cain 2006; Doering *et al.*, 1997; Foltz *et al.*, 1991; Mellor 2005), financial and risk management (Brink and McCarl, 1978a, 1979b; McCarl *et al.*,1977), harvest and on-farm drying systems (Davis and Patrick 2002), and climate change ramifications (Doering *et al.*, 1997; Pfeifer and Habeck 2002).

The above-mentioned studies acknowledge several limitations of LP. Deterministic LP model does not take into account any stochastic properties or risk. The input parameters are used as 'exact' values; therefore, the results are only as good as the information provided to the model. The LP model has 'perfect foresight' meaning that if all field operations are not able to be completed, then that hectare will not even be planted.

Given the capabilities and limitations of this LP model, four basic assumptions of on-farm trials guided this study. On-farm trials: (1) were implemented at time periods with the highest potential corn production, (2) were harvested in the time period with highest potential

[6] Throughout the manuscript, whole farm refers to the notation that conducting on-farm trials will have cost implications across the entire operation.

 

**Table 1:** Good field days required to calibrate yield monitor

| Number calibration sessions | Hours required for each yield monitor calibration | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 0.0 | 0.1 | 0.2 | 0.4 | 0.5 | 0.6 | 0.7 |
| 2 | 0.0 | 0.2 | 0.5 | 0.7 | 0.9 | 1.2 | 1.4 |
| 3 | 0.0 | 0.4 | 0.7 | 1.1 | 1.4 | 1.8 | 2.1 |
| 4 | 0.0 | 0.5 | 0.9 | 1.4 | 1.9 | 2.4 | 2.8 |
| 5 | 0.0 | 0.6 | 1.2 | 1.8 | 2.4 | 2.9 | 3.5 |
| 6 | 0.0 | 0.7 | 1.4 | 2.1 | 2.8 | 3.5 | 4.2 |
| 7 | 0.0 | 0.8 | 1.6 | 2.5 | 3.3 | 4.1 | 4.9 |
| 8 | 0.0 | 0.9 | 1.9 | 2.8 | 3.8 | 4.7 | 5.6 |
| 9 | 0.0 | 1.1 | 2.1 | 3.2 | 4.2 | 5.3 | 6.4 |
| 10 | 0.0 | 1.2 | 2.4 | 3.5 | 4.7 | 5.9 | 7.1 |

Note: assumes harvest can occur 8.5 hours per good field day.

corn production, (3) were implemented and harvested on a good field day and (4) diverted 100% of resources away from crop farming operations while being implemented and/or harvested. This diversion of labour and machinery resources was effectively modelled by reducing the number of days suitable for fieldwork and may be more relevant to farmers inexperienced with conducting planned on-farm trials rather than experienced farmers who may conduct experiments more efficiently.

Although yield monitors have reduced the time required to harvest on-farm trials, delays relative to production practices result due to yield monitor calibration, weighing loads, or other practices. Proper calibration of a yield monitor has been estimated to take at least two hours if a weigh scale is available in the field. It is expected that Midwestern corn and soybean farms utilizing yield monitor information would calibrate once for soybean and once each for wet and dry corn, additional calibrations may be important if the farm is conducting on-farm trials. Table 1 presents the days required for calibration under differing scenarios. There are several realistic examples where the farmer would calibrate four or more times per season. If planned comparisons include hybrids, then an additional calibration may occur for each treatment.[7] If the yield monitor was calibrated four times, taking 2 hours per calibration, then the number of good field days for harvest would be reduced by 0.9 days, thus influencing harvest timeliness.

The number of yield monitor calibration events for a given on-farm trial determines the number of days suitable that will need to be offset at the end of the season. At the very least, an evaluation of Table 1, may inform decision makers on the time cost of conducting on-farm experiments. Furthermore, making agricultural equipment manufacturers aware of this time cost could help to drive improvements in the current calibration methods to reduce the required time commitment.

## Representative Farm Scenario

A base farm that was considered timely with respect to planting and harvesting was chosen for this study. Tillage operations on the 1,214 ha conventional tillage farm included a 12.8 m field cultivator covering 11.1 ha $hr^{-1}$ after harvest of both corn or soybean and a 5.5 m chisel plough following corn harvest covering 4.4 ha $hr^{-1}$. Corn was planted to 0.76 m rows with a 24-row planter at 8.6 m $hr^{-1}$ and soybeans planted to 0.38 m rows with a 31-row split-row planter at 8.5 ha $hr^{-1}$. It was expected that planting takes 11.8 suitable field days. Corn was harvested with a 12-row header at 3.6 ha per hour and soybean is harvested with a 9.1 m platform at 4.98 ha $hr^{-1}$. Corn and soybean can be harvested 10 and 7 hours per day, respectively. Total harvest time takes 28.4 suitable field days. Both corn and soybean acreage received post-emerge herbicide applications with a 27 m self-propelled sprayer.

Representative long-run prices were chosen so that LP model results were useful for long-term planning. Eleven-year average long-run corn and soybean planning prices were \$98.43 $Mg^{-1}$ and \$229.65 $Mg^{-1}$, respectively, for 1999 to 2009[8]. Corn and soybean base yields were expected to be 1.73 Mg per ha and 0.53 Mg per ha, respectively, when planted and harvested in the optimal time periods. Per ha variable costs were \$452 and \$262 for corn and soybean, respectively.

The base yields for corn and soybean were the best yields in a typical year when planted and harvested in the respective time periods with highest production potential. In other words, yields are not expected to be higher than the base yields in a typical year; however, lower yields are expected when planting and/or harvesting operations were conducted during time periods before or after the time period with the highest yield potential. For instance, the week of April 26 to May 2 has the highest corn yield potential with the next week of May 3 to 9 considered having the next best corn yield potential (Table 2). The time period September 27 to October 10 has the highest corn yield potential when planting occurs in the April 26 to May 2 time period (Table 2). It was assumed that if the farm manager implements an on-farm trial with anticipation of gathering data useful for farm management decision making, then the experiment would be implemented and harvested during the time periods with highest yield potential for the respective crop. The planting time period with the greatest yield potential for soybean was

[7] It should be noted that cultivar trials are not recommended as on-farm experiments where the yield monitor is used to distinguish yield differences. Each calibration may alter the ability of the yield monitor to adequately determine relative yield measurements.

[8] \$US. In mid-September 2014 \$US1 was approximately equivalent to £0.62 and €0.78 (www.xe.com)

**Table 2:** Corn yield potential by plant and harvest time period as a percentage of the very best yield

| Planting Periods | Harvest Periods | | | | |
|---|---|---|---|---|---|
| | September 20 to 26 | September 27 to October 10 | October 11 to 31 | November 1 to 14 | November 15 to December 5 |
| Yield Adjustment (%) | | | | | |
| Apr 22–25 | 90 | 96 | 94 | 90 | 85 |
| Apr 26–May 2 | 0 | 100 | 98 | 94 | 89 |
| May 3–9 | 0 | 95 | 98 | 94 | 89 |
| May 10–16 | 0 | 92 | 94 | 90 | 85 |
| May 17–23 | 0 | 0 | 84 | 84 | 79 |
| May 24–30 | 0 | 0 | 74 | 74 | 69 |
| May 31–June 6 | 0 | 0 | 0 | 0 | 56 |

two weeks later than corn, May 10 to 16, while the harvest time period for highest soybean yield potential was the same as corn (Table 3).

Planting and harvest period yield penalties expected for corn (Table 2) and soybean (Table 3) were estimated for the Midwestern corn and soybean farms. Other regions and crops may have increased or decreased penalties. This could substantially alter analysis results for other crops and locations.

Other LP model parameters were assigned based upon prior information of farmer behaviour. There were two full time labourers and four hired hourly labourers available for \$10 $hr^{-1}$ who could work 5, 6 or 6.5 days $wk^{-1}$ depending on the time period. In general, tractors and implements could be used 12 hours $day^{-1}$. Acreage was constrained such that corn and soybean were grown in a one-to-one rotation.

### Whole-farm Analysis

To simulate the effect of conducting an on-farm trial, the days suitable for fieldwork were modified in each model run. Days suitable are the days that fieldwork can be conducted when it is not raining, the soil is not too wet, and the crop is able to be harvested (Williams and Llewelyn 2013; Griffin, 2009c). The number of days suitable for fieldwork is reduced as resources are diverted away from other field operations during implementation and harvesting, according to assumption four of the model. Each LP run changed information relative to time required to implement and/or harvest an on-farm trial by modifying the days suitable for fieldwork.

Three scenarios representing different time requirements to implement on-farm trials were used: 1) no additional time, 2) one-half day, and 3) one full day. Therefore, the days suitable for fieldwork were adjusted for the planting (April 26 to May 2) time period by removing 0, 0.5, and 1.0 from the current 2.4 suitable field days, respectively. The 2.4 suitable field days for April 26 to May 2 time period were determined to be the days suitable for fieldwork in the 75$^{th}$ to 85$^{th}$ percentile worst year.

The planting days suitable for fieldwork were held constant at 2.4, while the harvest time period was modified by removing 0, 0.5, and 1.0 days from the current 8.2 suitable field days for September 27 to October 10 for the 55$^{th}$ to 65$^{th}$ worst years. In additional scenarios, days suitable for fieldwork during the planting period and harvesting period were changed together; omitting 0, 0.5, and 1.0 days from the available days suitable for fieldwork. This resulted in nine additional scenarios as shown in Table 4.

## 3. Results

LP results indicated a reduction in contribution margin compared to the base situation of no on-farm trials; where contribution margin is defined as returns to land, unpaid labour, and management. This reduction occurs because of yield penalties incurred from diverting planting and harvesting time away from production.

**Table 3:** Soybean yield potential by plant and harvest time period as a percentage of the very best yield

| Planting Periods | Harvest Periods | | | | |
|---|---|---|---|---|---|
| | September 20 to 26 | September 27 to October 10 | October 11 to 31 | November 1 to 14 | Nov 15 to December 5 |
| Yield Adjustment (%) | | | | | |
| Apr 26–May | 92 | 98 | 96 | 93.5 | 89 |
| May 3–9 | 92.1 | 98.1 | 96.1 | 93.6 | 89.1 |
| May 10–16 | 0 | 100 | 98.1 | 96.1 | 91.1 |
| May 17–23 | 0 | 99.9 | 98 | 96 | 91 |
| May 24–30 | 0 | 0 | 94 | 92.5 | 89 |
| May 31–June 6 | 0 | 0 | 90 | 88.5 | 85 |
| June 7–13 | 0 | 0 | 85 | 83.5 | 80 |

 

**Table 4:** Costs from planting and harvesting on-farm trials

| Reduction in days suitable April 27–May 2 | Reduction in days suitable October 11–31 | | |
|---|---|---|---|
| | 0 | 0.5 | 1.0 |
| 0 | $0 | $859 | $1,818 |
| 0.5 | $2,684 | $3,543 | $4,501 |
| 1.0 | $5,448 | $6,307 | $7,266 |

In the scenario where the planting operation was delayed for one-half day, a $2,684 reduction in contribution margin resulted (Table 4). Contribution margin is decreased by $5,448 when a full day's resource is devoted to the on-farm trial and away from planting.

Like planting operations, yield penalties were associated with harvest operation delays. Although one motivation for farmers to conduct on-farm trials with precision agriculture technology is that yield monitors have reduced the time requirements at harvest, some delay of harvest may still be necessary to carry out proper on-farm testing. In scenarios where the yield monitor may need to be calibrated for differing hybrids, moisture, or even if weigh wagons or spot checks were used instead of yield monitors, harvest operations may be delayed. When harvest operations were delayed by 0.5 and 1.0 days during the September 27 to October 10 time period, contribution margins decreased by $859 and $1,818, respectively, considerably less than if the planting operation were delayed by the same time.

The before-mentioned results of harvest operation yield penalties assumed no delayed planting. Although planting time delays without harvest time delays may be possible with yield monitors, the converse is not likely if on-farm trials were implemented at planting. A sensitivity of both planter and harvest time delays are presented in Table 4. When days suitable for fieldwork during both the planting and harvesting time periods were both reduced by 0.5 days, a reduction in contribution margin of $3,543 resulted. When days suitable for planting were decreased by one full day while the harvesting period days suitable was reduced by 0.5 days a $6,307 reduction in contribution margin was calculated. When one full day was removed from both planting and harvesting time periods, a $7,266 reduction in contribution margin was calculated.

Since planting and harvest yield penalties are mutually exclusive in these scenarios, the impacts are independent and additive meaning that the same values are added moving columns from left to right or moving rows from top to bottom. Removing half a day from harvest regardless of the planting time penalties will cause an $859 reduction in revenue. Likewise, removing half a day from planting time will reduce revenue by $2,684 regardless of how many fieldwork days reduced during harvest time.

## 4. Discussion

Griffin (2006) reported several on-farm research results including corn hybrid trials. He reports that a 1.83 metric ton per ha statistical difference between two corn hybrids for an estimated $8.77 per ha difference between corn hybrids after product costs (Table 5). Assuming that half the 1,214 ha farm was in corn production, that the farmer chooses a single hybrid and that the hybrid would be available on the market for at least one year, then the estimated total whole-farm benefit of the on-farm experiment would be $5,323 [($8.77 * 1,214)/2=$5,323]. Assuming that one-half day were taken in the spring and fall to implement and harvest the corn hybrid comparison, yield penalty costs would have been $3,543 resulting in a net benefit of $1,780 per farm. However, if planting took a complete day, then the yield penalty costs would have been $6,307 (Table 4), $984 more than the expected benefit of the experiment. This simple example based on a real-world experiment demonstrates that understanding both the costs and the benefits of an on-farm experiment is important for farm management decision making. With this example, a recurring loss is expected from an annual on-farm hybrid test. However, positive returns are possible if downtimes were reduced or different set of experimental factors were tested.

## 5. Conclusions

Conducting on-farm trials is not a costless venture. Diverting one-half day of resources away from production

**Table 5:** Example of Potential Benefits

| | Corn 1 | Corn 2 |
|---|---|---|
| Expected yield MT ha$^{-1}$ | 62.235 | 60.405 |
| Gross returns $ ha$^{-1}$ | 509.0 | 495.0 |
| Product cost ($ bag$^{-1}$) | 158.9 | 151.9 |
| Produce applied (bags ha$^{-1}$) | 0.89 | 0.89 |
| Total product cost ($ ha$^{-1}$) | 141.35 | 135.13 |
| GR minus product ($ ha$^{-1}$) | 368.65 | 359.88 |
| Difference | 8.77 | |

Note: Adapted from Griffin (2006).

to plant on-farm trials cost nearly $2,700. Diverting one full day of planting time reduced crop revenue by nearly $5,500. However, at this point in time it is unknown what the long-term benefits to a farming operation might be by conducting on-farm trials versus relying upon university recommendations based on traditional small-plot experiments.

Additional losses are incurred when there are additional delays at harvest. While yield monitors may reduce the time required to collect on-farm trial data, delayed harvest operations lead to reduced yield potential and crop quality. However, when harvest operations were delayed, whole farm profitability decreased by over $800 when harvest resources were diverted for 0.5 days and nearly $3,900 when diverted for 2.0 days.

In scenarios where both the planting and harvesting time periods are affected by on-farm trials, even greater costs occur. If both operations require all farm resources to be diverted away from production for one full day, yield reductions associated with implementing and harvesting the on-farm trial cost over $7,000 in reduced contribution margin. These costs are solely due to yield penalties associated with farm equipment being diverted away from other farming operations, and do not include inputs, application costs, other direct costs, human capital, analysts, or other fees associated with on-farm testing.

Many studies and extension publications stress the importance of yield monitor calibration. Regardless of the number of times the yield monitor was calibrated, some delay of harvest occurs. Whether yield monitor calibration intervals are a function of on-farm trials or exist otherwise impacts the partial budgeting for on-farm trials. If an on-farm trial is to be harvested with a yield monitor, it is likely that the farm manager would properly calibrate the yield monitor to increase the probability of collecting data usable for farm management decision making. Without a formal use of yield monitor data, calibration would still be important but may have lesser value to the farm manager. Unlike some farm operations such as transportation of equipment, yield monitor calibration is assumed to always occur during a good field day because grain suitable for harvest is necessary.

Farmers considering on-farm trials for the first time should consider implementing trials during time periods other than planting such as midseason herbicide or fungicide applications to minimize yield penalties and downside risk. In addition to being implemented at planting time, cultivar trials may require additional calibrations and results have time limited usefulness due to the short duration that cultivars remain available on the market. In addition, turn-around time on proper analysis for cultivar trials may not be sufficient to obtain early-order discounts, especially for corn hybrids which may be due by the end of harvest. As experience of the farmer increases, they may opt to implement on-farm trials at planting. Other precision agriculture technology such as automated controllers, automated boom shutoffs, and automated row shutoffs reduce the costs and human error associated with implementing on-farm experiments. Overall, the costs of individual on-farm trials are highly dependent upon the efficiency and ability of the individual farmer to manage and plan for the required field operations.

Emerging technologies such as on-the-go applicators and telematics should be evaluated for their incremental value for on-farm experiments. Telematics allow automated wireless transfer of data between field equipment and cloud based computing. On-the-go applicators have ability to design and implement an experiment without human intervention. The value of broadband connectively in rural areas should be estimated to indicate to the industry and policy makers the foregone value of being able to effectively use agricultural telemetry.

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**Dr Terry Griffin,** of the University of Arkansas, earned his Bachelor's degree in Agronomy and Master's degree in Agricultural Economics from the University of Arkansas, and a PhD from Purdue University. His doctoral research developed methods to analyze site-specific yield monitor data from field-scale experiments using spatial statistical techniques. Terry has contributed to outreach efforts of the Land Grant System in Arkansas, Illinois and Indiana. Terry and Dana have three wonderful children.

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# Marketing efficiency of cassava products in Delta State, Nigeria: A stochastic profit frontier approach

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**ABSTRACT**

The present study estimates the level of marketing margin and marketing efficiency of cassava products (i.e., root tuber, gari, fufu, tapioca, starch, and flour) of 105 marketers from three regions of Delta State, Nigeria using a stochastic profit frontier approach. Results reveal that a rise in purchase price of cassava products as well as unit marketing cost significantly reduce marketing margin. A rise in sale price of cassava products increase marketing margin as expected. Marketing experience significantly improves marketing margin as expected. The mean level of marketing efficiency is very low estimated at 55% implying that marketing margin can be substantially increased by eliminating inefficiency arising out of inappropriate allocation of resources, response to prices and scale of operation. Marketing efficiency is significantly higher for marketers who are farmers and the gender of marketer has no impact on efficiency. However, marketers in the Northern Delta region are relatively efficient but inefficient in Central Delta relative to Southern Delta. Policy implications include investment in market infrastructure to reduce fluctuation in prices and marketing costs and training on marketing and market functions for marketers to develop marketing experience.

**KEYWORDS:** marketing margin; marketing efficiency; stochastic profit frontier; cassava and cassava products; Delta State, Nigeria

## 1. Introduction

Cassava (*Manihot esculenta)* is an important staple crop for 550 million people in developing countries (Nweke, 2004) and it is the sixth major staple in the world after rice, wheat, maize, potato and sweet potato (Nassar and Ortiz, 2007). In Africa, cassava is gradually changing its status from a famine-reserve, rural food staple and non-tradable crop to a cash crop destined for urban consumption, livestock feed, export and industrial raw materials (Nweke 2004). The world leading producers are Nigeria, Ghana, Brazil, Democratic Republic of Congo, Indonesia, Tanzania and Thailand with African countries producing more than 50% of the total world production (FAO, 1995; 2011; Nassar and Ortiz, 2006). Nigeria ranked first in the world in cassava production in 2009 where 3.1 million ha was planted producing 37 million tonnes with an average yield level of 11.8 t/ha (FAOSTATS, 2011).

Cassava has a number of uses ranging from consumption to industrial use through processing of the cassava root tuber (CRT), e.g., into gari, starch, akpu, tapioca, and dried chips among others. Gari are fine white or yellow granules processed from harvested CRT which is peeled, then grated into pulp, then fermented, dried and roasted into fine granules. Akpu is a pasty product of cassava, which is sieved first and then fermented, boiled or cooked and pounded to pasty moulded products. Tapioca is produced from peeled CRT, sliced into chips, then soaked, fermented, dried or roasted into dried flakes. Further processing involves grinding and milling into flour.

Chukwuji *et al.*, (2007) and Farinde *et al.*, (2007) noted that the problem of spoilage and bulkiness of cassava root tuber could be overcome through processing. Dada *et al.* (2007) emphasized that value chain improvement is imperative to sustain cassava sector as it will help to strengthen the links between supply and demand. Furthermore, Kaine (2011), Chukwuji *et al.* (2007) and Osomtimehin *et al.* (2006) concluded that processing of cassava root tuber increases its shelf-life in storage and that adding value leads to an increase in marketing margin of the processors.

Several studies (e.g., Chukwuji *et al.* 2007; Liverpool-Tasie, 2011 among others) suggest that any attempt to increase productivity growth and efficiency in crop production and processing without markets for the products is unlikely to result in success. Sugino and Magrowani (2007) indicated that increase in the demand for processed crop products has a tendency to encourage processing by the processors. Marketing of cassava in Nigeria is generally limited by constraints such as lack

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of information and infrastructure, such as good road networks, storage facilities, capital and credit provision (Asogwa *et al.* 2011; Erhabor and Omokaro, 2011; Okoh and Dominic, 2004; Okoh, 1999). It is imperative that expansion of marketing will greatly enhance productivity, income and employment opportunities for the cassava sector.

Given this backdrop, the main objectives of this study are to: (a) examine the level of marketing margin or profitability in selling cassava and its products; (b) estimate the level of marketing efficiency of individual marketers (i.e., retailers or wholesalers) of cassava and its products; and (c) identify the socio-economic determinants of marketing efficiency of cassava and its products.

In order to analyse marketing efficiency and its determinants, we have applied a stochastic profit frontier approach which is not commonly seen in the existing literature[3]. Conventionally marketing efficiency is computed simply as the ratio of total revenue to total marketing costs or a variant of this (e.g., Odiomenem and Otanwa, 2011; Umar *et al.*, 2011; Afolabi, 2009; Mafimisebi, 2007). Also, standard linear regression methods are commonly used to identify socio-economic determinants of marketing/gross margin (e.g., Odiomenem and Otanwa, 2011; Umar *et al.*, 2011; Afolabi, 2009; Mafimisebi, 2007; Olukosi and Isitor, 1990; Obasi and Mejeha, 2008; and Akinupelu and Adenegan, 2011) which invariably assumes perfect efficiency in marketing. Given widespread evidence of inefficiency in agricultural production in developing economies (Bravo-Ureta *et al.*, 2007), it is unlikely that marketing of agricultural products will be perfectly efficient, as we are aware that the marketing sector is riddled with several constraints (Asogwa *et al.* 2011; Erhabor and Omokaro, 2011; Okoh and Dominic, 2004; Okoh, 1999).

The paper is structured as follows. Section 2 presents the analytical framework and a description of the study areas and the data. Section 3 presents the results. Section 4 provides discussion and draws policy implications.

## 2. Methodology

### Measuring marketing efficiency using profit frontier function

The main assumption of using a profit function approach to analyze marketing efficiency is that the marketers engage in marketing activities to maximize marketing margin or profit defined as the difference between total revenue obtained from selling the products minus total variable costs incurred in the marketing process. In this framework marketing inefficiency can arise from two main components – allocative and scale inefficiency. A marketer is said to be allocatively inefficient if it is not using marketing inputs in optimal proportions (e.g., use of labour for loading, transportation, storage, marketing space, utilities, etc.) given their observed prices. A marketer can also be scale inefficient if the marketer does not sell the quantity of products at a selling price which is equal to the marginal cost of marketing. These two sources of inefficiencies can be combined and analyzed through one system which is the profit function framework (e.g., Ali and Flinn, 1989; Kumbhakar *et al.*, 1989; Ali *et al.*, 1994; Wang, *et al.*, 1996 and Rahman, 2003 used this framework to analyze efficiency in agricultural production).

A profit function approach is appropriate to estimate firm specific efficiency directly when firms face different prices and have different factor endowments (e.g., Kumbhakar *et al.*, 1989; Ali and Flinn, 1989; Ali *et al.*, 1994; Wang *et al.*, 1996; Kumbhakar, 2001; Rahman, 2003), which is more appropriate in the context of marketing. Broadly, the profit function approach combines the concepts of technical, allocative and scale inefficiency in the profit relationship and any errors in the production decision are assumed to be translated into lower profits or revenue for the producer (Ali *et al.*, 1994). Therefore, for our purpose, we define marketing efficiency as the ability of a marketer to achieve highest possible marketing margin or profit given purchase and selling prices of the products and the levels of fixed factors of the firm, and in this context marketing inefficiency is defined as loss of profit/margin from not operating on the frontier.

Furthermore, we adopt Battese and Coelli (1995) model to identify the determinants of marketing inefficiency where these can be expressed as a linear function of the explanatory variables reflecting firm specific characteristics and can be estimated along with firm specific marketing/profit efficiency scores in a single stage estimation procedure.

### The stochastic profit frontier model

The stochastic profit function is defined as

$$\pi_i = f(P_i, Z_i).\ exp\ (\xi_i) \quad (1)$$

where $\pi_i$ is normalized profit of the $i$th firm defined as gross revenue less variable cost, divided by firm-specific output price ($P_y$); $P_i$ is the vector of variable input prices faced by the $i$th firm divided by output price ($P_y$); $Z_i$ is the vector of fixed factor of the $i$th firm; $\xi_i$ is an error term; and $i$=1, ….., n, is the number of firms in the sample.

The error term $\xi_i$ is assumed to behave in a manner consistent with the frontier concept (Ali and Flinn, 1989), i.e.,

$$\xi_i = v_i - u_i \quad (1a)$$

where $v_i$s are assumed to be independently and identically distributed $N(0,\sigma^2_v)$ two sided random errors, independent of the $u_i$s; and the $u_i$s are non-negative random variables, associated with inefficiency in production, which are assumed to be independently distributed as truncations at zero of the normal distribution with mean, $\mu_i = \delta_0 + \sum_d \delta_d W_{di}$ and variance $\sigma_u^2$ ($|N(\mu_i, \sigma^2_u|$), where $W_{di}$ is the $d$th explanatory variable associated with inefficiencies on firm $i$ and $\delta_0$ and $\delta_d$ are the unknown parameters.

The marketing/profit efficiency of firm $i$ in the context of the stochastic frontier profit function is defined as

$$EFF_i = E[\exp(-u_i)|\xi_i] = E[\exp(-\delta_0 - \sum_{d=1}^{D} \delta_d W_{di})|\xi_i] \quad (2)$$

[3] The approach is commonly used in analysing agricultural production efficiency (e.g., Ali and Flinn, 1989; Kumbhakar et al., 1989; Wang, et al., 1996 and Rahman, 2003)

where $E$ is the expectation operator. This is achieved by obtaining the expressions for the conditional expectation $u_i$ upon the observed value of $\xi_i$. The method of maximum likelihood is used to estimate the unknown parameters, with the stochastic frontier and the inefficiency effects functions estimated simultaneously. The likelihood function is expressed in term of the variance parameters, $\sigma^2=\sigma_v^2+\sigma_u^2$ and $\gamma=\sigma_u^2/\sigma^2$ (Battese and Coelli, 1995).

## Empirical Model

The general form of the translog profit frontier, dropping the $i$th subscript for the firm, is defined as:

$$\ln \pi' = \alpha_0 + \sum_{j=1}^{2} \alpha_j \ln P'_j + \frac{1}{2}\sum_{j=1}^{2}\sum_{k=1}^{2} \tau_{jk} \ln P'_j \ln P'_k + \sum_{j=1}^{2}\sum_{l=1}^{2} \phi_{jl} \ln P'_j \ln Z_l + \sum_{l=1}^{2} \beta_l \ln Z_l + \frac{1}{2}\sum_{l=1}^{2}\sum_{t=1}^{2} \varphi_{lt} \ln Z_l \ln Z_t + v - u \quad (3a)$$

and

$$u = \delta_0 + \sum_{d=1}^{7} \delta_d W_d + \omega \quad (3b)$$

Where:

$\pi'$= restricted marketing margin/profit (total revenue less total cost of variable marketing inputs) normalized by price of output ($P_y$ – i.e., weighted average sale price of cassava and cassava products)

$P'_j$= price of the $j$th input ($P_j$) normalized by the output price ($P_y$)

$j$ = 1, weighted average purchase price of cassava and cassava products

= 2, weighted average marketing cost per unit of product

$Z_l$ = quantity of fixed input

$l$ = 1, education of the marketer (completed years of schooling)

= 2, marketing experience (years of cassava marketing experience)

v = two sided random error

u = one sided half-normal error

$ln$ = natural logarithm

$W_d$= variables representing socio-economic characteristics of the firm to explain inefficiency

$d$ = 1, age (years)

= 2, main occupation (dummy variable, farming = 1, 0 otherwise)

= 3, gender (dummy variable, male = 1, 0 otherwise)

= 4, credit received (dummy variable, received credit = 1, 0 otherwise)

= 5, subsistence pressure (number of persons per marketer household)

= 6, firms located in Central Delta region (dummy variable, Central = 1, 0 otherwise)

= 7, firms located in South Delta region (dummy variable, South = 1, 0 otherwise)

$\omega$ = truncated random variable

$\alpha_0, \alpha_j, \tau_{jk}, \beta_l, \phi_{jl}, \varphi_{lt}, \delta_0$, and $\delta_d$ are the parameters to be estimated.

## Study area, sampling procedure and the data

Data used for the study were drawn from three regions of Delta state, Nigeria which is situated at the South-southern (Niger Delta) part of the country. These are, North, Central and South Delta regions which have different agro-ecological characteristics. The major foods grown in Delta state are cassava (leading producer), yam, plantain, maize, and vegetables (MANR, 2006). Delta state was selected as the case study area for this research because it has the ideal climatic and soil conditions for cultivation of cassava and is a very important staple crop of the state.

Sampling of cassava marketers (i.e., wholesalers/retailers) was based on the cell structure developed by the Delta State Agricultural Developmental Programme[4]. First, nine local government areas (LGAs) of the total 25 LGAs in the state (3 LGAs from each region) were selected randomly. Next, 35 marketers of cassava and cassava products from each region (i.e., 10–12 marketers from each of the nine LGAs) were selected randomly. This provided a sample size of total 105 marketers (39 marketers from Delta Central, 40 from Delta South and 26 from Delta North regions) spread across 20 markets in these three regions for primary data collection. The criteria used for selecting markets are: (a) markets must trade in cassava and/or cassava products; and (b) markets must operate at least once a week. The average frequency of market day was estimated at 4 days (i.e., every 5th day is a market day with a range of 1–7 days).

For primary data collection, a structured questionnaire was administered containing both open and closed type questions. A team of two research assistants (who are agricultural officers from the regional office of the Ministry of Agriculture in Delta State) were trained by the co-author and all three members were involved in collecting primary data using face to face interview method with the marketers in the market place. Interviews took place mainly in English language although the co-author is a native of Delta State, Nigeria. Detailed information on the quantities of cassava and its products that are purchased and marketed, purchase and sale prices of each product, cost of marketing, and constraints in marketing were collected from each marketer. Also, demographic and socio-economic information from each marketer included age of the marketer, years of marketing experience, main occupation, family size, education (completed years of schooling), credit, and gender of the marketer. The survey was conducted during September to December, 2008.

# 3. Results

## Marketing margin of cassava and its products

Table 1 presents information on revenue, cost and marketing margin per kg of cassava and cassava products marketed for two rounds of supplies per marketer. A total of six products are identified: cassava

[4] The paper is developed from the data of co-author's doctoral research project which included an investigation of farm-level productivity and efficiency in production and processing of 315 cassava farmers (105 farmers from each region) and marketing activities/issues related to cassava and its products from 105 marketers (wholesaler/retailers) located in the same three regions where farm survey was conducted.

**Table 1:** Marketing margin of cassava and cassava products (per kg)

| Variables | Cassava root tuber | Gari | Cassava starch | Fufu | Tapioca | Cassava flour |
|---|---|---|---|---|---|---|
| **Prices (per kg)** | | | | | | |
| Sale price of the product | 28.41 | 79.84 | 110.05 | 101.37 | 252.93 | 206.43 |
| Purchase price of the product by the marketer | 16.22 | 57.22 | 78.51 | 71.52 | 121.08 | 134.63 |
| Ratio of price difference (Sale price/Purchase price) | 1.75 | 1.40 | 1.40 | 1.42 | 2.09 | 1.53 |
| **Revenue (per kg)** | | | | | | |
| Total revenue from sale (TR) | 28.41 | 79.84 | 110.05 | 101.38 | 252.93 | 206.43 |
| **Cost (per kg)** | | | | | | |
| Product purchase cost (PC) | 16.22 | 57.22 | 78.51 | 71.52 | 121.08 | 134.63 |
| **Marketing cost (per kg)** | | | | | | |
| Fees | 0.43 | 0.42 | 0.42 | 0.43 | 0.42 | 0.42 |
| Cost of utilities | 0.52 | 0.52 | 0.53 | 0.52 | 0.52 | 0.53 |
| Loading cost | 2.15 | 2.12 | 2.19 | 2.21 | 2.05 | 2.04 |
| Transportation cost | 3.42 | 3.43 | 3.40 | 3.48 | 3.46 | 3.62 |
| Rent | 0.47 | 0.46 | 0.47 | 0.48 | 0.47 | 0.46 |
| **Total marketing cost (MC)** | 6.99 | 6.97 | 7.00 | 7.12 | 6.93 | 7.07 |
| **Total cost TC = PC+MC** | 23.22 | 64.18 | 85.51 | 78.64 | 128.01 | 141.71 |
| **Marketing Margin (Profit) per kg ($\pi$= TR– TC)** | 5.19 | 15.66 | 24.54 | 22.74 | 124.93 | 64.72 |
| Percent of marketers selling the product (%) | 87 | 89 | 58 | 66 | 71 | 47 |

Source: Computed from Field Survey, 2008.

root tuber, gari, starch, fufu, tapioca and cassava flour[5]. Marketers are involved in marketing multiple products with a mean of 4.17 products. The marketing margin varies significantly across product types ($p<0.000$ from ANOVA) and is highest for tapioca followed by cassava flour and lowest for cassava root tuber. The main contributor to marketing margin is the difference between the purchase price and sale price of the products. Although such price difference is highest for tapioca (209%), the second highest difference (175%) is for cassava root tuber whereas its marketing margin is lowest. Gari is the most popular processed cassava which provides marketing margin three times that of cassava root tuber.

Processing cassava into various products is largely labour intensive. For example, average processing time of 100 kg of cassava root tuber into gari is 18 hours, cassava flour is 16 hours and tapioca is 28 hours, respectively when traditional method is used (Okorji *et al.*, 2003). Also, recovery rate of the processed product from fresh root tuber varies depending on a number of factors including moisture content, method of processing and use of equipment. For example, the approximate conversion rate of fresh root tuber into gari is 15–20% (Hahn, 1992). Therefore, the mark-up of the purchase price of the processed product seen in Table 1 somewhat reflects these underlying costs incurred in processing cassava into value added products by the farmers/processors.

The marketing cost of cassava and/its products is relatively low and is similar across products ranging from Naira (N) 6.93–7.12 per kg (Tables 1)[6]. A number of elements make up the total marketing cost. These are: (a) fees (includes commission, and fees for agent, association and council), (b) cost of utilities (includes costs of storage, security, electricity, and water supply), (c) loading cost (mainly labour cost for loading and unloading of products), (d) transportation cost (from the point of purchase to the market; the average distance was estimated at $2.93 \pm 3.13$ km with a range of 1–15 km), and (e) rent for market stall/space. Loading and transportation account for 79% of the total marketing cost. In the cassava marketing process, there are intermediaries (known as commission/assembling agents) who buy cassava root tubers and their products from farmers and processors. They may also be farmers and/or processors themselves buying small quantities from other farmers and processors as they come into the market. After procuring products, they reassemble and resell to the wholesalers, processors, industries, retailers and final consumers within the market. These intermediaries charge commissions at a fixed rate. Each market is managed by a marketing association who also charges fees. Also, each market is regulated by local council who also charges fees. Loading and unloading of cassava and its products is largely done by hired labourer paid at market wage rate. The main mode of transporting cassava and its products are by hired pick-up van noted by 92.7% of marketers.

## Quantity of products marketed and socio-economic characteristics of the marketers

Table 2 presents the distribution and summary statistics of the variables used in the profit frontier model and is also classified by regions. It is clear from Table 2 that the actual amount of products marketed varies by per marketer as well as by region. Overall, the dominant product marketed is gari followed by cassava root tuber and starch. This is because gari is an important staple in this state and hence the market for gari trade is relatively large as compared to other high value processed products. At the individual marketer level, the actual marketing margin from trading in cassava and its products is substantially high but lowest in Delta Central. High marketing margin was made possible by

[5] Other cassava products such as chips and biscuits are not found to be traded by these marketers.

[6] In late September 2014, 100 Naira was approximately equivalent to £0.38, €0.47, and $0.61 (www.xe.com)

**Table 2:** Summary statistics of the variables used in the model (per marketer)

| Variables | Definition and measurement | Delta Central | Delta South | Delta North | Overall | |
|---|---|---|---|---|---|---|
| | | Mean | Mean | Mean | Mean | Standard deviation |
| **Products, marketing margin and prices** | | | | | | |
| Cassava root tuber | Quantity sold per marketer (kg) | 2235.87 | 2710.70 | 4617.30 | 3006.45 | 2326.65 |
| Gari | Quantity sold per marketer (kg) | 2189.70 | 4292.55 | 3960.92 | 3429.41 | 2575.93 |
| Fufu | Quantity sold per marketer (kg) | 245.02 | 421.35 | 1439.35 | 606.95 | 793.07 |
| Cassava starch | Quantity sold per marketer (kg) | 1871.28 | 578.87 | 626.92 | 1070.81 | 1907.36 |
| Tapioca | Quantity sold per marketer (kg) | 730.52 | 606.75 | 412.69 | 604.66 | 687.28 |
| Cassava flour | Quantity sold per marketer (kg) | 67.67 | 577.25 | 925.77 | 473.90 | 761.14 |
| Marketing margin | Profit per marketer (Naira) | 172608.90 | 235540.25 | 261159.00 | 218505.90 | 162998.20 |
| Sale price | Weighted average of six product sale prices (Naira per kg) | 84.49 | 87.52 | 82.29 | 85.09 | 28.34 |
| Purchase price | Weighted average of six product purchase prices (Naira per kg) | 52.45 | 52.79 | 51.46 | 52.58 | 15.55 |
| Marketing price | Weighted average of unit marketing cost of six products (Naira per kg) | 6.83 | 6.86 | 7.30 | 6.95 | 1.22 |
| **Socio-economic factors** | | | | | | |
| Education | Completed years of schooling (Years) | 6.54 | 6.42 | 5.04 | 6.12 | 4.22 |
| Marketing experience | Years of marketing cassava and cassava products (Years) | 11.41 | 15.88 | 12.31 | 13.33 | 8.56 |
| Age | Age of the marketer (years) | 37.69 | 44.45 | 45.19 | 42.12 | 12.85 |
| Main occupation | Dummy (1= if farmer, 0= otherwise) | 0.56 | 0.45 | 0.58 | 0.52 | -- |
| Credit facility | Dummy (1= if received credit, 0= otherwise) | 0.28 | 0.55 | 0.42 | 0.42 | -- |
| Gender | Dummy (1= if male, 0= otherwise) | 0.38 | 0.30 | 0.50 | 0.38 | -- |
| Subsistence pressure | Number of persons per household | 6.18 | 5.40 | 5.38 | 5.83 | 2.25 |
| Central Delta state | Dummy (1= if Central Delta, 0= otherwise) | 1.00 | -- | -- | 0.37 | -- |
| South Delta state | Dummy (1= if South Delta, 0= otherwise) | -- | 1.00 | -- | 0.38 | -- |
| North Delta state | Dummy (1= if North Delta, 0= otherwise) | -- | -- | 1.00 | 0.25 | -- |
| Number of observations | | 39 | 40 | 26 | 105 | |

large differences in the purchase and sale prices of individual products (Table 1). Such large difference still existed between the weighted average purchase price of six products (computed at N 52.58 per kg overall) and the weighted average sale price of six products (computed at N 85.09 per kg overall). The weighted average marketing cost per unit of product sold is only N 6.95 per kg and is slightly higher in Delta North at N 7.30 per kg.

The lower panel of Table 2 provides the summary statistics of the socio-economic characteristics of the marketers which also vary by regions to some extent. The average level of education is just above the primary level of 6.12 years, average age (or overall experience) is 42.1 years, 52% of the marketers are actually farmers, only 38% are male indicating that cassava marketing is largely a female affair, subsistence pressure (i.e., family size) is 5.8 persons per household, and 42% of the marketers had some access to credit which establishes the case of a lack of financial support for an apparently costly business. The access to credit is lowest for marketers in Delta Central where only 25% received any credit.

## Marketing efficiency of cassava and its products

One main limitation and/or criticism in applying a profit function model in a cross-section of data is the lack of variation in input and output prices. The geographical dispersion of the sampled marketers and imperfections in the markets in Nigeria ensure adequate variability in prices at any given point in time. However, a valid test is required to confirm this intuition. In our sample, both the purchase prices and the sale prices of cassava and cassava products varied widely across regions. Formal F-tests for differences in the purchase prices and sale prices of cassava and its products among the three regions rejected the null-hypothesis of 'no-difference' for most of the cases (except purchase prices of gari and fufu), thereby confirming that significant price variations exist in our sample, and hence, the application of the profit function model is justified (Table 3). In the model, the weighted average sale price per kg and purchase price per kg of six products was used (i.e., total value of sales divided by total quantity of all six products sold/purchased) which are also significantly different across regions (Table 3). These weighted average sale and purchase prices actually reflect true prices received and paid by the marketers. This is because not all marketers are involved in selling all six products. The weighted average price of marketing per kg (i.e., unit marketing cost), however, is not significantly different across regions.

 

**Table 3:** Test of hypothesis

| Hypothesis | Null-hypothesis | Test statistic | Critical value | Decision |
|---|---|---|---|---|
| **Prices do not vary across regions** | | | | |
| Purchase price of cassava | $H_0$: $P_{j11}=P_{j12}=P_{j13}=0$ | F-statistic | 11.20*** | Significant variation in prices across regions |
| Purchase price of gari | $H_0$: $P_{j21}=P_{j22}=P_{j23}=0$ | F-statistic | 0.86 | No significant variation in prices across regions |
| Purchase price of starch | $H_0$: $P_{j31}=P_{j32}=P_{j33}=0$ | F-statistic | 18.06*** | Significant variation in prices across regions |
| Purchase price of fufu | $H_0$: $P_{j41}=P_{j42}=P_{j43}=0$ | F-statistic | 0.20 | No significant variation in prices across regions |
| Purchase price of tapioca | $H_0$: $P_{j51}=P_{j52}=P_{j53}=0$ | F-statistic | 46.62*** | Significant variation in prices across regions |
| Purchase price of cassava flour | $H_0$: $P_{j61}=P_{j62}=P_{j63}=0$ | F-statistic | 11.43*** | Significant variation in prices across regions |
| Weighted average purchase price of all six crops | $H_0$: $P_{j1}=P_{j2}=P_{j3}=0$ | F-statistic | 2.71* | Significant variation in prices across regions |
| Sale price of cassava | $H_0$: $P_{y11}=P_{y12}=P_{y13}=0$ | F-statistic | 6.94*** | Significant variation in prices across regions |
| Sale price of gari | $H_0$: $P_{y21}=P_{y22}=P_{y23}=0$ | F-statistic | 2.68* | Significant variation in prices across regions |
| Sale price of starch | $H_0$: $P_{y31}=P_{y32}=P_{y33}=0$ | F-statistic | 76.50*** | Significant variation in prices across regions |
| Sale price of fufu | $H_0$: $P_{y41}=P_{y42}=P_{y43}=0$ | F-statistic | 26.03*** | Significant variation in prices across regions |
| Sale price of tapioca | $H_0$: $P_{y51}=P_{y52}=P_{y53}=0$ | F-statistic | 39.45*** | Significant variation in prices across regions |
| Sale price of cassava flour | $H_0$: $P_{y61}=P_{y62}=P_{y63}=0$ | F-statistic | 12.12*** | Significant variation in prices across regions |
| Weighted average sale price of all six crops | $H_0$: $P_{y1}=P_{y2}=P_{y3}=0$ | F-statistic | 2.80* | Significant variation in prices across regions |
| Weighted average unit marketing cost of all six products | $H_0$: $P_{m1}=P_{m2}=P_{m3}=0$ | F-statistic | 1.39 | No significant variation in prices across regions |
| Functional form test (Translog vs. Cobb-Douglas) | $H_0$: $\tau_{jk}=\phi_{kl}=\varphi_{lt}=0$ for all $j$, $k$, $l$, and $t$. | LR: $\chi^2(v,\ 0.95)$ 18.31 | 121.97*** | Translog model is appropriate |
| Frontier vs. OLS (i.e., no inefficiency component) | $H_0$: M3T=0 | z-statistic | 50.29*** | Frontier is appropriate, not OLS |
| Presence of inefficiency | $H_0$: $\gamma=0$ | LR: $\chi^2(v,\ 0.95)$ 3.84 | 175.13*** | Significant level of inefficiencies exist |
| Effect of socio-economic factors on marketing inefficiency | $H_0$: $\delta_1=\delta_2=\ldots.=\delta_7=0$ | LR: $\chi^2(v,\ 0.95)$ 14.07 | 26.65*** | Inefficiencies are jointly explained by these variables |

Note: *** significant at 1 percent level ($p<0.01$).
**significant at 5 percent level ($p<0.05$).
*significant at 10 percent level ($p<0.10$).

Table 4 presents the maximum likelihood estimation of the stochastic profit frontier jointly with inefficiency effects function. Prior to discussing the results, we report the series of hypothesis tests conducted to select the functional form and to decide whether the stochastic profit frontier model is an appropriate choice rather than an average profit function. We also test for the validity of the variables used to explain marketing inefficiency. The results are reported at the lower panel of Table 3.

The first test was conducted to determine the appropriate functional form, i.e., the choice between Cobb-Douglas vs. translog functional form ($H_0$: $\tau_{jk}=\phi_{kl}=\varphi_{lt}=0$ for all $j$, $k$, $l$, and $n$). Generalised Likelihood Ratio (LR) tests confirmed that the choice of translog profit function is a better representation of the true marketing structure. Once the functional form is chosen, next we checked the sign of the third moment and the skewness of the OLS (Ordinary Least Squares) residuals of the data in order to justify use of the stochastic frontier framework (and hence the Maximum Likelihood Estimation procedure). The computed value of Coelli's (1996) standard normal skewness statistic (M3T) based on the third moment of the OLS residuals is presented in Table 3 which is tested against $H_0$: M3T=0. The null hypothesis of 'no inefficiency component' is strongly rejected and, therefore, use of the stochastic frontier framework is justified. The coefficient of $\gamma$ reported at the bottom of Table 4 also strongly suggests presence of marketing inefficiency. The null hypothesis of 'no efficiency effects' (i.e., $H_0$: $\delta_1=\delta_2=\ldots=\delta_7=0$) is rejected at the 1% level of significance, implying that all these variables jointly have an influence on the marketing efficiency scores of individual marketers. Thus, a significant part of the variability in margin/profit among marketers is explained by the existing differences in the levels of allocative and scale inefficiency.

A total of 64% of the coefficients on the variables are significantly different from zero, implying satisfactory fit which was also supported by Wald Chi-square test

**Table 4:** Maximum likelihood estimates of the profit frontier function

| Variables | Parameters | Coefficients | t-ratio |
|---|---|---|---|
| **Profit function** | | | |
| Constant | $\alpha_0$ | 8.6018*** | 170.66 |
| ln Cassava purchase price (lnP'$_W$) | $\alpha_W$ | −1.6521*** | −6.90 |
| ln Marketing cost per unit (lnP'$_M$) | $\alpha_M$ | −0.3913*** | −72.87 |
| ½ (ln Cassava purchase price)$^2$ (lnP'$_W$)$^2$ | $\tau_{WW}$ | −4.6789*** | −5.26 |
| ½ (ln Marketing cost per unit)$^2$ (lnP'$_M$)$^2$ | $\tau_{MM}$ | −2.2187*** | −35.78 |
| ln Cassava purchase price * ln Marketing cost per unit (lnP'$_W$ * lnP'$_M$) | $\tau_{WM}$ | −0.2430 | −0.18 |
| ln Cassava purchase price * ln Education (lnP'$_W$ * lnZ$_E$) | $\phi_{WE}$ | 0.8523** | 2.26 |
| ln Cassava purchase price * ln Marketing experience (lnP'$_W$ * lnZ$_X$) | $\phi_{WX}$ | 1.0590*** | 63.12 |
| ln Marketing cost per unit * ln Education (lnP'$_M$ * lnZ$_E$) | $\phi_{ME}$ | −0.0178 | −0.48 |
| ln Marketing cost per unit * ln Marketing experience (lnP'$_M$ * lnZ$_X$) | $\phi_{MX}$ | 0.0903 | 0.87 |
| ln Education (lnZ$_E$) | $\beta_E$ | 0.0050 | 0.17 |
| ln Marketing experience (lnZ$_X$) | $\beta_X$ | 0.0154** | 1.96 |
| ½ (ln Education)$^2$ (lnZ$_E$)$^2$ | $\varphi_{EE}$ | −0.0071 | −0.25 |
| ½ (ln Marketing experience)$^2$ (lnZ$_X$)$^2$ | $\varphi_{XX}$ | −0.1614*** | −6.09 |
| ln Education * ln Marketing experience (lnZ$_E$ * lnZ$_X$) | $\varphi_{EX}$ | 0.1114*** | 2.55 |
| **Variance Parameters** | | | |
| $\sigma^2=\sigma_u^2+\sigma_v^2$ | $\sigma^2$ | 1.5571*** | 86.73 |
| $\gamma=\sigma_u^2/(\sigma_u^2+\sigma_v^2)$ | $\gamma$ | 0.99*** | 184.23 |
| Log likelihood | | | |
| **Inefficiency effects** | | | |
| Constant | $\delta_0$ | −1.3822 | −1.06 |
| Age | $\delta_1$ | 0.0081 | 0.40 |
| Main occupation is farming | $\delta_2$ | −1.4789*** | −2.79 |
| Gender | $\delta_3$ | −0.7490 | −1.32 |
| Credit received | $\delta_4$ | 0.1594 | 0.31 |
| Subsistence pressure | $\delta_5$ | 0.1239 | 1.05 |
| Central delta region | $\delta_6$ | 1.4266** | 2.46 |
| North delta region | $\delta_7$ | −1.4469* | −1.65 |
| Number of observations | | 105 | |

Note: *** significant at 1 percent level ($p<0.01$).
**significant at 5 percent level ($p<0.05$).
*significant at 10 percent level ($p<0.10$).

result. To be consistent with theory, we expect the signs of the price variables to be negative, i.e., rise in input prices reduce marketing margin. Although signs of the fixed factors cannot be determined *a priori,* we expect a positive influence of marketing experience and education on marketing margin. The significance of the interaction term implies that there are non-linearities in the marketing structure and hence justifies the use of translog profit frontier model.

Based on the estimates of the profit frontier function, we computed basic features of the marketing structure, namely, profit/marketing margin elasticities with respect to changes in variable input prices and fixed factors. All the price variables and the fixed factors are mean corrected ($P_{ij}-\overline{P}_j; Z_{il}-\overline{Z}_l$)so that the coefficients on the first order terms can be read directly as elasticity of marketing margin. Table 4 clearly shows that the signs of the coefficients on the price variables are negative, consistent with theory, and the fixed factors have the expected positive signs. The purchase price of cassava product has a dominant impact on the marketing margin. The value of the coefficient on purchase price is –1.65, which is the elasticity value and is substantial. The implication is that a 10% rise in purchase price of N 5.3 per kg of cassava and its products will reduce marketing margin by 16.5% estimated at N 36,053.5 per marketer. The marketing cost per unit also significantly influence marketing margin but the effect is relatively low, 0.39%. The sale price elasticity is computed as 3.04 (=1+1.65+0.39) and is the most dominant factor in improving marketing margin as expected[7]. The implication is that a 10% rise in sale price of N 8.5 per kg of cassava and its product will increase marketing margin by 30.4% estimated at N 66,425.8 per marketer. Marketing experience significantly improve marketing margin (0.02%) but education has no significant influence.

## Determinants of marketing efficiency of cassava and its products

Prior to the discussion of factors influencing marketing efficiency, we present the distribution of marketing efficiency scores of the marketers. The mean level of marketing efficiency is estimated at 55% implying that marketing margin can be substantially increased up to 45% by eliminating inefficiency arising out of inappropriate allocation of resources, response to prices and scale of operation. A total of 52.4% of the marketers are operating at efficiency level of up to 50% which explains the very low level of mean marketing efficiency of these marketers (Table 5).

A total of seven variables representing firm-specific socio-economic factors were used to identify the determinants of marketing inefficiency of cassava and its products. The lower panel of Table 4 presents the results. Results show that marketers whose main occupation is farming (i.e., farmers) are relatively efficient. Gender and subsistence pressure (i.e., family

[7] The sale price elasticity $\eta_p=1+\sum\eta_{wi}$ , where $\eta_{wi}$ is the *ith* purchase price elasticity.

 

**Table 5:** Distribution of marketing efficiency scores of cassava and cassava products

| Efficiency range | |
|---|---|
| Up to 50% | 52.4 |
| 51–60% | 12.4 |
| 61–70% | 1.9 |
| 71–80% | 6.7 |
| 81–90% | 5.7 |
| 91–100% | 21.0 |
| Efficiency measures | |
| Mean score | 0.55 |
| Standard deviation | 0.29 |
| Minimum | 0.02 |
| Maximum | 1.00 |
| Number of observations | 105 |

size) have no significant influence on marketing efficiency. Marketers located at the Northern Delta region are relatively efficient whereas those in Central Delta region are relatively inefficient relative to marketers in Southern Delta whose effects are subsumed in the constant term of the model.

## 4. Discussion and policy implications

The present study examines the level of marketing margin, marketing efficiency and its determinants of cassava and its products by applying a stochastic profit frontier approach on a survey data of 105 marketers from three regions of Delta State, Nigeria.

Results reveal that marketing margin per kg varies significantly across products and is highest for tapioca followed by cassava flour and lowest for cassava root tuber. The main contributor to marketing margin is the difference between the purchase and sale prices of the products, particularly those with advanced level of processing (e.g., tapioca). For example, the average marketing margin per kg of tapioca is N 124.93 whereas for cassava root tuber it is only N 5.19 per kg. This point towards the importance of processing cassava into its value added products to generate higher revenue for the processors as well as marketers. That is a high purchase price of processed products benefits processors/farmers whereas a high sale price of the products benefits marketers. However, on the other hand, Table 2 shows that the highest amount of product traded by each marketer is gari (3,429.4 kg). But marketing margin generated from selling gari is second lowest (Table 1), which is the most popular form of processed cassava. Therefore, the reason for its popularity may lie with the fact that trading in gari requires relatively less upfront investment as compared to other processed products (e.g., tapioca, flour), and yet generates three times more return as compared to selling raw cassava root tuber which requires no processing but is bulky and highly perishable. In fact, 86.5% of the marketers in the survey responded that the main source of their marketing capital is personal savings. This is because although 42% of marketers responded that they had access to some form of credit, the amount from such credit may have been highly inadequate or it was used for other purposes. Also, only 16% of cassava root tuber is processed for industrial use and/or export (Nweke, 2004) which in turn is dominated by gari perhaps.

A rise in the sale price of cassava products boost marketing margin whereas increases in purchase price of cassava products as well as unit marketing cost significantly reduce marketing margin, as expected. The responses to purchase and sale prices of cassava products are in the elastic range (i.e., profit elasticity –1.65 for purchase price and 3.04 for sale price of cassava products), implying that movements in cassava prices exert substantial influence on marketing margin. Rahman (2003) reported profit elasticities of –0.92 for a rise in input prices (a total of five inputs) and 1.92 for a rise in output price for rice production in Bangladesh.

Significantly positive influence of marketing experience on marketing margin implies that the trade of cassava products requires relevant skills and knowledge about the products acquired mainly through long years of experience. Therefore, any new entrants in this trade will need to overcome the lack of experience through training. Lack of significance of education on marketing margin reinforces the mixed influence of education on efficiency and/or productivity in the agricultural sector. For example, Aye and Mungatana (2011) found significant influence of education on maize production efficiency in Nigeria, but Gelan and Muriithi (2012) did not find any significant influence of education on dairy farm efficiency in East Africa. Also, Asadullah and Rahman (2009) found significant influence of education on rice productivity in Bangladesh but we did not find such influence on profitability in our results.

Results also show that the farmers as marketers are more efficient. The implication is that cassava farmers perform better than general traders in marketing of cassava products as they are well aware of the various aspects of the products, e.g., quality, colour, smell, moisture content, and other attributes. Gender of marketers has no influence on marketing efficiency implying that the relative efficiency of male or female marketers are same. Whether women are more or less efficient than men in farming is a hotly debated issue and results vary among the few studies that were undertaken in Africa during the 1990s (Adesina and Djato, 1997). For example, Adesina and Djato (1997), using a deterministic profit function analysis, concluded that the relative degree of farming efficiency of women is similar to that of men in Cote d'Ivoire, which conforms to our result. Also, marketers located in Central Delta state are relatively inefficient whereas those in North Delta are efficient relative to marketers in South Delta. The reasons may lie with respect to differences in prices, market structure and other unexplained factors. It was observed that the quantity of products traded, unit marketing cost, prices and gross margin are significantly lower in Central Delta region as compared with other two regions.

A number of policy implications can be drawn from this study. Although price for cassava and cassava prices in Nigeria are determined by market forces, high fluctuation in prices (both sale and purchase prices) indicates that the market is not functioning properly. Lack of marketing and processing facilities, inadequate marketing infrastructure, poor road network and transportation facilities were reported as the major constraints by these marketers. All of these factors adversely affect supply of cassava and its products coming to the market and may result in fluctuation in purchase and sale prices, marketing costs and marketing margin. Therefore improvements in marketing infrastructure will address these issues and also reduce unit marketing cost which will in turn improve marketing margin. Results also showed that marketing experience significantly improve profitability. One way to improve marketing experience is through building capacity of the marketers. Therefore, investment in training targeted at cassava and cassava product marketers will improve marketing margin. The aforementioned policies needs to be supplemented by region specific measures aimed at improving overall market functions so that the observed regional differences can be reduced.

Although meeting all these policy options are formidable, but effective implementation of these policy measures will increase profitability of marketing cassava and its products that could contribute positively to agricultural growth in Nigeria.

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REFEREED ARTICLE

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# Reducing nitrogen applications on Irish dairy farms: effectiveness and efficiency of different strategies

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**ABSTRACT**

In the EU, nitrate pollution from agriculture is regulated by a command and control approach – the Nitrates Directive, with which all member states are expected to comply. Nitrogen restrictions impose production constraints on some farms and can result in reductions in farm income. This paper employs positive mathematical programming (PMP) to estimate the impact of nitrogen restrictions on farm incomes among dairy farms in the Republic of Ireland. The paper also investigates if compliance with the Nitrates Directive in terms of nitrogen application rates would be achieved more effectively by regulation than by taxation. Results show that restrictions on nitrogen use under the Nitrates Directive Action Plan imposes a cost on intensive dairy farms with reductions in income ranging from 0.1% cent to 36%. Findings also show that the limits on applications of nitrogenous material on dairy farms in Ireland would be achieved more effectively and more equitably by regulation than by a uniform tax on nitrogen fertilizer. In some cases a tax on inorganic nitrogen is found to be an ineffective way of achieving the levels of organic nitrogen permitted under the Nitrates Directive.

**KEYWORDS:** Nitrates Directive; input taxes; regulations; effectiveness

## 1. Introduction

Nitrate pollution is a serious problem throughout the EU and agriculture is one of the main contributors to the problem (EEA, 2012). The regulation of nitrates on farms in the EU is governed by the 1991 Nitrates Directive[3], with which all member states are expected to comply. The consequences of the Nitrates Directive have been explored from a number of angles including acceptance by farmers (Buckley, 2012), spatial optimization (Van der Straeten *et al.*, 2010), changes in productivity (Piot-Lepetit and Le Moing, 2007) and effects on farm income (Rigby and Young, 1996; Rigby, 1997; Lally and Riordan, 2001; Hennessy, Shalloo and Dillon, 2005; Lally, Riordan and van Rensburg, 2009; Belhouchette *et al.*, 2011; Van der Straeten *et al.*, 2012). The main objective of the Nitrates Directive is to reduce nitrate concentrations to below an acceptable level of 50 mg/litre and in theory a number of policy instruments such as emission or input taxes and tradable permits could be used to achieve this ambient level of pollution. However, in practice regulations are applied which restrict the use of organic and inorganic nitrogen. These restrictions may limit other abatement opportunities for farmers and impose production constraints on some farms and can result in reductions in farm income.

A number of studies have been undertaken to compare different instruments in terms of achieving ambient levels of pollution such as those specified in the Nitrates Directive. For example, Hanley, Aftab and Black (2006) and Martínez and Albiac (2004) have used biophysical economic models which are quite complex and include highly developed nitrate leaching and hydrological models which are undertaken on a geographical or water catchment area level. At farm level a small number of studies have been conducted to evaluate the impact of different types of policy instruments aimed at reducing nitrogen application rates and nutrient leaching (Berentsen and Giesen, 1994; Lally and Riordan, 2001; Picazo-Tadeo and Reig-Martínez, 2007; Semaan *et al.*, 2007; Fezzi *et al.*, 2008; Lally, Riordan and van Rensburg, 2009). However, studies that consider different instruments in terms of achieving the specific aims of the Nitrates Directive at farm level are rare. Some preliminary work on this topic has been conducted in Ireland (Lally, Riordan and van Rensburg, 2009), although this was confined to a small sample of specialist dairy farms located in the Munster region of Ireland. This present work is nationally representative and allows for a more comprehensive treatment of the effectiveness of regulatory and tax instruments in achieving the specific targets relating to nitrogen

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[3] The main objective of the EU Nitrates Directive (*Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources* (91/676/EEC)) is to reduce nitrate concentrations to below an acceptable level of 50 mg/litre. Under the Directive each member state must implement an Action Plan that ensures that the applications of nitrogen to farmland are within limits calculated to avoid a level of nitrate emissions to water supplies that would put them above the concentration level specified in the Directive. The premise of the Action Plan is that farmers should take all reasonable steps to prevent or minimise the application to land of fertilisers in excess of crop requirements.

application rates as set out in Ireland's National Action Programme. To our knowledge this is a novel exercise and the results reveal some new findings. In particular, this study shows that a tax on inorganic nitrogen may not always be effective in achieving the objectives of the Nitrates Directive in terms of nitrogen application rates.

The objectives of this paper are as follows:

1. To estimate the impact on farm incomes of restrictions on nitrogen use, as specified in the National Action Plan (NAP) under the Nitrates Directive, on dairy farms in the Republic of Ireland;
2. To evaluate the hypothesis that the limits on applications of nitrogenous materials on farms in Ireland as specified in the NAP would be achieved more effectively by regulation than by taxation.

The structure of the paper is as follows: the next section reviews the literature on measures to deal with nitrate emissions from agriculture; this is followed by a description of the methodological approach and an outline of the Irish NAP under the Nitrates Directive; results are then presented and a discussion and conclusions follow.

## 2. Background

Nitrate emissions from agriculture are diffuse in nature and follow a complex pathway through the hydrological system, making them very difficult to monitor. For this reason taxes or quotas on emissions, the standard economic approaches to pollution control problems, cannot be applied or cannot be applied at a reasonable cost. Instead policy makers are forced to rely on second-best policy instruments such as input taxes and input regulations. Ideally, such measures should be based on individual farmers' non-point pollution production functions. However, non-point pollution production functions are (i) often not known and (ii) likely to vary across farms, making it impractical for policy makers to apply pollution production function related measures. They are often therefore forced to rely on uniform measures as a means of dealing with nitrate emissions from agriculture. Helfand and House (1995) considered a number of uniform measures for dealing with non-point pollution and found that they do not lead to large losses in welfare relative to the least cost solution.

Many studies have been undertaken over the last twenty years to evaluate different uniform instruments in terms of achieving reductions in nitrogen use and nitrate emissions in different regions and in different farming systems. Examples of studies undertaken at regional level include Wu & Babcock (2001), Whittaker *et al*. (2003), Martínez and Albiac (2006), and O'Shea and Wade (2009).

Studies at farm level can be divided into two categories, those that evaluate the impact of a particular type of instrument and those that compare different instruments. Lally and Riordan (2002) and Hennessy, Shalloo and Dillon (2005) evaluate the impact on Irish dairy farm incomes of restrictions on organic nitrogen use. Picazo-Tadeo and Reig-Martínez (2006) evaluate the impact on Spanish citrus farmers' income of a mandatory reduction in nitrogen application while a number of other studies evaluate the environmental and economic consequences of a particular type of instrument (Berentsen and Giesen, 1995; Rigby and Young, 1996; Berntsen *et al*., 2003; Belhouchette *et al*., 2011).

A small number of studies have evaluated different types of policy instruments at farm level. Berentsen and Giesen (1994) evaluate the impact of different policies, including restrictions on nitrogen use and a levy on nitrogen inputs, to reduce nitrogen applications on Dutch dairy farms. Lally and Riordan (2001) estimate the impact on Irish dairy farm incomes of restrictions on nitrogen use and of a 10% tax on nitrogen inputs. Picazo-Tadeo and Reig- Martínez (2007) assess the impact on Spanish citrus farmers' income of two policies aimed at reducing consumption of inorganic nitrogen – levies on purchased nitrogen and nitrogen use permits for farms. Semaan *et al*. (2007) uses a bio-economic model to analyse the effects of three agricultural policies on farmers' revenue and nitrate leaching in the Apulia region of Southern Italy and Fezzi *et al*. (2008) assess the economic impact on UK farms of four nutrient leaching policies.

All of the above studies have evaluated the impact of different instruments from an economic and/or environmental perspective at either farm or regional level. This study compares the cost and effectiveness of (i) input regulations and (ii) a tax on inorganic nitrogen, as means of achieving the objectives of the Nitrates Directive in terms of permitted nitrogen use, on a sample of 30 case study Irish dairy farms.

## 3. Materials and methods

### Methodology

Positive mathematical programming (PMP) is used in this study to evaluate the effects of restrictions on nitrogen applications on dairy farm incomes. PMP is a methodology used to calibrate linear programming models. Linear programming (LP) models should calibrate against a base year or an average over several years in order to be useful for policy analysis (Howitt, 1995). However, in general, the optimal solutions tend to be overly specialized and do not conform to the number and level of realized activities observed on the farms under investigation. In addition analyses based on such results that deviate substantially from observed production quantities are not very useful for policy making and are unlikely to be accepted by elected decision-makers.

PMP allows exact calibration of a model solution to observed quantities, and constrains the simulation behaviour of the models less severely than previously employed approaches. These two properties have led to a significant interest and a continuing implementation of this approach in the area of agricultural sector modelling and it has been used by Arfini (1996), Röhm and Dabbert (2003), Buysse *et al*. (2007), Kan *et al*. (2009), Gallego and Gomez-Limon (2008), Gallego-Ayala and Gomez-Limon (2009), Fragoso *et al*. (2011), and Howitt *et al*. (2012).

The idea of PMP originated from the observation that unit costs recorded in farm accounts do not reflect the true cost of production. Farmers' production decisions are based on the costs recorded in farm accounts and other unobserved costs which may be due to technology, environment, risk etc. 'The observed levels of outputs, therefore, are the result of a complex decision based, in large part, on a cost function known to (or perceived by) the entrepreneur but difficult to observe directly. Furthermore, as the cost function is the dual to the production function, the recovery of the former is a perfect substitute for a detailed specification of the latter' (Paris, 1997).

PMP methodology consists of two stages – calibration and simulation. The calibration stage involves estimating or recovering a cost function, which takes the place of the hidden unobservable cost function used (either explicitly or implicitly) by the entrepreneur for making her decisions. This stage of the PMP methodology calibrates the model in such a way that it is capable of reproducing the base-period results. The prediction stage of PMP uses the calibrated model to generate responses in the endogenous variable induced by variations of some relevant parameters.

'The general idea of PMP is to use information contained in dual variables of calibration constraints which bound the LP problem to observed activity levels (Phase 1). These dual variables are used to specify a non-linear objective function such that observed activity levels are reproduced by the optimal solution of the new programming problem without bounds (Phase 2)' (Heckelei & Britz, 2005).

Phase 1 involves running a linear programming model with calibration constraints which bound activity levels to observed levels:

$$\begin{aligned} &\operatorname{Max}_{x} Z = p'x - c'x \\ &\text{subject to} \\ &Ax \leq b\ [\lambda] \\ &x \leq x^0\ (1+\varepsilon)\ [\rho] \\ &x \geq [0] \end{aligned} \quad (1)$$

where:

$Z$= objective function value, $p$=$(n \times 1)$ vector of product prices, $x$=$(n \times 1)$ vector of production activity levels, $c$=$(n \times 1)$ vector of variable cost per unit of activity, $A$=$(m \times n)$ matrix of coefficients in resource constraints, $b$=$(m \times 1)$ vector of available resource constraints, $x^0$=$(n \times 1)$ vector of observed activity levels, $\varepsilon$=$(n \times 1)$ vector of small positive numbers, $\lambda$= dual variables associated with the resource constraints and $\rho$= dual variables associated with the calibration constraints.

Adding calibration constraints to a linear programming model forces the optimal solution of the model to exactly reproduce the observed base year activity levels $x^0$, 'given that the specified resource constraints allow for this solution' (Heckelei and Britz, 2000). A perturbation parameter, $\varepsilon$, is included to guarantee that all binding resource constraints of the original model remain binding in the extended model.

At least one level of activity in the LP model is bounded solely by one of the fixed resource constraints and not by its calibration constraint. Therefore the 'vector $x$ can be divided into a vector or preferable activities $(x^p)$ bounded by the calibration constraints, and a vector of marginal activities $(x^m)$, which are constrained by the resource constraints' (Fragoso, Carvalho and Henriques, 2008). Assuming all elements in $x^0$ are non-zero and all resource constraints are binding, 'the Kuhn-Tucker conditions imply that:

$$\rho^p = p^p - c^p - A^{p'}\lambda \quad (2)$$

$$\rho^m = [0] \quad (3)$$

$$\lambda = (A^{m'})^{-1}(p^m - c^m) \quad (4)$$

The dual values of the calibration constraints are zero for marginal activities $(\rho^m)$, as shown in (3) and equal to the difference of price and marginal cost for preferable activities $(\rho^p)$, as seen in (2) the latter being the sum of variable cost per activity $(c)$ and the marginal cost of using fixed resources $(A^p\lambda)$.

In Phase 2 of the procedure, the dual values of the calibration constraints, $\rho^p$, are employed to specify a non-linear objective function, such that the marginal costs of the preferable activities are equal to the respective price at the base year observed activity levels, $x^0$' (Heckelei and Britz, 2005). For computational simplicity, a quadratic cost function is usually employed.

$$C^v = d'x + \tfrac{1}{2}x'Qx \quad (5)$$

where:

$d$=$(n \times 1)$ vector of parameters associated with the linear term and

$Q$=$(n \times n)$ symmetric, positive semi-definite matrix of parameters associated with the quadratic term.

The parameters are then specified such that the linear 'marginal variable cost' $(MC^v)$ functions fulfil:

$$MC^v = \frac{\partial C^v(x^0)}{\partial x} = d + Qx^0 = c + \rho \quad (6)$$

The standard specification solves the problem of the quadratic cost function by letting $d$=$c$ and setting all off-diagonal elements of the Q matrix equal to zero. The $n$ diagonal elements of $Q$, $q_{ii}$, can then be calculated as:

$$q_{ii} = \frac{p_i}{x_i^0} \text{ for all } i = 1, \ldots\ldots, n \quad (7)$$

The final nonlinear programming problem that is exactly calibrated to base year activity levels is

$$\begin{aligned} &Max_{x}\ Z = px - cx - \tfrac{1}{2}\, x'Qx \\ &\text{subject to :} \\ &Ax \leq b\ [\lambda] \\ &x \geq [0] \end{aligned} \quad (8)$$

PMP models are useful for policy analysis but also have some limitations. One limitation is that activities whose initial observed value is zero during the reference period are not included in the models. This means that the models do not allow farms to switch to such activities, such as renting in land, when faced with policy changes such as restrictions on nitrogen use.

## Farm models

The PMP models calibrate the base period results on the 30 case study farms. The models are then used to predict the impact on farm incomes of (i) restrictions on organic and inorganic nitrogen and (ii) a tax on inorganic nitrogen.

PMP models are based on an objective function which is optimised subject to a number of constraints. It is assumed that dairy farmers maximize profits. Therefore the objective function in the PMP models is the maximization of total gross margin subject to a number of constraints. Overhead costs are then deducted from total gross margin to estimate farm income.

A number of production activities are included in the objective function. The number of livestock activities included in the farm models varies between three and five depending on the farms. Dairy is the main activity while all farms also have an additional and separate cattle activity. The cattle activity is determined according to age category and according to male or female animals in some cases. Feed production (grass and silage) and the purchase of fertilizers and concentrates are included as separate activities. The feed production activities are a piecewise linear combination, representing the effect of nitrogen on grass and silage production at different levels of application[4]. The costs of grass and silage production at different nitrogen application rates are included in the objective function. The amount of nitrogen used on farm and the amount of concentrates purchased are determined within the model and so the costs are included in the objective function.

Farmers are limited in their production levels by a number of constraints and these are included in the farm models. The two most important constraints are land availability and the milk quota. Land availability places a physical limit on the amount of land available for grass and silage production, which largely determines the number of animals that can be maintained on farm. In the model it is assumed that all land is owned and no land is rented in or out. Irish dairy farms are limited in their production levels by the milk quota. The milk quota is equal to quota owned plus quota leased.

The following additional constraints are included in the model. A herd replacement balance constraint ensures that a minimum number of calves required for the replacement of the dairy herd are maintained on farm.

In Ireland most or all of the grass and silage fed to animals is produced on farm. Therefore a grass supply balance constraint is also included in the model. This ensures that the amount of grass and silage produced is sufficient to feed the number of animals on the farm.

There is little or no hired labour on the farms being considered in this study and therefore a labour constraint is included in the farm models. A number of feed requirement constraints for grass, silage and concentrates are included in the model to ensure that the minimum feed requirements for the animals are satisfied and to ensure that the maximum feed allowances are not exceeded[5].

### Study area and farms

Thirty case study specialist dairy farms located throughout the Republic of Ireland are considered in this study. Two independent techniques were used for data collection. First, data was obtained from the National Farm Survey (NFS) conducted by Teagasc[6] in 2006[7]. The NFS is collected annually as part of the Farm Accountancy Data Network (FADN) requirements of the European Union (FADN 2013). The sample is weighted to be representative of farming nationally across Ireland. Interviews are conducted with farmers on site by a team of trained NFS recorders. Second, a sample of 313 specialist dairy farms from the 2006 survey was selected for analysis and 75 of those farms, representing 4,639 farms, were found to exceed the 170 kg/ha limit on organic nitrogen application specified in the Nitrates Directive. Twenty one of the 75 farms, representing 1,310 farms, exceeded the limit of 170 kg/ha by a very small amount and were excluded from the study. Excluding those farms, farms with sheep and horse enterprises and outliers meant a sample of 30 case study farms, which applied in excess of 180 kg/ha organic nitrogen were selected for analysis. These 30 farms represent 1,681 dairy farms. NFS economic and structural data was used to calibrate the PMP farm models to the base period results, and those calibrated models were then used to estimate the impact on farm incomes of restrictions on nitrogen use and of a tax on inorganic nitrogen[8].

## 4. Ireland's Action Plan under the Nitrates Directive

Ireland's first NAP commenced on a phased basis on 1st January 2006, and ran for a period of four years. The plan was subsequently reviewed and extended in 2010, and again in 2013. Under the Plan farmers are required to comply with the regulations set out in the legislation[9] including restrictions on organic and inorganic nitrogen use as specified below:

1. The amount of livestock manure applied in any year to land on a holding, together with that deposited on land by livestock, cannot exceed an amount containing 170 kg nitrogen per hectare.
2. The amount of inorganic N that farmers can apply is estimated based on:

   a) a farm's stocking rate as expressed in terms of their expected emission of nitrogen in urine and faeces per hectare per year;
   b) the prescribed nitrogen availability (%) rates from managed livestock manure applied in the year of application; and

[4] Observed fertiliser response data and a quadratic function are used to estimate the relationship between fertiliser application rates and grass and silage yields. This estimated function is then used to calculate grass and silage yields at different nitrogen application levels, using linear incremental increases of 25 kg/ha (See Appendix). This information is then incorporated into the farm models in order to capture the relationship between nitrogen applications and grass and silage production which impacts on the carrying capacity of the farms.

[5] The feed constraints included in the models are based on the farm data and on advice from Teagasc advisors.

[6] Weights used are based on the sample number of farms and the population number of farms (from the Census of Agriculture) in each farm system and farm size category. The sample number of observations by size/system is simply divided by the population number of observations by size/system to get the weights that make the sample representative of the actual farming population. The method is based on the EU FADN typology – see Commission Decision 78/463.

[7] 2006 data is used as it coincides with the implementation of the Ireland's first NAP.

[8] Variable costs, labour costs and overhead costs are drawn from the farm data. Prices are drawn from the farm data and from Management Data for Farm Planning, a planning guide published by Teagasc.

[9] S.I. No. 31 of 2014 European Union (Good Agricultural Practice for Protection of Waters) Regulations 2014.

c) The length of the winter housing period on the farm. In this study we assume an average winter housing period of 18 weeks.

Farms with a winter housing period of 18 weeks and a grassland stocking rate of 170 kg/ha can apply a maximum of 202 kg inorganic nitrogen per hectare.[10]

Under the Nitrates Directive member states can apply to the European Commission for a derogation to go beyond the livestock manure limit of 170 kg nitrogen per hectare specified in the Directive. Ireland applied for a derogation in 2004 and it was granted in 2007 (OJEU, 2007). This allows individual farms with at least 80% grassland (on application to DAFM) to apply livestock manure up to a maximum of 250 kg per hectare, subject to strict conditions. Farms must apply for a derogation on an annual basis. The European Commission approved renewal of the derogation in 2011 (OJEU, 2011) and it ran until the end of 2013. Ireland has requested a further renewal of the derogation and is awaiting approval from the European Commission.

## 5. Results

All 30 farms considered in this study could potentially apply for a derogation. Seventeen of the 30 farms are within the application limits permitted for both organic and inorganic nitrogen under the derogation, two exceed the application limit for organic nitrogen (250 kg/ha) (Table 1) and the remaining 11 exceed the limit permitted for inorganic nitrogen only. Hence, 17 farms would be unaffected if granted a derogation, two would have to adjust their stocking levels and 11 would have to reduce their use of inorganic nitrogen. Given that the majority of the farms would be unaffected if granted a derogation this paper focuses on estimating the impact on all 30 farms if they could not qualify for a derogation and had to comply with the limits on organic and inorganic nitrogen set out in the NAP.

Of the 30 farms considered, 18 exceeded the limits set out in the NAP on the application of both organic (170 kg/ha) and inorganic nitrogen (202 kg/ha), and the remaining 12 exceeded the limit on organic nitrogen only (Table 1).

In order to estimate the impact on farm incomes of restrictions on nitrogen application rates as specified in the NAP all 30 farms models were run with restrictions on the use of organic and inorganic nitrogen of 170 kg/ha and 202 kg/ha respectively. Restrictions on organic nitrogen use alone leads to a reduction in the quantity of inorganic nitrogen applied on all 30 farms (Table 2) and in 28 cases this reduction brings the farms into compliance with the restrictions on inorganic nitrogen use[11]. The average reduction in inorganic nitrogen applications across all 30 farms is 120 kg/ha or 51%.

**Table 1:** Baseline application rates of organic and inorganic nitrogen (kg/ha) on the selected farms

| Farm | Organic nitrogen | Inorganic nitrogen |
|---|---|---|
| 1 | 227 | 344 |
| 2 | 208 | 258 |
| 3 | 226 | 313 |
| 4 | 236 | 311 |
| 5 | 193 | 226 |
| 6 | 193 | 171 |
| 7 | 191 | 282 |
| 8 | 191 | 231 |
| 9 | 197 | 160 |
| 10 | 204 | 260 |
| 11 | 184 | 147 |
| 12 | 243 | 355 |
| 13 | 229 | 300 |
| 14 | 204 | 204 |
| 15 | 229 | 308 |
| 16 | 202 | 155 |
| 17 | 213 | 286 |
| 18 | 230 | 308 |
| 19 | 224 | 177 |
| 20 | 220 | 236 |
| 21 | 261 | 139 |
| 22 | 216 | 196 |
| 23 | 192 | 121 |
| 24 | 184 | 220 |
| 25 | 205 | 337 |
| 26 | 284 | 135 |
| 27 | 189 | 186 |
| 28 | 197 | 134 |
| 29 | 181 | 328 |
| 30 | 191 | 200 |
| Average | 211 | 234 |
| Minimum | 181 | 121 |
| Maximum | 284 | 355 |

The restriction on organic nitrogen leads to a reduction in the number of animals on all farms which in turn leads to a reduction in the overall feed requirements. As a significant amount of the feed comes from grass and silage the inorganic nitrogen application falls as the number of animals falls.

Close inspection of column four shows that all farms experience a reduction in family farm income, ranging from 0.1% to 36%, with an average reduction of 7.9%. The reduction in farm income is most pronounced for the farms which are most intensive in terms of organic nitrogen applications, and which have to reduce the size of their dairy herd in order to comply with the restriction on organic nitrogen application rates. Eleven farms reduce the size of their dairy herd in order to comply with the restriction. While all farms considered experience a reduction in farm income due to the restriction on organic nitrogen of 170 kg/ha, it is possible for farmers to apply for a derogation which would allow them to farm up to 250 kg organic nitrogen per hectare.

### A tax on inorganic nitrogen

A further goal of the paper is to establish if the limits on applications of nitrogenous materials on farms in Ireland would be achieved more effectively by regulation than by taxation. To this end, the study estimates the rate of *ad valorem* tax on inorganic nitrogen required to move organic and inorganic nitrogen applications on

[10] The amount of inorganic nitrogen farms can apply is calculated using the following formula: Available nitrogen (kg/ha) – ((Grassland stocking rate (kg/ha)/no. of weeks in the year) x (weeks storage required) x appropriate nitrogen availability from livestock manure)). For a farm with a winter housing period of 18 weeks and a grassland stocking rate of 170 kg/ha the amount of inorganic nitrogen it can apply per hectare is calculated as follows: 226 – ((170/52) x 18 x 0.4) = 226 – 24 = 202. This calculation is based on the assumption that farms do not export organic manure.

[11] With the restrictions on both organic and inorganic nitrogen all farms with the exception of farm 29 applies 170 kg organic nitrogen per hectare. For Farm 29, the restriction on inorganic nitrogen applications results in a lower than permitted application rate of organic nitrogen at 161 kg/ha.

 

**Table 2:** Nitrogen application rates (kg/ha) and percentage changes in family farm income under the Nitrates Directive Action Plan

| Farm | Inorganic Nitrogen (kg/ha) | Change in inorganic N (kg/ha) % | Change in family farm income (%) |
|---|---|---|---|
| 1 | 113 | −67.3 | −12.8 |
| 2 | 113 | −56.1 | −10.2 |
| 3 | 167 | −46.6 | −7.9 |
| 4 | 91 | −70.7 | −19.7 |
| 5 | 175 | −22.5 | −1.6 |
| 6 | 110 | −35.7 | −2.6 |
| 7 | 165 | −41.6 | −1.7 |
| 8 | 159 | −31.2 | −1.5 |
| 9 | 106 | −33.8 | −6.2 |
| 10 | 113 | −56.5 | −8.0 |
| 11 | 104 | −29.0 | −0.2 |
| 12 | 66 | −81.5 | −35.9 |
| 13 | 136 | −54.6 | −7.8 |
| 14 | 81 | −60.5 | −5.6 |
| 15 | 131 | −57.5 | −1.6 |
| 16 | 69 | −55.3 | −1.7 |
| 17 | 119 | −58.3 | −3.8 |
| 18 | 135 | −56.1 | −4.5 |
| 19 | 44 | −75.0 | −9.9 |
| 20 | 47 | −80.2 | −9.8 |
| 21 | 49 | −64.4 | −34.1 |
| 22 | 114 | −42.0 | −8.1 |
| 23 | 76 | −37.1 | −1.7 |
| 24 | 170 | −22.6 | −1.3 |
| 25 | 202 | −40.1 | −5.3 |
| 26 | 0 | −100 | −28.8 |
| 27 | 147 | −20.9 | −0.1 |
| 28 | 99 | −26.0 | −0.8 |
| 29 | 202 | −38.5 | −1.8 |
| 30 | 118 | −40.8 | −0.6 |
| Average | 114 | −50.1 | −7.9 |

all 30 farms to within the limits specified in the NAP. The findings show that (i) the level of taxation required to incentivise compliance differs between farms and (ii) a tax is ineffective in reducing the application of organic nitrogen to the limits permitted on nine of the 30 farms. The average tax rate required to bring the other 21 farms into compliance with the restrictions on organic and inorganic nitrogen is 101 per cent. The lowest rate required is 15% and the highest is 239% (Table 3). This is in line with the findings of an earlier study by Lally, Riordan and van Rensburg (2009).

Excluding the nine farms which are ineffective to the tax the results for the 21 remaining farms show that a tax on inorganic nitrogen imposes a much larger compliance cost on farmers than does regulation of nitrogen use. The last two rows in column six show that the average reduction in farm income under regulation of nitrogen use is 3.8% while with the ad valorem tax the average reduction is 11.7%. The ad valorem tax results in a transfer to the government which on average is equivalent to 53% of the reduction in farm income.

For nine farms a tax on inorganic nitrogen is ineffective in achieving an organic nitrogen application rate of 170 kg/ha as specified in the NAP. The rates at which the tax becomes ineffective in reducing organic nitrogen applications range from 54% to 275% as outlined in Table 4.

On average these nine farms have higher incomes and a higher number of dairy cows than the other 21 farms for which the tax is effective. This may explain why the tax is ineffective for these farms. In order to comply with the restriction of 170 kg/ha organic nitrogen under the regulation scenario the first seven farms have to reduce the size of their dairy herd. Dairy is the most profitable activity on all farms considered in this study and therefore farms will not reduce the size of their herd unless absolutely necessary. With the regulation the seven farms have no choice but to reduce their dairy herd, but with the tax they have more flexibility. With the tax they reduce the amount of cattle on the farm (as they do with the regulation) but they do not reduce the number of dairy cows. As dairy cows are more profitable farms absorb the high rates of tax rather than reduce the size of the dairy herd and as a result organic nitrogen application rates continue to exceed those permitted under the regulation. A tax therefore may be an ineffective method of achieving the permitted application levels of organic nitrogen on farms which would have to reduce their dairy herd under a command and control system of regulation.

For the 21 farms where the tax is effective, the least costly method of achieving compliance with the restrictions on nitrogen use through taxation would be to impose individualised tax rates on each farm with no tax being imposed on farms already in compliance with the directive. This, however, would be administratively expensive and ineffective. In practice, a uniform *ad valorem* tax on sales of nitrogenous fertiliser would have to be applied. Applying a uniform tax rate of 101 per cent (the average effective tax rate) would over penalise 12 of the 21 farms, and would not be fully effective for the other nine farms. These nine farms would reduce their applications of organic and inorganic nitrogen but would not be in compliance with the limits specified in the Action Plan. For the nine farms where a tax is ineffective, farm incomes and inorganic nitrogen applications would fall with little or no impact on the applications of organic nitrogen.

## 6. Discussion

This study set out to explore the impact of restrictions on nitrogen use on Irish dairy farm incomes under the Irish NAP. The results show that restrictions on nitrogen use under the Nitrates Directive Action plan imposes a cost on dairy farms with reductions in income ranging from 0.1% to 36%. A further goal of the study was to see if the limits on applications of nitrogenous materials on farms in Ireland would be achieved more effectively by regulation than by taxation. The results indicate that in some cases a tax on inorganic nitrogen is ineffective in achieving the objectives of the NAP in terms of the application of organic nitrogen. In those cases the farms will absorb the cost of the tax, rather than reduce the size of their dairy herd and thereby their level of organic nitrogen.

Demand for inorganic nitrogen is very inelastic and the 21 case study farms where a tax is effective show that a very substantial tax, up to 239%, would be required in order to achieve compliance with the nitrogen application rates specified in the NAP. Ongoing research and analysis would be required to ensure that the tax, if deemed an effective instrument, is set at the appropriate

**Table 3:** Nitrogen application rates (kg/ha) and changes in family farm income with a tax on inorganic nitrogen

| Farm | Tax rate required to achieve compliance (%) | Organic Nitrogen (kg/ha) | Inorganic Nitrogen (kg/ha) | Change in inorganic N (kg/ha) (%) | Change in family farm income (%) |
|---|---|---|---|---|---|
| 1 | 143 | 167 | 89 | −74.1 | −26.7 |
| 3 | 141 | 168 | 65 | −79.2 | −31.8 |
| 5 | 62 | 168 | 100 | −55.7 | −7.5 |
| 6 | 70 | 170 | 97 | −43.1 | −9.9 |
| 8 | 65 | 170 | 124 | −46.2 | −7.1 |
| 9 | 239 | 170 | 48 | −70.3 | −19.3 |
| 11 | 27 | 161 | 63 | −56.9 | −1.6 |
| 13 | 181 | 170 | 81 | −73.0 | −17.7 |
| 14 | 149 | 170 | 71 | −65.4 | −12.5 |
| 15 | 96 | 170 | 129 | −58.2 | −6.9 |
| 16 | 99 | 170 | 61 | −60.5 | −5.1 |
| 17 | 136 | 170 | 104 | −63.5 | −10.8 |
| 18 | 109 | 168 | 117 | −62.0 | −12.3 |
| 20 | 174 | 170 | 45 | −81.1 | −18.1 |
| 23 | 70 | 164 | 44 | −63.4 | −4.8 |
| 24 | 61 | 170 | 148 | −32.4 | −9.8 |
| 25 | 150 | 161 | 119 | −64.8 | −25.8 |
| 27 | 15 | 166 | 105 | −43.2 | −1.9 |
| 28 | 58 | 170 | 52 | −61.4 | −5.2 |
| 29 | 55 | 161 | 202 | −38.6 | −6.4 |
| 30 | 28 | 168 | 111 | −44.5 | −4.0 |
| Average | 101 | 168 | 94 | −58.9 | −11.7 |
| Average with restrictions on organic and inorganic nitrogen applications | | 170 | 127 | −43.6 | −3.8 |

level. The appropriate level could change over time for a number of reasons, including changes in price levels and farming practices and structures. Dairy is the most profitable enterprise on the farms considered and further expansion in the dairy sector is expected when milk quotas are abolished in 2015. The profitability of the dairy sector in the future may have a significant impact on the effectiveness of a tax and on the rate at which it would be effective.

Where a tax on inorganic nitrogen is effective in achieving the application rates of organic and inorganic nitrogen specified in the NAP it imposes a much larger compliance cost on the case study farms than does regulation of nitrogen application rates. The tax would also be inequitable as farms already in compliance with the NAP would incur substantial losses in family farm income.

Reaction to policy changes depends on marginal changes in costs and in this study the changes in fertiliser cost due to the tax are quite substantial and are far removed from the baseline. Using the PMP models to predict the impact of such large changes in fertiliser costs may lead to some potential bias in the results. However, the results are useful in providing an indication of how farmers may react to a tax on inorganic nitrogen and they show that demand for nitrogen is inelastic, a finding that is consistent with studies by Breen *et al.*, (2012), Boyle (1982), Higgins (1986) and Burrell (1989).

As well as considering the compliance cost and effectiveness of the two measures considered in this study it is also important to consider the administrative cost of the measures.

The administrative cost of enforcing the regulations on nitrogen applications as specified in the Irish NAP should not be particularly large for two reasons. Firstly, the restrictions on organic nitrogen are relatively easy to enforce as data on livestock numbers on all farms in the

**Table 4:** Nitrogen application rates (kg/ha) and changes in family farm income with a tax on inorganic nitrogen

| Farm | Rate at which tax becomes ineffective in reducing organic nitrogen applications (%) | Organic Nitrogen (kg/ha) | Inorganic Nitrogen (kg/ha) | Change in inorganic N (kg/ha) (%) | Change in family farm income (%) |
|---|---|---|---|---|---|
| 2 | 54 | 190 | 179 | −30.4 | −3.2 |
| 4 | 67 | 202 | 181 | −41.9 | −5.5 |
| 10 | 180 | 174 | 125 | −51.8 | −17.1 |
| 12 | 121 | 217 | 207 | −41.8 | −12.8 |
| 19 | 105 | 187 | 66 | −63.0 | −5.8 |
| 21 | 159 | 214 | 0 | −100.0 | −24.2 |
| 26 | 275 | 214 | 1 | −99.3 | −12.1 |
| 7 | 67 | 172 | 171 | −39.5 | −5.3 |
| 22 | 67 | 217 | 160 | −18.3 | −4.1 |
| Average | 122 | 199 | 121 | 54 | 10.1 |

 

country are already recorded as part of the Cattle Movement Monitoring System (CMMS) and these are related to farm records for the making of direct payments to farms. Secondly, under the NAP all farms are required to comply with the regulations set out in the legislation. Enforcement takes the form of spot checks, a system that is already used under a system of cross compliance. Farmers subject to a spot check must be found to be in compliance with the legislation in order to receive their single farm payment. Under the legislation, farmers are required to keep records of (i) their nitrogen purchases and (ii) the dates and times of applications of chemical and organic nitrogen. As farmers may be subject to inspection under a spot check there is a strong incentive for them to comply with the restrictions on inorganic nitrogen use.

The results of this research indicate that in some cases, a tax may be an ineffective means of achieving the objectives of the Nitrates Directive in terms of the application of organic nitrogen. Therefore, a tax on inorganic nitrogen would have to be complemented with a restriction on organic nitrogen use, increasing both the compliance cost to farmers and the administrative cost. Combining a tax with restrictions on organic nitrogen use would over penalise farmers and it would be unnecessary, as the restriction on organic nitrogen application rates alone would bring 93 per cent of the farms into compliance with the restriction on inorganic nitrogen use.

Collection of the tax alone would not automatically ensure compliance with restrictions on organic and inorganic nitrogen use and the tax would have to be accompanied by monitoring of farm practices. Farming practices would have to be monitored in the same way as under the regulatory approach and would involve the same monitoring costs. These costs when added to the costs incurred by the Revenue Commissioners in administering the tax would make the tax a more expensive instrument to administer than a regulatory measure. While the administrative costs of the tax would exceed those of a regulatory measure, a tax does have some appeal for policy makers in that it would generate revenue for the government. However, a tax would be inequitable and would probably be politically unacceptable unless accompanied by some form of rebate system. Such a system would reduce the net revenue from the tax to the government and would impose even further administrative costs on the public authorities.

## 7. Conclusions

The main contribution this paper makes is in evaluating different instruments as a means of achieving the aims of the Nitrates Directive at farm level. The overall conclusions are (i) that restrictions on nitrogen use as specified in the NAP result in a reduction in farm income on intensive dairy farms and (ii) that the limits on applications of nitrogenous material on dairy farms in Ireland would be achieved more effectively and more equitably by regulation than by a uniform tax on nitrogen fertilizer.

The results and conclusions are consistent with those reached by Lally, Riordan and van Rensburg (2009) and moreover this present study uses a more recent and larger data set. Notably this work reveals some new findings regarding a tax on nitrogen. It indicates that for some farms the tax becomes ineffective beyond a certain level. In those cases the farms will absorb the cost of the tax, rather than reduce the size of their dairy herd, making the tax an ineffective way of achieving the levels of organic nitrogen permitted under the Nitrates Directive.

In an ideal world policy makers might wish to employ market instruments of emission taxes or quotas to deal with nitrate pollution from agriculture. In such circumstances farmers would have flexibility in how they respond and could adopt a range of abatement measures which would mitigate damage done to farm incomes. However, in reality due to the diffuse nature of nitrate pollution from agriculture, a command and control measure, the Nitrates Directive is used to deal with the problem in Europe. With regulation, abatement opportunities are more limited and the Nitrates Directive imposes production constraints on intensive farms through restrictions on nitrogen use which in turn can result in reductions in farm incomes, as shown in this study. Since the Nitrates Directive applies across all European countries intensive dairy farms in other member states may be similarly affected. Using tools such as positive mathematical programming to investigate the effects of nitrogen restrictions on income is therefore unlikely to remain an isolated phenomenon, particularly in the light of future changes to the dairy quota.

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## Appendix

Table A: Nitrogen response function for silage and grazing land

| Nitrogen Application Rate (kg/ha) | Silage Land | Grazing Land |
|---|---|---|
| | Yield (Tons DM/ha/Year) | Yield (Tons DM/ha/Year) |
| 0 | 7.3 | 5.8 |
| 25 | 7.8 | 6.2 |
| 50 | 8.3 | 6.6 |
| 75 | 8.8 | 7.0 |
| 100 | 9.3 | 7.4 |
| 125 | 9.7 | 7.8 |
| 150 | 10.1 | 8.1 |
| 175 | 10.5 | 8.4 |
| 200 | 10.9 | 8.7 |
| 225 | 11.1 | 8.9 |
| 250 | 11.4 | 9.1 |
| 275 | 11.7 | 9.4 |
| 300 | 11.9 | 9.5 |
| 325 | 12.1 | 9.7 |
| 350 | 12.3 | 9.8 |
| 375 | 12.4 | 9.9 |
| 400 | 12.6 | 10.1 |
| 425 | 12.6 | 10.1 |
| 450 | 12.7 | 10.2 |
| 475 | 12.8 | 10.2 |
| 500 | 12.8 | 10.2 |

 

# Introduction

Welcome to the first Special Issue in the life of the International Journal of Agricultural Management, containing six papers originally given at the 35$^{th}$ conference of the Commission Internationale de l'Organisation Scientifique du Travail en Agriculture, or CIOSTA. Since then the papers have been through a rigorous peer-reviewing process, and I am grateful to the Guest Editors, Dionysis D. Bochtis, Thiago Libório Romanelli and Dimitrios Aidonis for their efforts in organising the process and providing me with a clear quality audit trail.

In addition, this issue contains two excellent reviews of books concerned with realising the potential – often underestimated – of women in agriculture and rural business.

Having established the Journal, and seen it through three and a half volumes, I feel it is time for me to relinquish the Editor's chair to someone who will bring new vigour and a fresh eye to the job. I am delighted that, after a rigorous selection process involving some excellent candidates, the Institute of Agricultural Management and the International Farm Management Association have appointed Dr Matt Lobley, of the University of Exeter, United Kingdom, as my successor. I know that he will make an excellent job of it, and will take the Journal to new heights.

My aim has always been to combine intellectual rigour and quality of argument with a welcoming and, for novice authors, nurturing approach. I will not regret the reduction in my workload, but I will miss the contact with the many 'virtual' friends I have made across the world, be they authors, reviewers, typesetters, publishers or association officers. I thank them all, and trust that Matt will enjoy the same commitment and support.

Martyn Warren

# EDITORIAL

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# Agricultural sustainability through agrifood system management

The increasing demand for agricultural products under the constraints imposed by the limited resources and the prevention on negative environmental impacts requires an improved knowledge on farm management and on the related technologies and methods. Besides, the concern on the human participation in the production systems, in a myriad of roles such as workers, consumers, suppliers, investors and society, highlights this theme to be approached. For this wide range of issues and possible point-of-views is why this special issue has been conducted trying to provide indicative instances of a multidisciplinary scientific effort towards sustainable agrifood systems management.

This special issue contains extended peer reviewed selected papers form the 35th CIOSTA Conference held in Billund, Denmark in July 2013. CIOSTA (Commission Internationale de l'Organisation Scientifique du Travail en Agriculture, Founded in Paris, 1950) conferences focus on the optimisation of bio-production management and work organisation based on system engineering approaches and innovative technologies. Themes addressed in CIOSTA conferences include decision support systems for the whole range of planning levels, sustainability assessments of management approaches, evaluation of accident risks associated with agricultural operations, information management systems, precision farming based operations planning, agri-food and biomass supply chains, farm logistics, etc.

An essential managerial task in agricultural production management is the task time analysis. An example of this process is presented in the paper by Heitkämper et al. (Working time requirement for different field irrigation methods). This paper specifically deals with the task time analysis of various irrigation systems. The working hours and the influencing variables were statistically analysed and integrated in a model calculation system. The paper by Quendler et al. (Comparative incident analysis of pressure cleaner injuries among employees on Austrian farms) lies within the topic of evaluation of accident risks associated with agricultural operations aiming to identify the risk factors that may cause an accident during the human-machine interaction. The issue of the development and implementation of new technologies in the agrifood product processes in order to cope with the increasing demand for traceable products under food quality and safety requirements, is covered in paper by Bechar and Vinter (Development of a weight-based technique for 'packages labelled by count' of agricultural products) in which authors developed an innovative weighing procedure of 'packages labelled by count' based on a mathematical model which reduces the variability in package sizes. The development and adoption of such technologies and in general of advanced ICTs in agricultural production systems is the topic of the next paper by Wermeille et al. (Stakeholders involvement on establishing public-private partnerships through innovation in agricultural mechanisation: a case study) in which authors present and analyse an experimental Public-Private Partnerships Action launched at the European level aimed at gathering together all stakeholders involved crop protection and to boost among them concrete innovation in ICT. Agricultural production management includes also the management of the related supply chains. As logistics is a substantial part of any production system, the identification of any involved processes is of crucial importance for achieving the business goals, design appropriate measures and allocate sufficient resources for their improvement. The paper by Folinas et al. (Logistics process prioritization in the agrifood sector) proposes a methodological framework and a corresponding mathematical model for the identification, categorization and prioritization of logistics processes in the agrifood sector. Finally, the paper by Mantoam et al. (Material and energy demand in actual and suggested maintenance of sugarcane harvesters) covers the issue of sustainability in agricultural production systems. The presented study evaluates material and energy demand in the maintenance of sugarcane harvesters as a prerequisite for an accurate energy balance estimation for the case of biomass production used for bio-energy generation.

We would like to thank all individual authors for their contribution to this special issue, the reviewers for ensuring its quality, and Martyn Warren (Editor-in-Chief, International Journal of Agricultural Management) for supporting our work which we expect to provide a significant contribution on the scientific challenges in the process of optimising agricultural production management.

Guest Editors: Dionysis D. Bochtis[1], Thiago Libório Romanelli[2], Dimitrios Aidonis[3]

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# REFEREED ARTICLE

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# Working time requirement for different field irrigation methods

KATJA HEITKÄMPER[1], THOMAS STEHLE[2] and MATTHIAS SCHICK[2]

**ABSTRACT**

Prolonged dry periods are occurring with increasing frequency during the growing season due to climate change. Irrigation is, therefore, becoming more important for the improved exploitation of crop yield potential. The choice of a suitable irrigation system depends on various factors such as the crop to be irrigated, availability of water, soil condition, and topography, availability of technical and financial resources, as well as technical know-how, and manpower availability.

Three widespread irrigation methods of mobile, fixed and micro irrigation have been analysed in the geographical areas of Germany and Switzerland concerning their working time requirement for transport, assembly, operation, and dismantling. The working hours and the influencing variables were statistically analysed and integrated in a model calculation system. The results showed the working time requirement for the selected irrigation methods under modelled conditions. Regarding the required manpower, for a 1 ha plot, hose reel irrigators required 1.8 h, pipe sprinklers 9.5 h and drip irrigation systems 12.3 h total working time.

**KEYWORDS:** labour science; model calculation; irrigation methods

## 1. Introduction

Prolonged dry periods are occurring with increasing frequency during the growing season due to climate change. Irrigation is, therefore, becoming more important for the improved exploitation of crop yield potential. The choice of a suitable irrigation system depends on various factors such as the crop to be irrigated, availability of water, soil condition, and topography, availability of technical and financial resources, as well as technical know-how, and manpower availability.

In addition to the investment required and the possible applications of an irrigation system on farm, consideration should also be given to labour planning aspects when making a purchasing decision. Therefore, an up-to-date planning basis is needed for the different methods. Hardly any labour-planning data are available; most of the existing key figures are out of date. According to DIN 19655 (Deutsches Institut für Normung, 2008) five methods of field irrigation can be distinguished (Fig. 1).

According to the International Commission on Irrigation and Drainage (ICID, 2014a) in Germany a total of 540,000 ha are irrigated, which represents the 4% of the arable and permanent crop area (APC), in Switzerland app. 40,000 ha are irrigated which represents the 9.3% of the APC. Sprinkler and micro irrigation are the most common irrigation methods in Germany with over 98% of the total irrigated area (ICID, 2014b). Beyond these methods, mobile sprinkler, fixed sprinkler and drip irrigation are the most widespread methods. On large-scale farms (>20 ha) increasing use is being made of fixed rotary and linear sprinklers (Sourell, 2009).

The irrigation method is considered to be mobile when the equipment for irrigation or its parts are moved to and from the plot during the vegetation period of the irrigated crop. Pipe irrigation with fixed sprinklers and drip irrigation are considered to be fixed methods, as the irrigation equipment remains installed at the plot during the vegetation period of the crop.

This study aimed to make the relevant key figures of labour requirement for current field irrigation methods available as an aid for farmers and consultants. The focus is on the working time requirements measured in manpower hours per area (MPh/ha) for the working processes of 'transport', 'assembly', 'operation', and 'dismantling' of three selected irrigation systems, namely: hose reel irrigators, pipe irrigation with fixed sprinklers, and drip irrigation.

## 2. Material and Methods

### Working time measurement

For the study purposes, data were collected on seventeen (17) farms with vegetable crops in Germany and Switzerland. Regarding the irrigation systems, on nine (9) farms hose reel irrigators were installed, on five (5) farms drip irrigation systems and on three (3) farms pipe systems were used. The farm size varied between 3 ha and 250 ha, while the plot sizes were ranged between 0.5 ha and 5.0 ha.

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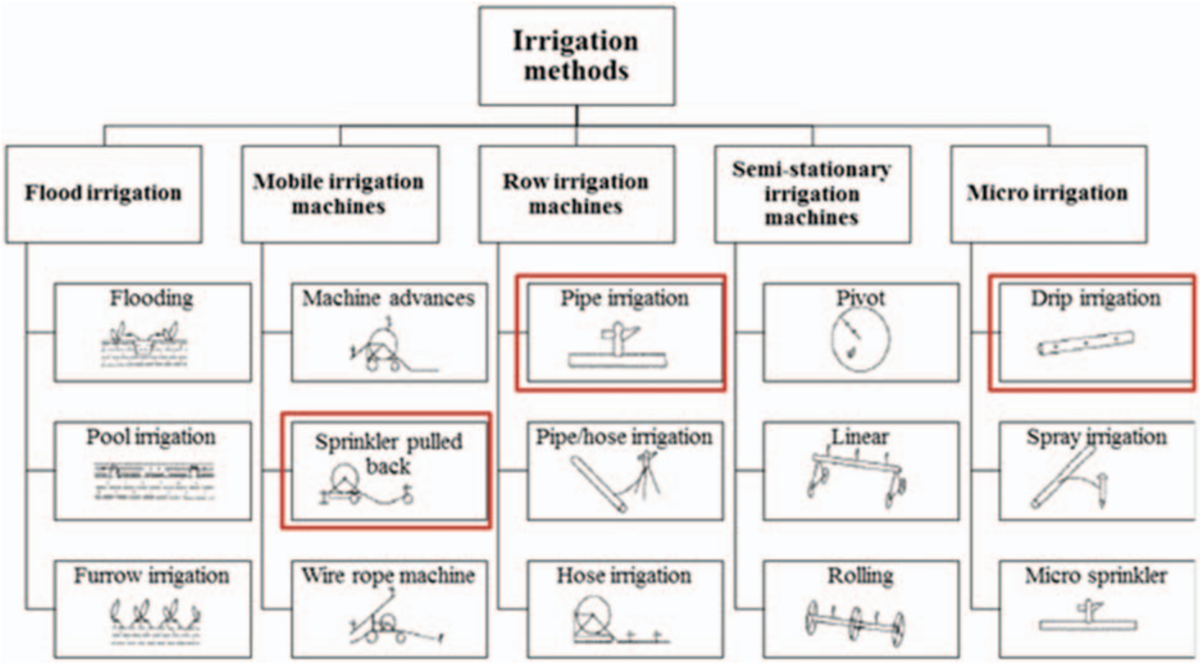


**Figure 1:** Overview of different methods of field irrigation (according to DIN 19655, 2008–11) (adapted from Teichert, 2009)

The working time was recorded on a work elements level in the form of direct measurements taken during observations of the performed work. Time studies were carried out in the form of flyback timing (REFA, 1972). The start and end points for each workflow segment and element were set prior to measurement. A Pocket PC (Dell Axim, Dell, USA) and a special time recording software (Ortim b3, DMC-Ortim, Germany) were used for time recording. In each case one segment of elapsed time (measured in cmin $=10^{-2}$ min) was allocated to the associated work element.

An initial evaluation of the working time studies was performed while data were collected. The arithmetic mean was continuously calculated for cyclic measurement segments. Also, at this stage, the *epsilon* value and standard deviation were already given as a measure of sample quality for the cyclic measurement segments. The values of the corresponding influencing variables of non-cyclic workflow segments have been added to the work elements during measurement. The influencing variables such as field sizes, farm to field distances, irrigation system dimensions (e.g. sprinkling width used, line spacing, sprinkler spacing), on which the model calculation is based, were also recorded during work observation on the farm.

## Statistical evaluation and model calculation

For further processing, the recorded data were checked with descriptive statistical procedures (normal distribution, outlier, coincidence) (Schick, 2008).

Subsequently, the planning time values, consisting of the arithmetic means, were calculated and added to the database. The database is part of a long-term project collating planning time values for work elements across all agricultural areas. In this database, each element has a unique alphanumeric code assigned, a name with beginning and end points, and the appropriate statistical parameters, including contents description, author, and creation date. Some work elements were not measured but modelled. Therefore, for these elements the model is also included in the database.

The PROOF model calculation system was used for modelling the working time requirement of the investigated irrigation methods. PROOF is a modular system based on a spreadsheet software (Schick, 2008). The model calculation system involves the logical linking of work elements with the quantitative and qualitative influencing variables affecting them. All influencing factors are entered in the model calculation system as variables and can be altered at any time within the upper and lower bounds. A warning message is automatically displayed in the event of entries falling outside these limits (Riegel and Schick, 2007).

## Investigated irrigation methods and assumptions

The following methods were chosen by the German Association for Technology and Structures in Agriculture (KTBL) to be analysed in this project: mobile irrigation machine with mobile sprinkler, pipe irrigation with fixed sprinklers, and drip irrigation. The connection to the hydrant is the same in all three methods. Depending on the distance between the field and the hydrant, the irrigation system is connected to the hydrant by laying pipelines or hoses, in many cases even a combination of both. The lines are generally laid manually, or by machine where distances are relatively large (>100 m). The pump can be switched on by remote control, by mobile phone or directly at the pump. With older diesel-driven pumps the water pressure needs to be adjusted, particularly when several machines are simultaneously operating from the water main. In the case of new electrical installations, the above procedure is performed automatically. In the examined model, the water pressure at the pump was adjusted automatically.

**Figure 2:** Mobile sprinkler (Rollomat) (left), Assembly of fixed sprinkler (centre), Laying of drip irrigation (right) (source: Agroscope)

**Hose reel irrigator**
The hose reel irrigator, also referred to as 'Rollomat', belongs to the mobile irrigation machines. A cylindrical hose drum is hinged on a chassis (Fig. 2, left). A sprinkler trolley can be placed on the irrigator for transportation. It is either equipped with a jet spray bar or a single gun sprinkler. In the model a jet spray bar with a range of 18 m was used. At the field the sprinkler trolley was hitched to the tractor and the hose stretched across the plot. Depending on the plot size and shape the hose reel irrigator has to be moved after one strip is irrigated. The hose reel irrigator can be set up and operated by one person.

**Pipe sprinkler**
The second method belongs to the fixed irrigation systems. Pipe sprinklers are used mainly on relatively large farms and for crops which need repeated watering (Fig. 2, centre). Pipes of 6 m length are assembled in lines. Every 18 m a sprinkler is positioned on the pipe. The installation is usually done by two to three people.

**Drip irrigation**
The third method is the drip irrigation which belongs to the micro irrigation systems. In Germany and Switzerland it is used mainly for bedding and ridge cultivation crops (potatoes, asparagus, etc.). The drip hoses referred to as drip tape are laid by a combined laying and reeling device (Fig. 2, right) and can be single-row or multi-row. In the model a two row system is used to lay the tape above ground. The distance between rows depends on the crop and is assumed 1.5 m. Two persons are required for the installation.

## Assumptions for the model calculation

In the calculation model the following assumptions were taken. All three methods use a hose of 300 m length to connect to the head unit and water source. The farm to field distance is 1,000 m. The rectangular plot has a field length of 141 m and width of 71 m (app. 1 ha, standardized plot defined by KTBL, 2010). The working time requirement does not include the irrigation time. All of the nine farms using drip irrigation systems for vegetables dismantle the system after one vegetation period.

# 3. Results

## Total working time requirement

The total working time requirement for the three investigated irrigation methods considering transport, assembly, operation and dismantling varies from 1.8 h/ha for hose reel irrigation to 9.5 h/ha for pipe/sprinkler irrigation and 12.3 h/ha for drip irrigation (Fig. 3).

Processes of transport and assembly of the hose reel irrigation system require 0.6 h/ha each, while processes of operation and dismantling require 0.3 h/ha each. The mobile irrigation is the system with the least required working time. As far as pipe sprinkler irrigation is concerned, the transport is the work process with the highest working time requirement with 4.4 h/ha. This is due to the fact that pipes are usually stored on pallets and are loaded manually to the transport vehicle. Finally, the drip irrigation system requires most of the working time for assembly with 6.3 h/ha.

## Working time requirement for hose reel irrigation

The hose reel irrigation system is equipped either with a jet spray bar or a single gun sprinkler. After the

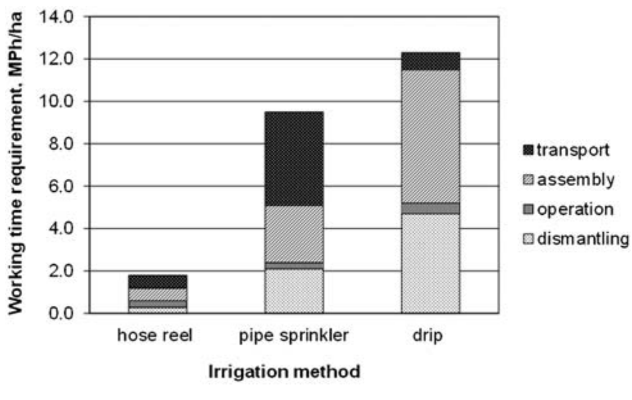


**Figure 3:** Total working time requirement for hose reel, sprinkler and drip irrigation. **Notes:** Plot size: 1 ha. MP: manpower

 

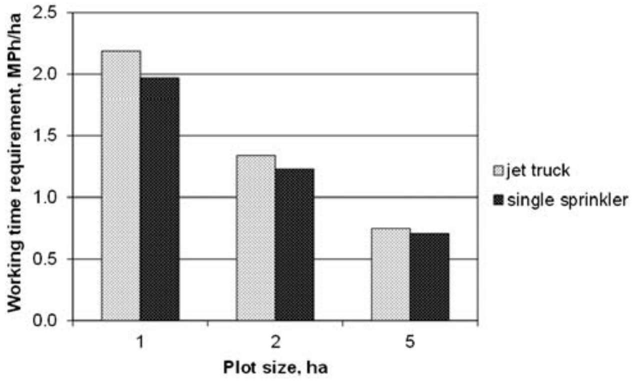


**Figure 4:** Comparison of working time requirement for hose reel irrigation equipped with two different sprinkler types for various plot sizes. **Notes:** Sprinkling width 30 m. MP: manpower

sprinkler trolley is lowered the jet spray bars are extended. This work is not needed on gun sprinkler trolleys. The difference in the working time required for the assembly of the jet truck compared to the single gun sprinkler is 0.2 h/ha (Fig. 4).

### Working time requirement for pipe sprinkler irrigation

The pipe sprinkler irrigation system can be installed with different line spacing and sprinkler spacing. Line distances of 18 m or 24 m and sprinkler distances of 12 m or 18 m are common. The spacing affects the number of lines that have to be installed and, therefore, the working time required (Fig. 5).

A line spacing of 24 m instead of 18 m reduces the required working time for 1 ha by 17.2%. On the other hand, a sprinkler spacing of 18 m compared to 12 m reduces the working time requirement only by 2.8%, as in both cases a person has to walk along the same number of lines.

### Working time requirement for drip irrigation

Plot sizes and shapes in horticulture often vary from those in agriculture. In many cases, plots are narrower in horticulture. Therefore, a second type of plot has been defined referred to as 'horticultural plot'. The plot length was 250 m and the plot width 40 m (1 ha area in total). The plot shape influences the working time requirement significantly. Figure 6 provides a comparison of the working time requirement for drip irrigation on horticultural and agricultural plots. It is shown that a plot with a greater plot length requires less working time in total, with the horticultural plot requiring 14.2 h/ha and the agricultural plot 18.1 h/ha. Especially the relative proportion of time required for connecting the drip tape to the water supply system increases in agricultural plots, as more lines have to be connected. The time saved for laying the tape in a shorter row does not compensate for the connecting of additional lines in agricultural plots.

## 4. Conclusions

The analysis of the three different irrigation methods showed differences in the working time requirements. The hose reel irrigator is the most flexible system and can be installed in various plots during the vegetation period. However, with the fixed irrigation methods, sprinkler and drip irrigation, it is possible to irrigate the whole plot at the same time which is essential under specific climate conditions. The decision for the appropriate irrigation method depends on many aspects, such as water requirement of the crop, water availability, soil and climate conditions, etc.

In this study, drip irrigation was found to be the irrigation method with the highest working time requirement with 12.3 h/ha under modelled conditions. Various studies have been conducted about drip irrigation compared to traditional irrigation methods. For example, Woltering (2011) mentions 1.1 h/ha per day for a 0.05 ha drip irrigated plot in Niger. According to Murali (2012) drip irrigation requires a total of 30 h for 1 ha of sugar cane for the whole vegetation period, which is only 10% of the working time required for furrow irrigation.

However, the available publications on studies of irrigation seldom focus on the working time requirement and often lack information of how labour data was taken. Usually, this data is collected using work diaries and, therefore, apply to the working time consumption of a work process including minor interruptions which can

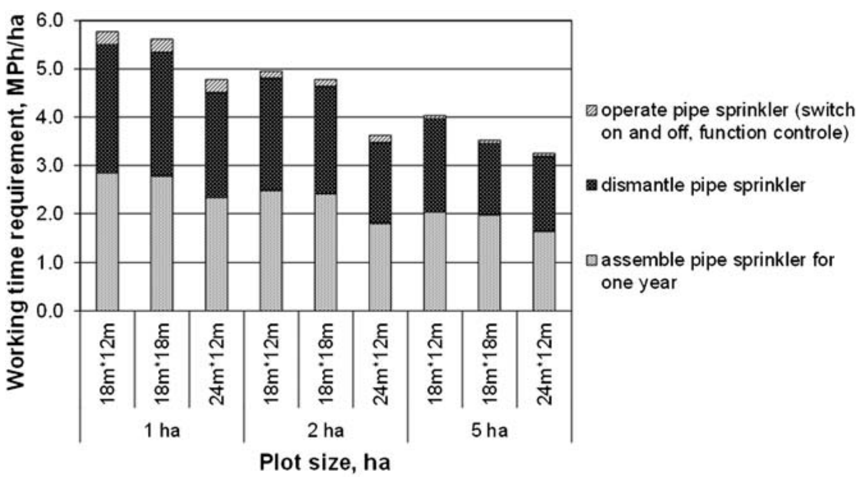


**Figure 5:** Working time requirement for pipe sprinkler irrigation with different line and sprinkler spacing. **Notes:** Line spacing (m) x sprinkler spacing (m). MP: manpower

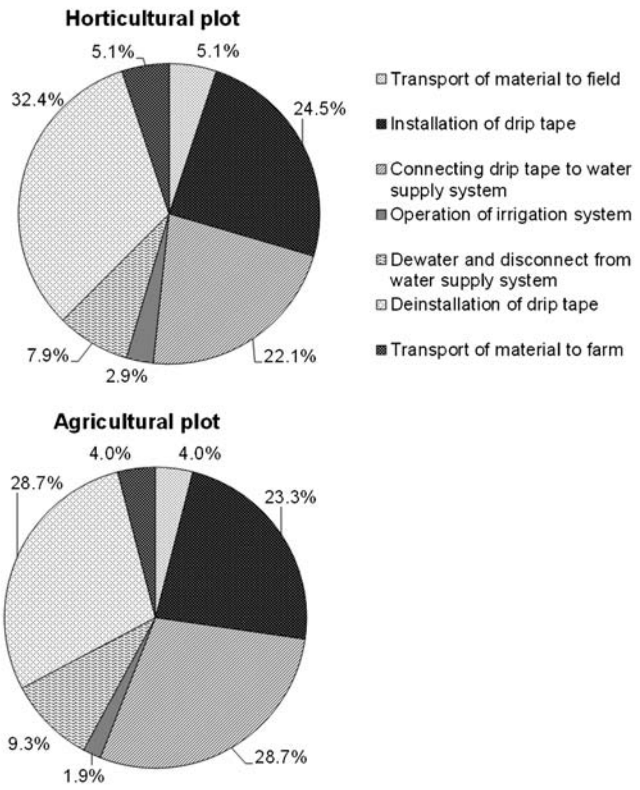


**Figure 6:** Comparison of working procedures as relative proportions of total working time requirement when drip irrigating horticultural and agricultural plots, drip pipe spacing 0.75 m. **Notes:** Total working time requirement horticultural plot 14.2 MPh/ha. Total working time requirement agricultural plot 18.1 MPh/ha. MP: manpower)

have various origins, e.g. malfunctions, waiting time, rest time, etc. The PROOF model calculation system computes the working time requirement, which means only the time exclusively needed to perform the work according to the best practice is given. This is probably the reason for differences of data reported in other studies.

Another aspect is the useful life of the irrigation system. According to the farmers involved in the project all systems can be used over a period of up to 30 years and more when being well maintained. Especially, when drip irrigation is used in permanent crops such as wine and fruit trees, the annual working time requirement is reduced to regular controls and annual maintenance.

This study demonstrated the potential and the limits of cost-effective plant production from a labour-economics point of view. Qualitative aspects of irrigation that are also significant for high productivity and cost-effective working methods will have to be considered in a future study.

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# Comparative incident analysis of pressure cleaner injuries among employees on Austrian farms

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**ABSTRACT**

Reports of the Austrian Insurance Institutions (AUVA and SVB) about accidents at work indicate that employees in agriculture are exposed to accident risks. For a detailed investigation, data of the accident databank and the accident reports of the victims of accidents with high pressure cleaners for the period from 2008 to 2010 were analysed descriptively and analytically. The aim of the case study which was based on a small sample size with precise filled out accident reports, was to evaluate the usefulness of the European Statistics on Accidents at Work (ESAW) suggested variables and categories for the identification of safety deficits in the national databank, and furthermore, to identify the risk factors that may cause an accident during the human-machine interaction. The results showed that the victims were farm managers; the majority of them were over 40 years of age. Half of the incidents happened in autumn and on weekdays, especially in the afternoon, while cleaning machinery, stable parts and central heating boilers, as well as while filling the lye in the store tank, removing the hose, and transporting machinery. All incidents occurred due to different deviations and contacts with the machine or machine parts. Missing protective equipment and clothing, as well as improper handling and securing of the work area could be identified as safety deficits. The database analysis did not reveal the relevant parameters of the human-machine interaction by virtue of their generalisation. The analysis of the accident reports was required for the identification of the accident scenarios and causes related to the agricultural terminology and the incidental human-machine interaction, which allowed the determination of safety deficits for first prevention recommendations.

**KEYWORDS:** pressure cleaner; incidents; databank data; report; injury

## 1. Introduction

In 2010, the agricultural and forestry industry of Austria reported 6,520 accidents at work (SVB, 2010). The agricultural and forestry industry has one of the highest fatality rates of all occupations in Austria as well as in Europe and countries of other continents (European Agency for Safety and Health at Work, 2011; Bunn, *et al*., 2008). The vehicles, machinery, and devices used in this occupational sector caused 2,096 accidents at work in the year 2010, 31 of which were fatal. These accidents regarded 507 persons injured and 19 deaths at work with machinery, devices, and animals per 100,000 persons employed in forestry and agriculture in Austria (SVB, 2010). The rate of fatal agricultural-related injuries is 6.3 times greater than for the salaried workforce in Austria, which had 3 fatal accidents (2 at work and 1 on the way to work) per 100,000 persons in the year 2010 (AUVA, 2012). In the European Union, agricultural workers suffer 1.7 times the average rate of non-fatal occupational accidents and 3 times the rate of fatal accidents, making the sector particularly hazardous (European Agency for Safety and Health at Work, 2011).

Accidents and injuries cause painful situations for accident victims and their families, as well as economic costs. Analyses of the circumstances surrounding an injury-causing event are essential for determining injury mechanisms and guiding prevention efforts.

In previous studies, agricultural machinery has been identified as a principal source of non-fatal and fatal injuries or disability, but there exists still little information on the risk factors, especially related to the human-machine interaction (Gerberich, *et al*., 1998). The contextual nature of the farm environment plays an important role in the occurrence of injuries. Available studies have mainly evaluated demographic factors and few of them the safety device usage, so that there is a lack of analytic epidemiologic studies to identify potentially preventable risk factors for machine-related farm injuries (Layde, *et al*., 1995; Narasimhan, *et al*., 2010).

To describe the circumstances surrounding injury events, core data are needed to characterise the conditions preceding the event, the details of the event and the outcomes of it. Administrative health databases collect various coded data and narrative text fields for

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routine, monitoring, and analysis of injury causation and incidence.

Most of these administrative data systems, especially those relying on aggregate coded data, lack the details needed to understand the complexity of the injury event and to design effective injury prevention initiatives. For example, the widely used system for coding causes of injury is the external-cause-of-injury and poisoning (E-codes) of the WHO's (World Health Organization's) International Statistical Classification of Diseases and Related Health Problems (ICD-9), which, despite limitations in the specificity of its codes, provides a useful means of standardising external causes across different sources. This means that external cause codes have an imitated structure providing incomplete coverage and insufficient details to identify relevant injury factors (Wellmann, *et al*., 2004).

Several studies have pointed out the advantages of narrative text for providing further details to complement routine coded data of injury statistics or for classifying an injury post data collection if the dataset has not the required coding for the scientific questions to be examined (Smith, *et al*., 2006). The methods of obtaining information from the reports, the narrative text, are inconsistent and differ depending on the studies and the research field. The approaches range from basic keyword searches of text strings to complex statistical approaches using Bayesian methods and computerised technical methods (McKenzie, *et al*., 2010).

The system used for coding incidental information of Austrian accidents at work is the European Statistics on Accidents at Work (ESAW). The ESAW is a useful means for standardising external causes across different data sources (Eurostat, 2012). The variables contact and deviation have recently been added to the ESAW variables in order to elucidate the causes and circumstances of accidents, details of the cause-effect mechanism which used to be unknown. This extension of the variables should facilitate the development and prioritisation of preventive strategies. The ESAW can be used worldwide because it is very similar to the international system adapted and recommended by the International Labor Organization (Jacinto and Soares, 2008). It has not been evaluated yet to what extent there exist limitations in the specificity of its codes for the identification of circumstances of machinery injuries in agriculture and forestry, especially relating to the incidental human-machine interaction.

In this paper, based on this insufficient documentation results, a showcase regarding comparative incident analysis for one machine type, is presented, which implements the variables and categories of ESAW database and the identified ones in the accident reports by phrase analysis. The investigated machinery selected for this case study was the high pressure cleaner.

By analysing of the narrative texts of accident reports further details about the causes and circumstances of accidents in the agricultural language can be acquired.

## 2. Material and Methods

Comparative accident analysis was carried out using the databank data of recognised work-related accidents with pressure cleaners for the period 2008 to 2010 and anonymised reports. For a show case, accidents with pressure cleaners were selected for the comparative analysis that had a small sample size and sound filled out reports. The databank data and reports were provided by the Austrian Social Insurance Institutions in Vienna, the SVB (Social Insurance of Farmers), which documents incidents of farming occupations, and the AUVA (Austrian Workers Compensation Board), which collects information about incidents involving employees in agriculture and forestry (SVB, 2010).

The reports were written by the victims or their relatives within 5 days after an accident which caused incapacity to work for more than three days. The relevant information of these reports is documented in the databank, according to the EUROSTAT methodology for the European Statistics on Accidents at Work (ESAW). The variables of EUROSTAT cover the main characteristics of the accident: firstly, the victim and employer, where the accident happened, who was injured and when, the seriousness of the injuries and consequences of the accident. Secondly, it contains information on how the accident occurred, under what circumstances and how the injuries came about (Eurostat, 2012).

The variables that were examined for a type of machinery were personal characteristics of the victims (e.g., age, gender, and position in the farm organisation), incident time and date, injury characteristics (e.g., type of injury, body part, and body side), causes and circumstances (e.g., working environment and work process). Causes and circumstances in the databank were described by the variables working environment, work process, specific physical activity, deviation, and the contact. These variables have generalised categories so that they may apply to all professions for comparison purposes (Eurostat, 2012). Based on the identified information gaps about the incidental human-machine interaction during the work process, the variables workplace, task and cause (classified in agricultural terms) and the injury characteristics and safety defects were predefined for analysing the content of the accident reports. These are factors that would lead to and explain the injury once an accidental incident occurs.

For the identification of the relevant variables and their categories in the accident reports, the narrative text analysis was used. Keyword search was applied to identify un-coded circumstances of machinery injuries (Wellmann, *et al*., 2004). Each narrative text variable was coded according to the established categories. This method was selected as it affords an in-depth examination of the circumstances of incidents, especially for factors not captured by standardised ESAW coding schemes (McKenzie, *et al*., 2010; Smith, *et al*., 2006). For the classification of the incidental tasks in agricultural terms, the REFA method was applied (Lücking, *et al*.,2009; Luger, 2002). From the identified incidental human-machine interactions, the safety defects were derived.

## 3. Results and Discussion

The results of the databank analysis helped to identify the persons at risk, their gender and age, the accident

 

**Table 1:** Employment status, personal characteristics and accident time specific parameters of occupational accidents with high pressure cleaners in the Austrian agriculture (2008-2010)

| Parameters | Number (n) |
|---|---|
| **Employment status** | **(n=12)** |
| Farm managers | 12 |
| Others | 0 |
| **Gender** | **(n=12)** |
| Male | 12 |
| Female | 0 |
| **Age (years)** | **(n=12)** |
| Under 40 | 4 |
| Over 40 | 8 |
| **Season** | **(n=12)** |
| Spring | 2 |
| Summer | 2 |
| Autumn | 6 |
| Winter | 2 |

time and date, the injury characteristics, the generalized causes and circumstances. The results of the accident report analysis offered key information about the causes and circumstances in the agricultural language.

## Personnel characteristics and accident date and time

A total of 12 incidents were documented in the databank; 11 incidents occurred with pressure cleaners and one incident with a compressor. The victims were male and professional farm managers (100%, 12/12); the majority of them were over 40 years old (66.7%, 8/12), and the incidents happened predominantly in autumn (50%, 6/12), on weekdays (75%, 9/12), and especially in the afternoon (50%, 6/12) (Table 1). The data for personal characteristics were anonymised in the reports. Most of the accidents happened in the year 2010 (50%, 6/12), followed by 2008 (25%, 3/12), 2009 (8.33%, 1/12) and 2006 (10%, 1/10); the information about two accidents was inaccurate.

Differences consisted in the information quality between these sources. The databank incorrectly categorised one compressor accident, while the accident reports did not include personnel information about the accident victims.

The injuries identified by databank data and report analysis were mainly wounds and superficial injuries (50%, 6/12; 60%, 6/10), followed by fractures (25.0%, 3/12; 2/10, 20%), sprains and others (9.09%, 1/11; 20%, 2/10), and chemical burns (8.33%, 1/12) (Figure 1). There was missing the documentation of one fracture and the chemical burns in two out of 11 accident reports.

The affected parts of the body were mainly the upper body parts (91.7%, 11/12), like extremities (33.3%, 4/12; 36.4%, 4/11) and head parts (33.3%, 4/12; 27.3%, 3/11), torso (25%, 3/12; 27.3%, 3/11) and the lower extremities (8.33%, 1/12; 9.09%, 1/11). The report analysis identified one eye injury that most likely occurred during the compressor accident which was not recognised by the report analysis.

The injuries occurred predominantly on the left (81.8%, 9/11; 77.8%, 7/9) and rarely on the right body side (18.2%, 2/11; 22.2%, 2/9). In the report databank information was missing about one fracture, the body part eye and twice the right body side, because the compressor incident and the chemical burns were not mentioned in the report of the lye incident.

Minor differences exist between the data in the databank and the data obtained through the report analysis in relation to injury type, body parts and body sides injured. However, the above provides important information for the identification of required body-related prevention measures.

## Causes and circumstances of accidents

Major differences in information quality were recognised for the variables on causes and circumstances. The databank variable working environment was the workplace where the accident happened, the work process described the type of work and task, and the specific physical activity gave a broader description of the

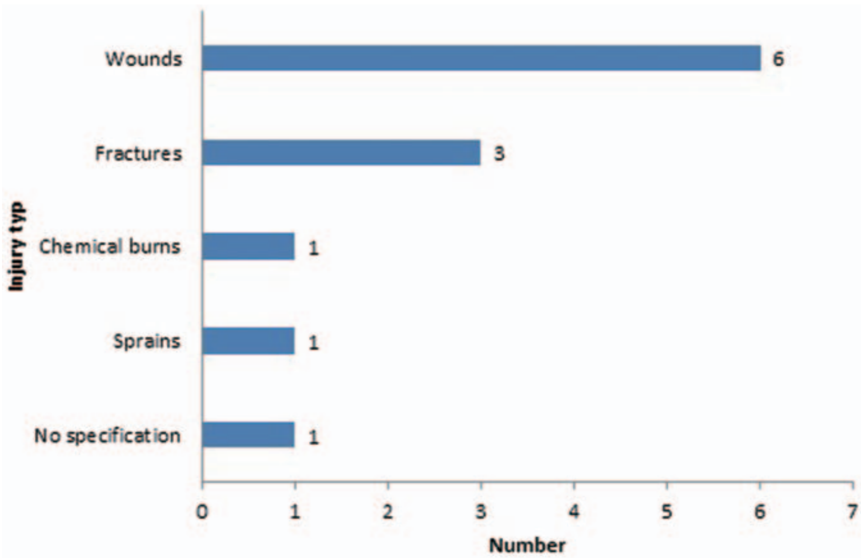


**Figure 1:** Injury type of accidents with high pressure cleaners in the Austrian agriculture (2008–2010) (n=12)

activity that the victim was performing when the accident happened.

The deviation depicted the abnormal event leading to an accident, the way in which the circumstances of the accident differed from normal practice, but the change from normal practice does not describe the root cause of the accident, nor the responsibilities (Eurostat, 2012).

The variable contact described how the victim came into contact with the 'Material Agent' that caused the injury. It described precisely how the victim was injured (Eurostat, 2012).

All accidents happened in the court of the farms (100%, 12/12; 100%, 9/9). The working environments of accidents were the breeding areas (33.3%, 4/12; 66.7%, 6/9), storage buildings (3/12, 25%), the court exterior area (33.3%, 4/12; 33.3%, 3/9) and unspecified farming area (8.33%, 1/12). These results corresponded mainly with the report analysis results. Two accident reports did not include any information about the working environments.

The identified categories of the work process were 'work-related tasks' (83%, 10/12) and 'agricultural type work, forestry, horticulture, fish farming, etc.' (16.7%, 2/12).

The identified specific physical activities were 'working with tools' (50%, 6/12), 'holding, handling objects' (33%, 4/12), 'operating machinery' (8.33%, 1/12) and 'walking, running, going up, going down, etc.' (8.33%, 1/12) (Table 2).

These are occupational independent terms describing accident work processes; they are not used agriculture-specific terms describing work-related tasks or physical activities in agriculture. Therefore, a comparison on this level with the information in the reports was not performed. Instead, accidental tasks, based on the REFA method (1984), were identified. According to Schneider and Heim (1974) a safety analysis requires the recognition of the task and the integration into elements.

The task analysis revealed that the agricultural tasks resulting in accidents were cleaning of machinery (70.0%, 7/10), stable parts and central heating boilers, filling the lye into the store tank (10.0%, 1/10), removing the pressure cleaner hose (10.0%, 1/10), and loading the high pressure cleaner for transportation on a tipper box (10.0%, 1/10).

Task 'Holding, handling objects' (4/12) of 'specific physical activities' corresponded probably with the tasks of 'filling the lye into the store tank' (1/10), 'removing the hose' (1/10) and 'transporting the high pressure cleaner' (1/10). The incidental cause 'working with tools' (6/12) was mainly given during the cleaning (7/10) when handling the lance. Cause 'walking, running, going up, going down, etc.' (1/12) corresponded probably with the cause slipping (1/10), which is mentioned as an accident occurring during cleaning. The counterpart of cause 'operating machinery' (1/12) could not be identified.

The accidents deviations were the 'loss of control' (75%, 9/12), 'fall of person and uncoordinated movements' (16.7%, 2/12) and 'breakage, bursting, slip, fall, collapse' (8.33%, 1/12). The 'loss of control' (75%, 9/12) occurred when the lance was inserted into the corn harvester during cleaning of machinery in the farm yard (9.09%, 1/11), the bouncing of the water jet on the chest and feeding equipment (18.2%, 2/11), slipping of the container from the hands during filling in the lye (9.09%, 1/11), bouncing of the hose on body parts (9.09%, 1/11) and bursting of the hose (1/11, 9.09%), rolling away of the high pressure cleaner on the tipper box and tripping over the hose (18.2%, 2/11). The 'fall of person' (2/12) was probably caused by tripping over the hose (9.09%, 1/11) and the 'breakage, bursting, slip, fall, collapse' (8.33%, 1/12) probably referred to the slipping and collapsing on a tractor wing (9.09%, 1/11).

**Table 2:** Work task, incidental cause and deviation of accidents with high pressure cleaners in the Austrian agriculture (2008-2010)

| Parameters | Number (n) |
|---|---|
| **Work task** | **(n=10)** |
| Cleaning objects | 7 |
| Filling lye in the tank of the cleaner | 1 |
| Transportation of the cleaner | 1 |
| Removing the hose of the cleaner | 1 |
| **Incidental cause** | **(n=12)** |
| Working with tools | 6 |
| Holding, handling objects | 4 |
| Walking, running, going up, going down, etc. | 1 |
| Operating machinery | 1 |
| **Deviation** | **(n=12)** |
| Loss of control | 9 |
| All of person and uncoordinated movements | 2 |
| Breakage, bursting, slip, fall, collapse | 1 |

The variable 'contact' of the databank, which expressed how the accident occurred, corresponded with the identified accident causes in the accident reports.

The variable 'struck by object in motion, collision with' (33.3%, 4/12) corresponded with slipping (27.3%, 3/11) and hose bursting (9.09%, 1/11). The 'horizontal or vertical impact with/against a stationary object' (25%, 3/12) was comparable with rupture of the hose in the victim's hand (9.09%, 1/11) or the hose and the brass nozzle coming in contact with the eye (9.09%, 1/11), the slipping and collapsing on a tractor wing (9.09%, 1/11), as well as the rolling away of the high pressure cleaner on the tipper box and falling to the ground, the toe (9.09%, 1/11). The 'contact with sharp material agent (knife/blade etc.)' (16.7%, 2/12) occurred by getting dirt into the eye (9.09%, 1/11) and bouncing of the water jet on the chest during cleaning (9.09%, 1/11). The 'contact with hazardous substances on/through skin and eyes' (8.33%, 1/12) matched with 'getting the lye into the eye' (9.09%, 1/11).

These variable categories of the accident work environments with process, deviation, and contact were generalised terms for the use in different professions. Identifying the agricultural accident tasks and their specific causes was not possible, but required an additional phrase analysis of the report contents. The report analysis revealed the relevant parameters of the incidental human-machine interaction for the derivation of safety deficits and first prevention measures.

## Safety deficits and prevention measures

The safety deficits identified were the missing use of protective equipment, like eye and face protection (18.2%, 2/11) and protective clothing (9.09%, 1/11).

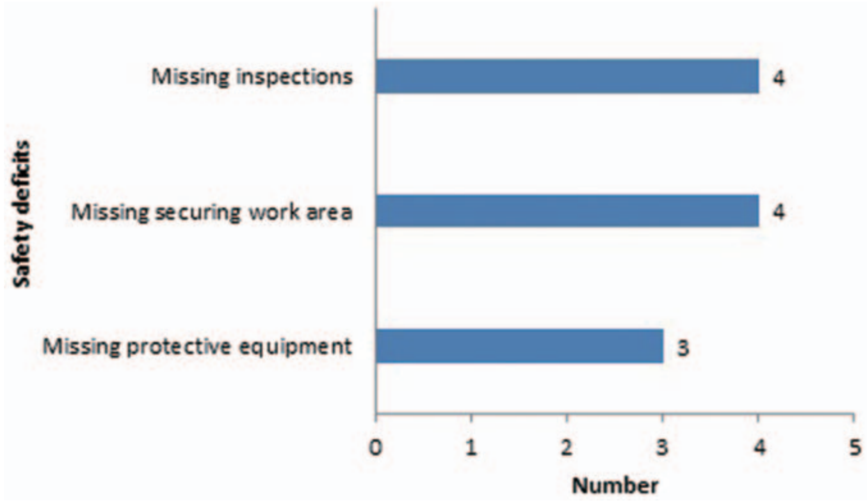


**Figure 2:** Safety deficits of accidents with high pressure cleaners in the Austrian agriculture (2008–2010) (n=11)

When handling the machinery, the load securing was not applied during the transport of the high pressure cleaner (9.09%, 1/11), the shutdown of the corn harvester for the cleaning task was missing (9.09%, 1/11), and the hose and nozzle had not been inspected for damages before starting the cleaning process (18.2%, 2/11).

Deficits in securing the work area in maintaining order and in wearing safety shoes or boots were probably the main reasons for slipping incidents during cleaning (27.3%, 3/11) followed by the incident of removing of the hose (9.09%, 1/11).

Removing of obstacles, like the hose (27.3%, 3/11), in the walkway and handling area and wearing of waterproof and no-slip shoes or boots (36.4%, 4/11) reduce the risk of slipping and stumbling (DGUV, 2012).

No eye and face protection were used during filling the lye into the store tank (9.09%, 1/11), cleaning the feeding equipment and central heating boilers, which is why the materials (lye concentrate, uncoupled dirt, hose parts, and nozzle) injured head parts (36.4%, 4/11), especially the eyes and the face.

Inattention and lack of safety clothing were responsible for the injuries caused by the impinging water jet in the chest area (9.09%, 1/11). Wearing of safety goggles (36.4%, 4/11) and safety clothing (tear proof) (9.09%, 1/11) during cleaning and lye refill tasks is recommended in the manufacturer manual. The quality aspects of the safety goggles are described in EN 166 and EN 170; important is the choice of the right mechanical and chemical strength and the fog freedom.

To ensure that safety goggles, face protection and safety clothing are worn by operators, warning and information signs (pictograms) should be attached in a highly visible area of the high pressure cleaner and protection equipment should be sold with any new high pressure cleaner (Bundesverband der Unfallkassen, 2002).

Missing inspections (18.2%, 2/11) of hose and nozzle for damages were responsible for detaching the nozzle and bursting the hose. The bursting of the hose and the detaching of the nozzle can be avoided by early registration of damages by checking the equipment before each use. These procedures and setup as well as maintenance and minimum requirements for the hose are recommended in EN1829-1, Directive 2006/42 EC and manufacturer manuals (Deutsche Norm, 2010; Richtlinie 2006/42/EG, 2006). High quality products indicate leaky hoses and nozzles damaged by an alarm display, recognised by pressure loss (Nilfisk-Alto, 2012; Kärcher, 2012).

The load securing and safety shoes were not in use (9.09%, 1/11) during the transport of the high pressure cleaner on a tipper box, which caused the toe injury.

Transport requirements are mentioned in EN 1829-1 and manufacturer manuals (Deutsche Norm, 2010). Measures are locking bar, beam, tension or tie-downs, and wheel chocks to ensure immobility during transport and wearing safety shoes with steel caps. High quality high pressure cleaners are already equipped with brakes, crane hooks or eyelets for fixation.

## Summarised results

Reports of the Austrian Insurance Institutions (AUVA and SVB) about accidents at work indicate that employees in agriculture should provide information for accident risks. There are no studies available that examine the machinery-related reasons for this risk. To close this research gap, the data of the period 2008 to 2010 of the accident databank and the accident reports of the injured victims were analysed in detail.

Databank data analysis, narrative text analysis and inclusion of work into REFA were selected to analyse and compare the results of these two data sources in terms of information quality and relevance to the identification of safety deficits and further development of sustainable prevention measures.

**Table 3:** Prevention measures for accidents with high pressure cleaners in the Austrian agriculture (2008-2010)

| Parameters | Number (n) |
|---|---|
| **Prevention measures** | **(n=11)** |
| Inspection before operating | 4 |
| Securing work area | 4 |
| Face protection and safety clothing | 3 |

The results of the databank analysis was helped to identify, with minor inaccuracy, the persons in danger, their gender and age, their specific occupational sector, the scene of the incident, and times and injury characteristics.

Twelve incidents were documented in the databank, but only eleven of them occurred with pressure cleaners; the twelfth incident occurred with a compressor. The victims were farm managers; the majority of them were over 40 years old. Half of the incidents happened in autumn and on weekdays, especially in the afternoon.

The databank analysis did not reveal the relevant parameters of the human-machine interaction during the incident, a factor that is necessary to determine safety deficits. The variable categories of causes and circumstances were generalised terms for the application to different occupations; an identification of the agricultural tasks leading to an accident and their specific causes was not possible. It was necessary to choose a more specific categorisation; a classification of the work processes based on tasks of the REFA method (1984), which was applied and approved while performing a keyword search in the accident reports.

This search revealed that the agricultural tasks carried out when an incident occurred were mainly cleaning machinery, stable parts and central heating boilers followed by filling the lye into the store tank, removing the hose and transporting machinery.

The deviations or incidental circumstances identified included entering the lance in the corn harvester during cleaning, the bouncing of the water jet on the chest and feeding equipment, slipping of the container from the hands during filling in the lye, bouncing of the hose on body parts and bursting of the hose, rolling away of the high pressure cleaner on the tipper box, and falling to the ground during transport and most often falling over the hose as well as slipping and collapsing on a tractor wing.

The contacts or incidental interactions included slipping, being hit by the lance on the hand or hit by the hose and the brass nozzle on the eye, slipping and collapsing on a tractor wing as well as being hurt on the toes by the high pressure cleaner falling from the tipper box to the ground. Eye injuries were caused by dirt and ley, chest injuries by the bouncing of the water jet because of inattention, and finger injuries by a bursting of the hose.

The safety deficits identified were mainly the missing use of protective equipment like eye and face protection and protective clothing. During transport of the pressure cleaner a load securing was not used. During cleaning of the corn harvester the shutdown was neglected. The hose and nozzle were not inspected for damages before starting the cleaning process. Deficits in securing the work area, in maintaining order and in wearing safety shoes or boots were probably the main reasons for slipping incidents during cleaning and removing of the hose.

## 4. Conclusions

Overall, based on the databank analysis, it was possible to identify the personal, time and place characteristics of incidents with minor inaccuracy. The variable categories of the incidental work field and process of the databank were generalised terms for the application to different professions. The report analysis results are necessary for the identification of the accident scenarios and causes according to agricultural terminology in order to recognise the human-machine interactions leading to the accident. The identification of them allowed the determination of safety deficits for deriving the first prevention measures. In order to derive more accurate preventive measures, additional information about the accident machine and the machine-specific part-related interactions of humans are necessary. For this purpose, database results can be linked with accident reports and additional interviews with accident victims and accident machinery evaluations can be carried out to close information gaps and to ensure a practice-oriented further development of prevention measures. To derive more accurate preventive measures, missing information about the accident machine and the machine-specific part-related interactions of humans must be supplemented by interviews of accident victims and machinery evaluations to close information gaps.

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# Development of a weight-based technique for 'packages labelled by count' of agricultural products

AVITAL BECHAR[1] and GAD VITNER[2]

**ABSTRACT**

Accurate weight-based packing of 'packages labelled by count' necessitate very low coefficients of variation of unit weight. For agricultural products with relatively high coefficient of variation, the usual weighing methods are therefore not suitable. In this paper, a method that supports the count-to-weight transform of pre-packed packages of products with wide variability of characteristics is presented. The developed innovative weighing method utilises a weighing procedure where the coefficient of variation of the product's unit weight is used in order to determine the critical package weight and to comply with the package nominal definitions. The method involves a weighing procedure of 'packages labelled by count' which is based on a mathematical model which reduces the variability in package size and eliminates the cases of under filling of packages.

The method was validated experimentally. The results revealed that the variability of package size is high when counting manually. In contrast, by implementing the proposed method the standard deviation of the quantity in a package was reduced by 30%. Moreover, the number of packages with quantity less than the nominal was reduced to zero. In general, the developed method can be applied when the coefficients variation is high and the counting procedure is inaccurate and/or expensive.

**KEYWORDS:** Decision analysis; coefficient of variation; weighing procedures; cuttings

## 1. Introduction

The actual quantity of product units in pre-packed packages is an issue that concerns both the consumers and the producers. The consumers have the right to expect packages to bear accurate net content information, while on the other hand, the producers aim to pack the specified nominal quantities at a minimum cost. Routine verification of the net contents of packages is an important part of any weights and measures program intended to facilitate value comparison and fair competition.

There are several methods to quantify the contents of pre-packed packages: counting, weighing, or volume measurement. Every manufacturer aims to pack the specified nominal quantities into a package, at minimum cost. In various industries (food, agriculture, plastics, machined products, wood, pharmaceuticals, etc.) there is a need to create packages with a nominal content defined by a specified numerical quantity. Some products, e.g., screws, may be packed by automatic means, mainly due to very small weight variability, while others, must be packed manually, either because their wide variability of characteristics and complex handling prevents any economic justification for an automated solution, or because there is no feasible automated solution available.

When the product quantities involved in each package unit are large, two problematic issues need to be addressed:

i) The manufacturer tends to design a packaging strategy which ensures that the nominal quantity is achieved. This is usually done by adding a fixed percentage, e.g., 10%, of the nominal quantity to each package;
ii) There is a problem with the employee performing the counting task. This is a very monotonous and tedious job, which encourages the employee to apply large personal safety margins.

The outcome of both these issues is packages that contain more than the nominal quantity (overfilling).

The literature dedicated to packaging methods for agricultural products is limited. Most of the studies deal with the quality aspects of the products, packaging materials, traceability and packages atmosphere rather than the methods used to fill the packages. Anthony (2001) developed a system to reduce the packages forces of cotton bales up to 35%. In examination of flower cutting packages Vitner *et al.* (2006) reported on a significant variability of the number of cuttings per package with the mean close to 20% above the nominal level, resulting in excessive overfilling. They proposed a method resulting in a significant reduction in overfilled packages which translates to increase in revenue. Li *et al.* (2005) developed an automatic packaging system for automatic packaging of milk standards with filling

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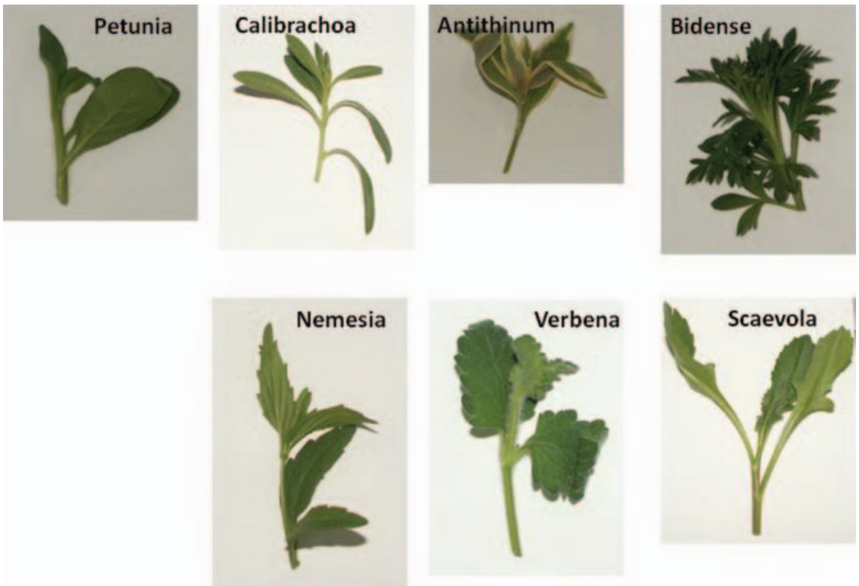


**Figure 1:** Typical ornamental plant cuttings

accuracy of 40. ± 1 ml, meeting the industrial standards and a capacity of 30 to 40 vials per min. In the developed automatic packaging system, the capping, filling, and label printing operations were automated through a programmable logic controller (PLC). A wheat flour milling traceability system (WFMTS), incorporating 2D barcode and radio frequency identification (RFID) technologies was developed by Qian *et al*. (2012). The system increased the total operational cost by 17.2% and the sales income by 32.5%.

A useful statistic value for comparing the variability of variables with different means and different standard deviations is the coefficient variation (CV) which is defined as the measure $\sigma/\mu$, where $(\sigma)$ is the standard deviation and $(\mu)$ is the mean. Different products have different CV values. In packaging of plant cuttings, Vitner *et al*. (2006) found that the CV ranged from 0.17 to 0.23. Bechar *et al*. (2001) investigated injuries to apples during harvest and transportation, and found that the CV was 0.17. Zion and Lev (1996) investigated a weighing method as an alternative procedure for sorting Aster, Hipericum, Solidaster, and Solidago cuttings, and reported that their CVs were ranged from 0.22 to 0.54. Cronin *et al*. (2003), investigated the weight variability in extruded food products and found that the CV was ranged from 0.047 to 0.096. Hauhouot-O'Hara *et al*. (2000) calculated the CV of the length, width, and thickness of seeds in the process of selecting the size and shape of holes in screens used to separate chaff from wheat. Morales-Sillero *et al*. (2008) used CV as an aid in verifying the influence of nutrient supply on olive dimensions (weight, length, and equatorial diameter). Hoffmann *et al*. (2007) used CV measurement to determine the distribution of foreign material inside the box during potato harvesting.

This study aims to develop a weight-based method for 'packages labelled by count' of agricultural products which minimises the difference between the actual number of units in a package and the nominal number. A mathematical weight CV-based model was developed to support the production of packages of cuttings that were 'labelled by count'. The model determines the critical package weight, which is the most compatible with the package characteristics according to the specific product's CV.

## 2. Material and Methods

### Count-to-Weight Transform Methodology

In order to utilize the transform methodology, it is assumed that the package weight, $w$, is distributed normally (i.e., the package weights are normally distributed, under the assumption that the number of individual items in each pack is large, usually above 30) based on the Central Limit Theorem:

$$w = N \sim \left(n \cdot \mu, \sqrt{n} \cdot \sigma\right) \quad (1)$$

where $\mu$ is the average weight of one product unit and $n$ is the nominal number of product units in a package.

Five basic packaging characteristics were defined:

$\bar{n}$ – the mean number of items in a package;

$n_L$ – the minimum number of items in a package;

$n_U$ – the maximum number of items in a package;

$\Delta n$ – the range of numbers of items in a package, $\Delta n = n_U - n_L$; and

$CR_n$ – the ratio between $\Delta n$ and $\bar{n}$ (Bechar and Vitner, 2009).

**Figure 2:** Lavateramaritima(left) and Picking Lavateramaritima cuttings (right)

**Table 1:** Descriptive statistics for the different cutting varieties. The data represents statistics on weights of a single cutting

| Species | Mean [g] | SD. [g] | No. of samples | Min [g] | Max [g] | CV |
|---|---|---|---|---|---|---|
| Bidens | 0.17 | 0.05 | 102 | 0.08 | 0.31 | 0.28 |
| Candy snap | 0.20 | 0.04 | 110 | 0.13 | 0.32 | 0.20 |
| Calibrachoa | 0.10 | 0.02 | 114 | 0.06 | 0.15 | 0.19 |
| Petunia | 0.30 | 0.08 | 104 | 0.11 | 0.56 | 0.27 |
| Scaevola | 0.61 | 0.24 | 105 | 0.25 | 1.44 | 0.39 |
| Verbena | 0.14 | 0.03 | 106 | 0.08 | 0.24 | 0.24 |
| *Nemesia sp.* | 0.12 | 0.04 | 95 | 0.05 | 0.24 | 0.32 |

Any farmer aims to deliver to the market packages that comply with the specified nominal number of units, and she/he may adopt various strategies, depending on market or customer demands, such as the minimum quantity package strategy in which the number of units in a package ($n_L$) should not be less than $n-\delta$, where $\delta$ is an integer number in the range of $n+1>\delta>-\infty$. The basic characteristics of the package can be calculated according to the product CV and the farmer's strategy.

The weight distribution of the cuttings creates a package weight range and for a given population of packages with mean weight $W_\mu$, the maximum and minimum number of items in a package is $n_U$ and $n_L$, respectively.

The critical package weight is the minimum allowable weight of a package enabling the worker to decide whether a package complies with the requirements; it is calculated according to the basic characteristics of the package, the average weight, and standard deviation of the product:

$$W_\mu = n_U \cdot \mu - 3\sqrt{n_U} \cdot \sigma \tag{2}$$

The critical weight, $W_\mu$, assures that the maximum number of cuttings in a package will not exceed $n_U$. The maximum and minimum number of items in a package and the range of numbers of items in a package can be expressed in terms of the coefficient of variation, CV, and the nominal number of items in a package Bechar and Vitner (2009):

$$n_U = \frac{9}{2}CV^2 + n + 3CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \tag{3}$$

$$n_L = \frac{9}{2}CV^2 + n - 3CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \tag{4}$$

$$\Delta n = 6CV \cdot \sqrt{\frac{9}{4}CV^2 + n} \tag{5}$$

As for example, in the case of Candy Snap, the mean weight of a single plant cutting is $\mu$=0.20 g and the standard deviation is σ=0.04 g. The mean weight of a package, $W_\mu$, with nominal number of 200 plant cuttings is 40 g. The number of cuttings in such a package will range between 193 ($n_L$) and 209 ($n_U$). If the requirement is that the number of cuttings in a package should not be below 200, then the average package weight will be 41.7 g. The mean number of cuttings in a package will be $\bar{n}$=208.5 and the maximum number of cuttings in a package will be $n_U$=218 cuttings. A similar detailed analysis was presented by Bechar and Vitner (2009).

## Weighing Procedure

In order to examine the characteristics of different cuttings, and verify the equations, cuttings of seven ornamental plant varieties were weighed with an MP-3000 digital scale (Chyo Balance Corp., Tokyo, Japan). The varieties were: Bidens, Antithinum Candy Snap, Calibrachoa Celebration Dark Blue, Petunia Surfinia, ScaevolaSaphira, Verbena Temari and Nemesia sp. (Fig. 1). Typical dimensions of the cuttings were 25 mm to 70 mm for the width and 40 mm to 85 mm for the length. Each cutting was weighed and the number of cuttings for each variety was counted. For each variety the mean weight, the standard deviation and the CV, were calculated.

## Validation

An experiment was conducted to examine the developed method. The experiment was executed in a cutting nursery located at central part of Israel (Fig. 2, right). The examined cutting was *Lavateramaritima* (Fig. 2, left). Since cuttings are seasonal crops, in the time of the experiment the cuttings described in the previous section were not available in the nursery that the experiment was performed. In the experiment, two methods were examined:

i) the current method - the workers picked cuttings and put them in a package (a plastic bag). The workers counted the number of cutting during their work. When the number of cuttings reaches the required figure, the bag is closed and the worker continued with a new bag.
ii) The modified method - the worker picked cuttings without counting into a container, after picking a certain amount, the minimum allowed weight of a package was calculated and

**Table 2:** Package characteristics of *Nemesia sp.* for various values of $\bar{n}$

| $\bar{n}$ | 10 | 20 | 50 | 100 | 200 | 500 | 1,000 | 5,000 | 10,000 |
|---|---|---|---|---|---|---|---|---|---|
| $W_\mu$ | 1.20 | 2.40 | 5.99 | 11.98 | 23.96 | 59.89 | 119.8 | 598.9 | 1197.8 |
| $n_L$ | 7.38 | 16.12 | 43.62 | 90.79 | 186.8 | 478.8 | 969.9 | 4932 | 9904 |
| $n_U$ | 13.56 | 24.81 | 57.32 | 110.1 | 214.1 | 522.1 | 1031 | 5069 | 10098 |
| $\Delta n$ | 6.18 | 8.69 | 13.70 | 19.35 | 27.35 | 43.23 | 61.13 | 136.7 | 193.3 |
| $CR_n$ | 0.618 | 0.435 | 0.274 | 0.193 | 0.137 | 0.0865 | 0.0611 | 0.0273 | 0.0193 |

 

**Table 3:** The product regression equation coefficients

| variety (i) | CV | $n_U$ | | $n_L$ | | $\Delta n$ | | $CR_n$ | |
|---|---|---|---|---|---|---|---|---|---|
| Eq. coeff. | | $a_0$ | $a_1$ | $a_0$ | $a_1$ | $a_0$ | $a_1$ | $a_0$ | $a_1$ |
| Bidens | 0.285 | 1.2368 | 0.9794 | 0.8085 | 1.0206 | 1.7185 | 0.4994 | 1.7185 | −0.5006 |
| Candy snap | 0.196 | 1.1573 | 0.9859 | 0.8641 | 1.0141 | 1.1769 | 0.4997 | 1.1769 | −0.5003 |
| Calibrachoa | 0.193 | 1.1553 | 0.986 | 0.8656 | 1.014 | 1.1626 | 0.4997 | 1.1626 | −0.5004 |
| Petunia | 0.270 | 1.2228 | 0.9805 | 0.8178 | 1.0195 | 1.625 | 0.4995 | 1.625 | −0.5005 |
| Scaevola | 0.392 | 1.3391 | 0.9718 | 0.7468 | 1.0282 | 2.3752 | 0.499 | 2.3752 | −0.501 |
| Verbena | 0.236 | 1.1926 | 0.983 | 0.8385 | 1.017 | 1.421 | 0.4996 | 1.421 | −0.5004 |
| *Nemesia sp.* | 0.322 | 1.2715 | 0.9768 | 0.7865 | 1.0232 | 1.9459 | 0.4993 | 1.9459 | −0.5007 |

then cuttings were loaded on a scale. When the scale reaches the minimum allowed weight, the worker inserts the cuttings into the package. In each method, 20 packages were filled and packed. The nominal number of cuttings per package for both methods was 50. However, in the current method, the farmer packaging strategy was to pack 54 cuttings in each package in order to ensure that the nominal quantity is reached. In both methods, after the packaging stage was completed all packages were opened and the number of cuttings in each package was accurately counted. In addition, above 150 cuttings in each method were weighted separately in order to evaluate the cuttings population characteristics.

## 3. Results

### Cuttings weight characteristics

A total of 736 cuttings from seven varieties were weighed. The values of CV for the various varieties ranged from 0.19 for *Calibrachoasp*. to 0.39 for *Scaveolasp*. The results shown that varieties with similar average weights, i.e., *Calibrachoa sp., Verbana sp.* and *Nemesiasp*., had differing CV values that derived from the natural characteristics of each product. Thus, for two varieties with the same average weight, different critical weights will be determined. Table 1 presents descriptive statistics for all varieties.

### Count-to-Weight Transform Methodology

Package characteristics analyses were conducted for all cutting varieties. At first, the required package characteristics were determined, the variety CV was taken from Table 1, and then the critical package weight, $W_\mu$, and the remaining package characteristics were calculated. Table 2 listed the critical weights, $W_\mu$, and the package characteristics, calculated for *Nemesia sp.* and different n̄. For each package characteristic and each variety, a polynomial regression equation was found. A general form of the equation is:

$$f_{ij}(x_i) = a_{0ij} \cdot x_i^{a_{1ij}} \quad (6)$$

where index $i$ represents the product type (i.e., variety in our case), index $j$ represents the calculated package

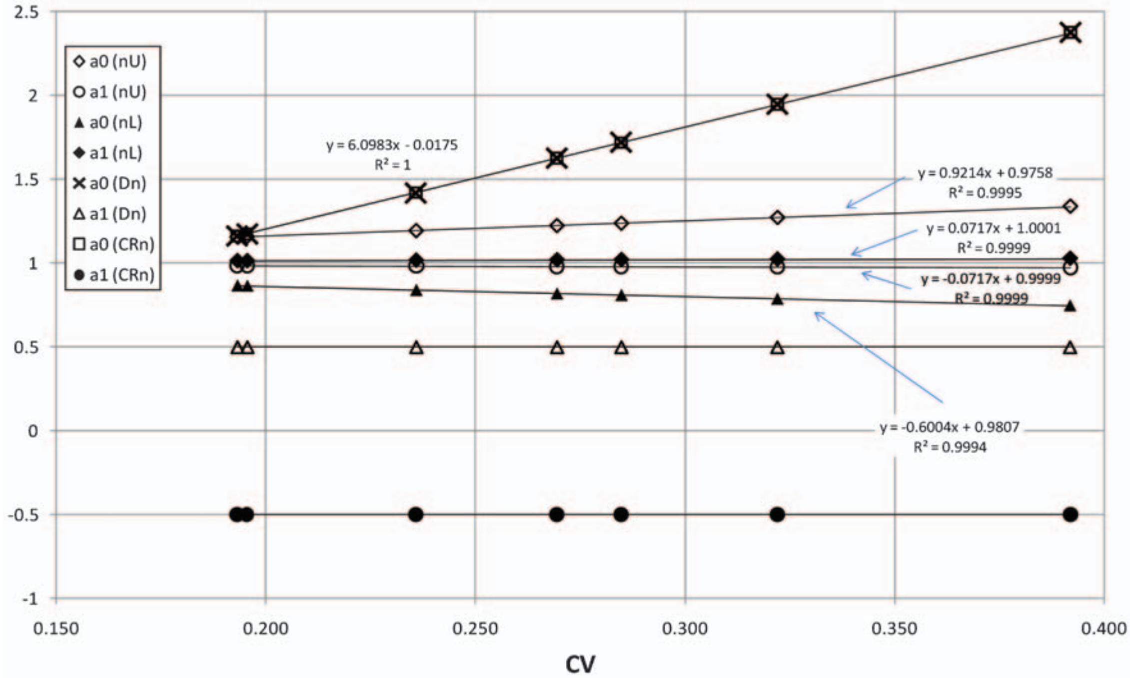


**Figure 3:** Calculated strategy regression equation coefficients and the correlation coefficients for all package characteristics in the minimum package strategy

**Table 4:** The strategy regression equation coefficients for the minimum package strategy

| | $\bar{n}$ | | $n_L$ | | $n_U$ | | $\Delta n$ | | $CR_n$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\alpha_o$ | $\alpha_1$ | $\alpha_o$ | $\alpha_1$ | $\alpha_o$ | $\alpha_1$ | $\alpha_o$ | $\alpha_1$ | $\alpha_o$ | $\alpha_1$ |
| $a_0$ | - | - | −0.600 | 0.981 | 0.921 | 0.976 | 6.098 | −0.017 | 6.098 | −0.017 |
| $a_1$ | - | - | 0.071 | 1.000 | −0.071 | 1.000 | 0 | 0.500 | 0 | −0.500 |

characteristics, $x$ represents the predetermined package characteristic (e.g., $\bar{n}$), $f$ is the calculated package characteristics and, $a_o$ and $a_1$ are the equation coefficients. This equation is designated as the 'product regression equation' because its coefficients are dependent on the specific product CV. The coefficient of determination, $R^2$, was higher than 0.9997 for all varieties.

The polynomial regression equation coefficients, $a_o$ and $a_1$, of each package characteristics are given in Table 3.

The results indicate that the values of $a_o$, $CR_n$, and $\Delta n$ are equal and the value of $a_1$ is opposite for $CR_n$ and $\Delta n$. Since $CR_n$ equals $\Delta n$ divided by $\bar{n}$, and in the minimum package strategy, $\bar{n}$ equals $n$, for high $\bar{n}$ (i.e., above 100), Eq. 5 could be simplified to $\Delta n \approx 6CV \cdot \sqrt{n}$, therefore:

$$CR_n \approx 6CV \cdot \frac{1}{\sqrt{n}} \quad (7)$$

The relationships between the value of CV and the coefficients $a_o$ and $a_1$ were investigated. For each package characteristic, a linear regression equation was determined:

$$a_{k,j}(CV) = \alpha_{0kj} \cdot CV + \alpha_{1kj} \quad (8)$$

where index $k$ can be 0 or 1, to designate the coefficient $a_o$ or $a_1$, respectively, index $j$ indicates the calculated package characteristics. This equation is referred to as the 'strategy regression equation' since the equation coefficients $\alpha_o$ and $\alpha_1$ for each package characteristic depend only on the strategy. For all strategy regression equation, $R^2$ was higher than 0.9995.

Figure 3 shows the effect of CV on the product regression equation coefficients of the various package characteristics and on the calculated strategy regression equation coefficients and their correlation coefficients in the minimum package strategy. Table 4 shows the polynomial regression equation coefficients, $a_o$ and $a_1$, of each package characteristics found for the minimum package strategy.

In practice, when applying the present model, the farmer needs to have the product CV in order to determine the critical package weight and to comply with the package definitions.

## Nursery Experiment

The descriptive statistics on cuttings population in the two packaging methods were calculated based on 365 cuttings and it shows that the cuttings characteristics of the two methods are similar and the differences are insignificant (Table 5).

For the calculation of the critical weight, the mean, standard deviation and CV values of *Lavateramaritima*in the modified method (Table 5) were used. In the modified method, the 'minimum quantity' package strategy was used for the nominal number of cuttings in a package (50 cuttings). The critical weight was calculated by applying Eq. 2. Table 6 presents the descriptive statistics of package size in both methods. The results indicate that the range of the number of cuttings in a package (between the largest package to the smallest package) was reduced from 19, in the current method, to 8 in the modified method. The standard deviation and the CV were reduced by 30% and 33%, respectively. Moreover, the amount of packages containing cuttings below the nominal number (50) and the farmer's strategy (minimum of 54 cuttings) were 5% and 30%, respectively, in the current method. The amount of packages containing cuttings below the nominal number was reduced to zero with the modified method.

Figure 4 illustrates the distributions of package size in the current and modified methods respectively.

# 4. Conclusions

The goal of every manufacturer is to pack the specified nominal quantity in each package, while incurring minimum cost. Products with high weight variability must be packed manually because, in general, automatic weighing scales are utilized only in packing products with very low weight variability.

An innovative method for packing 'packages labelled by count' was presented. A mathematical model to support the preparation of such packages by means of a weighing procedure was developed on the basis of the definition and characteristics of the coefficient of variation (CV) of the product weight. It uses the product CV in order to determine the critical package weight and to comply with the package definitions.

The experiment results revealed that the variability of the package size was high when counting manually, even when the packages nominal number was relatively low. The modified method which involves weighing procedure of 'packages labelled by count' reduced the variability in package size and minimized to zero the under filling of packages.

The procedure can be utilized as a management tool by farmers to determine the package characteristics, the

**Table 5:** Descriptive statistics of cuttings population in the two packaging methods

| Method | Mean [g] | S.D. [g] | CV | *n* | Min [g] | Max [g] |
|---|---|---|---|---|---|---|
| Current | 0.503 | 0.167 | 0.333 | 214 | 0.17 | 0.98 |
| Modified | 0.505 | 0.172 | 0.341 | 151 | 0.18 | 0.99 |

**Table 6:** Descriptive statistics of package size in both methods

| Method | Mean | S.D. | CV | N | Min | Max |
|---|---|---|---|---|---|---|
| Current | 54 | 3.29 | 0.0610 | 20 | 45 | 64 |
| Modified | 55.8 | 2.28 | 0.0409 | 20 | 52 | 60 |

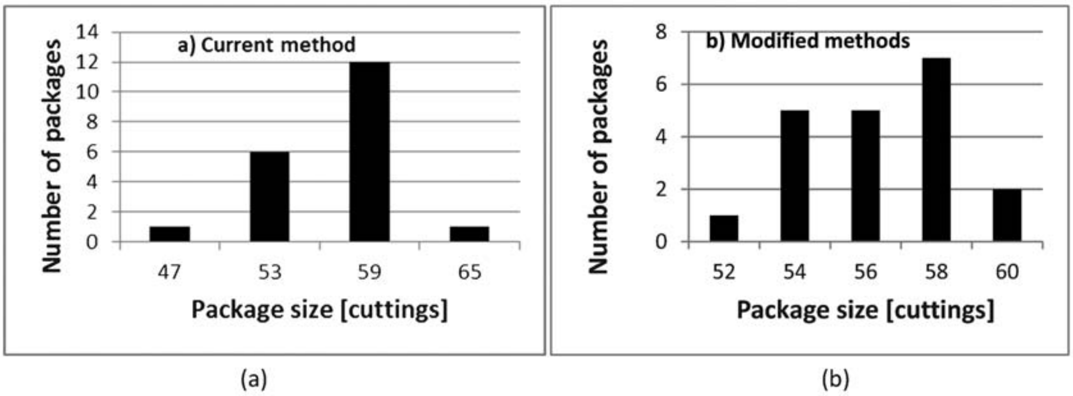


**Figure 4:** Package size distribution of a) current and b) modified methods

working instructions for preparation of packages, and to satisfy given commercial constrains at minimum costs.

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REFEREED ARTICLE

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# Stakeholders involvement on establishing public-private partnerships through innovation in agricultural mechanization: a case study

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**ABSTRACT**

Agricultural production has to increase drastically for the next years in order to meet societies' needs. At the same time, using sustainable ways to produce this huge amount of food and resources is becoming increasingly critical. Innovation, both in technologies and in uses/ practices, is strongly encouraged in Europe as a solution to these challenges. As this process remains very complex to manage, analysing it in real conditions seems crucial, especially to improve it. Then, in this paper, we will present and analyse an experimental Public-Private Partnerships Action launched at the European level. This one-year action aimed to gather together all the players involved at the European level for crop protection and to boost concrete innovation in ICT (Information and communication technology) to reduce the use of pesticides, especially around three types of technologies using ICT and robotics. For small and medium-sized enterprises, the particular area of agricultural machinery, solutions have to be found to offset the necessary confidentiality of private stakeholders' interests, and also to give them some reassurance, or at least advantages, on the results of such partnerships.

**KEYWORDS:** innovation process; value-chain; robotics; ICT

## 1. Introduction

Agricultural production has to increase drastically for the next years in order to meet societies' needs and, at the same time, should be more sustainable (Alexandratos, 2012). Innovation is seen, in Europe among others, as the key solution to cope both with these challenges and to economic growth and employment. A lot of studies were done since the 80s' on innovation and several aspects, especially on its process, were highlighted. A main dimension revealed is the complexity of this process and the large number of people it implies. In short, innovation does not belong only to one kind of people (research or R&D - research and development services) but is composed by complex interactions between lots of different stakeholders. However, even if we know more about the innovation process, and as highlighted by the latest European initiatives, there is still today a gap between research and practices. This gap, and the work which remains to be done, is not so much part of the innovation theory elaboration, but is rather operational challenges (Hall, 2007).

Hence, this paper aims to contribute at this last level of operational challenges with a case-study, by producing materials, testing and analysing the management of innovation process in agriculture. This initiative, launched within the context of a European ERA-NET, a project funded by the European Commission in order to link several researches within specific themes relevant to society, aimed to promote the set-up of public-private partnerships (PPPs), or at least to strengthening the links between the stakeholders, around innovations using ICT and robotics in agriculture targeted on the case of pesticides use.

For this study, the focus was both on the 'management' part of an innovation process and on the specificities related to 'technological' innovation in agriculture. Indeed, ICT, automation solutions, and robotics could play a considerable role in the development of sustainable and efficient farming systems by developing precision agriculture, as a result of the innovation process (new tools) or during the process it-self (by strengthening information exchange and networking among all relevant stakeholders).

## 2. Literature Review

Innovation 'is one of those words that suddenly seem to be on everybody's lips' and there is so many studies on the subject that the question of a new scientific field arose (Fagerberg & Verspagen, 2009). However, it seems

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worthwhile to briefly revisit what is mean by 'innovation' and what it defines and, secondly, to review some ways of managing the innovation process developed during the years, especially those involving several kind of stakeholders.

### From Innovation to innovation systems

Innovation was first regarded as a 'source of energy' for economy in social sciences in 1939 by J. Schumpeter, but it is only a few years after that the interest around the question grew, in the 1960s for the United States and around the 1980s' in Europe (Fagerberg & Sapprasert, 2011). These studies moved gradually from focusing on isolated aspects of innovation to more holistic and complex approaches describing 'systems of innovation'. In other words, these studies highlighted the fact that for innovation success or failure isn't often due to technical or scientific problems but 'generally involves ethical; social, management, organisational and institutional problems' (Smits, 2002). Therefore, one of the main solutions investigated to improve the innovation process by taking into account its complexity is to create and strengthen the links between the several stakeholders involved: end users, industry, public research, and intermediaries.

### Methods of innovation with the involvement of the main stakeholders

The interest on involving several stakeholders in the innovation process is far from new, and how to involve them and how to manage interactions and processes could take different forms. Briefly, we could highlight three main aspects which differentiate these methods: the kind of stakeholders they involve, the degree of involvement of stakeholders they designed, and the form of organisation chosen (degree of openness and confidentiality).

First, these methods could choose to focus on some kind of stakeholders. For example, it could focus on end users' involvement: 'Farmers' knowledge really does count' was proclaimed and studied since the 1990s, if not before (Hall, 2007). It could otherwise focus on industries participation (it is the case for PPPs used by industrial development and among others by UNIDO, 2008). Or finally, it could imply the participation of the greatest possible number of stakeholders (Bos & Groot Koerkamp, 2009).

These methods could also vary regarding the degree of involvement of the stakeholders. It could simply begin with interviews of stakeholders. Examples with end users (farmers) could be found in participatory methodologies (Chambers, 2008) and surveys of end users (Jørgensen *et al.*, 2006). Other methodologies, such as open innovation and Living Lab, not only include stakeholders' views or ideas in the innovation process, but make them work together with information and knowledge exchanges as well as with the sharing of results (advantageous or not). For example, it is the case in agriculture for the development of PPPs (Spielman, Hartwich, & von Grebmer, 2007) or for the RIO Reflexive Interactive Design (Bos & Groot Koerkamp, 2009).

Then, another main difference between all these methods is the degree of openness and information exchanges. Open innovation, 'one of the hottest topics in (current) innovation management', which helps practitioners and scholars to 'rethink the design of innovation strategies in a networked world' (Huizingh, 2011) focuses obviously on the openness and the sharing of information. Rather, PPPs allow the exchange and work on a more confidential level.

## 3. Study Development

The study was based on a European initiative launched by the ICT AGRI Era-net. This initiative, named PPP Action, took place during one year (from November 2011 to about October 2012).

### The ICT AGRI ERA-NET organization

ICT-AGRI ERA-NET [European Research Area Network for Coordination of Information and Communication Technology (ICT) and Robotics in Agriculture and Related Environmental Issues] is one of the ERA-NETS, funded under the 7th Framework Programme for Research (FP7). Initiated on May 2009 and running until March 2014, this ERA-NET has 18 partners and 14 observers from 21 countries. Its key concerns are to strengthen the international competitiveness of the European Union and to reduce the negative impact of agricultural production on the environment by using ICT and Robotics.

To date, ICT-AGRI ERA-NET 1 mains results are a Strategic Research Agenda for ICT and robotics, 2 calls which have funded several research projects and a Meta-Knowledge Base (an online resource). A second ICT-AGRI ERA-NET, including more partners, was launched in 2014 and is more orientated towards innovation.

### The PPP Action

Even if ICT AGRI ERA-NET 1 was more focused on the coordination of research activities in Europe, it showed a growing interest toward innovation. Hence, from November 2011, the ERA-NET has launched an experimental one-year action on innovation. This initiative named 'PPP Action' aimed at promoting PPPs in a broader sense: all types of partnerships between actors from public research and other stakeholders such as end users, private companies and intermediaries (industrial clusters, professional associations…).

The action had a twofold objective. First, this PPP Action aimed to bring together the stakeholders of the innovation process in agriculture around a same challenge: the reduction of the use of pesticides in agriculture. Results expected could be, in the best case, the set-up of concrete partnerships involving public research, industries and end users. A less ambitious conclusion of this action could be the set-up and strengthening of linkages between these stakeholders.

The second objective of this PPP Action was reflexive: it concerns the study of the action it-self. A methodology, based on existing methods, was designed and tested in order to manage this experimental action.

### The three 'supports' to boost exchanges and discussions between stakeholders

The three suggestions used to start and boost exchanges and discussions between the players were the following:

- An **E-services package**, a sharing services platform using ICT,
- **Smart adjustments tools on sprayers** which aim at improving techniques and conditions of pesticides application on short and mid-term,
- **Combined and modular robotic solutions** which, over a longer term, could combine multi-actions from a single robotic platform.

For these three suggestions, their different components and corresponding actors were identified. These aspects refer to technological elements and actors, but not only: societal, legal, and contextual aspects and actors were also identified collectively and were involved. The main idea was to start the discussion and not to realize these three suggestions. Any proposition of participants on other possibility was encouraged.

In order to gather together the main stakeholders concerned by the reduction of the use of pesticides, a method was designed, based on several existing methodologies. Three aspects of this method seemed crucial.

- First, we have decided to develop PPPs, with a focus on private companies, without excluding other stakeholders. Indeed, private partners could be interested more directly by the ICT AGRI activities (for example with the opportunity to participate to scientific project funded by ERA-NET)
- Secondly, as particularly highlighted in open innovation approaches, some flexibility was left in order for creativity and collective work to develop. In our case, the degree of openness was up to the players involved and could have been different regarding the content as well as for the type of partnerships created.
- Lastly, as our challenge was mainly operational with time constraints, we have decided to use existing methods (the value chain approach) with some improvements due to the specificities of our action.

In order to nurture the first spark of discussion between the players of our PPP experimental action, **a value-chain approach** was adopted. This approach, applied originally inside the firm, allows to identify all the players who are involved in the innovation process 'from conception, through the different phases of production, delivery to final consumers, and final disposal after use' (Kaplinsky & Morris, 2001). Then, each brick of the innovation process provides a useful basis for the discussion and collective work. Our main objective was to create the right condition to stimulate interactions and collective work of the participants.

## 4. Survey Impressions

The experimental PPP action of ICT AGRI ERA-NET ran during one year at the European level and both the evolution of the action and the results (positive and negative) are important to be analysed. The concrete positive results were: links made between several partners interested by crop protection, better knowledge of these players, a 200 participants conference organized with two other European projects and some recommendations for next innovation management action. We present and discuss in this Section the main mitigated aspects of the management of this action and some recommendations.

### Finding the right stakeholders and involving the intermediaries first

Most of the difficulties we met during our experimental action were due to the time and challenge of identifying **the right stakeholders**. Hence, **intermediaries** such as industrial clusters, national or local associations, and also era-net, have a very important role to play there, and they should be encouraged to do so. In our action, the involvement of intermediaries and the lack of mapping of these players were underestimated and not done at the right scale: local intermediaries showed more interest and were more active than most of the intermediaries contacted at the wider level.

### Creating a motivation for all the stakeholders involved

Strongly linked to the previous aspect, the **motivation of the players** and **the way to manage it** are also important. Indeed, PPPs are interesting for both public and private players (Hartwich, Janssen, & Tola, 2003). For public players, it ties research more closely to users' needs (and can augment investments in research). And for the private sector, it improves competitiveness (as other forms of outsources activities). But, in the operational action, stakeholders do not really measure the interest of these partnerships and are not able to see, in a lot of different existing actions and initiatives, which one is interesting for them. A constant reminder of the interests and gains for each player is necessary, as well as other form of motivation (such as financial help to set up the project for example).

### Mapping and – or coordination of innovation funding programs

Several funding mechanisms for innovation, promoting projects with industrial partners, exist in some European countries. It could be important to map these mechanisms in order to inform the stakeholders, or even better, to support them to benefit from these mechanisms in trans-national projects including companies.

### Managing the confidentiality and the diversity

As we experienced in the PPP action, some private partners (large companies or SMEs – small and medium-sized enterprises) expressed their interest without participating directly to the collective work. The main reasons of this distance could be the early stage of the project and a need for confidentiality: Ways of managing these interests and some confidentiality required should be found while at the same time going on with the collective work. Also, involving the different intermediaries of the players at different moment of the innovation process could offer more efficiency. For example, an earlier involvement of private companies and consumers (or their representatives) was strongly suggested by all the stakeholders involved in our action and could offset the issue of 'economic viability' which appears to be essential, as well as other issue already highlighted such as 'ease of use, reliability and legislation or liability issues' (Blackmore, 2007). A specific work on motivate them had to be done and took several forms: examples of successful PPPs, assessments on the impact of such partnerships, financial (or other types of) advantages to linked with public research, and end users associations.

## 5. Conclusions

To conclude, this work stresses the importance of the intermediaries' role (both for public and private players), the involvement of local intermediaries and projects, and the necessary space to create to let the partners choose their types of partnerships or organisation. Then, for the particular area of agricultural machinery, solutions have to be found to offset the necessary confidentiality of private stakeholders' interests, and also to give them some reassurance, or at least advantages, on the results of such partnerships. This is particularly true for SMEs. Regarding ICT innovation, on the contrary, open innovation and sharing of information and exchanges seem a good way to boost partnerships.

In all the cases, a main point which should be developed is the sharing of these experiences which try to boost innovation, at the European level. Exchange of experiences and good practices of innovations, as well as bad ones, such as in a 'community of practice', as suggested by Hall (2007), will significantly help to manage better these innovation process.

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# Logistics Processes Prioritization in the Agrifood Sector

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**ABSTRACT**

As logistics become a substantial part of a firm's operations, the corresponding processes increases in importance. Identifying key logistics processes using a structured approach will align their outcomes to deliver the business goals, design appropriate measures and allocate sufficient resources for their improvement. This paper proposes a methodological framework for the identification, categorization and prioritization of logistics processes in the agrifood sector. Finally, a proposed mathematical model for the prioritization of logistics processes is presented. The proposed model is based on the fundamental idea of Data Envelopment Analysis (DEA) method, measuring the efficiency of the logistics processes by taking into account the multiple inputs utilised and outputs produced by them.

**KEYWORDS:** logistics processes; agrifood supply chain; business process management; methodological framework; linear programming model

## 1. Introduction

Processes lie at the heart of everything that organisations do to maintain their existence and grow (Dalmaris *et al*. 2007). According to Rensburg (1998) business processes are simply defined as a series of interrelated activities linked together to produce customer value. Davenport and Short (1990) define business process as a set of logically related tasks performed to achieve a defined business outcome. Porter (1985) and Davenport (1993) argue that business processes can be subdivided into primary and supporting. Primary Business Processes are those involved in the creation of the product, its marketing and delivery to the buyer (Porter, 1985). Supporting Business Processes facilitate the development, deployment and maintenance of resources required from primary processes. Supply Chain Management focuses on primary processes from the point of origin to the point of consumption (Lambert and Cooper, 2000). The success of the supply chain networks highly depends on the effectiveness and efficiency of logistics processes (Bask and Juga, 2001). Companies must identify, model and optimize their logistics processes so as to remain competitive; and not only their inner processes but the common processes that share with the other members of a supply chain (Christopher and Jüttner, 2000).

In most business environments, a maximum 12 to 15 functions are considered as key business processes. Some of them may span horizontally and internally across most of the departments of a company, or even externally and across the entire supply chain, while companies may implement different practices for monitoring and assessing them (Quesada and Gazo, 2007).

Companies may also have distinct key processes when compared to its competitors, which may be related to the company's own approach and strategies for pursuing new opportunities and meet challenges according to its own unique geographic location, market positioning, future aspiration, technology portfolio or regulatory frameworks. Intuitively, a company's stakeholders are aware of the activities or processes that are important for their organization, for example for a manufacturing company, the importance of production and sales processes are well appreciated by all (Curran and Ladd, 1999; Radjou, 2003). On the other hand, there are processes which have an equal or bigger impact on the organization although they never receive the appropriate attention such as the logistics processes.

The identification and prioritization of the business processes has been the main objective of many research initiatives (Kanji, 2002; Kaplan and Norton, 1992, 1993, 1996, 2000). Doyle *et al*. (2009) proposed a user interface to establish dynamic prioritization of business process instances. Moreover, Quesada and Gazo (2007) developed a methodology to help manufacturers determine and rank key internal business processes based on critical success factors.

As logistics become a substantial part of a firm's operations, the corresponding processes increase in importance (Sweeney and Park, 2010). Identifying key logistics processes using a structured approach, aligning their outcomes to deliver the business goals, designing appropriate measures and allocating sufficient resources for their improvement is the key to success.

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This paper proposes a systematic approach, by the use of a mathematical model, for the identification and prioritization of logistics processes is proposed. The proposed methodology is demonstrated in a case study dealing with enterprises of the Agrifood sector. The research is focused on the enterprises of the Agrifood sector because of its high significance for the Greek and the EU economy.

The logistics processes in the Agrifood sector include a number of processes such as the collection, aggregation, storage and transport of agricultural produce from the farm to the consumer. Why do we concentrate in this sector?

- First, the great majority of the agrifood companies do not have the required know-how, the high-skilled workers and the advanced information technology infrastructure in order to design, execute, control and monitor the above business processes (Manikas and Terry, 2009; Manikas *et al.* 2010).
- Second, a significant proportion of them does not maintain and use any enterprise information system (ERP, CRM, SCM, etc.) at all, and even if they do, it does not support a holistic approach of the monitoring and management of business processes (Argyropoulou *et al.* 2007).
- Third, a lot of companies maintain a quality standard (such as ISO, HACCP); however they are not able to use it as a tool/mechanism for the effective re-design of logistics processes and the improvement of their competiveness.

Another critical point is the opportunity that is given to these companies. Companies can focus on the key logistics processes in order to optimize their critical aspects such as time and cost issues, resources planning and scheduling, as well as, queues and delays (Christopher, 2005; La Londe and Masters, 1994; Johnson *et al.* 1999).

The following sections of the paper are organized as follows; Section 2 presents and analyses the proposed methodological framework for the identification and the prioritization of the logistics processes. The next section (Section 3) presents the mathematical model for the prioritization of the logistics processes, while Section 4 presents a case study of the application of the proposed methodology to the agrifood supply chain. The findings reveal the priorities that the managers of the examined companies consider about logistics processes. Finally, at the Conclusions part, the findings of the survey are discussed and the scope of further research is provided.

## 2. Materials and Methods

In this paper, a methodology is proposed for the identification and prioritization of logistics processes including four main steps (Figure 1):

Step 1: Assessment of business structure and functions.

Step 2: Classification of the generic areas of business processes.

Step 3: Identification of logistics processes based on the generic framework.

Step 4: Weighting, prioritization and selection of logistics processes.

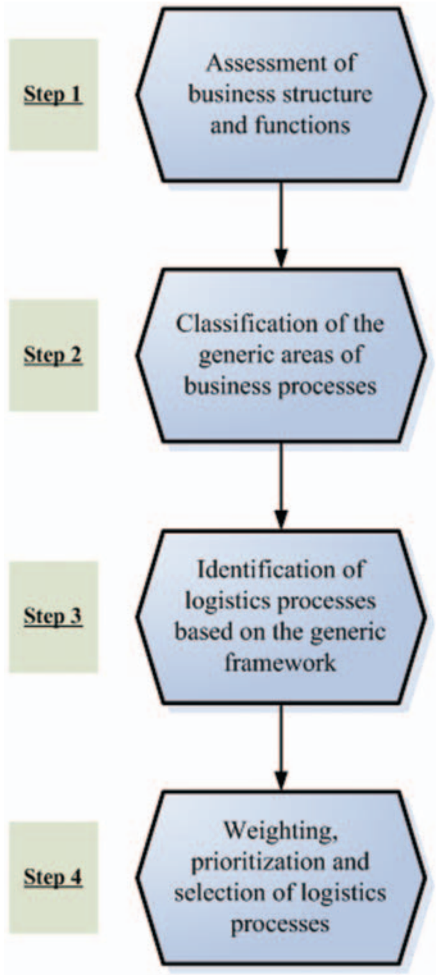


**Figure 1:** Methodological framework for identification and prioritization of logistics processes

Prior to the beginning of any taxonomy of logistics processes, it is important to carry out an assessment of the business structure and functions. In other words a detailed cartography of internal and external business environment needs to be conducted.

The next step deals with classification of the generic areas of business processes. Generally speaking, a business process consists of logically related activities performed together to produce a defined set of results according to a company's strategy. Since every company has different strategic objectives goals and mission, internal business processes may differ from one organization to another. Thus, it is necessary to identify the internal business processes and classified them under a generic framework. Camp (1995) proposed a list of the most important internal business processes that should be considered when evaluating firm's performance against other competitors. He proposed 11 areas of business processes: 1) Market Management, 2) Product design and engineering, 3) Product operations, 4) Supplier management, 5) Customer engagement, 6) Logistics and inventory management, 7) Product maintenance, 8) Business management, 9) Information and technology management, 10) Financial management, and 11) Human resource management. The first six are considered as 'operational' business processes and the rest as 'support' business processes.

APQC International Benchmarking Clearinghouse in partnership with Arthur Andersen & Co (1996) proposed a Process Classification Framework of 13 areas: 1) Understand markets and customers, 2) Develop vision and strategy, 3) Design products and services, 4) Market and sell, 5) Produce for manufacturing and deliver for service organization, 6) Produce and deliver for manufacturing organization, 7) Invoice and service customers, 8) Develop and manage human resources, 9) Manage information, 10) Manage financial and physical resources, 11) Execute environmental management program, 12) Manage external relationships, and 13) Manage improvement and change. Correspondingly with Camp's framework the first seven processes are 'operating' processes and the rest 'management and support' processes.

Diaz *et al.* (2004) identified 9 generic intra-organizational business processes: 1) Product development, 2) Procurement, 3) Order fulfilment, 4) Transformation, 5) CRM, 6) Asset management, 7) After-sales services, 8) Human resources management, and 9) Business process management. These processes are grouped in three types: 'core' (the first six processes) and 'support' business processes (the rest). In the literature many research initiatives regarding the classification of business processes can be found (Curran and Ladd, 1999; Radjou, 2003; Malone *et al.* 1999; Lambert *et al.* 1998). There are also a number of business processes models such as the Value Chain Model (Porter, 1985) the QFD model, etc. All of them proposed the logistics processes as key and critical business processes.

In Step 3 the identification of logistics processes based on the generic framework is carried out. In this step, a careful recognition of logistics processes in each generic business area need to be done in order to match supply chain capabilities to demand requirements from the point of origin to the point of consumption (Lambert *et al.* 1998; Day, 1994).

The last step deals with the selection of the key logistics processes. Particularly, in this step, the logistics processes that came out from the previous step should be prioritized and classified based on specific criteria. The criteria should be selected according to the business strategy and needs. For example, criteria can be pertained to operational efficiency, generation of profit, generation of competitive advantage, etc.

## 3. Results and Discussion

### Problem Definition

As mentioned above, the selection of the key logistics processes in the agrifood business sector is an important issue. Based on our extensive work in the agrifood supply chain management as well as on the related bibliography (see Section 2), we have identified eight (8) generic business areas and their logistics processes (Table 1).

In order to identify the key logistics processes in this particular business sector, we have selected the criteria and categorized in two main groups: inputs and outputs. In Table 2, the selected inputs and outputs of the key logistics processes are provided. The above selection is based on the works of Davenport (1993), Dervitsiotis (2006), Madison (2005), Ioannou (2005), and Laguna and Marklund (2004).

### Model Formulation

In the relevant literature, there are many techniques – methodologies employed for the measurement of the level of processes' efficiency and productivity. In this subsection, we present the proposed model aiming at the prioritization of logistics processes. The proposed model is a binary linear programming model and is based on the basic idea of Data Envelopment Analysis (DEA) method, measuring the efficiency of the logistics processes by taking into account the multiple inputs utilised and outputs produced by them.

Nowadays, DEA has been recognised as an important tool for the analysis and evaluation of the performance of manufacturing and service operations (Cooper *et al.*, 2011; Talluria *et al.*, 2006).

Below, we provide the related nomenclature:

$i = 1,\ldots,I$: group of logistics processes.

$j = 1,\ldots,J$: logistics processes.

$k = 1,\ldots,K$: output produced.

$p = 1,\ldots,P$: input utilized.

Next, in Table 3 we provide the nomenclature for the decision variables and the parameters of the model.

Consequently, the following binary linear programming model is formulated:

Maximize:

$$\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{j=1}^{J}\left[\left(\left(c_k\frac{\left(out_{kij}-out_{ki}^{\min}\right)\left(S_{\max}-S\min\right)}{out_{ki}^{\max}-out_{ki}^{\min}}\right)+1\right)-\left(\left(c_p\frac{\left(in_{pij}-in_{pi}^{\min}\right)\left(S_{\max}-S\min\right)}{in_{pi}^{\max}-in_{pi}^{\min}}\right)+1\right)\right]\cdot y_{ij}$$

Subject to:

$$\sum_{j=1}^{J} y_{ij} \leq N_i,\ \forall i \tag{1}$$

$$y_{ij} \in \langle 0,1 \rangle \tag{2}$$

The objective function aims at maximising of the performance of the logistics processes taking into account the results – outputs produced minus the necessary inputs utilized. As it can be easily seen, the quantified values of all inputs and outputs are scaled in a range of 1–10, in order to facilitate monitoring and direct comparison between them. Equation (1) provides the maximum number of logistics processes that can be selected in each group. Finally, equation (2) represents binary constraints.

## 4. Case Study

A brief and illustrative case study is presented herein for demonstrating the applicability of the proposed model while further obtaining managerial insights on the properties of the optimal solution. Our goal was to identify the three (3) key logistics processes of each business area in the agrifood sector. In order to succeed that, a survey conducted from July 2010 to February 2011, to the managers (CEO's, Operations and Logistics Managers) of the 80 largest agrifood companies in Greece. Of the questionnaires distributed, 57 completed questionnaires were returned by those surveyed. The effective response rate was very good (71%). A

 

**Table 1:** Main business areas and the related logistics processes in the agrifood sector

| Group | Logistics processes |
|---|---|
| Production support | Planning of primary production [PR1]<br>Procurement for production [PR2]<br>Harvesting [PR3]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5]<br>Production planning [PR6]<br>Selection of production machines and lines [PR7]<br>Layout planning [PR8] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Planning of distribution network [DIST2]<br>Planning of transportation management [DIST3]<br>Control and monitoring of transportation management [DIST4]<br>Selection of transportation means [DIST5]<br>Selection of transportation materials [DIST6]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8]<br>Planning of distribution tasks [DIST9] |
| Warehousing and Inventory Management | Location of warehouse or distribution center [WARE1]<br>Layout of warehouse or distribution center [WARE2]<br>Selection of warehousing facilities [WARE3]<br>Selection of warehousing materials [WARE4]<br>Coding of products and storage positions [WARE5]<br>Materials management [WARE6]<br>Inventory management [WARE7]<br>Inventory control (monitoring) [WARE8]<br>Demand forecasting [WARE9]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Management of infrastructure for order handling [ORDE2]<br>Planning of picking [ORDE3]<br>Execution of picking [ORDE4]<br>Orders packing [ORDE5]<br>Planning of shipment facilities [ORDE6]<br>Shipments management [ORDE7]<br>Execution of shipments [ORDE8]<br>Returns management [ORDE9] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Monitoring of execution of procurement [PROC3]<br>Proposals management [PROC4]<br>Selection of suppliers and assignments [PROC5]<br>Evaluation of suppliers[PROC6] |
| Materials handling | Planning of inbound materials handling [MATE1]<br>Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3]<br>Traceability and monitoring of production and material handling [QUAL4] |
| Environment | Unused final and semi-final products handling [ENV1]<br>Byproducts handling [ENV2]<br>Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4]<br>Byproducts transportation management [ENV5]<br>Energy consumption management [ENV6] |

corresponding number of interviews were arranged with the above managers. The main objective of the survey was the assessment of the logistics processes of the examined companies (sample) according to the inputs and outputs of the proposed methodology. Managers were asked to rank the logistics processes that were presented in Table 1. Managers could choose from 7: Very high significance to 1: Very low significance, in order to evaluate the logistics processes that were categorized to 8 groups according to Table 1.

The resulting optimization model consists of 56 binary variables, and 64 non-negativity constraints. It was solved on a Pentium 4 computer with 3.6 GHz CPU, and 1 GB RAM, via the CPLEX® v.9.1 solver and through the mathematical programming language AMPL®. The computational time is a few seconds for all the generated problem instances and thus the solution performance of the proposed model is quite satisfactory.

An interesting 'what-if' analysis involves the exploration of different scenarios for the selected inputs and

**Table 2:** Selected inputs utilised and outputs produced by key logistics processes

| Inputs | Outputs |
|---|---|
| Data Resources<br>Capital Resources<br>Labour Resources<br>Technological Resources | Value added to end products and services<br>Free of defects, errors and delays<br>Operational efficiency |

outputs. Sensitivity analysis paradigm can be used to cover the above requirements because it gives the ability to apply what-if analysis in order to explore the impact of varying input assumptions and scenarios (Triantaphyllou and Sanchez, 1997). For the scope of this work, we have applied a simple sensitivity analysis in inputs (adopting the common 3:1:1 ratio), by using eight (9) different scenarios (Table 4).

The key logistics processes of each business area for all different scenarios are shown in Appendix tables 1 to 9.

## 5. Conclusions

This paper focused on the logistics processes of a specific sector, the Agrifood Supply Chain. These processes can be described to be of high task complexity and high knowledge intensity. For these processes a methodological framework (based on the DEA paradigm) for the identification, categorization and prioritization of logistics processes in the agrifood sector was proposed and applied using a number of 'what-if' analyses and a corresponding number of scenarios. The following resources were applied as inputs to the above analysis: Data, Capital, Labour and Technological resources.

According to the findings of the above scenarios for each category we have the following:

- Production support: for all scenarios we have the same result: first, the Planning of primary production, second Production scheduling and materials planning, and third the Production of finished and semi-final products regardless the significance of the resources. This result was expected due to the nature of the industry and the specific needs of the products. Agrifood companies have invested a lot in the planning of production process. Therefore, it is critical for the agribusiness companies to develop a number of performance measurement indexes and metrics for this process.
- Transportation and Distribution: the Planning of distribution tasks appears to almost all the scenarios. The Monitoring and tracing of product, and Routing and scheduling of transportation means appears in most scenarios. Once again the planning is considered as the most critical process. Moreover, it refers to the planning of the tasks. So mangers must standardize this process and apply continuous improvement approaches.
- Warehousing and Inventory Management: in this category the following scenarios appear in most cases and equivalently for the first key processes: Inventory management, Inventory control (monitoring), and the Layout of warehouse or distribution center. The Physical inventory appears in the third place in most cases.
- Order processing: In most cases the Order handling is the most significant logistics process. Picking and Packing follows. This is expected because mainly to the nature of the (perishable) products.
- Procurement: the Planning of procurement is the most significant logistics process.The Execution and the Monitoring of the Procurement procedure appear in most scenarios after the Planning.
- Materials handling: Forecasting of inbound materials handling, Execution of inbound materials handling, and Monitoring of inbound materials handling are the most significant processes according to the respodents.
- Quality management (including traceability): Quality control, Total Quality Management, and Quality of services appear in most scenarios. Most managers consider them as the processes that support their companies' competiveness.
- Environment: in this category the Packaging materials handling it considered as the most critical logistics process. This evident need further proofing since many companies address sustainability as a driving

**Table 3:** Decision variables and parameters of the proposed model

| | | |
|---|---|---|
| Variables | $y_{ij}$ | Binary decision variable that determines the selection or not of logistic process j in the i group. For $y_{ij}=0$ the specific logistic process is not promoted, whereas for $y_{ij}=1$ the logistic process is proposed |
| Parameters | $out_{kij}$<br>$out_{ki}^{max}$<br>$out_{ki}^{min\,j}$<br>$in_{pij}$<br>$in_{pi}^{max}$<br>$in_{pi}^{min}$<br>$c_k$<br>$c_p$<br>$S_{max}$<br>$S_{min}$<br>$N_i$ | Amount of output *k* produced by logistics process *j* in the *i* group<br>Maximum amount of output *k* produced in the *i* group<br>Minimum amount of output *k* produced in the *i* group<br>Amount of input *p* utilised by logistics process *j* in the *i* group<br>Maximum amount of input *p* utilised in the *i* group<br>Minimum amount of input *p* utilised in the *i* group<br>Weight percentage deviation for output *k*<br>Weight percentage deviation for input *p*<br>Maximum value of selected scale<br>Minimum value of selected scale<br>Maximum number of selected processes in group *i* |

 

**Table 4:** Sensitivity analysis scenarios

| Input Scenario | Data Resources | Capital Resources | Labour Resources | Technological Resources |
|---|---|---|---|---|
| 1 | 100% | 0% | 0% | **0%** |
| 2 | 0% | 100% | 0% | **0%** |
| 3 | 0% | 0% | 100% | **0%** |
| 4 | 0% | 0% | 0% | **100%** |
| 5 | 25% | 25% | 25% | **25%** |
| 6 | 50% | 16.67% | 16.67% | **16.67%** |
| 7 | 16.67% | 50% | 16.67% | **16.67%** |
| 8 | 16.67% | 16.67% | 50% | **16.67%** |
| 9 | **16.67%** | **16.67%** | **16.67%** | **50%** |

force that increases competitiveness as well as value to a company processes. Energy consumption management follows.

A number of limitations/restrictions of the above research can be stated; first, the subjectivity of the answers, due to the fact that the respondents came from the production and quality functional areas of the companies. Furthermore, the answers could also have differed in cases of companies that came from different sectors. A bigger sample might have provided with more reliable results. However, the size of the companies and their positions in the Greek market strengthened the quality of the sample and the credibility of the research outcomes. Finally, the difficulty of the accurate definitions of logistics processes can lead to incorrect results. Usually, in most companies there is a strong relationship between the processes and especially between logistics processes. For most processes across the value chain the output of one process is the input for another process.

Future studies of this subject should consider expanding the proposed methodology into specific sectors and/or products. Having a bigger sample will help identify both the key logistics processes and the appropriate key process indicators. Moreover, the usage of more criteria can be suggested in order to estimate the significance of the logistics processes, except for the criticality for the customer, their cost, their contribution to the added value of services and products, and the reasons that generate problems, errors and delays.

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# Appendix

## Appendix Table 1: Results of Scenario 1

| **Scenario 1** | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Control and monitoring of transportation management [DIST4]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8] |
| Warehousing and Inventory Management | Layout of warehouse or distribution center [WARE2]<br>Inventory control (monitoring) [WARE8]<br>Demand forecasting [WARE9] |
| Order processing | Order handling [ORDE1]<br>Order's packing [ORDE5]<br>Execution of shipments [ORDE8] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Evaluation of suppliers[PROC6] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Total Quality Management [QUAL2]<br>Quality of services [QUAL3]<br>Traceability and monitoring of production and material handling [QUAL4] |
| Environment | Unused final and semi-final products handling [ENV1]<br>Gas emission/pollutants production [ENV4]<br>Byproducts transportation management [ENV5] |

## Appendix Table 2: Results of Scenario 2

| **Scenario 2** | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production planning [PR6] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8] |
| Warehousing and Inventory Management | Materials management [WARE6]<br>Inventory management [WARE7]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Planning of picking [ORDE3]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Proposals management [PROC4] |
| Materials handling | Planning of inbound materials handling [MATE1]<br>Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Quality of services [QUAL3]<br>Traceability and monitoring of production and material handling [QUAL4] |
| Environment | Byproducts handling [ENV2]<br>Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4] |

## Appendix Table 3: Results of Scenario 3

| **Scenario 3** | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Planning of distribution tasks [DIST9] |
| Warehousing and Inventory Management | Inventory control (monitoring) [WARE8]<br>Demand forecasting [WARE9]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Management of infrastructure for order handling [ORDE2]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Proposals management [PROC4]<br>Evaluation of suppliers[PROC6] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4]<br>Energy consumption management [ENV6] |

## Appendix Table 4: Results of Scenario 4

| **Scenario 4** | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Control and monitoring of transportation management [DIST4]<br>Monitoring and tracing of product [DIST7] |
| Warehousing and Inventory Management | Layout of warehouse or distribution center [WARE2]<br>Inventory management [WARE7]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Management of infrastructure for order handling [ORDE2]<br>Shipments management [ORDE7] |
| Procurement | Planning of procurement [PROC1]<br>Monitoring of execution of procurement [PROC3]<br>Proposals management [PROC4] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Byproducts handling [ENV2]<br>Packaging materials handling [ENV3]<br>Energy consumption management [ENV6] |

 

## Appendix Table 5: Results of Scenario 5

| Scenario 5 | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8] |
| Warehousing and Inventory Management | Inventory management [WARE7]<br>Inventory control (monitoring) [WARE8]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Planning of picking [ORDE3]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Proposals management [PROC4] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4]<br>Energy consumption management [ENV6] |

## Appendix Table 6: Results of Scenario 6

| Scenario 6 | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8] |
| Warehousing and Inventory Management | Inventory control (monitoring) [WARE8]<br>Demand forecasting [WARE9]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Planning of picking [ORDE3]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Evaluation of suppliers[PROC6] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Unused final and semi-final products handling [ENV1]<br>Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4] |

## Appendix Table 7: Results of Scenario 7

| **Scenario 7** | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8] |
| Warehousing and Inventory Management | Inventory management [WARE7]<br>Inventory control (monitoring) [WARE8]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Planning of picking [ORDE3]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Proposals management [PROC4] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Byproducts handling [ENV2]<br>Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4] |

## Appendix Table 8: Results of Scenario 8

| **Scenario 8** | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Planning of distribution tasks [DIST9] |
| Warehousing and Inventory Management | Inventory control (monitoring) [WARE8]<br>Demand forecasting [WARE9]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Planning of picking [ORDE3]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Proposals management [PROC4]<br>Evaluation of suppliers[PROC6] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4]<br>Energy consumption management [ENV6] |

 

## Appendix Table 9: Results of Scenario 9

| Scenario 9 | |
|---|---|
| Production support | Planning of primary production [PR1]<br>Production scheduling and materials planning [PR4]<br>Production of finished and semi-final products [PR5] |
| Transportation and Distribution | Planning of distribution tasks [DIST1]<br>Monitoring and tracing of product [DIST7]<br>Routing and scheduling of transportation means [DIST8] |
| Warehousing and Inventory Management | Layout of warehouse or distribution center [WARE2]<br>Inventory management [WARE7]<br>Physical inventory [WARE10] |
| Order processing | Order handling [ORDE1]<br>Planning of picking [ORDE3]<br>Order's packing [ORDE5] |
| Procurement | Planning of procurement [PROC1]<br>Execution of procurement [PROC2]<br>Monitoring of execution of procurement [PROC3] |
| Materials handling | Forecasting of inbound materials handling [MATE2]<br>Execution of inbound materials handling [MATE3]<br>Monitoring of inbound materials handling [MATE4] |
| Quality management (including traceability) | Quality control [QUAL1]<br>Total Quality Management [QUAL2]<br>Quality of services [QUAL3] |
| Environment | Packaging materials handling [ENV3]<br>Gas emission/pollutants production [ENV4]<br>Energy consumption management [ENV6] |

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# Material and energy demand in actual and suggested maintenance of sugarcane harvesters

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**ABSTRACT**

Since green revolution agriculture has provided more yield *vis-à-vis* more energy demand. Currently, in the search for bioenergy, Brazilian sugarcane has gained attention, but as an energy source its efficiency has to be monitored. Energy balance is the physical evaluation of required inputs, but rarely studies present data about material. For agricultural machinery, the specific determination of the energy demand is required, since indices from automobile industry from late 1960s are still adopted. Besides, maintenance is usually based on a percentage of the energy spent on manufacturing. This study evaluates material and energy demand in the maintenance of sugarcane harvesters as: a) suggested by the manufacturer and b) actually done by sugar mills. So, part replacements, labour and material requirements are surveyed. Energy flows are determined by the material demand and material's energy embodiment. According to manufacturer, the maintenance requires 72.8% (2.52 TJ) of the total energy in the life cycle of a sugarcane harvester, while the actual maintenance represents 95.0% (17.93 TJ) of the total energy. The indices change from 158.9 MJ $h^{-1}$ to 869.7 MJ $h^{-1}$ (regarding life time); from 203.2 to 1,112.0 MJ $kg^{-1}$ (regarding mass) and from 13.26 to 72.59 MJ $kW^{-1}$ (regarding power).

**KEYWORDS:** life cycle assessment; repair; bioenergy; agricultural mechanization

## 1. Introduction

Energy demand increases as the development of economies and societies happens (Adubakar and Umar, 2006). Humankind has searched alternative sources to fossil energy, mainly using agricultural areas (Macedo *et al.*; 2008). Brazil accounts for around 41% of world's renewable energy, with sugarcane being the second most important source. Sugarcane is responsible for 16.1% of the primary energy in Brazil. Sugarcane provides the raw material for ethanol and bagasse production, responsible for 4.8% and 11.3% of the final energy consumption, respectively (BRASIL, 2014). In Brazil, sugarcane is produced on 8 million ha and mechanical harvesting has increased since 2000 due to economic reasons and environmental constraints (UNICA, 2010).The increasing demand for food, fibre and renewable energy generally demands more energy consumption by production processes (Romanelli and Milan, 2010). To evaluate and monitor production processes, the material flows converging into a product or service ought to be determined (Dyer and Djardins, 2006). The full life cycle of a product regards a set of activities and processes; each one requires a certain amount of material and energy (Manzini and Vezzoli, 2002). Unfortunately, most of the studies present neither data about material flows nor the boundaries of the evaluated system (Romanelli and Milan, 2010). The material flows are the basis for all kinds of environmental evaluation, such as energy flows, which identifies the total energy demand and the efficiency reflected by the net gain and output/input ratio. Besides, in the determination of the energy input all materials and services are taken into account (Romanelli and Milan, 2010).

For agricultural machinery, the determination of the required energy in a product is still considered relatively recent, since most of the indices are based on the automotive production from late 1960s, such as determined by Berry and Fels (1972), 81.2 MJ $kg^{-1}$.

Usually, energy demand in repair and maintenance is related to the energy required on the machinery production (Doering, 1980; Fluck and Baird, 1980; Mikkola and Ahokas, 2010). The energy demand of repair and maintenance for agricultural machinery varies considerably, with an observed range from 6% to 104%, Table 1 (Fluck, 1985).

For instance, Doering (1980) estimated the embodied energy in agricultural machinery, approaching the energy embodied in the materials and the energy used on assembling phase. He considered the methodology of the total repair accumulated to determine the percentage of required energy in repair and maintenance in the

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**Table 1:** Embodied energy in the repair and maintenance of agricultural machinery

| Source (apud Fluck, 1985) | Repair and Maintenance compared to Assembling % | Observations |
|---|---|---|
| Pimentel et al. (1973) | 6 | Corn production, USA. |
| Bridges and Smith (1979) | 6 | Following assumptions from Pimentel et al. (1973). |
| Smill et al., (1983) | 8 | Based on surveys done with dealers of agricultural machinery. |
| Foster et al., (1980) | 10 | Considered only manufacturing of parts |
| Doering et al. (1977) | 32 | Based on equations for cost of accumulated repair from ASAE and replacing machinery after 10 years. Energy on assembling excluded the embodied energy on raw material previously to the manufacturing. |
| Leach (1976) | 53 | For three power levels of tractors, applying the energy intensity of 200 MJ £$^{-1}$ for repair and maintenance, the average of repair cost was 53% of depreciation. |
| Burrill et al. (1976) | 104 | Apple ''Vermont'' production; based in the maintenance cost times the energy intensity of money. |

machinery useful life. He assumed 74.25% for AWD (all-wheel drive) tractors and crawlers, 89.10% for tractors 4x2 (rear wheel drive) and 45.88% for trucks, pick-ups, combine, and cotton pickers.

Fluck (1985) presented two models that can be used in the analysis of energy demand called ''industrial cost'' and ''cost of repair in useful life''. To specify energy, the first one considered machinery sales, part replacement and demanded services. The second model considered the energy required for repair and maintenance during the useful life of the machinery, which showed that energy demand in repair and maintenance is 38% higher than the assembling phase and presented a result twice higher than the one obtained by the ''industrial cost'' model.

Some studies determined indices for specific operations, such as Umar (2003) who determined 42.7 MJ ha$^{-1}$ of indirect energy for maintenance, repair and transportation of a tractor-rake combination. This number corresponds to a tractor with mass of 2,780 kg and a useful lifetime of 12,000 h combined with a rake equipment with mass of 564 kg and useful lifetime of 2,000 h, both with operational field capacity of 1.21 ha h$^{-1}$. Although it is an interesting datum, it would be directly applicable only in similar conditions.

Abubakar and Umar (2006) reported that energy required for maintenance, repair and transportation was not taken into account due to the lack of data of mass of agricultural machinery available in the industries. They concluded that results were not complete, since the neglected activities pose a significant contribution for energy.

This study aimed to compare the material and energy demands in the repair and maintenance suggested by the manufacturers and the one actually performed in sugar mills. As secondary goals, it is intended to determine which are the materials most used in the repair and maintenance and also to assess how close the suggestions made by the manufacturer is to reality in practical field operational conditions.

## 2. Material and Methods

The repair and maintenance phase considers both either direct inputs (e.g. parts) and indirect inputs (e.g. labour, tools). In this study, the evaluation is performed for two distinct scenarios: the recommendations of the manufacturer and the maintenance observed in a sugar mill.

So, the frequency of part replacement, labour and material requirements was surveyed in the owner's manual (manufacturer's suggestion) or by evaluating records of service orders (sugar mill). For the first scenario, besides the activities suggested in the owner's manual, some activities had to be added because it was not approached by the manual. For instance, the replacement of basal cutting blades replacement is not considered, so this datum was obtained with the post-sale team, dealers and producers. It is important to mention that the replacement of these blades vary due to field conditions (stones), soil texture (sandy, clayey), operators' skills etc. Another datum obtained from the post-sale department of the manufacturer was the life cycle of the evaluated machines, which are used around 3,100 h per year during seven years, resulting in a life cycle of approximately 21,700 h. For the index of embodied energy per time of work, it is necessary to know the life cycle of the sugarcane harvester, which is claimed as uncertain, since it depends upon the level of utilization (Mikkola and Ahokas, 2010).

This study evaluated self-propelled sugarcane harvesters, with 6-cylinder diesel engine power of 260 kW, equipped with metallic tracks, with total weight of 16,972 kg. This kind of harvester represents around 85% of the market share in Brazil. The remaining 15% uses rubber tires instead of metallic tracks.

For the manufacturer's suggestion, it was considered the maintenance schedule of the owner's manual, based on Mantoam *et al*. (2014). For the actual maintenance the services required in the repair shop of a sugar mill was considered. The maintenance of nine harvesters was surveyed during two years either in the harvesting season (April-November) or in the rainy season (December-March), when the industry and machinery are repaired, divided in three groups (three harvesters in each): machines in the first, second and third year of operation. In average, each harvester operated 3,059 h per year. When the survey began, the harvesters presented an average use of 5,260 h.

After the determination of the material flow of all inputs, they were multiplied by the indices of energy embodiment for each input to determine the energy flow. The indices of energy embodiment were obtained from the work of Boustead and Hancock (1979). Therefore, they were used for the input energy flows to be determined. The determination of the embodied energy in indirect inputs, embodied energy in infrastructure depreciation, embodied energy in directly used inputs and embodied energy in repair and maintenance were required in order to sum up the embodied energy in the life cycle of a sugarcane harvester (Eq.1).

The embodied energy in directly used inputs and the embodied energy in repair and maintenance are determined by the quantity of material used and their respective energy indices (Eq. 1).

$$E_{RM} = \sum_i I_{RM}(i) \cdot EI_{RM}(i) \quad (1)$$

Where: $EE_{RM}$ represents the embodied energy in repair and maintenance (MJ), $I_{RM}$ represents the inputs used in the repair and maintenance (kg, L, unit),while $EI_{RM}$ stands for energy index of the inputs used in the repair and maintenance phase (MJ kg $^{-1}$, MJ L $^{-1}$, MJ unit $^{-1}$).

Although the actual situation may indicate the most reasonable option, it should be highlighted that repair and maintenance activities are particular for each sugar mill decision maker or managers. This makes distinct fleets difficult to be compared. Sugarcane harvester is believed to be the machine that is used more in agriculture with around 3,100 h of use within eight months of harvesting. Consequently, it is likely that the share presented by maintenance on energy demand should not be attributed to other machinery. Besides this, sugarcane presents high silicon content in its composition, whose abrasiveness makes sugarcane harvester to last less than harvesters or combines of other crops.

## 3. Results and Discussion

The material flows in the repair and maintenance in the harvester life cycle, either for the suggested or the actual maintenance by the manufacturer, are presented in Table 2. There is discrepancy on the items listed from both scenarios. Ten of them are listed only in the actual scenario, namely: PLG; solvent; lead; nylon; paint; aluminium; coper; polyethylene; glass; anticorrosive. This can be caused either by unforeseen accidents (glass), or for neglected activities in the manual (PLG used for welding to avoid parts to be rusted, which is very common for this type of harvesters).

Material flows for repair and maintenance are presented in an annual basis and there is discrepancy

**Table 2:** Material flow used in repair and maintenance phase suggested by manufacturers and done by sugar mills

| Items | Unit | Material Flows | | Comparison |
|---|---|---|---|---|
| | | Suggested | Actual | Suggested/Actual |
| | | Unit $y^{-1}$ | Unit $y^{-1}$ | |
| Hydraulic/Lubricant oil | l | 1162.5 | 50,152.1 | 43.14 |
| Carbon steel | kg | 3646.9 | 9,119.2 | 2.50 |
| Labour | h | 715.2 | 2,891.6 | 4.04 |
| Rubber | kg | 84.0 | 1,122.4 | 13.36 |
| Diesel oil | l | 505.2 | 78.3 | 0.15 |
| Iron | kg | 1602.4 | 45.3 | 0.03 |
| Polypropylene | kg | 1.7 | 44.3 | 26.73 |
| Cellulose film | kg | 10.5 | 5.3 | 0.51 |
| Grease | kg | 222.1 | 1.7 | 0.01 |
| Glass fibre | kg | 1.4 | 2.8 | 1.94 |
| Polyethylene | kg | 112.7 | - | |
| Forged steel | kg | - | 519.3 | |
| PLG | kg | - | 135.7 | |
| Solvent | l | - | 111.4 | |
| Lead | kg | - | 43.9 | |
| Nylon | kg | - | 34.7 | |
| Paint | l | - | 33.2 | |
| Aluminium | kg | - | 30.2 | |
| Coper | kg | - | 22.8 | |
| Polyethylene | kg | - | 15.5 | |
| Glass | kg | - | 4.8 | |
| Anticorrosive | l | - | 2.5 | |

 

**Table 3:** Total energy required for repair and maintenance suggested by the manufacturer and actually performed by the sugar mill

| Consumption phase | Suggested | | Actual | |
|---|---|---|---|---|
| | Energy demand | | Energy demand | |
| | GJ | % | GJ | % |
| Repair and maintenance | 2,523.3 | 72.8 | 17,928.8 | 95.0 |
| Parts and components | 924.8 | 26.7 | 924.8 | 4.9 |
| LPG, electricity, water | 18.8 | 0.5 | 18.8 | 0.1 |
| Infrastructure | 0.6 | 0.0 | 0.6 | 0.0 |
| Total | 3,467.5 | 100.0 | 18,872.9 | 100.0 |

**Table 4:** Energy indexes recalculated for repair and maintenance at the sugar mill

| Indicator | Unit | Energy indices | |
|---|---|---|---|
| | | Suggested | Actual |
| Energy per time | MJ $h^{-1}$ | 158.9 | 869.7 |
| Energy per mass | MJ $kg^{-1}$ | 203.2 | 1,112.0 |
| Energy per power | MJ $kW^{-1}$ | 13,262.0 | 72,588.4 |

again. The highest one is the volume of hydraulic oil that is 43 times higher in the actual scenario. This is caused mainly by poor maintenance, as this type of oil leaks causes unnecessary cost and environmental threats (in soil and watersheds). On the other hand, grease would be expected to be used more than it actually does (just 3%). This may be caused by poor maintenance, which can increase the replacement rate of other items such as steel and iron. Most of the steel is due to the basal cutting blades, which are replaced on every 32 h in average, generating around 1 kg or residues (8 knives).

Further studies should be developed to assess the share of the replaced materials that could be reused or recycled. It is also necessary to verify the distinct kinds of maintenance and the variables that may affect the material demand and consequently, the energy demand and economic cost for sugarcane production.

In order to make the comparison, the annual average of the actual maintenance is extrapolated to the whole life cycle (i.e. seven years). Since the machines are considerably new (5,200 h use out of expected 21,700 h), it is assumed that this would not overestimate the final result (Table 3).

After determining the indicators considering the new value for repair and maintenance, its contribution increased from 72.8% to 95.0% (2,523.3 GJ to 17,928.8 GJ). The total energy consumption increased up to 444.3%, from 3,467.5 to 18,872.9 GJ.

Indicators are calculated considering the embodied energy in time, mass and power of the sugarcane harvesters (Table 4). The increases found considering the automobile industry by Berry and Fels (1972), 81.2 MJ $kg^{-1}$. The new values should be used to recalculate the efficiency of sugarcane as an energy source.

## 4. Conclusions

In many cases, the maintenance suggested by manufacturers does not foresee all activities necessary in the actual use. Moreover, variables such as field conditions, decision making, and operator's skill make previsions difficult to be accurate. The results of this work indicate that there is discrepancy between the suggested and actual maintenance performed for sugarcane harvesters.

Further studies should be carried out to deeply monitor distinct kind of maintenance to check their material demand and consequently, economic cost and energy demand. Also, for further research, more detailed study on hydraulic oil is suggested, since it increases cost and may cause environmental hazards in soil and watersheds.

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# BOOK REVIEW

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## Rural Women in Leadership: Positive Factors in Leadership Development

**Lori Ann McVay**

September 2013, published by CABI, Oxford, UK. Hardcover, 160 pages. ISBN 9781780641607. Price: £75/ €100/$145.

The book examines an area that has received little attention in research. Over the years, research seems to emphasise the obstacles rural women face in food production and in making food available. Lori Ann McVay focuses on the positive factors that contribute to rural women's leadership development using Northern Ireland as the study site. The study set out to understand how they overcome barriers on their journey to leadership at all levels, from the home to international levels by identifying internal and external factors that account for leadership development.

The study uses a qualitative feminist approach, by means of in-depth interviews and participant observations, to examine the personal and community identities, family and community relationships, and leadership role models for rural women leaders. The focus on women's experiences formed the foundation of the study, requiring a methodology with feminist viewpoint, and to promote researcher-researched relationship, and attempt to make visible women's hidden contributions, looking at it from a localized perspective. She wanted to appreciate their lived reality including their religion and church involvement, educational experience, extracurricular activities and leadership opportunities. In addition to twenty-two women who participated in the study and had unique narratives of their path to becoming a leader, she chose two women as case studies, who were at different extremes of the leadership spectrum – Alice and Doreen - to provide in-depth accounts of their leadership journeys. The author recognizes the impossibility of generalizing rural women's experience to women elsewhere.

Women's narratives revealed that leadership skills were often present and in use in some way prior to their appointment or election to a leadership role. Many of these women excelled in their leadership roles though they seem to downplay their own effectiveness and success stories; an attitude of minimization. For some women, the term leader refers to a position or a title. A participant said that the concept of leadership has changed with time but needs personal power, self confidence, openness and humility (p. 34). Many of the women saw leadership and responsibility as closely linked.

The literature review seems to focus on feminist views without mention of successes of women in leadership and the change dynamics of work-life balance where women can succeed in both professional and family life. The issue is that rural and farm women are not powerless, they have been successful agents of rural development despite all forms of opposition. The book further noted that most men and women continue to function in socially prescribed patterns but that women are primarily concerned about their relations and family commitments. Underpinning the relations and family commitments are several external and internal factors.

The external factors include interactions with people, experience with organizations, connectedness with mentors who model leadership, and encouragement from other people. Marriage as an event and the family into which a person marries affect their leadership journey. Other events noted are exposure through international travels, and leadership training. The 'Troubles' of Northern Ireland or the 'Northern Ireland Conflict' which occurred in the 1960s and ended with the Belfast Good Friday Agreement has shaped leadership development in the rural sector. Communities that once had 'Troubles' seem to produce people who work for change and who create political awareness. Participation in leadership position in church was important in leadership development as the church provided a framework from which they analysed gender roles. The way the church sees women was important in shaping their leadership perspectives. At school, attitudes of teachers and administrators towards developing leadership in students became a significant factor in leadership formation at an early age.

The internal factors include the make-up of a person and attitude towards life in general. These factors can enhance or limit leadership, define leadership journeys, leadership style, and success in leadership. The courage to break free from family and cultural norms and transform the negative attitudes of others into motivation to increase personal effectiveness were noted as enhancing the ability to lead effectively. Self confidence is needed to challenge the status quo in organizations including political party decisions. People who take initiative stepped into situations to get things done. The 'quietly confident' (p. 107) were able to take charge though they are not interested in public view. Although religion has the potential of producing barriers and insecurity, religious faith serves as a tool to break through negative religious ideologies. This hope for others that stem from faith in God can enhance leadership potentials. Belief in oneself is key. A factor such as internal drive is traced to family of origin, upbringing, rural identity and self-characterisation as a worker. Personal responsibility for success and the desire to succeed on own merit were also mentioned.

The book is fascinating to read for two reasons. One, this book comes at a time when the world is focusing on empowering women to ensure that they feature at all levels of leadership. Two, the way it outlines the concept of leadership as being important in all social organizations and relationships, from the household unit, to small firms (farms), to communities, nations, and international levels. The narratives, however, seem rather repetitive and somewhat overly detailed. Questions of objectivity can be raised about how the author seemed quite eager to find a feminist voice in the responses of the participants. The description of feminist ideals as the ability to break free from family and cultural norms are debatable in narrating stories of a person like Doreen who has high educational achievements and rich life experiences. Important dimensions that could have been incorporated are the basis for comparing the positive factors that enhance the leadership for both men and women. But again, the focus was feminist methodology and the author came out as a strong support for feminism. Her understanding and conclusions of who is a leader is seen in her affirmations of specific qualities in the participants. An analysis of the stories in the context of leadership concepts and existing models would have been desirable. However, the author asserted that their own voices were given precedence in the analysis of data.

I noted that the internal and external factors discussed in this book work together in shaping the leadership path of the women studied and can apply to other women elsewhere. The internal factors were reinforced by the presence of external factors, making the two aspects to interact in defining the leadership paths of individuals. The discussion on internal factors brought out certain issues in leadership that can help the reader to appreciate the findings in the context of leadership concepts. For example, the discussion on self confidence, which brought out the importance of giving and receiving feedback as contributing to a person's leadership development, is consistent with the leadership literature.

The book provides insights into how rural women perceive leadership and their leadership journeys. The study will be a very important resource for leadership consultants in understanding and nurturing specific leadership skills in rural women. Leadership practitioners can build their models and work with the findings of this research.

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# BOOK REVIEW

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## Empowering Rural Women: Micro-enterprise through Achievement Motivation

### Kiron Wadhera and George Koreth

Published by Sage, London, UK, 2012. 224 pages. Paperback: ISBN 9781780641607, Price £14.99[1]. Ebook: ISBN 9788132109426; £37.50.

*'Empowering Rural Women'* is a pioneering piece of research written by Kiron Wadhera and George Koreth. Kiron Wadhera is currently a consultant to the government of Dehli, India in developing citizens partnerships with the government on a city wide basis. George Koreth is currently advising the government of Dehli on building and sustaining a citizen's partnership in good governance. The authors embarked on this line of research in the hope of influencing policy makers, educationists and national social policy that aim at improving the standard of living amongst the rural poor. A major hope for this research is that new policy directions would help these disenfranchised groups to help themselves in a sustainable way.

The book came about because of a lack of significant study undertaken on women entrepreneurs and their challenges and successes (in comparison to research carried out on urban, successful male entrepreneurs). In identifying this research gap, the authors set out to provide original research on poor rural women micro entrepreneurs, at the same time measuring their achievements and motivations. The research establishes a clear relationship between presence/absence of achievement motivation and the success/failure of these women is sustaining their enterprises.

Wadhera's doctoral study reviewed the research conducted by the NGO; Asian Centre for Organisational Research and Development (ACORD). Initiated in 1994, ACORD has undertaken various projects in the area of social development, health, agriculture and communication and awareness building. Having reviewed ACORD project findings, Wadhera's research was driven by the question 'Did those successful women micro entrepreneurs who emerged from ACORD's rural programmes have an 'inner drive' - the 'achievement motivation' described and measured in the case of urban men by McClelland et al in 1953. McCelland refers to an entrepreneur as an individual with a strong need for achievement. The need for achievement was identified as a major factor in poverty alleviation through micro enterprise among rural women. Perception of opportunity as others may not see, and response to a perceived opportunity, have also been found to be important for a person with entrepreneurial inclination in order to start an enterprise. The authors identify a cashless material lone model with they believe is replicable and scalable for rural women micro entrepreneurs which can be used effectively to solve some of the problems that are related to rural backwardness as cash will not then be used for consumption or mis-appropriated by males in the family. This model was successfully trialled and developed by ACORD.

The authors worked with poor rural illiterate and semi-literate women in the 27 villages of the Bharatpur district, Rajastan, India. They acknowledged those women who overcame several social and structural barriers to step out of their homes and set up and run their micro-enterprises. Women from 18 of these villages participated in the research either through answering questionnaires and/or tests and allowing survey teams to do observational studies of their houses and household possessions. The work is based on information gathered from 183 women who attempted an enterprise and from an equal number of male members and their families. Of these women 45 were analysed to identify the presence or absence of their needs for achievements.

From a Western perspective, rural India is still quite conservative and lags behind in development indicators relative to urban areas. Women in rural India are all the more challenged as they face discrimination on multiple levels (patriarchy, gender, education and economic etc). The book states that Women's work roles have been secondary to executing the maternal, emotional and social life of the family, and women therefore direct their lives around the needs of the family, whereas men organise their lives around the demands of their work.

As a relatively privileged Westerner, the lack of access to education and the dependency on male/community approval and support struck me as considerable obstacles that I thankfully don't need to consider when running my own business. In essence, the main premise of the book is that success is dependent on an inner drive for achievement, and that the development of that drive is based on extrinsic and intrinsic influences. This resonates beyond the profile of the study group and encompassing all nationalities, regardless of gender or social status. As a facilitator of community programmes, it also interesting to note that in the villages where women entrepreneurs had developed successfully, others followed and the wider family and community began to thrive.

Empowering Rural Women captures how some women, despite being illiterate and poor, show the presence of an inner need for achievement, which had a clear relationship with the women's efforts in sustaining their micro-enterprise. The women who displayed the need for achievement in their profiles did not give up when faced with failure. Two out of three started a different venture and succeeded. The remaining third actively searched for other opportunities to earn and found employment that enabled her to earn more income. In contrast those who did not display a need to achieve in their profile did not succeed because they lacked self-motivation, and in all of these cases, they began the program on insistence from their husbands, the ACORD staff or relatives.

[1] In mid-January 2015, £1 was approximately equivalent to $US 1.51 and €1.28 (www.xe.com)


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The successful women entrepreneurs often got support/encouragement from their husbands and families to initiate the enterprise, provided the husbands were included in the early discussion processes. Very often the successful business became a family business. In several cases where the women were managing tea shops and provision stores, the spouse's sons and other members of the family added new lines of micro enterprise such as vegetables and selling or helped to extend the enterprise. Women with a need for achievement in their profile by and large chose those activities for their micro enterprise which involved selling, trading, and farm related sales rather than only production or skilled development. Those that did not succeed chose the production model and thus avoided the risk and uncertainty of trying to sell, and they did not try again when the first venture failed.

As they worked on their micro enterprise, even the illiterate developed basic skills like simple calculation, bargaining, selling as well as self-confidence and increased social status with their family as well as increasing their standard of living. Many reported an improvement in the food, clothing and education of children. They got better levels of respect and acceptance within the family and the society in which they lived. Involvement in micro-enterprise also has the added value of increasing self confidence amongst these women, and this sense of empowerment resulted in some women having more of a say in the decision making within the household and in the family's finances.

In an environment where there is a greater media spotlight on the effectiveness of spending on aid programs, this research is commendable in how it has rigorously measured the critical factors of success for women entrepreneurs in socially disadvantaged societies. Wadhera engaged in worthwhile research, not only on women in rural disadvantaged societies, but also on what drives and prevents women in succeeding in entrepreneurship.

The conclusions of the study deserve to be taken seriously by policy makers and educationalists. In respect of health, nutrition, sanitation and gender, the findings offer an evidence-based methodology to policy makers in ensuring that India increases its social indicators and meets its Millennium Development Goals.

**Karen Brosnan, Independent Consultant**

REFEREED ARTICLE

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# Chinese aquaculture farmers' value system and on-farm decision making

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**ABSTRACT**

The Chinese aquaculture industry, which employs millions of farmers and provides low cost protein for consumers worldwide, is critically important to domestic economic growth and global food security. Central to the safety of aquaculture products are farmers, who are ultimately responsible for following good production practices. We assess how farmers' value system is related to on-farm decision-making, with particular attention given to the overuse of antibiotics, a major problem in this industry. Primary data was gathered through farmer interviews in three aquaculture-producing provinces in Southern China. Using a best-worst scaling framework, we find that producers care most about attributes and practices that are directly related to their operation and are impartial to consumer preferences. Our results show that producers who value food safety the most are more likely to stop using antibiotics in their operations.

**KEYWORDS:** farmer preferences; food safety; aquaculture; antibiotics; China

## 1. Introduction and background

Food safety issues are undermining developments in emerging agrifood supply chains. While the majority of the food security debate in developing countries has centred on the availability (or lack thereof) of a sufficient, nutritious, food supply, food safety has not received adequate research attention. Yet, communities in developing and emerging countries face an increased risk of serious health problems due to the consumption of unsafe food. Food products that do not meet the safety and quality standards of high-value markets, not only cause significant economic losses to producers, but also to the country of origin and neighbouring countries where the products are sold (Emmott, 2013). Central to the safety of any food supply are farmers, who are ultimately responsible for following good production practices. In China, food safety has received increased global attention due to a series of incidents that caused serious health problems, and significant economic consequences. Specifically, there are rising concerns over the safety of aquaculture products from China, which produces the majority of the world's farmed fish, and is the largest exporter to the international market (FAO, 2008; Gale and Buzby, 2009). Though Chinese food safety issues have gained the attention of researchers in recent years, most of the focus has been on consumer behaviour and issues regarding China's agricultural marketing system (e.g. Wang *et al.*, 2008; Waldron *et al.*, 2010; Ortega *et al.* 2011, 2012, 2014a). Moreover, China's top-down approach to food safety places more emphasis on the end product than on production practices. Given the lack of upstream supply chain knowledge with regards to food safety, this study draws from the economics, marketing, and psychology literature to study Chinese aquaculture producer preferences and explores how their value system informs on-farm decision-making with regards to food safety.

The study of preferences has been reserved mostly to applications of consumer issues. However, many of the decisions made along the food supply chain involve various agents, of which, arguably, producers have the most influence regarding the safety and quality of our food. Individual's value systems, defined by Rokeach (1973), as an organization of beliefs concerning preferable modes of conduct or end-states of existence along a continuum of relative importance, have been linked to preferences for various product attributes. Methods traditionally employed in consumer-oriented research have been adapted to better understand producer preferences, namely producer willingness to change. Schulz and Tonsor (2010) utilized a choice experiment to assess U.S. cow-calf producer preferences for voluntary traceability systems and Olynk, Wolf and Tonsor (2012) estimated changes in dairy producers' welfare when various production technologies were removed from their option sets. In a development context, several

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studies have modelled farmers' preferences for biodiversity (Birol *et al.* 2009), environmental management (Richardson *et al.* 2013), livestock traits (Ruto *et al.* 2008) and drought tolerant characteristics in staple crops (Ward *et al.* 2014).

The use of best-worst scaling has been gaining recent attention from applied economic researchers. Lusk and Briggeman (2009) identified a set of food values and found a significant relationship between consumers' value system and their stated and revealed preferences. Wolf and Tonsor (2013) explored Michigan dairy farmers' policy preferences using seven policy options related to the 2012 U.S. Farm Bill and found differences between large and small dairy operators. Pruitt *et al.* (2014) analysed various users' preferences for agricultural market information and outlined implications for the maintenance of public investments given a tightening of U.S. federal budgets. Erdem *et al.* (2012) investigated stakeholders' perception regarding responsibility for food safety via best-worst scaling and find that consumers tend to think farmers are more responsible for ensuring meat safety than farmers do. This study builds upon this approach by (i) identifying a set of important producer-based value attributes regarding aquaculture production in China, (ii) assessing how aquaculture farmers value these attributes, and (iii) determining how farmers' value system relates to on-farm food safety decision-making.

China's aquaculture industry is mostly concentrated in the central, eastern and southern provinces where the Yangtze and Pearl rivers provide water for these operations. An in-depth study of the aquaculture sector by Broughton and Walker (2010) points out that the system operates as two entities: a low-standard sub industry that supplies for the domestic market and a separate one for products bound for the export market, that is governed mostly by higher international safety and quality standards. Though mostly separate, the researchers of the present study found that some farmers supply to both channels and have fishponds that operate under varying standards. The majority of domestic production is focused on carp and other local species while tilapia and shrimp dominate the export market. The majority of products raised for domestic consumption are sold in the live market, where there are over 340 wholesalers who buy products from individual farmers or distributors and sell to supermarket retail, wholesale or restaurant buyers; the average time to consumption post farm gate is less than a week (Broughton and Walker, 2010). In contrast, the export supply chain is dominated by an increasing number of processors. Given processing and shipment of these products to foreign markets, time to consumption is anywhere from several weeks to months. While inspection of Chinese aquaculture products in some importing countries is based on risk assessment, the researchers found that some Western buyers have their own quality inspectors or rely on third-party auditors to test the product. Even so, various critics have raised concerns over imported fish and Chinese production standards in Western markets (see Ortega *et al.*, 2014c).

Issues ranging from environmental sustainability, to ethics and food-product safety have caught the attention of Western consumer watch groups such as Monterey Bay Aquarium's Seafood Watch which have placed Chinese aquaculture products under their 'avoid' recommendation list. Moreover, a series of production guidelines have been developed by third party organizations to promote responsible aquaculture practices across the industry. Given the lack of information available regarding Chinese aquaculture producers, this study is one of the first to document farmers' preferences for select value attributes governing the global aquaculture industry.

**Table 1:** Aquaculture producers' value attributes

| Attribute | Description |
|---|---|
| Food Safety | Extent to which consumption of product will not cause illness |
| Traceability | Ability to identify the origin, and movement of the product through the supply chain |
| Animal Welfare | Ethical and responsible treatment of live product |
| Water Quality | Using quality water in operation |
| Environmental Impact | Sustainable environmental practices |
| Food Safety Certification | Willingness to undergo food safety inspection |
| Scape Control | Protecting native species |
| Regulatory Compliance | Abiding by laws and regulation |
| Drug Management | Responsible use of veterinary drugs including antibiotics |
| Community Relation | Developing good standing with the local community |
| Consumer Knowledge | Producer awareness and knowledge of final end consumer |

## 2. Methods

Given that Chinese producer data on these value attributes does not exist and related data on farmer behaviour is not widely available, fieldwork to gather primary data was necessary. A producer survey was developed to obtain information from Chinese aquaculture producers regarding their production practices (including their use of antibiotics), socio-demographic characteristics, as well as their knowledge of the various stages of production in their operation. A choice experiment (CE) using best-worst scaling was utilized to assess farmer preferences. Through consultation with experts on the Chinese aquaculture industry, academics, trade officials and a thorough review of the literature that included an assessment of various standards developed by voluntary certification programs, eleven aquaculture value attributes were identified for evaluation[4]. These range from ethical standards such as community relation, animal welfare and environmental sustainability to product quality standards, including food safety, drug management as well as regulatory issues such as food safety certification and regulatory compliance. A complete list of the value attributes and their corresponding description is presented in Table 1.

Best–worst scaling is based on random utility theory, a well-tested theory of human decision-making

[4] Literature reviewed includes reports by FAO (2010), Washington and Ababouch (2011), and Guidelines for Best Aquaculture Practice Standards for Tilapia and Shrimp Farms provided by the Global Aquaculture Alliance.

 

Which of the following value attributes is most important and which is least important to you in your operation? (Select only one value as most important and one as least important)

| Most important | Value Attribute | Least Important |
|---|---|---|
| | Food Safety | |
| | Traceability | |
| | Environmental Impact | |
| | Regulatory Compliance | |
| | Drug Management | |
| | Consumer Knowledge | |

**Figure 1:** Example of Best-Worst choice task

hypothesized by Thurstone and generalized by McFadden (McFadden, 1974, 2001; Thurstone, 1927). Several advantages of using best-worst scaling over other revealed preference methods, including their reliance on the use of relative trade-offs, have been documented in recent years (see Flynn *et al.*, 2007; Lusk and Briggeman, 2009). In this study, farmers were shown a series of choice sets (Figure 1) containing the various value attributes identified and asked to select which was the most (best) and least (worst) important to them[5].

When answering each question, producers are assumed to be choosing the two attributes that maximize the difference between the two items on an underlying scale of importance (Lusk and Briggeman, 2009). Allowing $\lambda_j$ to formally represent the location of value attribute $j$ on the underlying scale of importance, the latent unobservable level of importance for famer $i$ is given by

$$I_{ij} = \lambda_j + \epsilon_{ij} \tag{1}$$

where $\epsilon_{ij}$ is a random error term. Therefore, the probability that farmer $i$ chooses attribute $j$ as most important and attribute $k$ as least important is equal to the probability that the differences between $I_{ij}$ and $I_{ik}$ is greater than all other $J$*($J$-1)-1 possible difference in the choice set. If the error term is independently and identically distributed type I extreme value, then this probability takes the multinomial logit (MNL) form:

$$Prob(j = best \cap k = worst) = \frac{e^{\lambda_j - \lambda_k}}{\sum_{l=1}^{J}\sum_{m=1}^{J} e^{\lambda_l - \lambda_m} - J} \tag{2}$$

The parameter $\lambda_j$ can be estimated through maximum likelihood estimation using equation (2). The dependent variable takes a value of 1 for the attributes chosen by a farmer, and 0 for the remaining J*(J – 1) – 1 pairs of attributes that are not selected. $\lambda_j$ represents the importance of value attribute $j$ relative to the attribute ranked least important (identified ex-post), normalized to zero, to avoid the dummy variable trap. To explore preference heterogeneity, a random parameters model (RPL) was estimated. The importance parameter for farmer $i$ and issue $j$ is denoted by

$$\tilde{\lambda}_{ij} = \bar{\lambda}_j + \sigma_j \mu_{ij} \tag{3}$$

where $\bar{\lambda}_j$ is the mean and $\sigma_j$ is the standard deviation of $\lambda_j$, and $\mu_{ij}$ is a random variable which follows a standard normal distribution. This specification implies the assumption that the importance ranking location of attribute $j$ is normally distributed with mean $\bar{\lambda}_j$ and standard deviation $\sigma_j$. Following Train (2003) and Huber and Train (2001), individual–specific estimates can be obtained by using the estimated parameters as a prior and using each farmer's actual choices to form an individual-specific posterior estimate.

In order to obtain results consistent with standardized ratio scaling techniques, the share of importance ($S$) for each value attribute, equal to the forecasted probability of being chosen as most important, can be calculated as

$$S_j = \frac{e^{\lambda_j}}{\sum_{k=1}^{J} e^{\lambda_k}} \tag{4}$$

The 'share of preference' for all value attributes must sum to one. Moreover, each share of preference reflects both the true importance of the attribute in producers' value system (measured on a ratio scale) as well as the relative uncertainty in the importance famers place on the attribute (Lusk and Briggeman, 2009). In other words, if the share of preference for one attribute is twice that of another attribute, the result can be interpreted as the former attribute being twice as preferred as the latter (Wolf and Tonsor, 2013).

The producer survey was conducted in the summer of 2011 in three major leading aquaculture-producing provinces of China: Fujian, Guangdong and Guangxi (Figure 2). Agricultural economists from China and the U.S. reviewed the surveys, and ten enumerators were trained to conduct the producer interview and administer the questionnaire that included twelve best-worst choice tasks. Expert advice was sought from applied economists as well as local county officials to obtain a sample of farmers from the region. Three to five counties with fishing villages were randomly selected in each of the


**Figure 2:** Study location

[5] The experimental design for the best-worst choice experiment was borrowed from Finn and Louviere (1992).

**Table 2:** Sample summary statistics

| Variable | Mean or % | SD |
|---|---|---|
| Male | 90.0% | |
| Age | 46.47 | 9.52 |
| Education (years) | 8.37 | 2.60 |
| Years in Aquaculture | 11.36 | 7.77 |
| Farm Size (mu) | 123.81 | 339.94 |
| Net Income (CNY/year) | 86,788.57 | 118,957.31 |
| Net Income from Aquaculture (CNY/year) | 61,760.38 | 101,279.73 |
| Number of Workers | 3.44 | 4.89 |
| Contract Farming | 13.8% | |
| Cooperative Member | 5.5% | |
| Export Oriented | 18.2% | |
| Sample Size (n) | 110 | |

Source: Authors' survey data.

provinces. A total of 150 questionnaires were administered, of which 110 were complete and included in the data set used throughout this analysis.

The majority of aquaculture farmers in our sample were men (90%), 46.5 years of age with 8.4 years of education (Table 2). On average, they had over ten years of experience in aquaculture, farmed about 123 *mu* (approximately 20 acres) and had a net income of approximately 86,788 CNY[6] per year (approximately $13,438) of which 71% was derived from their farming operation. The top aquaculture products raised were carp, tilapia, catfish and shrimp. Approximately 18% of operations in our sample were export oriented and 14% of farms operated under contracts.

Information regarding farmers' level of knowledge and perceived food safety risks at various stages of the supply chain was gathered through a series of 5-point Likert-scale questions, where 1 represented no knowledge/concern and 5 highly knowledgeable/concerned. On average, farmers were found to be more knowledgeable (scores of 4 or 5) of their input suppliers (fingerling, feed and pharmaceutical providers) for whom they also showed heightened concern regarding food safety risks (Table 3). Farmers were least knowledgeable of exporters as well as various regulatory agencies. On average, producers expressed the most concern (scores of 4 or 5) for food safety risks for upstream production related stages of the supply chain including input suppliers and on-farm water and disease management. Farmers attributed the lowest level of food safety risk to processors and downstream stages of the supply chain including retail management practices and the ultimate consumer.

## 4. Results

### Relative importance of value system attributes

Results from the RPL model, presented in Table 4 indicate the relative importance of each of the value attributes. Estimates are shown relative to 'consumer knowledge', which was determined to be the least important value and indicates how little producers care about the importance of consumers' effect on their business. This result is particularly important as it further contributes to the knowledge

[6] At the time of the study (summer 2011) 1CNY was equal to approximately £0.096, $US0.155 USD and €0.107.

**Table 3:** Farmers' level of knowledge and food safety concern over supply chain stages

| Supply Chain Stage | Percent (%) knowledgeable | Percent (%) concerned |
|---|---|---|
| Suppliers of fingerlings | 73.15 | 86.24 |
| Suppliers of feed | 51.00 | 84.40 |
| Suppliers of pharmaceuticals | 47.22 | 69.72 |
| Production- water quality | N/A | 83.33 |
| Production- disease management | N/A | 84.26 |
| Production- technical knowledge | N/A | 64.81 |
| Processors | 17.16 | 10.28 |
| Exporters | 5.56 | N/A |
| Wholesale/retail | 54.20 | 30.79 |
| End consumer | 42.45 | 31.48 |
| Local regulatory agency | 34.86 | N/A |
| National regulatory agency | 11.92 | N/A |
| Foreign regulatory agency | 1.83 | N/A |

Source: Authors' survey data.

asymmetry that exists between both ends of the Chinese food supply chain (Ortega *et al.*, 2011).

RPL model results reveal that water quality, on average, is the most important attribute for aquaculture farmers. Farmers in this region attribute most fish diseases resulting in production losses to poor water quality. Water quality is by and large determined by exogenous conditions, as fish are raised in outdoor ponds with water supplied from nearby rivers, lakes, or other water bodies. The overall low water quality in China has created significant concerns for aquaculture farmers. However, farmers can contribute to their own on-farm water quality by controlling fish density, feed and drug use, and adopting new technology. Farmer awareness of this important issue is a good start for the promotion of environmental protection in China.

Food safety, animal welfare, regulatory compliance, and traceability are the next most important issues to farmers. Interestingly, these are either monitored by the government (latter two) or easily picked up by the public or media. Violating any of these may lead to legal and financial consequences. Drug management, scape control, and environmental impact are less important factors concerning farmers. Veterinary drug use is loosely controlled in China and environmental regulations are more geared towards targeting industrial rather than agricultural pollution. Additionally, the negative impact to the environment of dumping polluted water into rivers or lakes or fish escape, will not directly impact own farm production.

Food safety certification, community relations, and consumer knowledge (chosen as the base because of its least important status) were the least important for farmers. Farmers haven't noticed the potential market premium for food safety certification because their output is not produced as branded product for processors, rather sold to wholesalers as bulk commodities. Their neighbours tend to be in the same business, a wide existing phenomenon in China that farmers in the same

 

**Table 4:** Random parameter logit results and derived shares of preference

| Variable | | Coefficient | | Shares of Preference |
|---|---|---|---|---|
| Water Quality | Mean | 3.871 | (0.171)* | 0.407 |
| | SD | 1.265 | (0.128)* | |
| Food Safety | | 3.281 | (0.159)* | 0.226 |
| | | 0.863 | (0.111)* | |
| Animal Welfare | | 2.290 | (0.186)* | 0.084 |
| | | 2.866 | (0.246)* | |
| Regulatory Compliance | | 1.820 | (0.168)* | 0.052 |
| | | 1.597 | (0.164)* | |
| Traceability | | 1.793 | (0.180)* | 0.051 |
| | | 2.370 | (0.166)* | |
| Drug Management | | 1.700 | (0.158)* | 0.046 |
| | | 1.889 | (0.172)* | |
| Scape Control | | 1.682 | (0.169)* | 0.046 |
| | | 2.231 | (0.150)* | |
| Environmental Impact | | 1.580 | (0.131)* | 0.041 |
| | | 0.405 | (0.191)* | |
| Food Safety Certification | | 1.009 | (0.147)* | 0.023 |
| | | 1.329 | (0.116)* | |
| Community Relation | | 0.496 | (0.166)* | 0.014 |
| | | 1.915 | (0.159)* | |
| Consumer Knowledge | | 0.000 | | 0.010 |
| Log likelihood | | −2991.53 | | |

Note: Standard Errors are presented in parentheses. Asterisk, '*', denotes statistical significance at the 0.05 level.

village tend to produce the same commodity using similar practices. Additionally, many supply chain layers separate farmers from the end consumers, thus they do not obtain direct signals indicating that many of these consumer demands and values are important.

Because the utility parameters have no natural interpretation other than their relative ranks, derived shares of preferences from equation (4) for each of the values were calculated and are presented on the right side of Table 4. Our results show that producers have the highest mean preference share for water quality (40.7%), which is almost twice as preferred as food safety (22.6%), the next most important value attribute. Animal welfare received a share of 8.4%, indicating that farmers understand the effects of good fish handling practices on product quality. While food safety contributed almost a fifth to overall preferences, regulatory compliance, traceability, drug management and food safety certification, in aggregate, had a 17.2% share of preference. Concerns regarding environmental impact or scape control made up 8.7% of the mean preference share and less than a 4% share was attributed to community relation or consumer knowledge. In other words, community relation and consumer knowledge are ten times less important to farmers than the most important value attribute, water quality.

Correlations between producers' values were calculated using farmer-specific RPL model estimates (Table 5). Given that all of the correlation coefficients are below 0.5, this indicates that each of the values identified represent a unique concept within farmers' value system (Lusk and Briggeman, 2009). Values exhibiting a correlation coefficient greater than 0.2 are highlighted in light grey in Table 5. Water quality is positively associated with both drug management as well as environmental impact, meaning that farmers who believe water quality is important are also likely to believe that drug management or the environmental impact of their operations is important. On the contrary, farmers who believe water quality to be important are less likely to believe that traceability or food certification is important. While traceability was found to be positively associated with scape control and food safety certification, farmers who valued it were less likely to find environmental impact and drug management important. It is worth noting that traceability and food safety certification do not make products safer, rather, they are just indicators to consumers. On the other hand,

**Table 5:** Pearson correlations between producer values from individual-specific RPL estimates

| Value | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality | 1 | 1.00 | | | | | | | | | |
| Food Safety | 2 | 0.16 | 1.00 | | | | | | | | |
| Animal Welfare | 3 | 0.07 | −0.10 | 1.00 | | | | | | | |
| Drug Management | 4 | 0.37 | −0.02 | 0.14 | 1.00 | | | | | | |
| Scape Control | 5 | −0.17 | −0.10 | −0.06 | −0.04 | 1.00 | | | | | |
| Environmental Impact | 6 | 0.28 | −0.16 | 0.10 | 0.18 | −0.21 | 1.00 | | | | |
| Regulatory Compliance | 7 | −0.17 | 0.17 | −0.10 | −0.07 | 0.04 | −0.21 | 1.00 | | | |
| Traceability | 8 | −0.32 | −0.02 | 0.14 | −0.32 | 0.47 | −0.36 | −0.04 | 1.00 | | |
| Food Safety Cert. | 9 | −0.22 | −0.05 | −0.17 | −0.14 | 0.12 | −0.23 | 0.06 | 0.22 | 1.00 | |
| Community Relation | 10 | −0.01 | 0.04 | −0.06 | −0.04 | −0.04 | −0.01 | 0.08 | −0.04 | 0.07 | 1.00 |

drug management and water quality contribute directly to product quality and safety. It is reasonable that farmers rank items in the same category closely and those in different categories remotely resulting in the positive and negative correlations.

### Value attributes and on-farm decision-making

To explore how farmers' value system is related to on-farm decision-making, we gathered data on each farmer's willingness-to-stop using antibiotics through a separate discrete choice experiment. Individual parameter estimates from the best-worst RPL model were obtained and used to calculate correlation coefficients between each farmer's share of preference and the premium (or discount) needed to stop using antibiotics (Ortega *et al.*, 2014b). The use of antibiotics was selected to assess how farmers' value system affects on-farm decision-making due to the food safety implications of this practice in the Chinese aquaculture industry. Table 6 shows Pearson correlation coefficients between each farmer's value attribute share of preference and their willingness-to-stop using antibiotics. Our empirical results show that producers who value food safety the most, are more likely to stop using antibiotics in their operations. This finding highlights the association present between food safety and the use of antibiotics and links farmers value system and preferences to their on-farm behaviour.

## 5. Discussion and conclusion

While research on preference structures has focused mostly on consumer studies, we demonstrate how farmers' value system plays a role in on-farm decision-making. In this study we adapt a best-worst research framework to better understand producer preferences and how they relate to decisions that affect product safety and quality. Our results reveal that producers were found to have the least concern and knowledge regarding the end users of their products, and they also indicated that knowledge of consumers and safety certification were not important to them (although they find safety itself important). The latter is at odds with findings that consumer value food safety certification (Wang *et al.* 2008). We find that attributes which farmers value most are those directly related to their operation, such as water quality, safety, and animal welfare which they can link directly to product quality and output. Farmers also have the strongest concerns about their input suppliers, which is also directly connected to their product. While farmers' focus on their operation may ensure product safety, efforts should be made to convey this message to consumers to enhance their confidence and unveil unsafe products in the marketplace. Such bridging of information asymmetry can be accomplished through certifications of food safety, eco-friendly practices, and other attributes consumers value (Ortega *et al.* 2011).

**Table 6:** Correlations between shares of preferences for producer Values and Willingness to Stop Using Antibiotics

| Value | Pearson Correlations |
|---|---|
| Water Quality | – 0.144 |
| Food Safety | 0.201* |
| Animal Welfare | 0.070 |
| Drug Management | 0.029 |
| Scape Control | – 0.198* |
| Environmental Impact | – 0.032 |
| Regulatory Compliance | 0.063 |
| Traceability | – 0.015 |
| Food Safety Certification | – 0.052 |
| Community Relation | 0.158 |
| Consumer Knowledge | – 0.014 |

Note: One asterisk (*) denotes the correlation between the producer value and the willingness to stop using antibiotics is significantly different from zero at the p = 0.05 significance level.

Our results also suggest that some safety issues in the Chinese aquaculture sector go beyond on-farm production practices. Factor inputs including feed, veterinary drugs, and water management can all contribute to food safety incidents. Furthermore, although processors, wholesalers and retailers can also contribute to safety problems, farmers do not seem concerned, likely because they would not be held responsible if a safety event occurred. However, in the event of a food safety incident, a significant demand shock for the product will impact the commodity at the farm gate. Results from both sides of the supply chain suggest that farmers should be cautious in choosing whom to work with. Contracting with suppliers and buyers (wholesalers or processors) is recommended as it fits with the Chinese government policy of encouraging contract farming (Wang *et al.* 2014) and is likely to decrease food safety incidents by increasing transparency among links in the supply chain. We also find that foreign regulatory agencies, either government or third party certifiers, are not well understood by Chinese aquaculture producers. More outreach from these parties is needed so that trust and good relations can be established to enhance the safety and quality of products that are imported by the home countries of these foreign agencies.

While this study explores Chinese aquaculture famers' value system, additional work is needed to fully understand how farmer preferences and production level decisions affect product safety. A limitation of the present study is that it only addresses aquaculture farmers in a specific region of China and does not take into account the behaviour of other agents in the supply chain. Further, additional insight can be obtained by comparing how farmers' value systems vary across various types of agricultural producers. A study of preferences for these and other individuals along the supply chain and across various commodities will better inform food policy regarding product safety and is left as an area of future research.

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REFEREED ARTICLE

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# Determinants of modern technology adoption in multiple food crops in Nigeria: a multivariate probit approach

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**ABSTRACT**

Farmers generally produce multiple crops while selectively adopting modern technologies in them to meet various needs. The present study jointly determines the factors influencing decisions to adopt modern technologies (i.e., HYV seeds and/or fertilisers) in multiple food crops (i.e., rice, yam and cassava) using a survey data of 400 farmers from Nigeria by applying a multivariate probit model. Model diagnostic reveals that the decisions to adopt modern technologies are significantly correlated, implying that univariate analysis of such decisions are biased, thereby, justifying use of multivariate approach. Results reveal that 68% of the farmers grew at least two food crops. Output price is an important determinant of HYV adoption. Farming experience is positively associated with HYV adoption whereas remoteness of extension services is negatively associated. HYV technology adoption is relatively higher for small farms whereas large farms use more fertilisers. Access to credit positively influences modern technology adoption. High profit is the main motive for adopting modern technologies. Policy recommendations include investments in extension infrastructure and credit services as well as measures to stabilise and/or improve output price efficiency, e.g., government procurement of outputs during harvest, grading and standardisation of food crops, reducing transaction costs of marketing and trade policies.

**KEYWORDS:** socio-economic determinants; multivariate probit analysis; multiple crop production; modern technology adoption decisions; Nigeria

## 1. Introduction

The right to food is one of the most consistently mentioned policy goals in international human rights documents, but it is the one that is most frequently violated (Clover, 2003). The New Partnership for African Development (NEPAD) report states that it will require an investment of $18 billion a year in rural infrastructures to achieve MDG-1 of halving hunger from its 1990 level by 2015 in Africa (Boon, 2007). Long before the recent financial crisis, Africa was already in food crisis, as one in three adults and children are under-nourished and half of all Africans live on less than one dollar a day (Nambiro *et al.*, 2008). The recent food, energy and financial crisis have turned an already serious problem into a catastrophe. Price increases to the tune of 60% or more for food and other products (Binswanger and McCalla, 2008) has driven an additional 100 million Africans further into poverty (Adesina, 2009). The situation in Nigeria is not any different from the rest of its neighbours.

Agriculture remains an important sector in the Nigerian economy, and is a major source of raw materials, food and foreign exchange and employs over 70 percent of the labour force and has the potential to diversify its economy (Liverpool-Tasie *et al.*, 2011). Of the 178.5 million people (World Population Review, 2015), more than 70 million lives in rural areas engaged in small scale semi-subsistence agriculture (Liverpool-Tasie *et al.*, 2011). The Nigerian agricultural sector has a high potential for growth, but this potential is not being realised and productivity is low and basically stagnant (Aigbokhan, 2002). Ehui and Tsgas (2009) also observed that the farming system is mostly small scale characterised by low level of modern technology adoption and is largely dependent on the vagaries of the weather.

Cassava, yam and rice are the three main staple food crops in Nigeria where the former two have a wide range of industrial and commercial uses as well. Nigeria is one of the leading producers of cassava in the world (Ayoade and Adeola, 2009; Knipscheer *et al.*, 2007; Nweke, 2004). Nigeria also accounts for 68% of global yam production and yam ranks highest as an important source of dietary calories for its people (Asiedu and Maroya, 2012). On the other hand, although the demand

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for rice as a staple was low during the 1960s, it has started to rise since the 1990s, growing at an annual rate of 14% by mainly substituting other coarse grains, roots and tubers used for consumption (Erhabor and Ogojho, 2011). Awerije and Rahman (2014) noted that cassava has strong potential to support agricultural growth in Nigeria but currently is constrained by low level of productivity and efficiency, lack of processing and poor marketing infrastructure. Similarly, the potential of yam also has not been realized mainly due to constraints in unavailability and affordability of high quality seed yams, on-farm post-harvest losses, low soil fertility, and unexploited potential of yam markets by smallholder farmers (Asedu and Maroya, 2012). Nkonya *et al.* (2010) noted that the current yield of rice, cassava and yam is only 1.9, 12.3 and 12.3 mt/ha whereas the potential yields are 7.0, 28.04 and 18.0 mt/ha, respectively. Liverpool-Tasie *et al.* (2011), examining trends in production of selected crops (millet, yam, maize, cassava, and rice) for the period (1994–2006), noted that the output produced for most crops was stagnant or declining, with the exception of cassava, which saw modest increases in output. They also concluded that food crop production in Nigeria is far below its potential and the demand is far greater than locally produced supply (Liverpool-Tasie *et al.*, 2011).

Therefore, given such poor productivity performance of these major crops, it is important to identify: (a) the type of food crops grown at the farm level, (b) the extent of multiple cropping undertaken at the farm level; and (c) identify factors influencing adoption of modern technologies in them, so that the total production of food crops can be improved at the farm level, provided that the farms are managed properly, which in turn will contribute to support Nigeria's agricultural growth.

Farmers generally produce multiple crops while they selectively adopt modern technology in some or all of the crops in order to meet their consumption and various other needs depending on their socio-economic circumstances. In fact, farms are businesses where decisions are made and implemented by the farmer alone under relatively more external pressures than any other businesses (Groenwald, 1987 and Errington, 1991 cited in Willock *et al.*, 1999). Therefore, such a complex decision making process cannot be realistically accommodated by examining factors influencing adoption of modern technology of each crop separately. Literature abounds with examination of factors influencing adoption of modern technology in crop production at the farm level largely focusing on single crop only (e.g., Mariano *et al.*, 2012; Uaiene *et al.*, 2009; Shiyani *et al.*, 2002; Ransom *et al.*, 2003; Baidu-Forson, 1999), although in reality farmers produce multiple crops (e.g., Rahman, 2008, Benin *et al.*, 2004; Floyd *et al.*, 2003). To our knowledge, there is no single study that has jointly determined the factors influencing adoption of modern agricultural technology in multiple crops. Furthermore, farmers may not even adopt modern technology as a complete package (e.g., High Yield Variety (HYV) seeds, fertilisers, irrigation and/or pesticides together), but selectively choose any component(s) of the package, e.g., only fertilisers but not irrigation or HYV seeds, which is more common, particularly in Africa.

Therefore, in order to realistically identify the host of factors influencing such a complex decision making process, i.e., adoption of modern technology selectively or totally as a package in any one or all of the multiple crops, we utilise a multivariate probit model which is capable of jointly estimating all the relevant parameters of the model and also provides evidence of jointness in the decision making process. This is the main contribution of our research to the technology adoption literature. In other words, the specific objective is to jointly determine the factors influencing adoption of modern technology components (i.e., HYV seeds and/or fertilisers) in any or all of the three major food crops (i.e., rice, yam and cassava). We do so by using farm-level cross-sectional data of 400 farmers from Ebonyi and Anambra states of Nigeria collected in 2012. This is because a more complete understanding of farmers' decision making process is of interest to policy makers and academics (Willock *et al.*, 1999).

The paper is structured as follows. Section 2 presents the analytical framework, study area and the data. Section 3 presents the results. Section 4 concludes and draws policy implications.

## 2. Methodology

### Conceptual model: the multivariate probit model

Several studies have analysed determinants of adoption of modern technologies. These are largely univariate probit, tobit or logit regressions of technology adoption of a single crop on variables representing socio-economic circumstances of farmers (e.g., Mariano *et al.*, 2012; Uaiene *et al.*, 2009; Shiyani *et al.*, 2002; Ransom *et al.*, 2003; Baidu-Forson, 1999). The implicit theoretical underpinning of such modelling is the assumption of utility maximization by rational farmers, which is described below.

We begin by postulating that the farmer produces a single crop, say rice. We also define modern technology in a broader sense in terms of specific elements or components, e.g., use of HYV seeds and fertilisers. We denote the adoption of HYV seed technology in rice as "$y$", where $y = 1$ for adoption and $y = 0$ for non-adoption. The underlying utility function which ranks the preference of the $i$th farmer is assumed to be a function of farmer as well as farm specific characteristics, "X" (e.g., education, farm size, family size, tenancy, extension services, etc.) and an error term with zero mean. The model is written as (Greene, 2012):

$$y^* = \mathbf{x}'\beta + \epsilon \tag{1}$$

$y$ = 1, if $y^* > 0$ (if HYV seed technology is adopted)
$y$ = 1, if $y^* \leqslant 0$ (*otherwise*)

Since the utility derived is random, the $i$th farmer will adopt HYV seed technology if and only if the utility derived from adoption is higher than non-adoption. Thus, the probability of adoption of the $i$th farmer is given by (Greene, 2012):

$$\text{Prob}(\text{Y} = 1|\mathbf{x}) = F(\mathbf{x}, \beta)$$

$$\text{Prob}(\text{Y} = 0|\mathbf{x}) = 1 - F(\mathbf{x}, \beta) \tag{2}$$

$$\text{where} F(\mathbf{x}, \beta) = \mathbf{x}'\beta.$$

The functional form of Eq (1) depends on the assumption made for the error term $\epsilon$, which is assumed to be normally distributed in a probit model. Thus for the $i$th farmer, the probability of the adoption of HYV seed technology is given by:

$$\text{Prob}(Y=1|\mathbf{x}) = \int_{-\infty}^{x'\beta} \varphi(t)dt = \Phi(\mathbf{x}'\beta) \quad (3)$$

where $\Phi(t)$ is the cumulative distribution function of the standard Normal. This is the single equation probit model for adoption of a HYV seed in rice crop only.

Since we are interested in accommodating multiple crops that farmers generally grow and selectively adopt components of modern technologies in them, we adopt the multivariate probit model with M number of equations that is based on the same principle. The resultant equation system is given by (Greene, 2012):

$$y_m^* = \mathbf{x}_m'\beta_m + \epsilon_m, y_m = 1 \textit{ if } y_m^* > 0, 0 \textit{ otherwise}, \ m = 1, \ldots \ldots M$$

$$E[\epsilon_m|\mathbf{x}_1, \ldots \ldots, \mathbf{x}_M] = 0$$

$$\text{Var}[\epsilon_m|\mathbf{x}_1, \ldots \ldots, \mathbf{x}_M] = 1$$

$$\text{Cov}\left[\epsilon_j, \epsilon_m|\mathbf{x}_1, \ldots \ldots, \mathbf{x}_M\right] = \rho_{jm},$$

$$(\epsilon_1, \ldots \ldots \epsilon_M) \sim \text{N}_M[\mathbf{0}, \mathbf{R}] \quad (4)$$

The joint probabilities of the observed events $[y_{i1}, y_{i2}, \ldots \ldots y_{iM}|\mathbf{x}_{i1}, \mathbf{x}_{i2}, \ldots \ldots \mathbf{x}_{iM}]$, $i = 1, \ldots, n$, that forms the basis for the likelihood function are the M-variate normal probabilities (Greene, 2012):

$$L_i = \Phi_M(q_{i1}\mathbf{x}_{i1}'\beta_1, \ldots \ldots \ldots, q_{iM}\mathbf{x}_{iM}'\beta_M, \mathbf{R}^*), \quad (5)$$

where,

$$q_{iM} = 2y_{iM} - 1$$

$$R_{jM}^* = q_{ij}q_{iM}\rho_{jm}$$

where $\rho_{jm}$ is the correlation between $\epsilon_j$ and $\epsilon_m$. The distributions are independent if and only if $\rho_{jm} = 0$. A user written full maximum likelihood estimation procedure is applied using STATA V10 software program (STATA Corp, 2010).

## Study area and the data

Data used for the study were drawn from the two states: Ebonyi and Anambra states of Nigeria. Based on the cell structure developed by the Agricultural Development Programme, three local government areas (LGAs) from each state were selected randomly. Then 10 communities/villages from each LGA were chosen randomly. Next, farmers were chosen from these communities using a simple random sampling procedure. The total number of farm households in each village formed the sample frame. Then the sample size ($n$) of household units in the study area is determined by applying the following formula (Arkin and Colton, 1963):

$$n = \frac{Nz^2p(1-p)}{Nd^2 + z^2p(1-p)} \quad (6)$$

where $n$ = sample size; N = total number of farm households; z = confidence level (at 95% level z = 1.96); p = estimated population proportion (0.5, this maximizes the sample size); d = error limit of 5% (0.05).

Application of the above sampling formula with the values specified, which in fact maximizes the sample size, yielded a total required sample of 450. However, a total of 600 questionnaires were distributed (300 in each state with 30 in each community). Although 290 questionnaires from Ebonyi and 190 from Anambra states were returned, complete information was available in only 249 and 141 questionnaires from these states, respectively. Therefore, the final sample size stands at 400 households. Details on input and output data on three major food crops (i.e., cassava, yam and rice) were recorded in addition to key demographic and socio-economic information from each of the farm households. The co-author and two trained research assistants, who are agricultural graduates, were used for collecting primary data.

## The empirical model

A multivariate probit model is developed to empirically investigate the socio-economic factors underlying the decision to grow multiple crops and use HYV seed technology and/or fertilisers in any or all of the food crops. The dependent variables are whether the farmer adopts HYV seed technology and/or fertilisers in each of the major staple food crops (i.e., rice, yam and cassava). For each case of adoption, the variable takes the value 1 and 0 otherwise. Furthermore, for each crop (e.g., rice) with two types of technologies (i.e., HYV seeds and fertilisers), there are four possibilities: (a) no modern technologies (*rice* = 0, *rfert* = 0); (b) only HYV seeds (*rice* = 1, *rfert* = 0); (c) only fertilisers (*rice* = 0, *rfert* = 1); and (d) both (*rice* = 1, *rfert* = 1).

Therefore, a total of six types of technology adoption functions are postulated, i.e., three crops with two types of technology adoption decisions in each. The following set of six equations provides possible combinations of $2^m - 1 = 2^6 - 1 = 63$ (Young *et al.*, 2009).

$y_1^* = \mathbf{x}'\beta_1 + \epsilon_1, y_1 = 1 \textit{ if } y_1^* > 0, 0 \textit{ otherwise}$
(HYV rice seed adoption, *rice*)

$y_2^* = \mathbf{x}'\beta_2 + \epsilon_2, y_2 = 1 \textit{ if } y_2^* > 0, 0 \textit{ otherwise}$
(HYV yam seed adoption, *yam*)

$y_3^* = \mathbf{x}'\beta_3 + \epsilon_3, y_3 = 1 \textit{ if } y_3^* > 0, 0 \textit{ otherwise}$
(HYV cassava seed adoption, *cas*)

$y_4^* = \mathbf{x}'\beta_4 + \epsilon_4, y_4 = 1 \textit{ if } y_4^* > 0, 0 \textit{ otherwise}$
(Fertiliser adoption in rice, *rfert*)

$y_5^* = \mathbf{x}'\beta_5 + \epsilon_5, y_5 = 1 \textit{ if } y_5^* > 0, 0 \textit{ otherwise}$
(Fertiliser adoption in yam, *yfert*)

$y_6^* = \mathbf{x}'\beta_6 + \epsilon_6, y_6 = 1 \textit{ if } y_6^* > 0, 0 \textit{ otherwise}$ (7)
(Fertiliser adoption in cassava, c*fert*)

 

where $\mathbf{x} = (1, \mathbf{x}_1, \mathbf{x}_2, \ldots .\mathbf{x}_n)'$ is a vector of $n$ covariates which do not differ between adopter categories (the deterministic component) and $\beta_m = (\beta_{m0}, \beta_{m1}, \beta_{m2}, \ldots \ldots .\beta_{mn})'$ is a corresponding vector of parameters, including an intercept which we want to estimate. The stochastic component, $\epsilon_m$, is thought of as those unobservable factors which explain the marginal probability of making a decision to adopt technology $m$ ($m$ = 1, 2, ….., 6). Each $\epsilon_m$ is drawn from a M-variate normal distribution with zero conditional mean and variance normalized to unity, where $\epsilon_m \tilde{N}(0, \Sigma)$, and the covariance matrix $\Sigma$ is given by (Young *et al.*, 2009):

$$\Sigma = \begin{bmatrix} 1 & \rho_{12} & . & . & . & \rho_{1m} \\ \rho_{21} & 1 & . & . & . & \rho_{2m} \\ . & . & . & & & . \\ . & . & & . & & . \\ . & . & & & . & . \\ \rho_{m1} & \rho_{m2} & . & . & . & 1 \end{bmatrix} \quad (8)$$

The particular interest is the off-diagonal elements of the covariance matrix, $\rho_{jm}$, which represents the unobserved correlation between the stochastic component of the $j^{th}$ and $m^{th}$ type of technology adoption decisions (Young *et al.*, 2009). Because of symmetry in covariances, we have $\rho_{jm} = \rho_{mj}$. The joint estimation of Eq (7) is not only efficient but also allows us to estimate the joint probabilities of the technology adoption decisions. The marginal probability of observing $m^{th}$ type of technology adoption can be expressed as (Young *et al.*, 2009):

$$\text{Prob}(y_m = 1) = \Phi(\mathbf{x}'\beta_m) \; for\; all\; m = 1, \ldots, 6 \quad (9)$$

where $\Phi(.)$ Denotes the cumulative distribution function of the standard Normal. Furthermore, the joint probability of observing all possible types of technology adoption decision comes from the M-variate standard Normal distribution (Young *et al.*, 2009):

$$\text{Prob}(y_1 = 1, \ldots\ldots, y_m = 1) = \Phi_m(\mathbf{x}'\beta_1, \ldots\ldots \mathbf{x}'\beta_m; \Sigma) \quad (10)$$

where $\Sigma$ is the covariance matrix.

The socio-economic variables selected to explain modern technology adoption decisions are: output price, subsistence pressure, farming experience, education of the farmer, farm size, tenurial status, extension infrastructure, main occupation of the farmer, and the amount of agricultural credit received. The choice of these explanatory variables is based on the literature with similar justification (e.g., Mariano *et al.*, 2012; Uaiene *et al.*, 2009; Rahman 2008, Benin *et al.*, 2004; Shiyani *et al.*, 2002; Ransom *et al.*, 2003). In addition, farmers were also asked about the motivation for adopting modern technology in these crops and to rank each of the motives (e.g., high yield, high profit, etc.) on a five-point Likert scale (i.e., 1 for least important motive and 5 for most important motive). This is because farmers' decision making process is also influenced by attitudes, objectives, behaviours and personality traits in addition to socio-economic factors (e.g., Willock *et al.*, 1999; Beedell and Rehman, 2000; Kobrich *et al.*, 2003; Bergevoet *et al.*, 2004). For example, Willock *et al.* (1999) and Beedell and Rehman (2000) applied the Theory of Planned Behaviour (TPB) to understand the conservation behaviour of the farmer in the UK. Similarly, Bergevoet et al (2004) applied the TPB model to understand the entrepreneurial behaviour of dairy farmers in the Netherlands. Although use of a social-psychology model provides a more complete understanding of farmers' decision making process, there are a number of limitations to this approach. These are: requirement of a multidisciplinary team of researchers (Willock et al, 2009); very time consuming (Beedell and Rehman, 2000; Beedell and Rehman, 1999); responses require great deal of concentration from the respondents on obtuse/complex questions (Beedell and Rehman, 1999); require large range of valid variables (Willock *et al.*, 1999) and obviously is highly resource intensive and costly. Furthermore, implementation of this approach will be even more challenging in rural Africa. Therefore, while recognising the importance of social-psychology theory in explaining farmers' decision making, we picked up a simple set of questions from this domain, i.e., revealed motives behind the adoption of modern technology, as applied by Rahman and Sriboonchitta (1995). Table 1 presents definitions of the variables used in the multivariate probit model.

## 3. Results

Table 1 also presents the summary statistics of the sampled farmers. According to Table 1, adoption of modern technologies in crops is variable and generally very low, which perhaps explains low level of productivity of these major crops in Nigeria. Only 35% of the sampled farmers adopted HYV technology in cassava which is highest in the sample while the figure is only 18% for yam and 12% for rice producers. The use of fertilisers is similarly low (under 30%) for all crops.

Among the socio-economic factors, we see that the output price of yam is very high as compared with rice and/or cassava price, the average farm size is small (1.27 ha), average farming experience is about 20 years, education attainment is above primary level (7.8 years of completed schooling), low extent of tenancy (only 17% of operated area is rented in), farming is the main source of occupation for 52% of the sample, distance to extension office is 3.6 km and the average level of credit received is Naira 2.6 thousand per households.

### Extent of multiple cropping and technology adoption

Table 2 presents the extent of multiple cropping and the level of HYV seed and/or fertiliser technology adoption amongst the sampled farmers. It is clear form Table 2 that farmers grow multiple crops instead of a single food crop. A total of seven combinations of cropping system were observed. Only 18% of the farmers produced a single crop of cassava with lowest average operation size of 0.53 ha whereas 'only rice' or 'only yam' produces are a third of that with slightly higher operation sizes. On the other hand a substantial 41% of the farmers grew a combination of yam and cassava with an average operation size of 0.99 ha followed by 24.8% of farmers growing all three major food crops with highest average operation size of 2.54 ha.

**Table 1:** Definition, measurement and summary statistics of the variables

| Variables | Definition | Mean | Standard deviation |
|---|---|---|---|
| **Dependent variables** | | | |
| High yield variety of rice (*rice*) | Proportion of total farmers growing | 0.12 | -- |
| High yield variety of yam (*yam*) | Proportion of total farmers growing | 0.18 | -- |
| High yield variety of cassava (*cas*) | Proportion of total farmers growing | 0.35 | -- |
| Fertilizer in rice (*rfert*) | Proportion of total farmers applying | 0.21 | -- |
| Fertilizer in yam (*yfert*) | Proportion of total farmers applying | 0.27 | -- |
| Fertilizer in cassava (*cfert*) | Proportion of total farmers applying | 0.25 | -- |
| **Independent variables** | | | |
| **Output price** | | | |
| Rice | Naira per kg | 18.40 | 24.96 |
| Yam | Naira per kg | 36.25 | 23.01 |
| Cassava | Naira per kg | 8.78 | 9.27 |
| **Socio-economic factors** | | | |
| Family size | Number of persons per household | 3.88 | 1.91 |
| Farming experience | Years | 19.78 | 13.62 |
| Education of farmer | Complete years of schooling | 7.84 | 4.73 |
| Farm size | Hectare | 1.27 | 1.11 |
| Share of rented in land | Proportion of operated area rented in | 0.17 | 0.34 |
| Distance to extension office | Km | 3.64 | 3.56 |
| Main occupation of farmers | Dummy (1 if farmer, 0 otherwise) | 0.52 | -- |
| Agricultural credit | Thousand Naira | 2.31 | 8.29 |
| **Motives for choosing technology** | | | |
| High yield | Number | 0.85 | 0.27 |
| High profit | Number | 0.53 | 0.41 |
| Number of observations | | 400 | |

Note: Exchange Rate: GBP1.00 = Naira 200.00.

The implication is that small farms with their small farm size tend to grow at least two crops whereas large farms tend to grow all three crops due to command over a much larger cultivated area.

However, when use of modern technologies was examined, the picture is rather mixed. Overall, 47% of the farmers adopted HYV seeds in any or all of their crops. The use of HYV technology is highest at 90% for farmers growing combination of rice and yam, followed by combination of rice and cassava (66.7%). Also, 47% of farmers applied fertilisers with an average application rate of 52.8 kg/ha in any or all three crops.

Seventy six percent of ‘only yam’ producers (who are only 5.3% of total farmers) have applied fertilisers with an average application rate of 125.1 kg/ha followed by 70% of ‘rice and yam’ producers (who are only 2.5% of total farmers) applying a highest rate of 162.2 kg/ha. The ‘only rice’ producers applied (who are only 6.25% of total farmers) applied fertiliser @ 87.36 kg/ha. Only 27.8% of ‘only cassava’ producers applied least amount of fertilisers of only 18.1 kg/ha, which perhaps explains low productivity of cassava in Nigeria. It seems that fertiliser application rate is highest in yam production followed by rice. The main reason of such high rate of fertiliser

**Table 2:** Extent of modern technology adoption in multiple food crops amongst sampled farmers

| Producer categories | Percent of total farmers (%) | Farm operation size (ha) | Percent of farmers within each crop category | | |
|---|---|---|---|---|---|
| | | | Adopting high yielding varieties (%) | Adopting fertilizers (%) | Amount of fertilizers applied (kg/ha) |
| Only rice producer (*rice* = 1; *yam* = 0; *cassava* = 0) | 6.25 | 0.79 | 40.00 | 68.00 | 87.36 |
| Only yam producer (*rice* = 0; *yam* = 1; *cassava* = 0) | 5.25 | 0.68 | 57.14 | 76.19 | 125.14 |
| Only cassava producer (*rice* = 0; *yam* = 0; *cassava* = 1) | 18.00 | 0.53 | 52.78 | 27.78 | 18.10 |
| Rice and yam producer (*rice* = 1; *yam* = 1; *cassava* = 0) | 2.50 | 1.20 | 90.00 | 70.00 | 162.21 |
| Rice and cassava producer (*rice* = 1; *yam* = 0; *cassava* = 1) | 2.25 | 1.24 | 66.67 | 66.67 | 55.44 |
| Yam and cassava producer (*rice* = 0; *yam* = 1; *cassava* = 1) | 41.00 | 0.99 | 47.56 | 37.20 | 51.93 |
| Rice, yam and cassava producer (*rice* = 1; *yam* = 1; *cassava* = 1) | 24.75 | 2.54 | 36.36 | 61.62 | 44.00 |
| Overall | 100.00 | 1.27 | 47.25 | 47.00 | 52.77 |
| Number of observations (farm households) | 400 | | | | |

 

application in yam is because it is mainly destined for market and about 30% of the output is retained as seed yam for replanting. Akanbi *et al.* (2007) noted that application of fertiliser improved growth performance and tuber yield of white yam in South Western Nigeria. Based on the research in experimental plots, they recommended 450 kg/ha of NPK as optimum in their experimental plots which is far higher than the fertiliser use rate observed in yam in this study. Liverpool-Tasie *et al.* (2014) noted that farmers in Nigeria do apply fertiliser but at variable rates depending on the regions but the use rate is below the economic optimum level. For example, the application rate of nitrogen fertiliser in rice varies from 43 kg/ha in high potential rice state and 51.75 kg/ha in non-high potential rice state (Liverpool-Tasie *et al.* 2014). In comparison, farmers in the study areas already applied substantially higher amount of fertilisers in their rice crop.

## Determinants of modern technology adoption in multiple crops: a multivariate probit analysis

Results of the full information maximum likelihood estimation of the multivariate probit model are presented in Table 3. The key hypothesis that the 'correlation of the disturbance terms across six technology adoption functions' are jointly zero is strongly rejected at the 1% level of significance, implying correlated binary responses between technology adoption decisions. This further

**Table 3:** Joint determination of factors influencing modern technology adoption decisions in multiple food crops: a multivariate probit model

| Variables | HYV rice seed technology | HYV yam seed technology | HYV cassava seed technology | Fertilizer in rice | Fertilizer in yam | Fertilizer in cassava |
|---|---|---|---|---|---|---|
| | Coefficient | Coefficient | Coefficient | Coefficient | Coefficient | Coefficient |
| Constant | -6.637*** | -4.982*** | -1.087*** | -1.362*** | -0.554 | -1.073*** |
| **Prices** | | | | | | |
| Output price | 0.093*** | 0.081*** | 0.012 | -- | -- | -- |
| **Socio-economic characteristics** | | | | | | |
| Family size | -0.025 | -0.003 | -0.005 | 0.076 | -0.064 | -0.077* |
| Farming experience | 0.014 | 0.058*** | 0.018** | 0.009 | 0.026*** | 0.012 |
| Education of farmer | 0.028 | -0.028 | -0.003 | -0.002 | -0.027 | -0.032* |
| Farm size | 0.174** | -0.768*** | -0.436*** | 0.361*** | 0.009 | -0.128* |
| Share of rented in land | 0.091 | -0.349 | -0.121 | 0.643*** | -0.027 | -0.181 |
| Distance to extension office | 0.040 | -0.105*** | -0.056** | -0.038 | -0.089*** | -0.043* |
| Main occupation of farmers§ | 0.277 | -0.704** | -0.482** | 0.520*** | -0.208 | -0.101 |
| Agricultural credit | 0.020** | 0.019* | -0.001 | 0.015* | 0.017** | -0.002 |
| **Motives for choosing technology** | | | | | | |
| High yield | -0.899*** | -0.208 | 0.993*** | -1.192*** | -0.257 | 0.445 |
| High profit | 0.456* | 0.555** | 0.643*** | 0.283 | 0.721*** | 1.201*** |
| **Model diagnostics** | | | | | | |
| Log likelihood | -863.635 | | | | | |
| Wald $\chi^2_{(63\ df)}$ | 340.43*** | | | | | |
| **Correlation between the error terms** | | | | | | |
| $\rho_{(yam,\ rice)}$ | 0.367*** | | | | | |
| $\rho_{(cas,\ rice)}$ | 0.004 | | | | | |
| $\rho_{(rfert,\ rice)}$ | 0.205* | | | | | |
| $\rho_{(yfert,\ rice)}$ | 0.123 | | | | | |
| $\rho_{(cfert,\ rice)}$ | 0.147 | | | | | |
| $\rho_{(cas,\ yam)}$ | 0.009 | | | | | |
| $\rho_{(rfert,\ yam)}$ | -0.179 | | | | | |
| $\rho_{(yfert,\ yam)}$ | 0.694*** | | | | | |
| $\rho_{(cfert,\ yam)}$ | 0.334*** | | | | | |
| $\rho_{(rfert,\ cas)}$ | -0.125 | | | | | |
| $\rho_{(yfert,\ cas)}$ | -0.010 | | | | | |
| $\rho_{(cfert,\ cas)}$ | 0.336*** | | | | | |
| $\rho_{(yfert,\ rfert)}$ | 0.025 | | | | | |
| $\rho_{(cfert,\ rfert)}$ | 0.151 | | | | | |
| $\rho_{(cfert,\ yfert)}$ | 0.657*** | | | | | |
| Wald $\chi^2_{(15\ df)}$ ($H_0$: Correlation between pairs of disturbance terms are jointly 0) | 157.506*** | | | | | |
| Predicted marginal probability | 0.117 | 0.178 | 0.355 | 0.210 | 0.277 | 0.257 |
| Number of observations | 400 | | | | | |

Note: *** = significant at 1 percent level ($p<0.01$)
** = significant at 5 percent level ($p<0.05$)
* = significant at 10 percent level ($p<0.10$)
§ = dummy variable.
Source: Computed from Field Survey, 2012.

establishes that the use of a multivariate model to determine crop choice decisions among farmers is justified. The lower panel of Table 3 shows that six of the 15 pairs of correlation amongst disturbance terms are significantly different from zero at the 10% level at least, which further establishes jointness of the decision making process. All of the significant correlations coefficients are positive. For example, the correlation coefficient between the disturbance terms of HYV yam and HYV rice seed adoption functions, $\hat{\rho}_{(yam,\ rice)}$, is positive implying that the unobservable factors which increase the probability of adopting HYV yam also increase the probability of adopting HYV rice. Similarly, the unobservable factors which increase the probability of applying fertilisers in yam also increase the probability of applying fertilisers in cassava, $\hat{\rho}_{(cfert,yfert)}$.

Globally, 30 of the 63 coefficients have a significant relationship with the adoption of modern technologies in multiple crops. Output price is a significant determinant of adopting HYV seed technology in rice and yam. The coefficient estimate on output price is the marginal effect of output price on the log of the ratio of probabilities; therefore, it is possible to produce a probability of a given outcome relative to the omitted category by exponentiating the index function (Young *et al.*, 2009). For example, a one Naira increase in rice price per kg is associated with an increase in the probability of adopting HYV rice seed technology by approximately 9.75% ($(e^{0.093}-1)*100\%$) relative to the probability of not adopting any technology in any food crops, i.e., the omitted category. Wiboonpongse *et al.* (2012) noted that price of potato is an important determinant in choosing early season potato in Northern Thailand. Similarly, Rahman (2011) noted that gross return (i.e. output price x quantity) is an important determinant of HYV seed technology adoption decision in rice production in Bangladesh which is consistent with the findings of this study.

Subsistence pressure (i.e., family size) is negatively associated with HYV rice seed adoption. The reason may be due to the fact that cassava is a staple crop although rice consumption has grown substantially in Nigeria. Therefore, large families tend not to adopt HYV seed technology in rice production.

Farming experience is another significant determinant of adopting both HYV seed and fertiliser technologies. For example, a one year increase in farming experience is associated with an increase in the probability of adopting HYV yam seed technology by approximately 5.97% ($(e^{0.058}-1)*100\%$) and fertiliser use by approximately 2.63% ($(e^{0.026}-1)*100\%$) relative to the probability of not adopting any technology in any food crops. Wiboonpongse *et al.* (2012); Rahman (2008) and Shiyani *et al.* (2002) also noted positive impact of farming experience in modern technology adoption.

Farmers' education variable does not have any significant influence except that it is negatively associated with fertiliser use in cassava, which contrasts with the findings of Mariano *et al.* (2012) and Rahman (2008). The implication is that educated farmers are more likely to move away from agriculture and, therefore, are not likely to use fertilisers to increase yield of cassava. Role of education on technology adoption is generally mixed in the literature. In most cases it shows no significant effect, but when it does, the effect is generally positive.

Small farms are more likely to adopt HYV technology relative to large farms, except rice where the effect is opposite, i.e., large farms are more likely to adopt HYV technology in rice. This is also indicated in Table 2 where it is shown that average farm size of farms with rice crop in the system is systematically larger than other categories. Shiyani *et al.* (2002) also noted that small farmers in comparison to large farmers replace local varieties with new varieties at a faster rate if additional gains are substantial in India, which agrees with the findings of this study. With respect to fertiliser adoption, again large farms are more likely to apply fertilisers in rice crop relative to small farms. The costs of fertilisers may be more expensive relative to the cost of HYV seeds, and hence large farms are more likely to apply fertilisers relative to small farms, because they are presumably less financially constrained. Rahman and Parkinson (2007) noted that the use of fertiliser is positively related to farm size in HYV rice production in Bangladesh. Tenancy has a positive effect on fertiliser adoption, implying that farmers who rented land tend to use fertilisers in rice production to maximize yield and are probably more market-oriented.

Distance to extension office is significantly negatively associated with modern technology adoption. This clearly indicates the importance of extension services in disseminating modern agricultural technologies. Longer distance implies remoteness of the extension services which exerts detrimental effect on modern technology adoption by the farmers. For example, farms located every one km further away from the extension office are associated with a decrease in the probability of adopting HYV yam seed technology by approximately 11.07% ($(e^{0.107}-1)*100\%$) and fertiliser use in yam by approximately 9.31% ($(e^{0.089}-1)*100\%$) relative to the probability of not adopting any technology in any food crops. Apart from its nutritional value, yam plays an important role in social and religious festivals. In many areas in West Africa, it is an integral part of the cultural heritage of the people and occupies an important place in many traditional marriages and religious festivals (Eyitayo *et al*, 2010). Ayoola (2012) noted that the number of extension contacts significantly increase adoption of yam minisett technology in Middle Belt region of Nigeria. Similarly, the role of extension in influencing modern technology adoption was also noted by Mariano et al (2012), Uaiene *et al.* (2009), Ransom *et al.* (2003) and Baidu-Forson (1999). Therefore, the observation of detrimental effect of the remoteness of extension services on modern technology adoption is not surprising.

Farming as a main occupation is negatively associated with HYV technology adoption in yam and cassava whereas it is positively associated with fertiliser use in rice, which is quite puzzling. The implication is that the full time farmers tend not to adopt HYV seed technology but adopt fertilisers, although positive association is expected for all technology choices. A possible explanation may be the unavailability of good quality HYV seed of crops which full time farmers could easily identify. Constraints associated with the availability of farm inputs (i.e., HYV seeds and fertilisers) were highlighted during the interviews with Agricultural Development Program (ADP) managers, country representatives of IFDC and UNDP in Nigeria (Chima, 2015). Availability of good quality seed for yam has also been identified as a main constraint in in adopting modern technology in Nigeria (Ayoola, 2012).

Access to credit is another important determinant of modern technology adoption, as expected. For example, an increase of credit access of 1000 Naira is associated with an increase in the probability of adopting HYV rice seed technology by approximately 2.02% ($(e^{0.020} - 1) * 100\%$) and fertiliser use by approximately 1.51% ($(e^{0.015} - 1) * 100\%$) relative to the probability of not adopting any technology in any food crops. Mariano et al. (2012) and Uaiene *et al.* (2009) also noted significant influence of access to credit on adoption of modern technology in rice in the Philippines and maize in Mozambique, respectively.

Among the revealed motives for adoption of HYV technologies, high profit is significantly positively associated with modern technology adoption, whereas high yield is significantly positively associated with cassava production only. Profit motive influencing adoption of modern technology was noted by Mariano *et al* (2012), Baidu-Forson (1999) and Rahman and Sriboonchitta (1995). The negative influence of 'high yield' motive but positive effect of 'high profit' motive on yam production signifies the point that farmers grow yam not for maximizing yield but to maximize profit. This is possible because market price of yam is higher than rice and cassava. Moreover, yam (particularly fresh ware yam) is still regarded as a luxury good and large tubers can particularly attract high prices often purchased for celebrations such as weddings (Kleih *et al.*, 2012). Since most farmers in the study areas produced yam for sale, significant influence of high profit motive is not a surprise. Also yam farming occupies a prestigious cultural significance in the study area (among the Igbo's in Nigeria). There is a prestige associated with its farming with traditional honours (known as Eze ji – King of yam) for the best yam famers in the communities (Coursey and Coursey, 1971; Kleih *et al.* 2012; Ikejiani, 2014).

## 4. Conclusions and policy implications

The aim of this study was to jointly identify the determinants of modern technology adoption in multiple crops by farmers in Nigeria using a multivariate probit model. Specifically, the probability of adopting HYV seed and/or fertiliser technologies in three principal food crops (i.e., rice, yam and cassava) was investigated. The model diagnostic revealed jointness in the decision making process which cannot be discerned from the univariate approach that is commonly used in the literature. This is because the decisions to adopt modern technologies in food crops are significantly positively correlated. In other words, the probability of adopting modern technology in one crop increases the probability of adoption of modern technology in another crop. The implication is that there is significant synergy in decision to adopt modern technologies in multiple crops.

Results reveal that farmers grow multiple crops instead of any single crop as 68% of the surveyed farmers grew at least two food crops. The level of modern technology adoption is low and mixed and farmers selectively adopt components of technologies as expected. Among the host of socio-economic factors, output price is an important determinant of HYV technology adoption. Remoteness of extension services significantly reduces probability of modern technology adoption and is the strongest determinant of all. Another important determinant of modern technology adoption is farming experience. Small farms are likely to adopt HYV seed technologies relatively more/faster than the large farms. On the other hand, large farms are more likely to adopt fertiliser technology relative to small farms. Access to credit is significantly positively associated with modern technology adoption. Among the revealed motives for adoption of modern technologies, high profit motive is a significant determinant.

The following policy implications can be derived from the results of this study. First, targeted investment in extension infrastructure and services will significantly increase modern technology adoption and deserves particular attention as the detrimental influence of the remoteness of extension office is the strongest in the index functions. Aye and Mungatana (2011) concluded that the extension services in Nigeria in general have not been effective, especially after the withdrawal of the World Bank funding from the Agricultural Development Project, which is the main agency responsible for extension services. Awerije and Rahman (2014) also suggested investment in extension infrastructure as well as building capacity of the extension workers on new and improved technologies including dissemination strategies to improve cassava productivity.

Second, provision of credit services will significantly promote modern technology adoption. This can be achieved through effective disbursement of credit through formal banking institutions and/or facilitating non-governmental development organizations (NGOs) targeted at the farming population.

Finally, measures are needed to stabilise output prices and/or improve price efficiency because high prices, although seem favourable to producers, are detrimental to food security and the poor in the long run (Gouel and Jean, 2012). Price stability can be achieved by a range of measures, such as, by government procurement of crops during harvest season when price falls substantially (i.e., storage policy), grading and standardisation of products, reducing transaction costs of marketing, and trade policy (i.e., involving taxes and subsidies). For example, Gouel and Jean (2012) noted that an optimal combination of storage and trade policies in poor developing countries exert a powerful stabilising effects for domestic food prices. Similarly, Kleih *et al.* (2012) noted that the price of yam changes substantially during the harvest season and marketing inefficiencies for yam include fragmented value chains, lack of capital and liquidity constraints and very high transportation cost. They recommended locally regulated grading and standardisation to improve price efficiency of yam, a suggestion with which we also concur based on our findings.

Although these policy options are challenging, effective implementation of these measures will significantly increase adoption of modern agricultural technologies in major food crops and subsequently raise crop production and support agricultural growth in Nigeria.

The present study examined the determinants of modern technology adoption based on socio-economic factors and farmers' revealed motives at a point/cross-section of time which provides a snap shot of the present scenario. However, for a complete understanding of the dynamics involved in the decision making process of the farmers, information from a cohort of selected farmers over a period of time using a wider range of variables from the socio-economic as well as social-psychology models is highly desirable.

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# Analysis of risk management tools applicable in managing farm risks: A literature review

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**ABSTRACT**

The objective of this study was to list and analyse risk management tools applicable in managing farm risks. A literature search of several large literature databases was conducted. By using risk management-related keywords, a total of 13,559 articles discussing risk management were identified. Of these, 157 articles were selected for closer analysis applicable to dairy, cattle, pig or crop production. Both journal articles and book chapters in English were included. The articles were categorized based on the applied risk focus and type of risk management tools presented. In accordance with this, potential farm risk management tools were searched from the research studies associated with production, assets, economics and finance, human health and safety, and the environmental risks on farms. An important outcome of the study was a tool case for farm risk management stages, in which either the potential farm risk tools can each be used to address a single risk or the tools can be holistically applied. Farmers face multi-risk management demands, but comprehensive literature studies on multi-risk management tools on farms have been rare. Farm risk management tools and information provided to farmers are not at a sufficient level if we compare them to the current risks and social demands that farmers are facing. The possible farm risks should be clarified to farmers that they can identify them on farms. Furthermore, in order to integrate farm risk management tools, the links between the risks should be made visible among farm operations and farm production processes. Complexity and usability are future challenges in the further development of tools for managing farm risks. Applying the new farm risk tools in a sustainable manner requires farm managers to adopt new knowledge management techniques. Education programmes are needed to address the new skills that are required, and communication and co-operation between different research disciplines is also necessary.

**KEYWORDS:** farm; risk management; literature review study

## 1. Introduction

Various risks can cause serious damage on farms, but also have broader effects on society and the food supply chain (Marvin *et al.* 2009; Lowe *et al.* 2008). Animal and plant diseases, institutional risks, market risks, natural catastrophes, health and safety risks and farm financial risks emphasise the traditional sources of risks and the particular importance of risk management on farms (Huirne *et al.* 2007; Hardaker *et al.* 2004; Jung 2001; Florey 2001). An important problem is that farmers not only have to manage single risks, but also combinations of risks in their daily work and decision making. Some risk incident studies have pointed out that the handling of multiple hazardous risks on farms is a challenging task for farmers (Leppälä *et al.* 2013; Leppälä *et al.* 2012; Huirne *et al.* 2007; Hall 2007; Robinson 1999).

Risk is usually considered as a specific hazardous event and its consequences, which have a particular frequency or probability of occurrence. The positive side of risk can also be seen as a potential business opportunity (ISO 31000). On a general level, strategies proposed by risk management tools include avoiding risk, eliminating the risk source, reducing the risk likelihood or consequences, removing or sharing risk and retaining risk. The risk management process is based on tools for 1. Establishing the context, 2. Risk assessment, including risk identification, analysis and evaluation, 3. The control or treatment of risks and 4. Risk monitoring (ISO 31000). The corporate risk management literature presents broad frameworks or practical risk identification tools such as risk checklists and flowcharts to prevent the main corporate risks that may threaten or halt important business activities (Carnaghan 2006; COSO 2004).

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Corporate management tools have to some extent been applied in the farm management literature, which provides well-developed tools for risk decision making and risk analysis techniques, such as future price probabilities and economic farm management options (Nuthall 2010; Kay *et al*. 2008; Hardaker *et al*. 2004). A challenge is that the management tools used in other industries may not be suited to small enterprises such as farms, where the farm manager is both the manager and operator in most of the activities. However, it appears that the need for risk management tools in agriculture from a broader perspective is increasing worldwide due to increased competition, environmental and sustainability problems, new policy objectives, new food safety regulations and the changing risk context in general (Leppälä *et al*. 2012; Nuthall 2010; Lowe *et al*. 2008; Florey 2001). Furthermore, as sustainable farming policies, especially in European and Nordic countries, are calling for a more holistic risk approach in farming, we should also ask what practical tools are available for holistic risk management on farms (Leppälä *et al*. 2012; Marvin *et al*. 2009; Lowe *et al*. 2008; Robinson 1999). The objective of this study was to list and analyse risk management tools applicable in managing farm risks.

## 2. Methods

The literature review was a part of the larger 'Maaturva' project, which aimed to define the main risks and risk management tools in farm risk management studies. The project included a risk expert workshop, literature review, farm risk inquiry among farmers, ten farm visits and interviews and four case studies aiming to identify and develop suitable risk management tools for various farm management activities. A ten-day educational farm risk management programme for farmers during 2006–2007 was also arranged within the project (Leppälä *et al*. 2008).

### Literature search

We conducted a comprehensive literature study to identify practical on-farm risk management tools by using two electronic databases, Scopus and CABI, and their respective search tools. The searches were limited to the titles, abstracts and keywords of agricultural journals articles and book chapters published from 1990–2011. To be included, the articles needed to be concerned with tools for managing risks on farms. Applicability to European agriculture was considered as an inclusion criterion for studies selected for analysis. The included studies were limited to the main production types in EU countries, which are crop, dairy, cattle meat and pig meat production (European Commission 2012). In the narrative synthesis method, the included studies are divided into groups to explore their relationships or differences and point out the diversity among them (Lucas *et al*. 2007). The chosen farm risk management studies were categorized by asking which risk management tools are focused on managing particular risks on the farm level. We also used the thematic summary method to categorise the studies into thematic risk tool groups (Snilstweit *et al*. 2012). Finally, we conducted a summary of the risk management tools applicable to managing risks on farms and identified some development challenges for various farm risk management tools.

### Risk expert workshop

The potential risks on farms were listed in a risk expert workshop to modify the keywords for the preliminary literature search and farmer risk survey. The workshop included experts in farm occupational health and safety, farm machinery standards, agricultural engineering, SME risk management, farm insurance and business, and security education, as well as a dairy and a crop farmer (Leppälä *et al*. 2008). The Corporate Security Advisory and VTT in Finland had commonly used an outline of corporate risk fields, including techniques to prevent risks such as production security, health and safety, personnel security, security of buildings, the environment, rescue planning, areal preparedness, data security, crime prevention and security for foreign affairs (Lanne 2007). These risk fields were combined with the common risk sources in EU agriculture, defined as price risk, production or yield risk, human risk, asset risk, financial risk and institutional risk (Jung 2001). The risk expert workshop included a brainstorming session to explore the main farm risk keywords. The keywords and themes were documented, photographed and categorized. The keyword list concerning the main risks on farms was later updated based on the keywords in latest farm risk management studies published 2006–2011. (NJF 2010; Nuthall 2010; Niemeläinen *et al*. 2008; Huirne *et al*. 2007; Hardaker 2006).

## 3. Results

The whole list of risks handled in the workshop included those associated with personnel, economics, finance, buildings, production, business interruption, contracting, crime, data, occupational health and safety, rescue planning, market and price, foreign affairs, areal preparedness and environmental security. The identified and refined farm risk keywords and risk tool categories were determined to indicate the most important risks for in-farm activities. The keywords used and total numbers of search results are presented in Table 1. The search results yielded a total of 13,559 hits, but after applying of all search criteria limitations, 157 studies were chosen for more detailed analysis (Table 1). A current list of the studies is available on request from the authors.

The risk tool categories were defined as: 1. People health and safety; 2. Production and product risks; 3. Farm asset risks; 4. Economic and financial business risks, and 5. Environmental risks. The other risk categories (crime, data and areal preparedness etc.) handled in the risk expert workshop were found to be currently marginal on farms, but might become current in the future if the risk conditions change. During the literature search, studies on these other risks were also found to be rare or off-farm in context, and were thus excluded from the present analysis. The farmers who participated and were interviewed in the project appreciated the simpler model of risk categories (Leppälä *et al*. 2012; Leppälä 2008).

### Farm asset risk management tools

Farmers manage valuable solid assets, including farm estates, arable land, forests, buildings, machinery and livestock. The analysed articles addressed farm asset risk management tools concerning invested property value

**Table 1:** Search protocol for Scopus and CAB Abstracts. The total number of search hits was 13 559, from which 157 articles were included in the analysis

| Keywords | Date range: 1990-2011, Scope: Title, abstract, keywords, journals, books | Date range: 1990-2011: Scope: Title, abstract, headwords | Farm risk management studies applicable to European agriculture |
|---|---|---|---|
| | Scopus | CAB Abstracts | Total |
| | Search results | Search results | Included articles |
| "Farm risk management" OR "agricultur* risk management" | 52 | 13 | 3 |
| Farm AND "risk management" | 468 | 365 | 30 |
| Farm risk AND security management or farm vulnerability | 281 | 41 | 7 |
| Farm risk AND "food safety" OR "food safety management" | 344 | 319 | 7 |
| Farm risk AND product quality management OR "farm production management" | 90 | 4 | 7 |
| Farm risk AND asset management OR farm property management | 138 | 20[1)] | 4 |
| Farm risk AND building management OR "animal house*" | 92 | 152 | 5 |
| Farm risk AND machine management OR "farm machinery" | 225 | 3752 | 21 |
| Farm risk AND economic management OR "farm business management" | 463 | 148[2)] | 22 |
| Farm risk AND injury OR "farm safety management" | 564 | 855[3)] | 24 |
| Farm risk AND "sustainable management" OR "environment management" OR "ecological risk" OR agriculture environment management | 216 | 3999[4)] | 18 |
| Farm risk AND fire OR "fire management" OR "farm fire safety" | 339 | 639[5)] | 9 |
| Total | 3272 | 10287 | 157 |

1) terms were farm risk AND asset management OR farm property
2) last terms were without inverted commas
3) terms were farm AND injury OR safety risk management
4) terms were "farm risk" AND environment management OR sustainable management
5) terms were farm AND fire OR agricultur* fire safety risk OR "farm fire management"

losses and technical engineering assets (Table 2). The risk focus of the studies included fire incidents, farm building facility losses, land or soil property losses, animal health risks or herd value losses and asset property losses caused by natural disasters.

The analysed fire safety risk studies presented the possible risk sources and risk management tools to prevent fire risks on farms. Risk control through building maintenance and safety checks to monitor unsafe electrical installations and devices used in farm buildings were typical fire risk management tools (BS 5502 2004; Scott 1991). Farm fires spread toxic smoke to large areas and fire accident damage and costs are very high, which should be considered in fire safety and rescue planning (BS 5502 2004; Kinsman and Maddison 2001). Computer-aided fire risk programmes with warehouse inventory and alarm instructions are important management tools in fire safety planning, but also help fire departments in actual rescue situations (Kinsman and Maddison 2001). When focusing on other building risks, farm building structural planning, production volume and space calculation models are useful investment tools, for example when enlarging farm building spaces and production volumes (Meyer 2010). Furthermore, good air ventilation, quality measures and devices, ergonomic design and hygiene control programmes help to maintain people safety as well as animal health, building materials and fodder quality (Banhazi 2009; Noordhuizen and Metz 2005).

Farmland investment strategies may help with land asset risks by providing useful land investment measures for farmers (Nartea and Webster 2008). Pasture and soil management includes cultivation techniques, planning tools and land-use indicator examples (Chamen *et al.* 2003; Logan 1991). These tools could improve soil quality and water system maintenance, which increases the value and quality of the invested farmland. Machinery asset risk studies include methods that help in field machinery selection, investments and maintenance. For example, power capacity measures help in machinery selection and investments (Kutzbach 2000). Another potential tool is a machinery lifetime and maintenance cost management calculator (Petrov and Trendafilov 2011). Farmers investing in automatic animal production equipment should note the building structure and space (Hovinen and Pyörälä 2011).

Feed safety management and specific herd welfare controls were found to be examples of animal disease risk management tools. Disease control is easier to maintain in smaller animal groups and by identifying

 

**Table 2:** Studies concerning asset risk management tools on farms

| Focus | Risk management tools | Author |
|---|---|---|
| Fire safety | Safety behavior, fire safety check and planning, fire alarms and extinguishers, standards, regulations, water sources, rescue planning, fire models, material safety and inventory, building maintenance | Allareddy et al 2007; BS 5502 2004; Kinsman and Maddison 2001; Scott 1991; Shutske et al. 1991 |
| Building facilities | Size and volume planning, checklists, spreadsheets, regulations, quality management, maintenance skills, air quality monitoring, building standards | Sorge et al. 2011; Moore et al. 2010; Meyer 2010; Boersema et al. 2009; Banhazi 2009; Noordhuizen and Metz 2005; BS 5502 1992 |
| Land/soil value | Farmland investment strategies, land management models, sustainable land use and planning, land monitoring and indicators | Nartrea and Webster 2008; Chamen et al. 2003; Bouma 2002; Logan et al. 1991; Foran et al. 1990 |
| Machinery assets | Machine capacity calculation, machinery selection, lifetime analysis, machinery investments, automation facilities, maintenance plan, costs, machinery standards | Petrov and Trendafilov 2011; Kutzbach 2000; ASAE 1998a |
| Herd value/ animal health | Wildlife and cattle contact management, feed safety management, herd welfare controls, farm biosecurity management, herd contamination risk pathways | Wilson et al. 2011; Sorge et al. 2011; Ellis-Iversen et al. 2008; Bas Rodenburg and Koene 2007; Leirs 2004; Faust et al. 2001; BS 5502 1990 |
| Natural or areal crisis risks | Flood risk management, natural crisis management, damage prevention, food logistic planning, land-use planning, insurances, evacuation plans | Posthumus 2009; Haen 2008; Linnabary et al. 1991 |

possible pathogen contamination pathways in the animal shed (Sorge *et al.* 2011; Bas Rodenburg and Koene 2007). Potential animal welfare risks in the animal shed also include sharp edges, structural damage, dirty water basins, uneven floors, insufficient bedding and inadequate space for animals (Sorge *et al.* 2011; BS 5502 1990). Animal herd contact with wildlife (rodents and other animals), neighbouring herds and farm visitors might also spread animal diseases from one farm to another (Wilson *et al.* 2011). If herd vaccinations are not sufficient and documented, these incidents may even lead to a need to dispose of the whole herd (Faust *et al.* 2001). Biosecurity management and building standards help farm managers to improve animal housing conditions to minimize animal and worker health risks (Wilson *et al.* 2011; Faust *et al.* 2001; BS5502 1990).

Studies on natural or areal crisis risks include tools for natural crisis management in particular areas, and strategies for preventing damage to farm assets. Land-use planning is an example of a way to mitigate the flood risk (Posthumus 2009). Furthermore, if the climate or an area becomes more unstable, insurances, food security and logistic planning, evacuation plans and other risk tools will be called for to mitigate the effects of storms, floods, droughts or other areal insecurity (Posthumus 2009; Haen 2008).

## Farm production risk management tools

Production risk management tools are aimed at handling hazards in farm production process tasks and activities (Table 3). The analysed studies included risk tools for crop and livestock production, machinery operations, work organization and climate management tasks. In animal production, strategies to control production risks include animal welfare measurement tools such as disease prevention programmes including a risk assessment questionnaire on production tasks for farmers and animal health tests (Sorge *et al.* 2011). Farmer education has been used in improving disease control (Sorge *et al.* 2011), upgrading process control methods, and complying with authorities or co-producers' regulations (Taylor 2004; Noordhuizen and Welpelo 1996). Animal herd health risks may reduce productivity, but also cause human health threats due to zoonosis risks (Holt *et al.* 2011).

In crop production, risk management tools are based on the handling of biological vegetative processes. Methods to minimize yield risks include the handling of drainage and irrigation systems (Balaghi *et al.* 2010), weed management and plant disease control with crop rotation, selection of the appropriate planting date, plant diversification (Dillon 1999), precision farming techniques for fertilizer and land nutrition management (Lowenberg-DeBoer 1999), traffic control on the field (Chamen *et al.* 2003) and crop yield and revenue insurances (Harwood 1999). The utilization of agricultural biotechnology is challenging. Biotechnology may reduce the use of pesticides and increase crop yields, but has raised conflicting opinions over animal and plant production biosecurity, food safety and possible long-term threats to environmental bioprocesses (Pidgeon *et al.* 2007; von Borell and Sørensen 2004).

Government regulations and quality management systems aim to ensure product quality and in this case food safety. Spreadsheet and checklist tools include standardized questions about operational food production risk factors that indicate, for example, animal disease risks (Boersema *et al.* 2008). Quality system management applications on farms, such as principle component analysis (PCA) (Holt 2011), standards and regulations, good farming principals or hazard analysis critical control points (HACCP), can be used in farm product risk management (Noordhuizen and Frankena 1999). The HACCP method has been criticized as being too complex and expensive to use on farms (Taylor 2004). Potential solutions have been proposed in the form of education and extension. Extension services educate farmers in the standard quality terminology and develop easy-to-use tools to be applied in farm management (Noordhuizen and Welpelo 2011; Taylor 2004).

A major part of farm production work involves dealing with farm machinery. Tools for handling machinery operational risks include maintenance programmes, machinery safety standards and manuals (ASAE 1998), machinery co-operation (Artz *et al.* 2010) and fleet or time management practices (Sørensen

**Table 3:** Studies concerning farm production and product risk management tools

| Focus | Risk management tools | Author |
|---|---|---|
| Animal production | Animal production and welfare management, hygiene controls, HACCP, automatic production programmes, process management, feeding management, workbooks, regulations, animal handling, vaccination, treatment records, biotechnology, farm-to-fork database | Davies 2011; Hovinen and Pyörälä 2011; Sorge et al. 2011; Rostagno 2009; Hurd et al. 2008; Boersema et al. 2008; Ellis-Iversen et al. 2008; Nowak et al. 2007; Sischo et al. 2004; Stott et al. 2003; Aumaitre et al. 2002; van Schaik et al. 2001 |
| Crop production | Crop rotation, soil management, automation, routing, regulations, insurances, biotechnology, precision farming, GPS, diversification, pest and fertilizer balance management | Pidgeon et al. 2007; Chamen et al. 2003; Bouma 2002; Kutzbach 2000; Dillon 1999; Harwood 1999; Lowenberg-DeBoer 1999; Logan et al. 1991 |
| Product quality/ safety | Education, farmer skill development, management systems, documentation, monitoring methods, traceability, insurances, regulations, biotechnology, biosecurity, farm simulator systems, standards and regulations, food chain quality assurance | Noordhuizen and Welpelo 2011; Nuthall 2010; Janssen et al. 2010; Pidgeon et al. 2007; Lund et al. 2005; Taylor 2004; von Borell and Sørensen 2004; Noordhuizen and Frankena 1999 |
| Machinery operations | Automatic systems, fault diagnostic systems, maintenance, standards, regulations, usability and fleet management, scheduling, routing | Petrov and Trendafilov 2011; Hovinen and Pyörälä 2011; Crasssaerts 2010; Sorensen and Bochtis 2010 ; Klee et al. 2003; Kutzbach 2000; ASAE 1998a |
| Work organization | Management skills, co-operation, worker management, regulations, working skills, work scheduling, record keeping, benchmarking, contracting, outsourcing | Nuthall 2010; Artz et al. 2010; Hueth 2009; Lund et al. 2005; Atkinson 2004; de Toro and Hansson 2004; Taylor 2004 |
| Climate management on the farm | Climate risk models, early-warning systems, insurances, risk scenarios, user-focused climate information, risk coordination strategies, greenhouse gas mitigation methods | Balaghi 2010; Haen 2008; Hay 2007; Fuhrer and Booker 2003; Kutzbach 2000 |

and Bochtis 2010). Farmer collaboration, for example in machinery purchase and maintenance, production tasks and workforce sharing, is one efficient way to save costs and time (Artz *et al.* 2010). Machinery collaboration or other farm collaboration requires good communication, co-operative system rules and networking skills (Artz *et al.* 2010; de Toro and Hansson 2004). Outsourcing of farming activities increases the needs of the farm manager for contract management and insurance arrangements (Hueth 2009).

## Human health and safety risk management tools on farms

Human health and safety risk studies have presented tools for preventing risks of injuries and diseases among farmers, their family members, farm workers and visitors (Table 4). The risk of serious injury is relatively high in farm work (Rautiainen *et al.* 2009). The basic management tools for farm health and safety management include administrative provisions or enforcement by law, technical innovations or devices and knowledge management tools such as human education or management skills aiming to affect human safety management and behaviour (Rautiainen *et al.* 2009; Lundqvist and Gustafsson 1992).

Technical innovations such as new ergonomic designs for personal protective equipment (PPE) and machinery safeguards are called for on farms in general (Carpenter *et al.* 2002). Automatic machinery systems may reduce the work strain for the farm manager and enable certain dangerous or routine work tasks to be performed on behalf of the farmer (Klee *et al.* 2003). However, the challenge is that automation is only good as long as it works without faults. Fault diagnostic systems and new types of safety sensors are aimed at increasing the reliability of automation in farm machinery applications (Crassaerts *et al.* 2010; Klee *et al.* 2003).

Safety assessment includes tools for risk identification, safety checks and a broad list of safety risk indicators found from safety statistics and surveys. Farm safety risk checklists can be used in farm adviser or farmer self-management and risk identification tools (Rautiainen *et al.* 2010). Common farm safety risk indicators include farm characteristics (safety risks in farm work in general) (Karttunen and Rautiainen 2011; Rautiainen *et al.* 2009), personal characteristics (stress, alcohol and medication use, weak experience, hearing problems and old age) (Voaklander *et al.* 2009; Rautiainen *et al.* 2009; Spengler *et al.* 2004; Sprince *et al.* 2002), unsafe working behaviour or safety culture (long working hours, lack of personal protective equipment, unsafe machinery or animal handling) (Darragh *et al.* 1998; Layde *et al.* 1995), unsafe facilities (unsafe tools and electrical systems, defective buildings, unsafe building structures, lack of fire safety) (Chapman *et al.* 2009; Shutske *et al.* 1997) and unexpected natural events (natural disasters, floods, wild animals) (Haen 2008). In practice, a common challenge in safety engineering and safety management is that some users choose to minimize safety costs and maximize efficiency by removing safety applications from machinery (Narasimhan *et al.* 2011).

As farming involves numerous health and safety risks, farm managers need new safety solutions such as new ergonomic management and user-friendly best practice management tools applied to farm safety management (Narasimhan *et al.* 2011; Legault and Murphy 2000). In addition, programmes have been provided on farms for farm worker safety education (Langley and Morrow 2010), older and disabled farmers (Cole and Donovan 2008) and youth safety management practices on farms (Park 2003). Participation in farmer collaboration networks, health and safety membership programmes and farm-specific risk management programmes may provide new solutions for farmers (Kinnunen *et al.* 2009). Collaboration with farm stakeholders (e.g. farmers, industry, trade, research, education, authorities) and across research disciplines is a challenge, but also

 

**Table 4:** Studies concerning human health and safety risk management tools on farms

| Focus | Risk management tools | Author |
|---|---|---|
| Administration provisions | Administration regulations and services, social security insurances, information, programmes, standards | Myers 2009, Kinnunen et al. 2009, ASAE 1998b, Chapman et al. 1995 |
| Health and safety equipment | Mechanical protection (shields, seatbelts, covers etc.), PPE, protection clothes, ergonomic development and tools, air conditioning, lighting and visibility development | von Essen et al. 2010; Bunn et al. 2009; Cole and Donovan 2008; Mayton et al. 2007; Hard and Myers 2006; Bentley et al. 2005; Carpenter et al. 2002; Pedersen et al. 1999 |
| Safety education and management skills | Safe working practices, knowledge, livestock handling, standards, self management (e.g. sleep, working pace, alcohol and medication use), safety and health campaigns and training, child safety, stress management, manuals, information, safety culture, electrical safety | Narasimhan et al. 2011; Langley and Morrow 2010; Chapman et al. 2009; Voaklander et al. 2009; Barten et al. 2008; Spengler et al. 2004; Stallones and Beseler 2004; Park et al. 2003; Sprince et al. 2002; Darragh et al. 1998; Driskill and Bouck 1997; Lundqvist and Gustafsson 1992 |
| Safety assessment tools | Safety surveys, statistics, safety materials, checklists, safety certification, health screenings, standards, manuals, risk reports, identification of depression symptoms, safety planning | Karttunen and Rautiainen 2011; Narasimhan et al. 2011; Rautiainen et al. 2010; Barten et al. 2008; Hard and Myers 2006; Suutarinen 2004; Stallones and Beseler 2002; Hard et al. 2002; Petrea 2001 |
| Safety control management | Safety control systems, medication, insurances, information, first aid guides, risk check tools, automation, warning signals, best management practices, grain storage engulfment prevention, machinery maintenance and investments | Crasssaerts 2010; Langley and Morrow 2010; Chapman et al. 2009; Rautiainen et al. 2009; Barten et al. 2008; Angoules et al. 2007; Klee et al. 2003; Kingman et al. 2004; Legault and Murphy 2000; Layde et al. 1995 |
| Safety network | Safety and health services, safety association memberships, health screenings, safety collaboration, worker safety checks, risk information management | Kinnunen et al. 2009; Thurston and Blundell-Gosselin 2004; Reed 2004; Chapman et al. 1995 |

recommend for farm safety reasons (von Essen *et al.* 2009).

## Farm environmental risk management tools

In farm environmental risk tools, the focus is on the prevention of farm environmental impacts and quality losses in the environment (Table 5). Administrative provisions and regulations are common management tools in farm environmental management for authorities, but also provide information and opportunities to farmers concerning environmentally friendly farm management practices. For example, agrobiodiversity is a 'free' environmental commodity that is supported and protected by EU subsidies (Baumgartner and Quaas 2010). However, policy makers should note that some agro-environmental indicators may have a poor performance ability in the environment, which could also be an environmental risk in agriculture (Makowski *et al.* 2010). Criteria and measures for sustainable agriculture are then essential (Eckert *et al.* 2000).

Animal production impact studies have included tools for manure management, preventing manure pathogens from causing human diseases (Kai *et al.* 2008; Goss and Richards 2008). A good example of an eco-tool for controlling environmental risks on animal farms is a

**Table 5:** Studies concerning environmental risk management tools

| Focus | Risk management tools | Author |
|---|---|---|
| Administration provisions | Environmental regulations, sustainable farming standards, subsidies, agroecosystem and biodiversity management, conflict resolution | Pannell 2011; Baumgartner and Quaas 2010; Makowski et al. 2010; Janssen et al. 2010; Atari et al. 2009; Eckert et al. 2000; Wagner 1999 |
| Animal production impacts | Manure and fertilizer management, greenhouse gas management, acidification, pathogen pathway models, environmental impact simulation | Kai et al. 2008; Goss and Richards 2008; Duru et al. 2007; Topp and McGechan 2003 |
| Crop production impacts | Agro-environmental indicators (e.g. ROC, AUC), machinery emission management, land and water emission management, environmental impact assessment (EIA), sustainable land use | Makowski et al. 2010; Cupera and Smerda 2010; Bachinger and Zander 2007; de Vos et al. 2006; Lacroix et al. 2005; Fuhrer and Booker 2003; Zentner et al. 2002; Coale et al. 2002; Bouma 2002 |
| Toxic chemical emissions | Pesticide management, certificate systems, buffer zones, sprayer cleaning and maintenance, information, pollution and chemical exposure management | Popp 2011; Harnly et al. 2009; Reichenberger et al. 2007; Sanchez-Bayo et al. 2002 |
| Environmental management | Waste management programs, GIS, environmental risk calculations, environmental SWOT, agroecological information system (AIS), stewardship programmes, risk scenarios | Río et al. 2011; Janssen et al. 2010; Atari 2008; Goss and Richards 2008; Meinke et al. 2001; Lang et al. 1995; Wossink et al. 1992 |
| Environmental education and skills | Educational programmes, resource analysis team, whole-farm planning, risk pathway models, accounting precautionary measures, information, low-input agriculture business plans | Clancy and Jacobson 2007; Summers et al. 2008; Wagner 1999 |

method involving the addition of sulphuric acid to slurry manure to reduce harmful air emissions and smell problems in the neighbourhood of pig farms. This method is classified as a Best Available Technology (BAT) in Denmark (Kai *et al.* 2008).

Crop production impact management includes simulation tools to analyse nutrient management to control water emissions (eutrophication) (de Vos *et al.* 2006), optimal crop rotation, conservation tillage and soil quality in plant production (Bachinger and Zander 2007; Zentner *et al.* 2002). Farmers could also use climate risk tools to analyse machinery fuel consumption and emissions to the atmosphere in the form of ozone gases (Cupera and Smerda 2010; Fuhrer and Booker 2003). Toxic farm chemical exposures have frequently been linked to pesticides used in crop management on farms. Buffer zones, constructed wetlands and subsurface drains reduce the negative effects of pesticides and potential spraying releases of ecotoxic and genotoxic chemicals on farms (Reichenberger *et al.* 2007). The cleaning of sprayers and hygiene management after spraying and during the spraying period control the risk of pesticide dust exposure in farm houses. For example, storing of work shoes in the home increases the risk of toxic chemical expose. (Harnly *et al.* 2009).

A holistic approach was common in the environmental risk management studies analysed in this review. With the help of computer-aided calculations, researchers, farmers and policy makers can improve data handling in order to control environmental risks, but also improve the integration of various risks. These computer tools include environmental system modelling and simulation models (Janssen *et al.* 2010) and geographic information system (GIS) applications (Rio *et al.* 2011). Areal spread maps are useful for farmers, showing the possible risk areas of farm crop diseases (Wagner 1999).

Farm environmental risks have long-terms areal effects, which make them a difficult problem for the future. Different climate, soil and cultural regions may require site-specific approaches to sustainable risk management (Meinke *et al.* 2001). Risk identification does not solve any problems without practical tools for controlling environmental risks. Environmental SWOT analyses carried out on farms include risk identification, but also identify possible business solutions for farms (Atari *et al.* 2009). Multidisciplinary risk workshops and farm-specific plans have been reported as useful tools in some agro-environmental programmes, but new skills and tools for farm environmental management are required (Summers *et al.* 2008; Clancy and Jacobson 2007).

## Economic risk management tools for farms

The economic risk management tools for farms in this review could be divided into administrative provisions, contracts or insurances to protect against uncertain future events, risk models to help in decision making, economic management control and network management (Table 6). A holistic and general farm view was common in economic risk management tools identified in this study. Often, the economic tools were applicable for both crop and animal farms. A commonly acknowledged financial risk is that farm production may not generate sufficient revenues to cover the costs of production or service farm debts (Franks 2010; Hardaker *et al.* 2004).

A farm owner needs to be aware of and understand policy regulations and institutional boundaries in farming, namely legislation, tax systems and subsidy systems (Jung 2001). Farmers in the EU face subsidy changes as an institutional risk (Flaten *et al.* 2005) or the risk of financial sanctions for breaching the subsidy terms and conditions (Jung 2001) and liquidity problems because of credit risk (Franks 2010). Insurances or subsidies for the main agricultural crisis risks such as animal disease epidemics are important risk management strategies (van Asseldonk *et al.* 2004). Choosing a relevant strategy for a farm is a complicated task. Basic strategy examples and risk management models are already available to assist the farm manager in decision making (Hardaker 2006; Hardaker *et al.* 2004). Farmers need easy-to-use tools, especially for economic risk management and strategic planning.

**Table 6:** Studies concerning economic and financial risk management tools for farmer use

| Focus | Risk management tools | Author |
|---|---|---|
| Administration provisions | Risk management strategies, accounting tools, diversification, off-farm incomes, regulations, subsidies, tax management | Franks 2010; Schaper et al. 2010; Špička et al. 2009; Lacroix et al. 2005; Asseldonk et al. 2004; Flaten et al. 2005; Jung 2001; Wossink et al. 1992 |
| Contracts, insurances | Hedging, contracting, insurances, diversification, spreading sales, risk strategy portfolio, holding reserves, expert simulation system (ESS), public–private partnerships, what-if analyses | Cole and Kirwna 2009; Velandia et al. 2009; Pennings et al. 2008; Berg and Schmitz 2008; Key and MacDonald 2006; Asseldonk et al. 2004; Meuwissen et al. 2001; Helms 1990 |
| Risk modelling | Risk modelling software programs, risk strategy portfolios, utility function techniques, linear programming, multi-risk analysis tools, risk prioritization, risk sharing, diversification | Barnett and Coble 2009; Ogurtsov et al. 2008; Nartrea & Webster 2008; Huirne 2007; Hardaker 2006; Hardaker et al. 2004; Stott et al. 2003; Wossink et al. 1992 |
| Management controls | Risk management systems, indicator selection, vulnerability check, HACCP, resilience planning, complexity handling, choice bracketing, disease controls, cost management, solvency ratio | Kleter and Marvin 2009; Haen 2008; Pennings et al. 2008; da Silva et al. 2008; Lien et al. 2006; Flaten et al. 2005. Meuwissen et al. 2001; Noordhuizen and Frankena 1999 |
| Networking and management skills | Collaboration, education, skill management, mentoring, change management, web tools, strategy map, 7 business principals, choosing indicators, specification techniques, worker management, marketing pools, forward and direct selling | Malcolm 2011; Nuthall 2010; Schaper et al. 2010; Olsen et al. 2009; Pennings et al. 2008; Lund et al. 2005; Parker 2000; Martin and McLeay 1998; Harwood 1999; Beal 1996 |

 

In the case of price risk and volatile product prices in the market, a farmer can enter into a contract with co-producers to fix certain product prices (Velandia *et al.* 2009). The product yield risk can be managed, for example, with suitable farm product insurances (Velandia *et al.* 2009; Jung 2001). Variables affecting the adoption of these risk management tools were proportion of owned acres, off-farm income, education, age, and level of business risks (Velandia *et al.* 2009). Economic risk analysis and modelling could help farmers with decision-making problems and the prioritization of risks (Ogurtsov *et al.* 2008; Hardaker 2006; Hardaker *et al.* 2004). Computer-based practical software programs that aid farms in risk management are available on the market (Nuthall 2010; Hardaker 2006).

Farm production tasks should be managed in the right manner, time and place; otherwise, part or all of the sales income could be lost. Hazard analysis of critical control points (HACCP), used in many quality management systems, should also include economic and financial critical control points and connect these points in a farm quality check (Noordhuizen and Frankena 1999). In addition, farmers should identify and combine current and future business strengths and risks on their farms to create farm-specific business risk plans (da Silva *et al.* 2006). With the help of choice bracketing, farm managers can deal with the complexity of risks and choose suitable risk management tools tailored to their own farm (Pennings *et al.* 2008). New business network tools using the Internet and communication or participation tools require new management skills from the farm manager, and can also be useful in farm risk management (Nuthall 2010; Lund *et al.* 2005).

## 4. Discussion

In this study, we listed and analysed risk management studies to find potential tools applicable in managing farm risks. Risk management tools were divided into five categories: asset, production, human safety, environmental and economic management tools. Altogether, a total of 13,559 articles discussing risk management were identified. Of these, 157 articles were selected for closer analysis in order to identify farm risk management tools. This study identified only a part of the available farm risk studies. However, the focus was not on finding all possible farm risk management tools and studies, but on identifying a comprehensive sample of useful studies and tools.

### Handling of various risks on farms

The findings from the present review highlight that risk management on farms is a complex task and includes many uncertain variables. While farm risk management tools should aim to help in complex decision making, they should avoid simple one-sided solutions, which may cause more problems than expected (Hall 2007; Robinson 1999). The balance is even more difficult to achieve in complex decisions, when various stakeholders have conflicting interests in farms. The simultaneous handling of many objectives or risks increases the complexity and problems in management. However, farmers prefer simple and relevant management tools (Leppälä *et al.* 2012). While single-risk management tools provide the means to handle one risk at a time, tools for multi-risk management enable holistic risk handling, for example in the event of natural hazards (Komendantova *et al.* 2014; Marzocchi *et al.* 2009). According to Komendantova *et al.* (2014), the multi-risk management approach is quite a new type of approach that requires further development and new innovations.

It appears that the holistic risk management approach has been increasingly applied in farm risk management studies during the last two decades. The determination of possible risks is needed in agriculture to help farmers to identify and control the risks on their farms. However, despite the multi-risk management demands in agriculture, comprehensive literature studies listing and analysing farm risk management tools according to the operational research focus of managing multi-risk consequences on farms have been rare. If demands for holistic risk management in agriculture are increasing, we should also have relevant methods and solutions for handling complexity and using holistic risk management tools efficiently on farms. It is known that farmers and other small-scale entrepreneurs have limited time for management duties. A Farm Risk Map has been developed to help farm managers in farm risk identification using a one-page figure and functional risk groups. (Leppälä *et al.* 2012).

### Farm risk management tool case

A summary of the literature review results is presented in Figure 1. The holistic risk management tools that were present in all risk tool categories are included the box at the centre, and individual single-risk tools from each risk category are placed around it. Farm managers can use individual risk management tools and various holistic risk management tools simultaneously on their farms. The risk management focus of the tools is on describing the risk management context in various farm risk management studies. The tools in each section are divided into risk management process stages to define how farmers could identify, control or monitor risks on the farm level. This list of risk management tools can be seen as a preliminary example of a farm risk management tool case, whereby a farmer can choose the appropriate potential tools to use in a particular situation.

The results of the review in Figure 1 demonstrate that risks are managed and analysed in the farm risk literature with different types of tools in different categories. Integration in risk management reflects correlations between risks (CAS 2003). Thus, in general, the holistic risk tools in Figure 1 indicate the potential integration tools that can be used in multi-risk situations to identify, control or monitor risks on farms.

The single-risk fields also have individual risk management features. The handling of these risk features may require detailed risk identification or risk prevention. Economic business management risk tools involve analysing and preventing the loss of money, but could have also effects on other risk fields. Risk management in farm work activities requires different types of risk tools. Asset risk management tools aim to protect the investment value of fixed assets on a farm such as estates, land and machinery in a technical engineering manner. Production risk management tools on farms aim to avoid operational and product quality risks in agricultural production activities (crop and animal production). Safety risk management tools identify health risks from places, resources or production

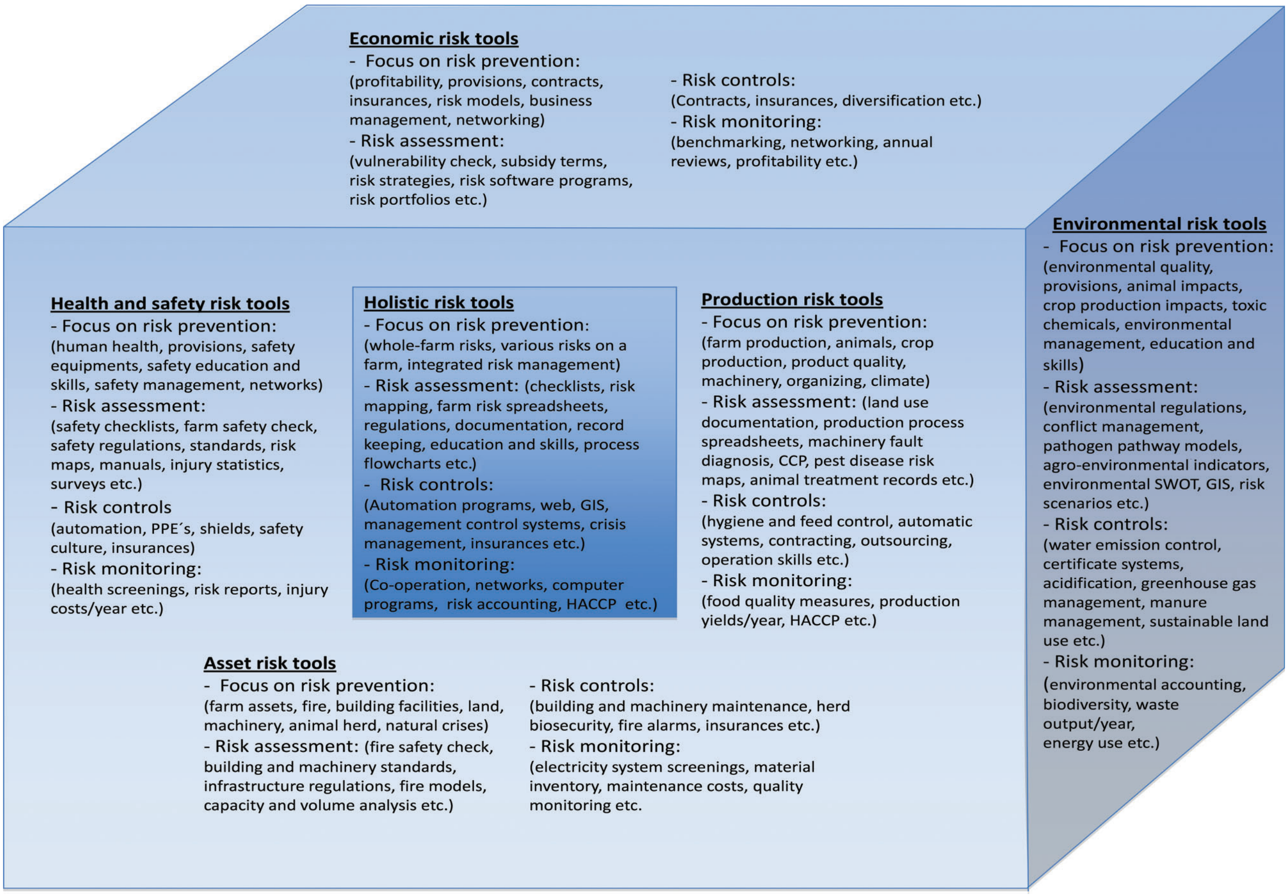


**Figure 1:** Farm risk management tool case for farm managers

activities and control them with specific safety management tools. Environmental risk management tools are focused on preventing farm environmental impacts and quality losses in the environment. The integration of risk management tools requires skills, methods and knowledge from different disciplines. Essentially, an optimal level of system functioning will not be achieved if system goals and activities are not coherent and consistent, for example in grain harvesting and grain dryer activities. In order to integrate farm risk management tools, the links between the risks should be made visible among farm operations and farm production processes. Sophisticated holistic risk management tools are called for in assisting farm managers in the multi-risk situations that they will face in the future.

The recent farm management literature provides well-developed analysis tools, for example, in insurances, product diversification, contract variables, the tax system, assets and investments, profit variability and cost–benefit analysis for farm risk management (Kay *et al.* 2012; Olson 2011; Nuthall 2010). These tools provide a good basis for the risk management process on farms, but should be more efficiently implemented by farmers, and also efficiently distributed for farmer use, including tools for risk management process stages.

## Future challenges

Many farm risk checklists have included important risk indicators based on farm characteristics, the personal characteristics of farmers, an unsafe working culture, unsafe facilities and unexpected events of natural hazards. However, each risk management category and the 'major hazards' should also include tools for handling the whole risk management procedure, including the identification, assessment, control and monitoring of risks (ISO 31000). The identification of risks is only useful if this knowledge is used in prioritizing risks and risk control activities such as problem fixing on farms.

Usability will be an important issue in the future development of holistic risk management. Risk management tools should be usable and suitable for managing and monitoring particular risks. For example, a continuing challenge for farm managers is to consider and coherently integrate safety, production environment and economic management goals in line with the changing production methods and increasing material volumes. In addition, if a beneficial multi-risk analysis tool is complicated for farmers to use in practice, it will not be adopted on farms.

Biotechnology and other novel agricultural production practices could be practicable but challenging for farms to implement without sufficient information and practical control methods. New risk management tools may have conflicting targets and evaluations in farm production. For example, in the use of biotechnology, a problem seems to be in the integration of economic and production benefits and long-term ecological and safety hazards. A shared vision of appropriate risk management tools would support effective risk prevention. The development of criteria and measures for sustainable agriculture is essential. Added to this, new knowledge management skills and education are also needed on farms, especially in managing the various risks, in operating in an organisational network with various stakeholders, in ageing and succession stages on farms, in applying new information-handling techniques, computer-aided applications and in implementing new automatic systems in farm activities. Risk management knowledge may benefit farm capabilities and working abilities by providing the farm manager and farm workers with important information on production processes. Information and its efficient use in practice is a key to corporate risk management and corporate economic development (Mingers and White 2010; COSO 2004).

Extant risk management research has commendably succeeded in devising risk management tools for minimizing and eliminating risks on farms. However, sustainable farming policies, especially in European and Nordic countries, are calling for a more holistic risk approach in farming. The integration of different fields of risk management research and cooperation between different researchers is required in order to reap the benefits of the emerging new holistic approach.

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# Impact of resource ownership and input market access on Bangladeshi paddy growers' efficiency

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**ABSTRACT**

Through a translog stochastic frontier model this study analyzes technical efficiency of Bangladeshi paddy growers and identifies factors explaining farm level inefficiency. A farmer can significantly raise production by increasing quantity of land, total labour and fertilizer in the paddy production. Use of organic manure also significantly contributes in paddy production. Among all the production inputs land has the most dominant impact on production. The estimated mean technical efficiency score of 78% implies that there are substantial scopes to increase paddy production through enhancing farm efficiency. The important efficiency influencing factors are ownership of land and machinery, farm location, access to credit, share of own supplied labour and seed to total requirement and capital constraint. The small farmers are more efficient than the marginal, medium and large farmers. Among different categories of households, higher mean technical efficiency scores are found with the food secured households, households having no earning from outside agriculture, households belonging to lower expenditure group and farmers cultivating paddy only in own land. Finally, the article offers some explanations for these results and suggests some policy options for improving farm efficiency.

**KEYWORDS:** translog stochastic frontier model; technical efficiency; ownership; input market; Bangladesh

## 1. Introduction

Enhanced efficiency enables farmers to make judicious use of different resources and thus contribute to farm production and hence income. This is especially important for a country like Bangladesh which has one of the world's lowest land person ratios. A major challenge for the country's policy makers is to feed her large population with limited resources. Until now the country has some notable success in this regard. During her independence in 1971, the country was struggling to produce enough food for her citizens. Since then though the population has almost doubled, the food production has almost tripled. Now the country has achieved near self-sufficiency at least in rice production (FPMU, 2014).

Until the 1980s, the major source of the country's production growth was the expansion in crop area. But this source dried out due to increasing population pressure and nonfarm demand for farmland. The quantity of agricultural land has been declining over the last three decades of previous century (Husain, Hossain and Janaiah, 2001). The country's rice sector is operating at its land frontier, leaving very little or no scope to meet the growing demand of the increasing population by increasing land supply (Rahman, 2003). Replacing traditional varieties by modern varieties was another important source of production growth. But there remains limited scope to increase adoption of modern rice varieties as the ceiling adoption level was almost reached two decades ago (Bera and Kelly, 1990). Furthermore, productivity in modern rice farming declined whereas the production cost increased and the output price remained almost constant. All these contributed to an 18% fall in real income from rice farming (Rahman, 2003). The most likely policy options in such a situation should be to increase production efficiency. Available literature analysing Bangladeshi rice farmers' efficiency shows considerable scope to increase production through farm efficiency (Wadud and White, 2000; Coelli, Rahman and Thirtle, 2002; Rahman, 2003; Asadullah and Rahman, 2009; Selim, 2010). Although the existing literature gives important insight about farm level efficiency and factors explaining efficiency, several crucial factors require further investigation. Ownership of different farm resources, access to market and tenancy are crucial factors explaining efficiency. In existing literature, efforts are mainly concentrated with land ownership and efficiency. It is generally hypothesized that ownership positively contributes to production by ensuring timely and adequate supply of quality inputs at low cost. But an alternative relationship is possible. The market may supply machinery at affordable cost especially when investment, maintenance and operational costs are high. Some of the farm owned inputs

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(e.g. seeds) might be of lower quality than those available in the market. Hence market access may contribute in farm efficiency, particularly in the case of small and poor farmers who own few of the production inputs.

The literature has witnessed a long debate regarding farm size and efficiency. The debate becomes especially crucial while arguing for land reform and farm restructuring. Perhaps the most prominent hypothesis here is the Schultz's (1964) 'poor-but-efficient' hypothesis. The hypothesis is theoretically and empirically supported in the works of Cornia (1985); Stiglitz (1989); Nerlove (1999); Ruttan (2003) and Abler and Sukhatme (2006); though some researchers challenged this hypothesis (Myrdal, 1968; Shapiro, 1983; Ball and Pounder, 1996; Ray, 2006). In general, larger farms in developed countries are more technically efficient, and/or more allocatively efficient; whereas the findings in developing countries mostly support Schultz's hypothesis (Gorton and Davidova, 2004). The most commonly cited explanation for the inverse relationship between farm size and efficiency is labour market dualism. Compared to the large commercial farms, the small farms have lower opportunity cost of labour. Ultimately the small farms apply own labour in such quantities that the marginal value product of family labour is less than the opportunity cost of labour measured using market wage (Carter and Wiebe, 1990). Efficiency levels between small and large farmers may also vary depending on several other socio-economic characteristics. For instance as the small farmers are generally poor they may face more financial difficulties to manage their required inputs than medium and large farmers, and the small farmers may become comparatively inefficient.

Efficiency may also depend on the household's income sources. Rahman (2003) and Asadullah & Rahman (2009) found situations where households with higher opportunity to engage in non-agricultural activities pay less attention to their rice production activities and hence tend to be less efficient. Alternatively Haggblade *et al.* (1989) and Hazell and Hojjati (1995) found that due to poorly functioning capital markets in Africa, the non-farm earnings are stimulating farm investments and improve agricultural productivity. Off-farm income opportunities are generally higher with richer households who own large farms than the poor households. An efficient farm may not be efficient in all the crops, particularly if the crop does not match its core objective function. Due to commercial motive the large farms are characterized to do more crop diversification and may become less efficient in paddy cultivation. Paddy is generally produced for food security purposes and has less profit potential particularly compared to fruit and vegetables and other cash crops. Alternatively as the marginal and small farms operate at subsistence and semi-subsistence level, they are more likely to be efficient in paddy production compared to the large commercial farms. The relationship between farm efficiency and household's food security is another issue which is not still addressed in literature. Analysing these factors is important as this will open a new dimension for the farmers and policy makers to increase farm production by reducing the effect of the inefficiency variables at the existing resource base and available technology.

This paper is organized in four sections. This introductory section is followed by the methodology section where along with the survey procedure, the conceptual model and specification of the stochastic frontier translog production function are presented. The results and discussion are presented in the third section. This is followed by conclusions and policy implications derived from the empirical results.

## 2. Methodology

### Survey and data

The study explores the data collected by Anik (2012). Anik (2012) collected data from 210 Bangladeshi paddy growers through a multistage sampling technique. The major focus of the survey was to estimate impact of farm level corruption on paddy growers' production and their food security. The survey covered six villages belonging to six different districts in the country. At the first stage all the 64 districts were ranked according to the quantity of rice produced during 2008-09 and from the list the above median rice producing districts were selected. These districts were then ranked based on the proportion of households experienced corruption in the service sectors.[3] The top and bottom three districts from this ranking were selected. Then, from each district, the highest rice producing sub district and from each sub district the village producing most were selected. The villages selected are namely: Enayetpur (Naogaon district), South Sordubi (Lalmonirhat district), Mosjidpara (Nilphamary district), Mukimpur (Sirajgong district), Rajapara (Comilla district), and Char Belabo (Narsingdi district). In the final stage, 35 paddy growing farm households from each village were randomly selected using the lists of farmers available with the local agricultural extension office.

### Conceptual model and estimation procedure

The impact of different inefficiency factors on farm production is estimated through a stochastic frontier model. Among different approaches of efficiency the stochastic frontier approach is the most prominent due to its theoretical reasonability and empirical competitiveness (Russell and Young, 1983; Battese, 1992; Battese and Coelli, 1995; Sharif and Dar, 1996a; Sharif and Dar, 1996b; Sharma and Leung 1999; Wadud and White, 2000; Tzouvelekas, Pantzios and Fotopoulos, 2001). The specific model for the $i^{th}$ farm can be defined as:

$$ln\ y_i = \alpha_0 + \sum_{j=1}^{5} \alpha_j\ lnx_{ij} + \frac{1}{2}\sum_{j=1}^{5} \beta_{jj}\left(lnx_{ji}\right)^2 + \sum_{j=1}^{5}\sum_{k=1}^{5} \beta_{jk}\ lnx_{ij_k}\ lnx_{ijk} + \tau_{OM} OM + \tau_{Pest} Pest + v_i - u_i \quad (1)$$

and,

$$u_i = \delta_0 + \sum_{d=1}^{4} z_{ij} + \omega_i \quad (2)$$

[3] The proportion was estimated from the Transparency International Bangladesh's (TIB) database of 'National Household Survey 2007 on Corruption in Bangladesh'. The survey followed a three stage stratified cluster sampling method and interviewed 5,000 households (60% from rural areas and the rest from urban areas) about their corruption experiences in different service sectors.

 

where the dependent variable $y_i$ is the quantity of paddy production in the *Boro*[4] season (kg. per farm); $x_i$ are the different production inputs; OM and Pest are the dummy variables of using organic manure and pesticides, respectively; $v_i$ is the two sided symmetric, normally distributed error term; $u_i$ is a non-negative random variable, associated with the technical inefficiency in paddy production those presented by $z_i$. All the variables used in the translog production function are measured at farm level. The list of the input variables include: cost of seed (BDT)[5], quantity of chemical fertilizers (kg.), quantity of total labour (includes both family and hired labour and measured in man-days) and quantity of land under paddy production (hectare). The input variables are mean corrected $(x_{ik} - \overline{x_k})$ prior to estimation. This is because the coefficients of the interaction variables multiplied by the same variable at the sample mean will be zero and the coefficients on the first order term can read directly as elasticity.

The inefficiency variables representing farm level ownership are: share of own land to total land, share of family labour to total labour, share of own seed to total seed, ownership dummy for major agricultural machineries, dummy for capital constrained farmer, dummy for marginal farmers, dummy for small farmers. The two dummy variables used to represent farmer's market access to credit (dummy for access to formal credit facilities) and input market (dummy for input restricted farmers). Two other variables used in the inefficiency model are the dummy for improved peri-urban infrastructure and share of off farm income to household's total annual income. Details description of the variables used in the inefficiency analysis appear in Table 2.

Technical efficiency ($TE_i$) of the $i^{th}$ farm is the ratio of the observed output for the farm, relative to the potential output defined by the frontier function, where the input vector $x_i$ is given. Given the specifications of the stochastic frontier model, the technical efficiency of the $i$th farm, is equal to:

$$TE_i = \frac{y_i}{\exp(x_i\beta)} = \frac{\exp(x_i\beta - u_i)}{\exp(x_i\beta)} = \exp(-u_i) \qquad (3)$$

The technical efficiency of a farm lies between zero and one and is inversely related to the inefficiency effect. The maximum likelihood estimate (MLE) method is used to estimate the unknown parameters. The stochastic frontier and the inefficiency effects functions are estimated simultaneously. The likelihood function is expressed in terms of the variance parameters, $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 + \sigma$ (Battese and Coelli, 1995).

## 3. Results

### Descriptive statistics of the variables used in the translog production function

The summary statistics of the variables used in the translog production function are presented in Table 1. The sampled farmers were classified into three categories following the classification of Department of Agricultural Extension (DAE). The groups are: marginal (less than 0.99 acre of land), small (1 to 2.49 acre of land), and medium and large (more than 2.50 acre of land). On an average a farm produces 4079.6 kg of paddy in 0.6 hectare of land using 77.3 man days of labour and 237.9 kg of different chemical fertilizers. The cost of seed incurred with this amount of production is 1177.2 BDT. Nearly one out of every four paddy growers applied organic manure. This practice is mostly common among the farmers who have cows at their backyards. Among the sampled farmers, 82.4% uses pesticides.

The small farmers cultivated paddy in more land than the other categories (marginal, medium and large farmers) (Table 1). Compared to other categories, the medium and large farms can be assumed to practice more crop diversification. They are likely to cultivate paddy only to meet their family requirement. As *Boro* is grown in winter season, which is most suitable for growing vegetables in Bangladesh, the medium and large farmers may find better use of their land with different high value added vegetables. Alternatively ensuring food security through staples might be the major objective for the small and marginal farmers. After growing paddy these farmers may have little land available to produce in sufficient volume for the market.

### Descriptive statistics of the variables used in the inefficiency effect model

The largest group in term of the proportion of farmers belonging is the group of marginal farmers (40%), followed by the small (37%) and medium and large (23%) farmer's groups. The farmers cultivated paddy mostly on their own land. Rented land is around one fifth (21%) of the total paddy land. Farmers' family labour fulfils 40% of total labour requirement. Farmers mostly rely on market for seed. The private traders are the major suppliers in the seed market. Seed from farmer's own source meet only 9% of the total seed requirement. About 6.42% of the sampled farmers own major agricultural machinery. From formal sources 22.46% farmers took agricultural credit. Around one out of every ten respondents was capital constrained, i.e. these farmers failed to manage enough capital to meet expenses related to paddy production. Due to poor functioning of the seed and fertilizer market, 5.35% of the farmers could not collect their required quantity of inputs from the market even though they had enough money. Nearly two out of every three farms were living in rural areas. Off farm income contributed nearly 33% of household's total annual income (Table 2).

### Parameter estimates of the stochastic production frontier

The MLE estimates of the translog stochastic production frontier model are presented in upper part of Table 3. The signs associated with all the non-cross production inputs are positive, as expected. Land, labour and fertilizer have significant effect on production. Both the dummy variables used in the model have positive coefficients, but the impact is significant only for organic manure.

The lower section of the table present estimates of different test statistics related to the model specification.

[4] There are three specific rice growing seasons in Bangladesh: *Aus* (mid-March to August), *Aman* (end June to early January) and *Boro* (mid-November to June). *Boro* is the major season in the country in terms of area and production.

[5] In the *Boro* season many of the farmers use different modern seed varieties, which are generally of high price than the traditional and local varieties. To capture the quality difference between modern and traditional varieties, cost is used instead of quantity.

**Table 1:** Summary statistics of the variables used in the translog production function by different categories of farmers (per farm basis)

| Variables | Marginal farmers | Small farmers | Medium and large farmers | All farmers |
|---|---|---|---|---|
| Total paddy production (kg.) | 3495.6 | 4849.7 | 3862.6 | 4079.6 |
| Cost of seed (BDT[1]) | 104.7 | 1317.5 | 1190.0 | 1177.2 |
| Quantity of fertilizer (kg.) | 194.0 | 274.2 | 256.4 | 237.9 |
| Quantity of total labour (man-days) | 68.6 | 88.7 | 74.4 | 77.3 |
| Cost of irrigation (BDT) | 4884.0 | 6532.9 | 5236.6 | 5573.5 |
| Quantity of land under paddy production (hectare) | 0.51 | 0.89 | 0.58 | 0.67 |
| % of farmers using organic manure | 20.0 | 21.7 | 34.9 | 24.1 |
| % of farmers using pesticides | 80.0 | 81.2 | 88.4 | 82.4 |

[1] BDT is local Bangladeshi currency known as Bangladeshi Taka. One euro is approximately 85 BDT (http://www.google.co.uk/finance/converter Accessed April 20th 2015)

The estimated value of $\gamma$ is almost near to 1 and significantly different from zero. Consequently, this argues for presence of high level of inefficiency in the production process. Other related hypothesis tests conducted argue for the translog stochastic production frontier model to represent paddy production structure in Bangladesh. The generalized likelihood ratio (LR) test ($H_0 : \beta_{jk} = 0$, for all $j$ and $k$) confirmed that the translog production function was a better choice over the Cobb–Douglas functional form. The rejected null hypothesis of no technical inefficiency effect in paddy production implies that significant technical inefficiency effects exist in paddy production. The p-value of the hypothesis of no inefficiency present in the model indicates that significant level of inefficiency is present in the model.

Furthermore, following Sauer *et al.* (2006) two different regularity conditions were checked. These are: (i) monotonicity, i.e. positive marginal products, with respect to all inputs ($\partial_y / \partial x_i > 0$) and thus non negative production elasticities; and (ii) diminishing marginal productivity ($\partial^2 y / \partial x^2 < 0$) with respect to all inputs (i.e. the marginal products, apart from being positive should be decreasing in inputs). Both these conditions were fulfilled for all the input variables used in the production function.

Among all the inputs used in paddy production, land has the most dominant effect on production. The estimated output elasticity for land is 0.629, implying that a 1% increase in land area will result in 0.629% increase in paddy production (Table 3). Relatively higher output elasticity of land compared to other inputs is in line with earlier studies in Bangladesh (Wadud and White, 2000; Rahman, 2003; Asadullah and Rahman, 2009; Selim, 2010) and also in the Asian context (Lau and Yotopulos, 1971; Bardhan, 1973; Ohkawa, 1972; Cornia, 1985; Battese and Broca, 1997). The sum of mean output elasticities for all the inputs are almost unitary.

## Determinants of technical efficiency

Results of the technical inefficiency effect models are presented in the lower section of Table 3. Farmer's own land share has a negative significant impact on farm inefficiency. The negative sign here implies that with increasing own land share farmers become efficient. This is in line with the findings of Coelli, Rahman and Thirtle (2003) and Rahman (2003). Both the studies observed tenants to operate at relatively lower level of efficiency than the owner operators. According to Rahman (2003) the reason might be due to relatively poor quality of land that is generally rented to tenants.

The estimated inverse relationship between family labour share and farm inefficiency indicates that farms with higher share of family labour to total labour are more efficient. Compared to hired labour, family labour

**Table 2:** Summary statistics of the variables used in the inefficiency model

| Variables | Description | Mean |
|---|---|---|
| Own land share | Share of own land to total land | 0.79 |
| Family labour share | Share of family labour to total labour | 0.40 |
| Own seed share | Share of own seed to total seed | 0.09 |
| Ownership of major machinery | Dummy of ownership of major agricultural machineries used for tillage, irrigation and threshing (1 for owners; 0 otherwise). | 0.64 |
| Credit | Dummy for agricultural credit recipient farmers from formal sources (1 for credit recipients, 0 otherwise) | 0.23 |
| Capital constrained farmers | Dummy of capital constrained farmer (1 = Capital constrained, 0 = Not constrained). Capital constrained farmers are those who failed to purchase their required quantity of inputs (e.g. seed/seedlings, fertilizer and pesticides) as they did not have sufficient capital. | 0.10 |
| Input restricted farmers | Dummy of input restricted farmer (1 = Input restricted, 0 = Not restricted). Input restricted farmers are those who were not capital constrained but failed to collect their required quantity of input (i.e. seed/seedlings, fertilizer and pesticides) as the inputs were not available in the market. | 0.54 |
| Infrastructure | Dummy for improved infrastructure (1 = Improved peri-urban infrastructure, 0 = Less developed rural infrastructure) | 0.37 |
| Dummy for marginal farmers | 1 for the marginal farmers, 0 otherwise | 0.40 |
| Dummy for small farmers | 1 for the small farmers, 0 otherwise | 0.37 |
| Off farm income share | Share of off farm income to household's total annual income | 0.33 |

**Table 3:** Maximum likelihood estimates of stochastic translog production frontier for the sample farmers

| Variables | Coefficient | SE |
|---|---|---|
| *Production function* | | |
| Seed | 0.029 | 0.026 |
| Fertilizer | 0.164*** | 0.034 |
| Labour | 0.189*** | 0.031 |
| Land | 0.629*** | 0.052 |
| Irrigation | 0.011 | 0.026 |
| 0.5 X Seed X Seed | 0.012 | 0.041 |
| Seed X Fertilizer | – 0.040 | 0.042 |
| Seed X Labour | 0.058 | 0.076 |
| Seed X Land | 0.036 | 0.103 |
| Seed X Irrigation | – 0.085* | 0.047 |
| 0.5 X Fertilizer X Fertilizer | – 0.066 | 0.122 |
| Fertilizer X Labour | 0.023 | 0.148 |
| Fertilizer X Land | – 0.023 | 0.172 |
| Fertilizer X Irrigation | 0.101 | 0.082 |
| 0.5 X Labor X Labor | – 0.475 | 0.320 |
| Labor X Land | 0.359 | 0.265 |
| Labor X Irrigation | 0.079 | 0.111 |
| 0.5 X Land X Land | – 0.541*** | 0.178 |
| Land X Irrigation | 0.191** | 0.105 |
| 0.5 X Irrigation X Irrigation | – 0.311 | 0.085 |
| Pesticides | 0.024 | 0.019 |
| Organic manure | 0.088*** | 0.020 |
| Constant | 8.287*** | 0.022 |
| *Technical inefficiency predictors* | | |
| Own land share | – 0.085** | 0.044 |
| Family labour share | – 0.237*** | 0.087 |
| Own seed share | 0.100** | 0.049 |
| Ownership of major machinery | 0.237*** | 0.042 |
| Credit | – 0.119** | 0.064 |
| Capital constrained farmers | 0.103*** | 0.048 |
| Input restricted farmers | 0.076 | 0.058 |
| Infrastructure | 0.125*** | 0.033 |
| Dummy for marginal farmers | – 0.056 | 0.035 |
| Dummy for small farmers | – 0.085*** | 0.037 |
| Off-farm income share | 0.009 | 0.024 |
| Constant | 0.318*** | 0.076 |
| *Variance parameters* | | |
| $\sigma^2 = \sigma_u^2 + \sigma_v^2$ | 0.0218*** | 0.001 |
| $\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$ | 0.99998*** | 0.00001 |
| *Hypotheses tests (p-value of the null hypothesis are reported)* | | |
| Functional form test: Cobb Douglas versus translog ($H_0 : \beta_{jk} = 0$, for all $j$ and $k$) | 0.000 | |
| No inefficiency effect ($H_0 = \delta_0 = \delta_1 = \ldots = \delta_{11}$) | 0.000 | |
| No inefficiency present in the model ($H_0 : \mu = \gamma = 0$)[a] | 0.000 | |
| log likelihood function | 141.85 | |
| Total number of observations | 187 | |

Notes: All the input variables were mean-differenced prior to estimation and therefore the coefficients on the first order term can be read directly as elasticities at the sample mean. *, **, and *** indicate significant at 10%, 5% and 1% levels, respectively.
[a] Since the test involves testing of $\gamma$ parameter, it has a mixed $\chi^2$ distribution. The value of $\chi^2$ is taken from Kodde and Palm (1986).

work more sincerely and laboriously and they are better manager of the farm resources. Ultimately the marginal physical productivity of family labour is higher than that of hired labour. Furthermore, farms able to use more family labour can loosen their burden on budget. All these may contribute to higher efficiency level.

The owner operators of agricultural machinery are more efficient than the tenant operators. The cost of machinery is higher for the tenants than the owners. The owners bear only operating and maintenance cost, whereas along with these costs the tenants pay some additional charges for hiring. Furthermore, owners can use machineries whenever they need, whereas the tenants may not always get machinery at time of their need.

Unlike the variables indicating ownership of land, machinery and labour, efficiency is lower for the farmers with higher own seed share. Quality degradation of the seed preserved in farmer's own storage facilities might be responsible for lower efficiency level.

Inability to manage enough capital for farming makes capital constrained farmers less efficient. This is evident from the positive relationship between inefficiency and dummy variable representing farmer's capital constrained situation. As a farmer who is not capital constrained operates with relatively higher level of input bundle than his counterpart who is capital constrained, the former is more likely to make proper adjustment of his input bundles and hence achieve higher efficiency level.

The estimated negative and significant relationship between inefficiency and credit means farmers with access to formal credit facilities are more efficient. Access to credit facilities may help even the capital constrained farmers to operate nearer to their optimal input bundles and operate at higher level of efficiency.

The positive sign for the peri-urban infrastructure coefficient implies that rural paddy farms are more efficient than the peri-urban farms. This relationship contradicts with the existing literature. Ahmed and Hossain (1990) identified poor rural infrastructure as one of the major obstacles to agricultural development in Bangladesh. Improved infrastructure ensures better access to input and output markets by reducing cost and time. Ali and Flinn (1989), Coelli, Rahman and Thirtle (2002) and (Rahman, 2003) also found farmers in remote villages are less efficient. But due to better communication and infrastructure off farm employment opportunities are relatively more in peri-urban areas compared to rural areas. Hence, the rural farmers may devote more effort in farming and ultimately operate at higher efficiency level compared to their counterparts who are in peri-urban areas. Furthermore, differences in number of dealers and distance from the input market between peri-urban and rural areas are not substantial. Moreover, none of the sampled rural areas have typical remote settings, e.g. no access through road, non-availability of mechanized or semi mechanized transportation vehicle, *etc.* Hence the differences in cost, effort and time of marketing between peri-urban and rural farmers may not be substantially high.

The negative sign associated with the dummy for small farmers mean that the small farmers operate with higher level of efficiency compared to the marginal, medium and large farmers. The relationship here is in line with the Schultz's (1964) hypothesis. Two possible explanations can be offered here. Firstly, in *Boro* season the competing crops with paddy in the season are wheat and different high value vegetables. As the small farmers mostly operate at the subsistence or semi-subsistence level, meeting household's calorie requirement through staple production is the top priority for these farmers. After producing paddy the quantity of land remaining available for the small farmers may not be sufficient for commercial production of different high value crops. Consequently a small farmer tries to maximizing paddy production and earnings through sell of surplus paddy. Ultimately they attain higher level of efficiency in paddy production. Alternatively, the medium and large farmers have more commercial vision. They produce paddy only to fulfil family requirement and maximize farming income through production of different high value crops. For limited access to different production inputs, compared to the small farmers the marginal farmers operate far below their optimal input bundle level and become less efficient. Secondly, the small farmers earn nearly one-fourth of their total household earnings from different non-agricultural sources, whereas it contributes more than one-third of other farmer's total annual income. Relatively more contribution of farming to total income may work as an incentive for the small farmers to be more efficient in paddy production.

The dummy of input restricted farmer has a negative, but insignificant effect on farm efficiency (Table 3). The relationship is insignificant as only 5.35% of the farmers are input restricted (Table 2). But the relationship here demands some attention. Market failure may restrict farmers' access to their required quantity of inputs, even if they can afford the cost. Farmers who are input restricted may operate at relatively lower level of input bundle than their optimal input bundle compared to their counterparts who are not input restricted. In Bangladesh unavailability of inputs is not always due to supply demand disequilibrium. Insufficient monitoring and supervision from the part of government often allows the dealers to create artificial crisis through hoarding (Anik, 2012).

## Technical efficiency in rice production

The summary statistics of technical efficiency scores for the rice farmers are presented in Table 4. The mean technical efficiency for the sample farmers is 78% and this is almost similar to earlier studies conducted with the Bangladeshi rice farmers (Wadud and White, 2000, Rahman, 2003; Asadullah and Rahman, 2009; Selim, 2010). The estimated mean efficiency indicates that a substantial 28% [(100-78)/78] of the rice production is lost due to technical inefficiency alone and a farm can increase production by 28% by improving its technical efficiency. Farmers exhibit wide range of variation in technical efficiency. Farmers' efficiency ranges from 48% to 99%. Wide variation in efficiency level is also observed in previous studies on rice production in Bangladesh (Wadud and White, 2000; Coelli, Rahman and Thirtle, 2002; Rahman, 2003; Rahman and Rahman, 2008).

Table 5 presents distribution of technical efficiency scores by different farm and household level characteristics. Mean efficiency score for the households with off-farm earnings is significantly higher compared to the score of the households having no income from outside agriculture. In the inefficiency effect model the variable off-farm income share do not have significant affect, though it is positively associated with inefficiency.

Households were divided into five equal quintiles based on their annual expenditure. The bottom two quintiles have higher mean efficiency scores than the top quintiles. Efficiency score declines while moving upward from the 2nd quintile. The difference in mean technical efficiency scores among the groups is significant. The explanation for this pattern is similar to those offered in case of negative association between technical inefficiency and the dummy for small farmers, i.e. farmer's crop diversification practices and contribution of different income sources. The households belonging to the top expenditure quintiles are likely to be the medium and large farmers practicing relatively higher level of crop diversification than the bottom quintiles. The top

**Table 4:** Technical efficiency in rice production

| Efficiency levels | Proportion of farmers |
|---|---|
| Up to 70% | 36.02 |
| 70-80% | 20.97 |
| 80-90% | 19.35 |
| 90% and above | 23.66 |
| *Efficiency scores* | |
| Mean | 0.78 |
| SD | 0.13 |
| Min | 0.48 |
| Max | 0.99 |

 

**Table 5:** Distribution of technical efficiency scores by different farm characteristics

| Farm characteristics | Mean efficiency score | P value of mean difference |
|---|---|---|
| Off farm income | | |
| Households with off farm income<br>Households with no off farm income | 0.76<br>0.82 | 0.004 |
| Expenditure group[1] | | |
| 1st quintile<br>2nd quintile<br>3rd quintile<br>4th quintile<br>Top quintile | 0.84<br>0.86<br>0.80<br>0.72<br>0.70 | 0.000 |
| Food security[2] | | |
| Secured<br>In-secured | 0.69<br>0.82 | 0.003 |
| Tenancy | | |
| Tenant<br>Owner-operator cum tenant<br>Owner operator | 0.72<br>0.77<br>0.79 | 0.066 |

[1] During the survey the households were asked about their consumption of different food items in last seven days. Food quantities consumed at the household level were converted to calories using the locally available food composition table (BIRDEM 2013). The variable was converted into adult equivalent (AE) ratio.
[2] A household with calorie consumption above 2122 kcal/day/AE was considered to be food secure.

expenditure quintile earned half of their income from non-farm sources. Contribution of off-farm income sources reduces as moving from top quintile to bottom quintile. Off farm income contributes less than one fourth of total annual income for the bottom three quintiles. As low expenditure quintile groups have few off farm employment opportunities they devote their full effort in farming and ultimately operate at upper level of efficiency.

The food secured households have significantly higher technical efficiency scores than the in-secured households. It is quite impossible for a food in-secured household to operate somewhere near their optimal input bundle, whereas the distance between optimal and actual input bundle is relatively lower for the food secured households. In extreme cases a member of a food in-secured household may not be physically capable to work efficient even provided with optimal input bundle.

The sample farmers were divided into three categories based on ownership of cultivated land. The groups are: tenant (farmers cultivating paddy only in rented in land), owner-operator cum tenant (farmers cultivating paddy in both own and rented in land) and owner-operator (farmers cultivating paddy only in own land). Among the three groups the group of owner-operators is the most efficient. The group is followed by the owner-operator cum tenant. The tenants are the most inefficient. The tenants are mostly the marginal farmers who cultivated paddy in only rented in land. These farmers own some farm land but the land are not suitable to cultivate paddy. The owner operators are mostly large and medium farmers who have sufficient quantity of land to meet their family's requirement of paddy. Only few farmers in the group (nearly 6% of the owner-operators) are marginal and small farmers and may have failed to access the land market due to financial constraints. They belong to the bottom two expenditure quintiles. The mean technical efficiency for the owner-operators who are marginal and small farmers is 9% lower than the group's mean score.

## 4. Conclusions and policy implications

Through a stochastic frontier model the present study analyzes technical efficiency of the Bangladeshi paddy growers in the *Boro* season. The estimated mean technical efficiency for the farmers is 78% and this indicates that there remains considerable scope to increase production by improving farm efficiency. The farmers exhibit wide range of variation in technical efficiency scores.

By increasing the quantity of fertilizer, labour and land, farmers can significantly increase their paddy production. Application of organic manure will also significantly increase paddy production. Among all the production inputs land has highest effect on production.

The farm specific variables used to explain farm inefficiency show that the small farmers are most efficient compared to the other categories of farmers. Efficiency level is higher with the owner-operators of land and agricultural machineries. Farm efficiency increases with increasing family labour share to total labour. Farmers collecting seed from the market are efficient than the farmers who use own seed. Farmers become less efficient when they are in capital constrained situations, i.e. they cannot manage their required quantity of input as they do not have enough capital. Access to formal credit facilities contributes in farm efficiency. Rural farms are more efficient than the peri-urban ones.

These econometric results offer some policy interventions. Farm inefficiency can be reduced significantly by ensuring farm level ownership of land and machinery. For the earlier mentioned input major reform initiatives are needed. The issue of absentee ownership of agricultural land should be addressed. Transfer of agricultural land to non-agricultural purposes should be discouraged by taxation. For fertile land government may plan for restricting by law. Distribution of government-owned land is another issue to address. Here, it is noteworthy to mention that since independence no government in the country has initiated the land reform programme. For ownership of agricultural machinery government may consider reducing import tax. Simultaneously initiatives should be taken to encourage innovation and production of different agricultural machineries at the local level. For this, agricultural research institutions should be encouraged through incentives and especial budgetary allocation. The financial institutes may provide medium and long term credit to the farmers for land and machinery. Short term credit might help a farmer to overcome capital constrained situation and purchase their required variable inputs. Strong monitoring is required to control misallocation of agricultural credit at the farm level and increase recovery rate.

But since all the farms cannot be ensured with ownership, an effective approach may be ways of improving service provisions, especially mechanization services. Service provisions are especially crucial for the food insecured and tenant farms as they have significantly lower level of efficiency. A detailed study at farm level on service availability and constraints is much needed. Strong monitoring is also needed in the input market to make sure that the dealers do not create any artificial crisis. Government may think for more competitive input market by allowing more market actors and dealers. Competition among sellers can alone tackle several marketing problems including corruption.

These interventions may make paddy farming attractive for the farmers. Even the peri-urban farmers and households with higher off-farm income may regain their interest in paddy farming. Inverse relationships between farm efficiency and expenditure and off-farm income are two important issues for further investigation.

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REFEREED ARTICLE

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# Different methods to forecast milk delivery to dairy: a comparison for forecasting

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**ABSTRACT**

To estimate future sales and to ensure customer deliverability, the dairy industry needs reliable forecasts for milk delivery from the farmers. In light of the shortage of milk in Norway in fall 2011, the dairy industry recognized that it needed better tools for forecasting milk delivery. Therefore I developed models which can help the industry avoiding similar situations in the future. I analysed the monthly milk deliveries to Norwegian dairy companies from January 2001 to December 2010 and fitted two time series models. I tested a multiplicative Holt Winters' exponential smoothing model (HW) and a multiplicative seasonal autoregressive integrated moving average model (SARIMA) for forecasting monthly milk delivery. The two time series models were compared with a model based on expert opinions, and a model based on historic monthly quantities. The test showed that a combination of the Expert model and the two time series models give reliable forecasts for a period of up to two years.

**KEYWORDS:** dairy; milk production; time series; Holt Winters' exponential method; SARIMA

## 1. Introduction

Organizations rely extensively on forecasts in making strategic decisions, and forecasting ability appears to be a distinctive organizational capability (Makadok and Walker, 2000). Thus forecast accuracy is essential to a firms success and performance (Barney, 1986; Makadok and Walker, 2000). Businesses often make decisions under acute shortages of information. Given these constraints, managers estimate future sales volume to make budgets, predict operating expenses, cash flows, pricing, advertising outlays, etc. Actual turnover and profitability depend on the accuracy of these decisions. Norway made the news headlines across the world in fall 2011 because of the so-called butter crisis. The inland milk production did not meet the total demand for dairy products, particularly for milk fat. One reason for this was the low-carbohydrate diets which became popular in 2011. This increased the demand for milk fat at a moment of time where the inland milk production was declining due to a bad roughage harvest. In practice the dairy companies had too little milk to produce enough butter before Christmas 2011, and therefore Norway had to import 1922 tons of butter in December 2011 and January 2012. For decades Norway had had a supply surplus as compared to inland demand. Therefore the shortage of milk fat came as a total surprise to the whole dairy industry. To increase inland production farmers were allowed to produce over quota in the quota year 2011/ 2012. The lesson learned from the butter crisis was that the dairy industry needed better tools for forecasting milk production, and this motivated the study. The present study aimed at improving the prediction of milk supply from Norwegian dairy farmers to the only two Norwegian dairy companies. In 2013 the 10,700 Norwegian dairy farmers produced 1,525 million litres of milk (TINE, 2013). The dairy companies have accurate records only of historical data of monthly milk supply from individual members over the years. These data represent a good starting point for developing time series models. This paper tests different time series models for forecasting monthly milk delivery to dairy and compare them with the traditional forecasting model, which I denote the Expert model. The paper proceeds as follows. First I briefly discuss different ways of forecasting milk delivery before I present historic data on monthly milk delivery and the different models I will test. In the result section I show how the different forecasting models perform. Finally I discuss the results and conclude.

### Forecasting milk delivery

Forecasting can be done in different ways. Qualitative forecasting techniques rely on experience that has not been captured in the form of hard data, and can e.g. rest on expert opinions. Quantitative techniques can be divided in causal models and time series models. Causal models are based on finding a cause and effect relationship, e.g. the milk yield per cow and the total milk

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delivery. It is important that the cause variable is a leading indicator, i.e. that it can be measured in advance of the production it is assumed to cause. The Expert model represents a mixture of qualitative and quantitative techniques, and I return to a more detailed description below. Time series models attempt to identify patterns that have been present in the past and assume they will continue in the future. A time series is a set of observations measured at successive points in time or over successive periods. We typically search for three major components in past milk production: An average, a trend and seasonal fluctuations. A time series that has no trend is called stationary; if a trend is present the time series is non-stationary. The seasonal component refers to a cyclical pattern that repeats over time. Forecasting methods based on time series proceed in three separate steps as follows:

1. Use past data (a training set) to estimate the parameters of the model.
2. Use estimated parameters to determine how well the time series model would have done in predicting past milk production.
3. Use estimated parameters to forecast production in the future.

Time series models are widely applied to forecast milk production and autoregressive integrated moving average (ARIMA) models (Box and Jenkins, 1970) are perhaps the most common. Sataya *et al.* (2007) tested several time-series models and concluded that ARIMA-models gave the best forecasts for milk production in India. Sankar and Prabakaran (2012) found that the most appropriate model for forecasting milk production in Tamilnadu in India was an ARIMA (1,1,0) model. A limitation with ARIMA models is that they do not take seasonal fluctuations into account. In many countries milk production is characterized by seasonal fluctuations within years, and relatively stable patterns between years (See e.g. IFCN, 2012). In such time series it is fair to assume constant variance of the disturbance term. Therefore seasonal autoregressive integrated moving average (SARIMA) models (Shumway and Stoffer, 2010) are well suited for time series of milk production. SARIMA models, which are similar to ARIMA models except that they take seasonal effects into account, are known as flexible tools for the analysis of time series. There are few applications of SARIMA models in dairy farming. An exception is Akter and Rahman (2010). They used a dataset from England and compared a SARIMA model with a Holt Winters' exponential smoothing model (Holt, 1959; Winters, 1960; Chatfield and Yar, 1988) together with several less advanced smoothing models. According to their findings the Holt-Winters' exponential smoothing technique, which I will denote the HW model, and the SARIMA model were the most accurate, and generated forecasts with errors less than 3 percent. They also concluded that forecasts for periods of more than a year could be used with caution. A weakness of their study was that they only had data for eight years, which gave a small training set to fit their models. Such a short period leads to relatively high errors and makes it difficult to generalize, as commented on by Akter and Rahman (2010). I support their conclusion that the question of how long we can forecast beyond the sampling period can be more precisely investigated when a longer data series is available. This study builds on the study of Akter and Rahman (2010) by applying the HW model and the SARIMA model as the preferred time series model candidates. However, I complement their study in two ways. First I follow their recommendations and apply a longer time series (13 years), which makes the findings more robust. Second, I compare the HW model and the SARIMA model with a model based on expert opinions. In addition I use the milk delivery each month in the last year of the training set as a benchmark to evaluate the other models. The rest of the paper is organized as follows: First I present the dataset. Then I present and test the forecasting models and the two criteria I use to evaluate them. Finally I compare the forecasts from the different models, discuss the results and conclude.

## 2. Materials and methods

Both the Norwegian dairy companies report how much milk they collect from the farmers each month to the authorities, and I use these figures. I apply these monthly milk delivery data from January 2001 to December 2013 in my analysis, and divide it in two datasets. The time series from January 2001 to December 2010 is the training set, which I use to fit the time series models. The time series from January 2010 to December 2013 is the test set, which I use to make forecasts. In Figure 1 shows the whole dataset.

From Figure 1 we can see a relatively stable level over the years, but with large repetitive seasonal fluctuations. The volume peaks during late autumn and winter and reaches the bottom level in summer. The overall picture is that there is no clear trend in the data. However, if we look more closely at Figure 1 we notice an increasing trend until 2008, then a decreasing trend from 2008, and finally an increasing trend from 2012 on. The volume peaks in winter 2008 due to the change of the quota year from January 1 to March 1. We also notice an increasing variance to the right in the figure. To simplify the interpretation of the time series smoothing was introduced. Kernel smoothing is a moving average smoother that uses a weight function, or kernel, to average the observations. I apply the Nadaraya-Watson kernel weighted average (Watson, 1966) which can be

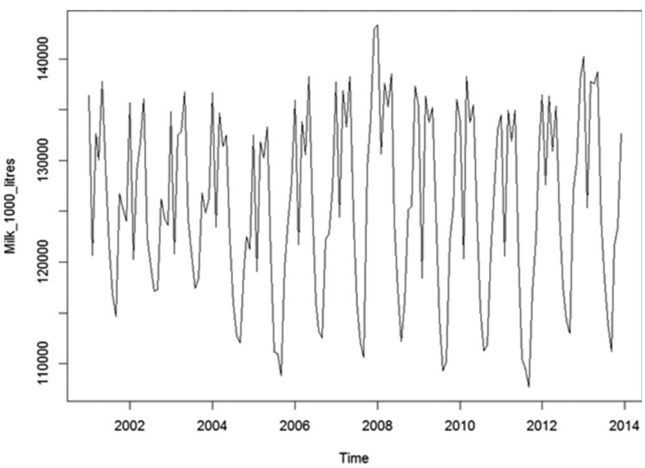


**Figure 1:** Monthly milk delivery in 1000 litres in Norway from January 2001 to December 2013

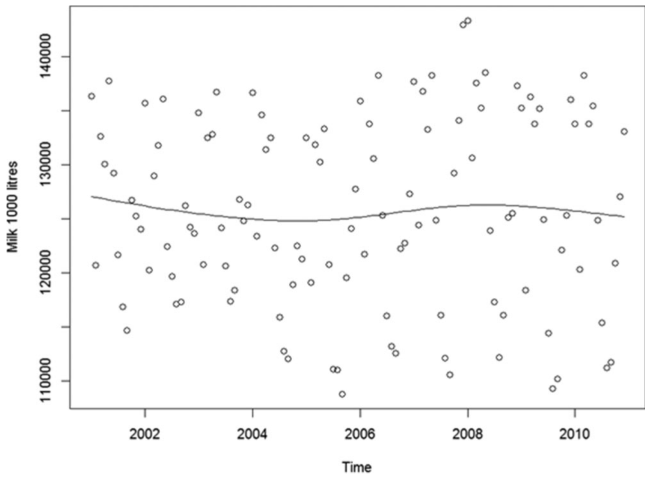


**Figure 2:** Monthly milk deliveries in 1000 litres in Norway from January 2001 to December 2010, smoothed with the Nadaraya-Watson kernel weighted average

introduced in R by the 'ksmooth' function. Figure 2 shows a smoothed curve of the training set where the level of smoothing is based on cross-validation, the simplest and most widely used method for estimating prediction error (See e.g. Hastie *et al*., 2009).

Smoothing the time series eases the interpretation. We notice a decreasing trend from 2001 to 2005, then an increasing trend until 2008, and finally a decreasing trend from 2008 to 2010. Decreasing milk production combined with increasing popularity of diets low in carbohydrate can explain the shortage in milk fat in Norway in 2011.

To explore the dominant seasonal components in the time series in more detail I apply the periodogram (See e.g. Shumway and Stoffer, 2010) which is given by:

$$I(\omega_j) = \Sigma_{h=-(n-1)}^{n-1} \gamma(h) e^{-2\pi i \omega j h} \quad (1)$$

Here $\gamma(h)$ is the auto covariance function, $h$ is the number of time lags and the frequency is given by $\omega_j = j/n$ for the number of cycles $j$ in n time points, $j=0,1,,,n-1$. Thus $\omega_j$ is the frequency measured in cycles per unit time. For $\omega = 1$ the time series makes one cycle per time unit or month. One cycle every twelve months corresponds to 0,083 cycles per monthly observation. In Figure 3 I present the raw periodogram for the training set.

In Figure 3 the frequency axis is labelled in multiples of 1/12. We notice the dominant spectrum occurring at $\omega = 1/12$, or one cycle per year. This corresponds to the regular seasonal pattern in Figure 1.

## Description of the models

In this section I present the different models which I will fit to the training set and compare in the result section. To analyse the time series I apply the statistical package R (http://CRAN.R-project.org/). First I briefly comment on the smoothing technique used in Figure 2. Smoothing techniques use observations close to the target point to fit a simple model to the dataset in such a way that the resulting estimated function is smooth. This is achieved by a weighting function or kernel, which assigns weights to observations close to the target point. The Nadaraya-Watson kernel weighted average assigns weights that die off smoothly with distance from the target point, making the fitted function continuous. For further details see e.g. Hastie *et al*., (2009).

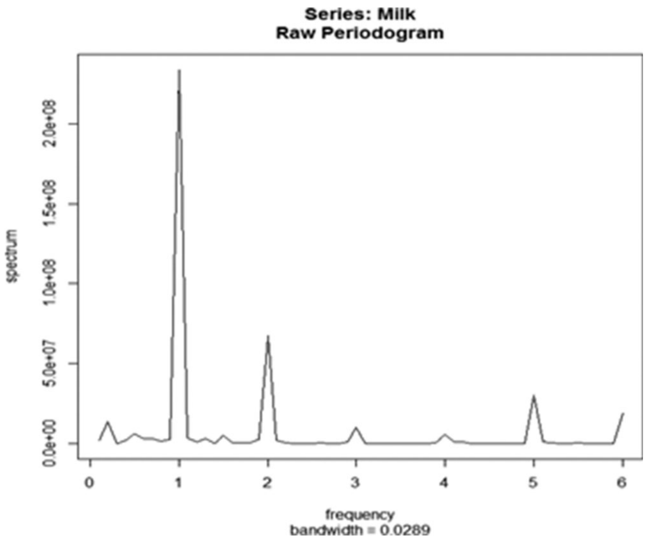


**Figure 3:** Periodogram for monthly milk delivery from January 2001 to December 2010

## The Naive model

In analysis of time series analysis with yearly seasonal cycles is common to use values from the last known year as a benchmark to evaluate forecasting models against. In the Naïve model I therefore set all forecasts equal to the value from the same month in the last year of the training set. For example, the forecast for all future February values is set equal to the last observed February value (2010), and so on. Here I use the Naive model more as a benchmark rather than the method of choice. If the other methods do not outperform the naïve model, they are not worth considering.

## The SARIMA model

In general the multiplicative SARIMA model is given by

$$\Phi_p(B^s)\varphi(B)\nabla_s^D\nabla_s^d y_t = \delta + \Theta_Q(B^s)\theta(B)w_t, \quad (2)$$

(Shumway and Stoffer, 2010), where $w_t$ is Gaussian white noise processes, or simply uncorrelated random variables. The general model is denoted ARIMA $(p, d, q) \times (P, D, Q)_s$. The ordinary autoregressive and moving average components are represented by the polynomials $\Phi(B)$ and $\varphi(B)$ of orders $p$ and $q$ respectively. The seasonal autoregressive and moving average components are represented by $\Phi_p(B^s)$ and $\Phi_Q(B^s)$ of orders $P$ and $Q$, and the ordinary and seasonal difference components by

$$\nabla^d = (1-B)^d, \text{and} \quad (3)$$

$$\nabla_s^D = (1-B)^D. \quad (4)$$

$B$ is the backshift operator:

$$B \cdot y_t = y_{t-1}. \quad (5)$$

There are a few basic steps to fitting SARIMA models to time series data. These steps involve plotting the data, possibly transforming the data, identifying the dependence orders of the model, parameter estimation, diagnostics, and model choice. First I construct a time plot of the data, and inspect the graph for any anomalies. In the example the variability in the data grows with time, and therefore it is necessary to transform the data to stabilize the variance. Here I apply first differencing,

$$\nabla y_t = y_t - y_{t-1}, \tag{6}$$

to stabilize the variance. This means that we simply look at the difference between two adjacent months.

The next step is to identify preliminary values of the autoregressive order, *p*, the order of differencing, *d*, and the moving average order, *q*. When preliminary values of *d* have been settled, the next step is to look at the sample ACF (Autocorrelation function) and PACF (Partial autocorrelation function) for whatever values of *d* have been chosen. With monthly milk production data, there is a strong yearly component occurring at seasonal lags s that are multiples of $s=12$, because of the strong connections of all biological activities to the calendar year. Because of this, it is appropriate to introduce autoregressive and moving average polynomials that identify with the seasonal lags. For diagnosis and fit of the SARIMA model I refer to the Appendix.

I tried models with different time lags, and to compare the models I use Akaike's Information Criterion (Akaike, 1969; 1973; 1974) and the Bayesian Information Criterion (Schwarz, 1978). Once I had fitted a suitable time series model to the historic data, I used the model to forecast future milk delivery. To assess the precision of the forecasts, prediction intervals are calculated along with the forecast. I choose the model with the lowest AIC- and BIC- values, AIC = 2016.31, and BIC = 2051.06. The variance $\sigma_w^2$ is estimated to 4932115, and the log likelihood to $-995.16$. The chosen model has the form:

(2,1,4)*(2,1,4)

The three values in the first bracket are related to year effects, and the last three to seasonal effects. The value two means that we apply the milk quantity in the same month as the one we are predicting for two years back in time. The value four means that for white noise we use the noise from the actual month we are predicting for four years back in time. Similarly, for the seasonal effect we use the milk quantity two months back in time in the actual year, and the noise four months back in time. The two number 1's mean that we differentiate by one month both between years and between months. Once it is developed, the SARIMA model is very easy to use and update. In practice it takes ten minutes to update it with new delivery figures every month.

## The Holt Winters' exponential smoothing model

When a time series can be described using a model with increasing or decreasing trend and seasonality, Holt-Winters exponential smoothing (HW) can be applied to make short-term forecasts (Holt, 1959; Winters, 1960). The HW is an exponential smoothing approach for handling seasonal data. It is a widely used tool for forecasting business data that contain seasonality, changing trends and seasonal correlation. A weakness of the HW is that it can be sensitive to unusual events and outliers. Exponential smoothing methods give larger weights to more recent observations, and the weights decrease exponentially as the observations become more distant. HW is based on three smoothing equations —one for the level, one for trend, and one for seasonality. The HW forecast is determined using three smoothing constants, α, β and γ, with values between 0 and 1, and the following four equations:

$$\text{Level:} \quad \ell_t = \alpha y_t / s_{t-m} + (1-\alpha)(l_{t-1} + b_{t-1}), \tag{7}$$

$$\text{Growth:} \quad b_t = \beta(\ell_t - \ell_{t-1}) + (1-\beta^*) b_{t-1}, \tag{8}$$

$$\text{Seasonal:} \quad s_t = \gamma y_t / \ell_t + (1-\gamma) s_{t-m}, \tag{9}$$

$$\text{Forecast:} \quad \hat{y}_{t+h|t} = (\ell_t + b_t h) s_{t-m+h} \tag{10}$$

Here $m$ is the length of the seasonal cycle (e.g., the number of months), $\ell_t$ represents the level of the series, $b_t$ denotes the growth or trend, $s_t$ is the seasonal component and $\hat{y}_{t+h|t}$ is the forecast for $h$ periods ahead. With a monthly time series $s_{t-m+h}$ becomes $S_{t-11}$ when forecasting one step ahead. For a more detailed description of the HW model I refer to e.g. Hyndman *et al.* (2008).

There are two versions of the HW model, the additive and the multiplicative. I apply the multiplicative version which uses seasonal factors as multipliers rather than additive constants, because the multiplicative model gives the best fit to the training set. In practice this also seems to be the most commonly used (Hyndman *et al.*, 2008). The HW model allows trend and seasonal pattern to change over time. Values of the smoothing parameters that are close to 0 mean that relatively little weight is placed on the most recent observations when making forecasts.

Every exponential smoothing method requires initialization of the smoothing process. A robust and objective way to obtain values for the unknown parameters included in any exponential smoothing method is to estimate them from the observed data. The unknown parameters and the initial values for any exponential smoothing method can be estimated by minimizing the sum of squared prediction errors (SSE) over the training set, where the one-step-ahead within sample prediction error is specified as

$$e_t = y_t - \hat{y}_{t|t-1} \; for \; t = 1, \ldots, T. \tag{11}$$

This procedure involves a non-linear minimization problem. The optimizing function 'optim' in R tries to find the optimal values of $\alpha$ and/or $\beta$ and/or $\gamma$ by minimizing the squared one-step prediction error. Further, in R the start values for level, trend and season are inferred by performing a simple decomposition in trend and seasonal component using moving averages on the first periods of the training set. A simple linear regression on the trend component is used for starting level and trend.

The estimated HW model yields a SSE of 807928649. The estimated values of alpha, beta and gamma are 0.399, 0.00, and 1.0, respectively. The value of alpha is relatively low, indicating that the estimate of the level at the current time point is based upon both recent observations and some observations in the more distant past. The value of beta is 0.00, indicating that the estimate of the slope of the trend component is not updated over the time series, and instead is set equal to its initial value. This makes good intuitive sense, as the level changes over the time series, but the slope b of the trend component remains roughly the same. In contrast, the value of gamma (1.0) is high, indicating that the estimate of the seasonal component at the current time point is just based upon very recent observations. For diagnosis of the HW model I refer to the Appendix. So far I conclude that the HW model provides an adequate predictive model for monthly milk delivery. Similar to the SARIMA model the HW model is easy to use and update with new monthly figures.

### The Expert model

This is the model which TINE SA cooperative dairy company uses today. To construct forecasts, dairy experts give their opinion on the most probable number of dairy cows per month, the daily milk yield per cow per month and the milk quota filling up to 14 months ahead in time. To judge the future number of cows the experts estimate the number of first calving heifers based on historic figures of inseminated and slaughtered heifers. Similarly, they estimate the number of cows that will be slaughtered based on historic figures. To make an assumption of the future milk yield per cow the dairy experts use historic figures and supplemental information on the forage harvest with respect to both quantity and quality. Finally, to make an assumption of the future milk quota filling the experts use historic data and also consider possible adjustments in the quota regulations. Thus in practice the Expert model is a combination of historic figures and expert opinions. The model is quite time consuming, and therefore the forecasts are made only every other month.

I now present the measures I use to compare the forecast from the Expert model with the forecast from the Naïve model, the SARIMA model and the HW model.

### Choice of accuracy measures for the forecasting models

There are many ways to evaluate the accuracy of forecasting methods. They all involve looking at past data and comparing the value that would have been forecasted using the model and the estimated parameters, $\hat{y}_{t|t-1}$, with the actual observation, $y_t$. Different accuracy measures often give different results (Hyndman *et al.*, 2008). Therefore the choice of accuracy measure must be adapted to the problem at hand. In this study there are two main goals of forecasting. For the dairy industry it is important to maximize exploitation of capacities. Therefore it is important to know the milk quantity in each month ahead. To measure the forecast accuracy of the different models in each month I apply a widely used measure of variability, the mean absolute percentage error (MAPE) (Hyndman *et al.*, 2008). Percentage errors have the advantage of being scale-independent, and so are frequently used to compare forecast performance between different data sets.

$$MAPE = 100/n \sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_{t|t-1}}{y_t} \right| \quad (12)$$

In MAPE a positive forecast error in one month is not outweighed by a similar negative error in another month. Thus all monthly forecast errors contribute to increase the MAPE- value, and therefore the MAPE is advantageous when the main interest is to measure the milk quantity of each month. However, measures based on percentage error have the disadvantage of having extreme values when $y_t$ is close to zero, and they also assume a scale with a meaningful zero.

The dairy industry also needs to know the total milk quantity over a longer period, e.g. two years ahead. To measure the forecast accuracy over a longer period I will also apply the sum of forecasting errors (SFE), which is simply calculated by

$$SFE = \sum_{t=1}^{n} (y_t - \hat{y}_{t|t-1}) \quad (13)$$

The SFE provides an indication of bias, i.e. the overestimation or under-estimation in the model. In SFE a positive forecast error in one month can be outweighed by a negative error in another month, since we do not take the absolute values of the errors. Both accuracy measures have in common that the lower the values, the better the forecast.

## 3. Results

In this section I present the results from the comparison of the four models.

Figure 4 shows the MAPE values for the four different forecasting models over different forecasting horizons in months.

From Figure 4 we can see that for the first six months the Expert model outperforms the other models, with very low values of MAPE. After six months the Expert model is outperformed by the HW model, and the Expert model does not give forecasts beyond 14 months. The HW model continues to give the most reliable forecast up to 18 months. After 21 months the HW model gives poorer forecasts than both the Naïve model and the SARIMA model. From 18 months on the SARIMA model performs better than the others up to 24 months, although the difference compared with the Naïve model is small both at 18 and 21 months. The SARIMA model produces the least accurate forecast of the models for the first six months, but has the best long term performance.

Figure 5 compares the different forecasting models according to the SFE. From Figure 5 we notice that the first three months the Expert model has the lowest SFE, which is in line with the finding in Figure 4. After six months the SARIMA model performs similarly to the Expert model, which in practice loses its' predictive power after six months. The HW model performs best after 12 months, with SARIMA second. They both perform significantly better than the Naïve model. From 12 months to 21 months the SARIMA model has by far the lowest SFE, and significantly lower than the Naïve model. However, the difference between the SARIMA model and the Naïve model declines sharply when we reach 24 months. Thus there seems to be less to gain from applying time series models for forecasting horizons beyond 24 months.

 

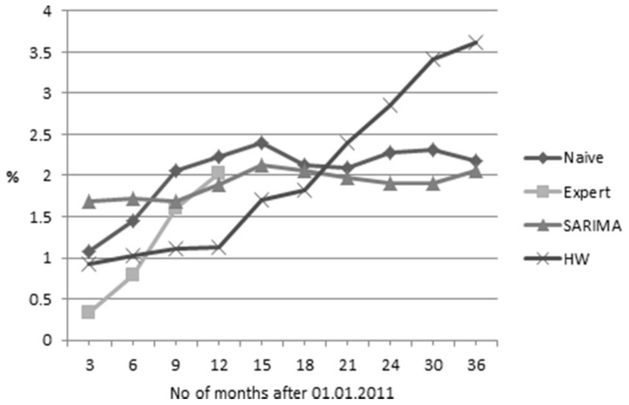


**Figure 4:** MAPE over different forecasting horizons in months for the forecasting models

## 4. Discussion and conclusion

Milk production in Norway first declined and then increased significantly during the forecast period. In spite of this the forecasting models fit the data quite well, at least in the first 18 months, with MAPE values equal to or less than approximately two. Thus the findings support the findings of Sataya *et al*. (2007) and Sankar and Prabakaran (2012) with respect to the SARIMA model, except that these authors did not take seasonality into account. The findings reported here show that the Expert model loses much of its predictive power after six months. This is noteworthy since its main application today is for forecasts 12 to 14 months ahead, and the findings show that for this purpose the time series models are preferable. Further investigation has revealed that the main cause of the prediction error is the misjudgement of future milk yield per cow.

If we look at the MAPE, the HW model performs best from 12 to 18 months, but if we look at the SFE the SARIMA model performs best. The findings reported here illustrate that the two accuracy measures serve slightly different purposes. If the purpose is to forecast the milk quantity in each month accurately, one should use the Expert model for the first six months, the HW model from six to 18 months, and the SARIMA model from 18 to 24 months. However, if the main interest is to measure the total milk quantity over a period of several months, one can use the SARIMA model the first six months, the HW model the next six months, and then the SARIMA model again from 15 to 24 months.

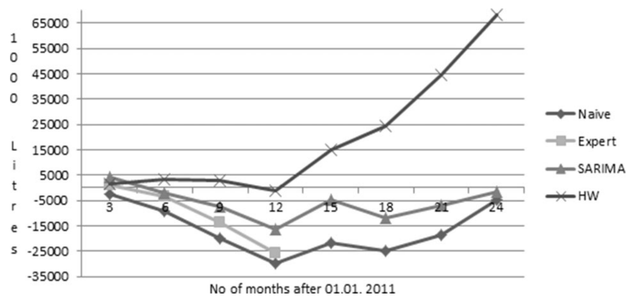


**Figure 5:** SFE in 1000 litres for the four models over different forecasting horizons in months

The finding that the HW model loses much of its predictive power between 15 and 18 months is somewhat contrary to the finding of Akter and Rahman (2010), who claimed that the HW model could be used for forecasts up to two years. When interpreting the differences between the two findings one should keep in mind that Akter and Rahman (2010) used a much shorter time series, which give higher forecast errors. In general the MAPE values in this study are lower than the ones reported by Akter and Rahman (2010). However, conflicting results like this are not uncommon when performing forecasting competitions between methods (Hyndman *et al*., 2008). As forecasting tasks can vary by many dimensions considering the length of forecast horizon, the size of test set, the forecast error measures and the interval of data etc., it is unlikely that e.g. time series models will be better than all other models for all forecasting scenarios. What we require from a forecasting method are consistently sensible forecasts, and these should be frequently evaluated against the task at hand.

According to the results forecasts beyond 24 months should be dealt with caution, and here the findings are in line with the findings of Akter and Rahman (2010). However, contrary to their advice I recommend the SARIMA model instead of the HW model when forecasts beyond two years are necessary. Even after two and a half years the SARIMA model still has a low MAPE, but after three years the difference compared with the Naïve model is negligible. If we take all three years together the Naïve model performs remarkably well.

Taken together the findings that time series models should be combined are in line with Hyndman *et al.* (2008), who claim that the SARIMA models and the HW models overlap and are complementary. They both have their strengths and weaknesses. The underlying presumption that correlation between adjacent points in time is best explained in terms of a dependence of the current values on past values represents means that both models depend heavily on the time period analysed. Thus analysis of other periods could produce other models. This dependence makes it necessary to recalibrate the time series models regularly. Unlike most prior studies this study compares time series models of milk delivery with a model based on expert opinions. I think the findings reported here show that time series models can make the dairy sector more proactive and capable of responding more quickly changes in milk production like e.g. crop failure, and at a lower cost. A possible avenue for future research could be to try to improve the performance of the Expert model by combining it with time series models. For example one could use time series models to forecast the number of cows and the milk yield per cow.

In conclusion the Expert model performs well for the first six months, but has the disadvantage that it is much more time consuming than the times series models. A combination of the Expert model, the HW model and the SARIMA model gives reliable forecasts of monthly milk delivery for a period of up to two years. Forecasts beyond two years should be dealt with caution. However, the SARIMA model still performs better than the Naïve model up to three years ahead.

## About the author

**Bjørn Gunnar Hansen** holds Master degrees in agricultural science and economics and business management, and a Ph.D. in business management. He currently works as a dairy scientist in TINE SA, the Norwegian cooperative dairy company, where the research was carried out.

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**Table 1:** The coefficients in the fitted time series model

| ar1 | ar2 | ma1 | ma2 | ma3 | ma4 | sar1 | sar2 | sma1 | sma2 | sma3 | sma4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -0.064 | 0.5755 | -0.2688 | -0.8171 | 0.1239 | -0.0380 | 0.8111 | -0.9815 | -1.2806 | 1.7292 | -0.8294 | 0.3242 |

## Appendix: diagnosis of the SARIMA and HW models

### The SARIMA model

The coefficients in the fitted model are given in Table 1.

In Table 1 the notions 'ar' and 'ma' refer to the autoregressive and moving average coefficients for year. Correspondingly, the notions 'sar' and 'sma' refer to the coefficients for months within year. Diagnosis of the model involves inspection of the residuals. Investigation of marginal normality can be accomplished visually by looking at a histogram of the residuals. In addition to this, a normal probability plot or a Q-Q plot can help in identifying departures from normality. I also inspect the sample autocorrelations of the residuals for any patterns or large values. Finally I check the Ljung Box Pierce Q-statistic to reveal possible accumulated autocorrelation between the residuals. In Figure 6 displays the diagnostic tools for the chosen model.

The standardized residuals show no obvious patterns. Notice that there are outliers, however, with a few values exceedingL 3 standard deviations in magnitude. The outliers that occur in 2008 are due to change of the quota year from January 1 to March 1. The ACF of the standardized residuals are low and show no apparent departure from the model assumptions. The normal Q-Q plot of the residuals shows some departure from normality at the tails. However, the model appears to fit well except for the fact that a distribution with heavier tails than the normal distribution could be employed. The Ljung-Box-Pierce Q- statistic uncovers no problems with autocorrelation between the residuals.

### The HW model

If the predictive model cannot be improved upon, there should be no correlations between forecast errors for successive predictions. In other words, if there are correlations between forecast errors for successive predictions, it is likely that the simple exponential smoothing forecasts could be improved by another forecasting technique. To figure out whether this is the case, I obtain a correlogram of the in-sample forecast errors for lags 1–20 (Figure 7).

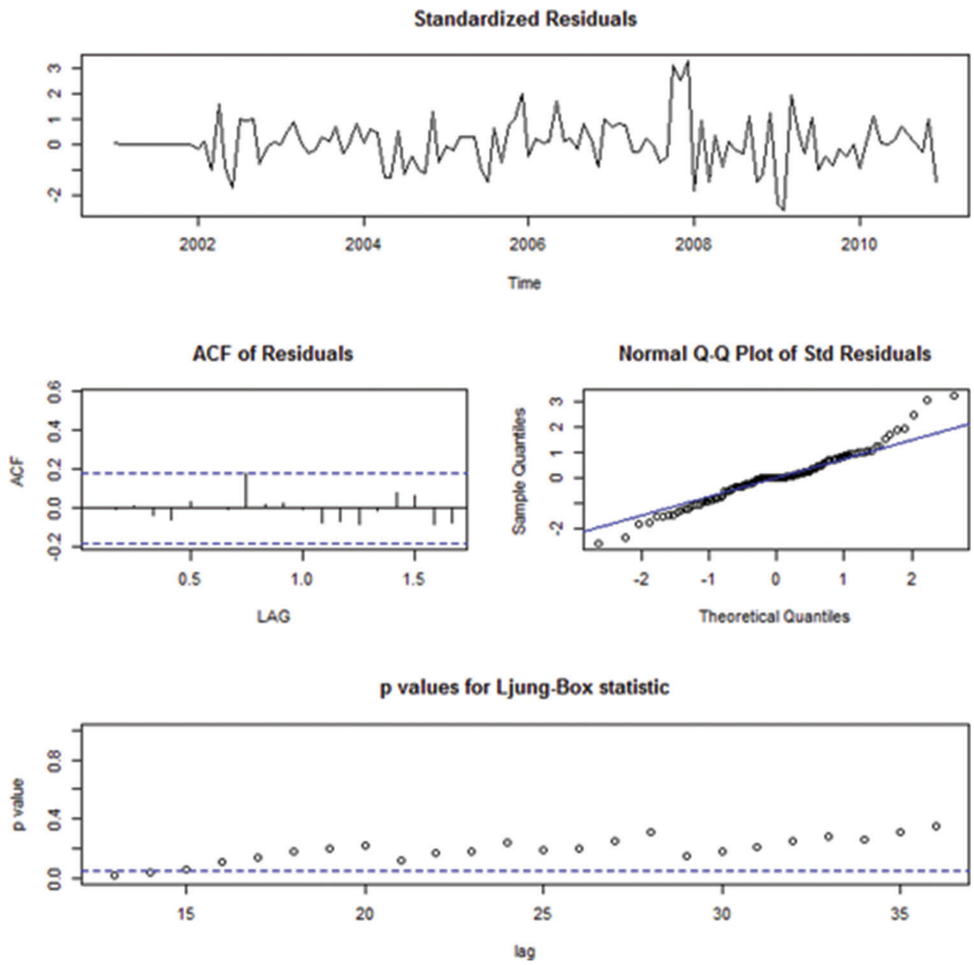


**Figure 6:** Analysis of residuals for the SARIMA model

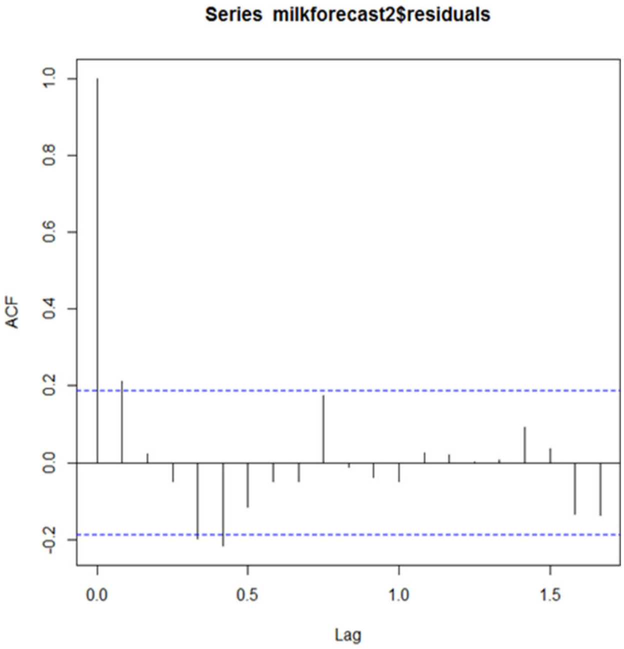


**Figure 7:** The autocorrelation function for in-sample forecast errors for the HW model

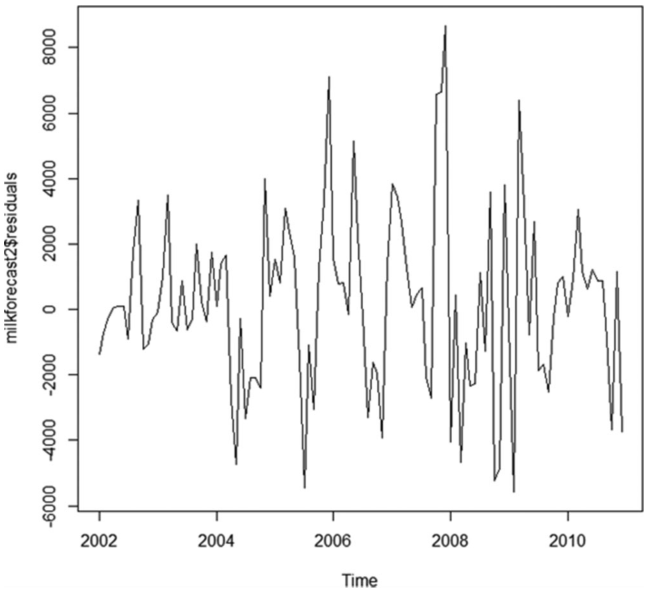


**Figure 8:** Residuals for the HW model

From Figure 7 we notice that there is very little autocorrelation between forecast errors between lags. To test whether there is significant evidence for non-zero correlations between residuals at lags 1–20, I carry out a Ljung-Box test. The Ljung-Box test statistic is 27.824 and the p-value is 0.11, so there is little evidence of non-zero autocorrelations in the in-sample forecast errors at lags 1 to 20.

I check whether the forecast errors have constant variance over time, and are normally distributed with mean zero, by making a time plot of the forecast errors (Figure 8) and a histogram with overlaid normal curve (Figure 9).

The plot shows that the in-sample forecast errors seem to have roughly constant variance in the middle of the time period. However, the fluctuations at the start and at the end of the time series are smaller than in the middle.

To check whether the forecast errors are normally distributed with mean zero, I plot a histogram of the forecast errors, with an overlaid normal curve that has mean zero and the same standard deviation as the distribution of forecast errors (Figure 9).

Figure 9 shows that the distribution of forecast errors is roughly cantered on zero, and is more or less normally distributed, although it seems to be slightly skewed to the left compared to a normal curve. However, the left skew is relatively small, and so it is plausible that the forecast errors are normally distributed with mean zero.

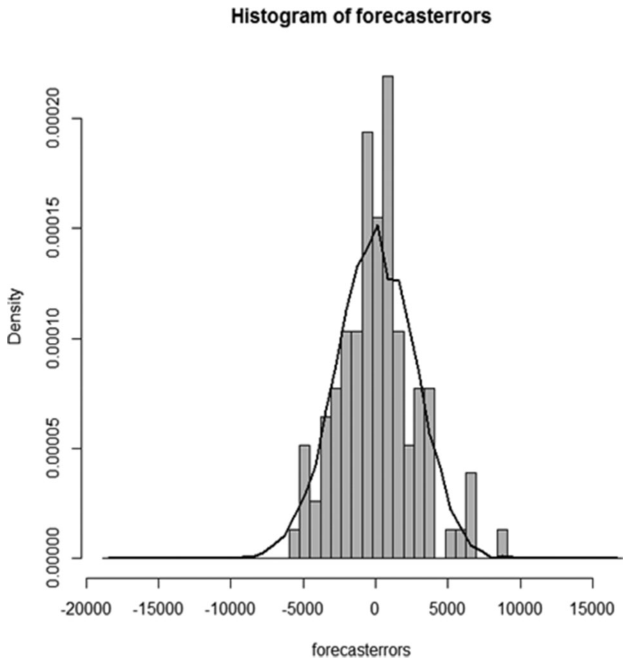


**Figure 9:** Histogram of forecast errors with overlaid normal curve from the HW model

 

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# The best of British farmers, what gives them the edge?

GRAHAM REDMAN[1]

ABSTRACT

Every farming community has a large range of financial performances which cannot be categorised by farm size, activity, operation or anything else. Almost no farmers are financially good or poor because of one outstanding activity or decision process. Instead, a top farmer is simply better than an average producer by being slightly better at most things. This article explains that, once a farm structure is correct, the producer can improve by a process of marginal gain. The suggestion of finding one hundred activities and working to improve on them all by one per cent will revolutionise any business. The difference between an outstanding farmer and an average producer is only one per cent. The article identifies the only recognisable difference in activities between top and bottom quartile producers is at the farm business planning stage.

KEYWORDS: competitiveness; marginal gain; farming; total factor productivity

The UK has many world-class farmers, but the industry as a whole appears to be commercially lagging behind many other countries. According to Government data, the efficiency of UK farming has risen by 1.4% per year on average for a generation, considerably lower than other comparable countries. Total Factor Productivity is a measure of how an industry gets better at turning inputs into outputs. It is an index so the performance change is measured. Total Factor Productivity data globally is not good but that which is available suggests UK efficiency gain is slow compared with other countries as explained in Figure 1.

The return on some inputs, like labour, is good, but on others, like land, it is poorer. Cost saving is a major opportunity for farming businesses through reducing business expenditure per unit of output. Reducing costs is the right commercial thing to do when it saves more cost than income it foregoes. Compare top quartile farmers with bottom quartile performers, it shows higher output per hectare accounts for only about 20 to 30% of the greater profits. Lower costs per hectare contribute the majority of the additional profit achieved by the top performers. This is demonstrated in DEFRA's Farm Business Survey data and Levy Body information such as from DairyCo's MilkBench data and is illustrated in Figure 2. Fixed costs can be associated with farm structure, so to minimise the overheads, the farm needs to be structured correctly.

This analysis demonstrates the importance to farmers of focussing on the cost of production rather than just the amount of production.

All sectors and all countries have very high levels of performance variation from the top to the bottom performers. This is true for each sector of agriculture regardless how it is divided. For example there is a considerable range of performance of large farms and small farms, arable and livestock alike. Top performers are almost always simply marginally better at everything rather than significantly better at anything. Marginal progress on all aspects of the business makes a considerable improvement to the overall figures. Minor improvements to many aspects of a business multiply rather than add up, meaning that small gains in performance in several areas of farming make a considerable difference to the overall farming profitability between top and bottom quartile performers.

Non-essential expenditure decreases and replacement policies are extended when profitability is low. This suggests that farmers are both a) sensitive to cash flow availability, and b) not totally commercial in decision-making when they have the resources not to be. We remember UK farmers generally combine their work with their lifestyle more than most other work sectors. Reinvestment is necessary to build the future business, whether though lime on fields, staff training, or buildings etc. Investing involves short term cost and long term ambition and farming is a very long term industry.

Young farmers are often more eager to build their businesses than older managers. They are generally more receptive to new ideas and are prepared to take greater risks (including accepting higher business gearing). A good education is almost always beneficial and time spent in a non-farming commercial environment can also be commercially valuable. This brings new commercial and operational ideas into the industry and onto the farm. Larger farms tend to achieve better results than

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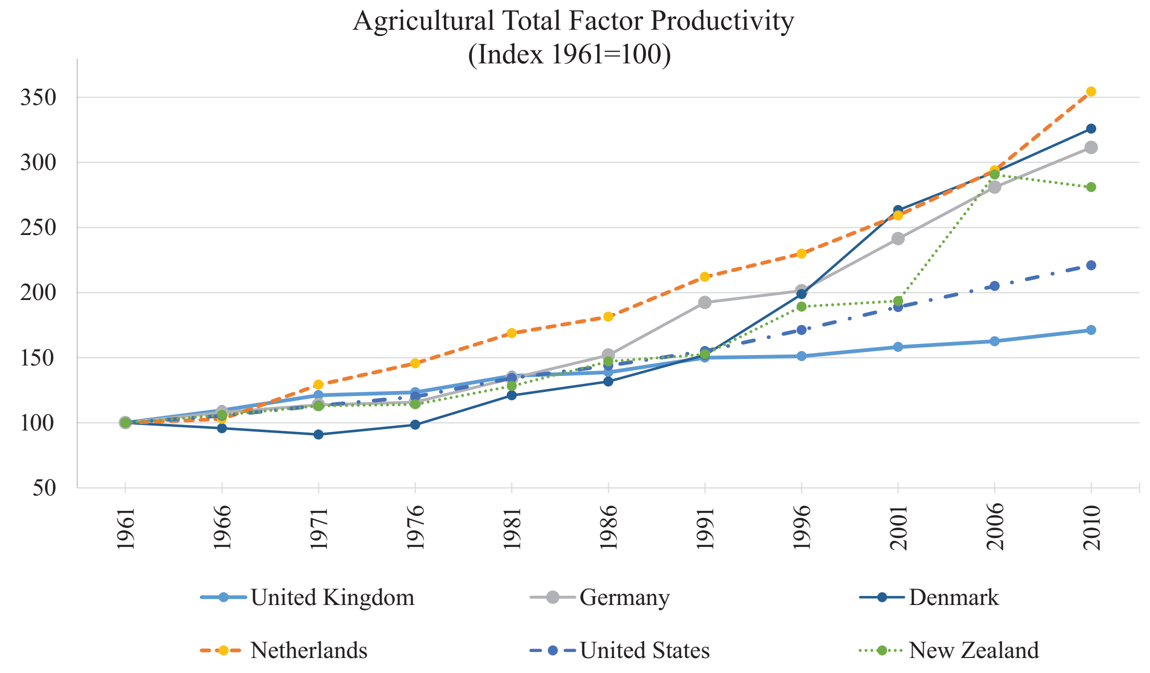


**Figure 1:** Agricultural Total Factor Productivity (index 1961=100). **Source**: USDA/FAO.

smaller ones as they can be more efficient with resources although this is not a priority for commercial success.

Improving efficiency at national industry level is directly related to expenditure in research and development (R&D). In the UK this has fallen by about 6% per year in real terms over the last 20 years from a relatively high base. To raise the performance of UK farming, this decline has to stop and so the Agri-tech channelled investment is welcomed. More of the R&D funds should be focussed towards near-market study, taking the strategic research and applying it to industry, or working with the farming industry, spotting problems and opportunities and collaborating to solve them. This method also tends to attract greater amounts of private funding too.

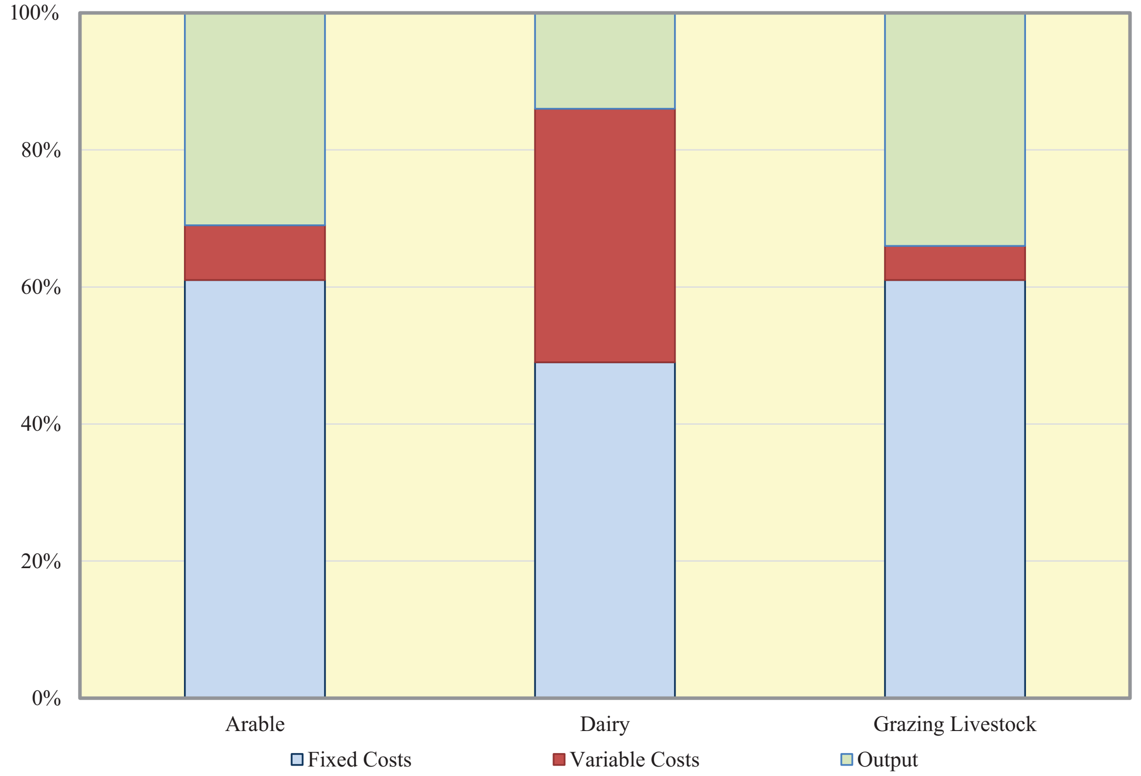


**Figure 2:** Chart Highlighting Where the Variation in Profit Occurs between Top and Bottom Quartile Farms. **Source:** Farm Business Survey and DairyCo.

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Knowledge exchange is clearly the next relevant step. After research has been completed, those who can use the new knowledge should find out about it. Public and private sectors both have obligations and key roles to play here. In the UK, the closest professional relationship to an arable farmer is the agronomist, although other information routes are also important. This means that the information these operators impart is critical in the development of farm efficiency on a relatively large scale.

It is rarely disputed that direct subsidies compromise competitiveness, but farming without them in an otherwise supported industry would not be prudent. However, there is much to learn from unsupported countries and sectors. Profitability of unsupported sectors for example is considerably more volatile than supported sectors, although overall profitability averaged over several years is not so great. As direct subsidies in the UK and EU decline through to 2019, farmers should consider more long-term (5 year) budgeting to assess business performance.

Barriers to changes of land occupation slow the restructuring and therefore performance of agriculture. Wider use of joint venture arrangements should be promoted in the UK. Whilst lifestyle farmers are free to make a choice, policies should be put in place to ease the exit of those who only continue farming because they feel they have no alternatives. Parts of the red meat sector in particular are held back by lifestyle farmers more than most other sectors, having the lowest barriers to entry and indeed exit. Some operators who have, for example, left dairying, or have a few acres of land, keep a small herd of cattle or flock of sheep. In contrast for example, few lifestyle farmers enter intensive pig farming.

The limited resources that support organisations such as the UK's levy body (Agricultural and Horticultural Development Board), could be focussed either on the top farms where potential gain is small or the bottom quartile where each operator has greatest potential to improve. However, the lower performers often have a reduced ambition to change, making impact difficult. Rather, spend resources working with the middle and top quartiles and allow the new practices to filter to other farmers. Those eager to raise their games will actively seek out support or new knowledge so the most receptive operators will be known.

In the UK few farms pass ownership with a sale, most are inherited. This is a real asset to the individual but a brake for the industry. In other countries such as Netherlands or New Zealand, land is sold, even between generations, helping the young farmer 'feel' the value of the asset. It also clarifies the currently murky relationship between unpaid labour from family members and farm inheritance.

The UK (and EU) farming industry, compared with other countries, is also hampered by having technologies held back or withdrawn from use. Genetically modified plant seeds are the obvious example, with more recently the loss of plant protection products. The UK (and EU) is increasingly operating with fewer tools than non-EU counterparts, putting farming under sustained pressure from ideological and political preferences. Furthermore, there is ample evidence that non sector specific commercial experience supports all business people from any industry. UK farmers are rehearsed at farm walks but might also learn business skills from other commercial environments.

As an industry, we can all look for opportunities to enhance the commerciality of the sector, either through tools like benchmarking and long term planning, or through culture change. Ultimately though, the success or failure of any business comes down to one variable, the entrepreneur at its helm. Regardless of the support, subsidy, information emails, loans, trade events or research, the talent and drive of the individual to be the ''best in class'' is the key determinant that turns ordinary into extraordinary. The hungry entrepreneur knows that he or she will take the spoils of a successful business just as he or she will feel the pain of failure. Only one person can be responsible for that and the rewards only come from extreme effort.

## About the author

**Graham Redman** is Partner of The Andersons Centre, agribusiness consultancy in the UK, and Author of the John Nix Farm management Pocketbook, a UK agricultural costings book.

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# Maize cultivars for anaerobic digestion and animal nutrition in Europe

MIKE WILKINSON[1]

**ABSTRACT**

Increased use of whole-plant maize for anaerobic digestion (AD) in Europe raises the question: Are maize cultivars developed for use in animal nutrition equally appropriate as feedstock for AD or should different phenotypes be selected? The main objective in growing whole-plant maize as feedstock for AD is maximum output of methane per hectare. There is less need for rapidly digested plant components such as starch in AD feedstock than in a ruminant diet because the typical digestion period is several weeks for AD compared with less than two days for the rumen. The ideal phenotype of maize for AD is a very high yielding plant with a low lodging score. Metabolisable energy (ME) intake from forage is a limiting factor to output of animal product per head, thus, in addition to high dry matter yield per hectare, a high concentration of ME in the maize plant is desirable. Major factors contributing to high ME in whole-crop maize are starch and digestible plant cell wall. The ideal phenotype of maize for animal nutrition is therefore a plant with a high proportion of ear, a low concentration of lignin, high cell wall digestibility and low lodging score.

**KEYWORDS:** Forage maize; phenotype; anaerobic digestion; biogas; animal feed; methane

## 1. Introduction

Ensiled whole-plant maize (*Zea mays*) is widely used throughout the world as animal feed. However, increasing quantities of the crop have been grown in Europe in recent years specifically as feedstock for anaerobic digestion (AD) for the production of methane biogas. In Germany, for example, of the total area of 3.6 million hectares of maize planted in 2014, 0.50 was for silage for animal feed, 0.33 was destined for biogas 0.17 was grown for grain (H. Messner, personal communication). In UK some 15,500 hectares of forage maize was grown in 2013 as feedstock for biogas, 0.10 of the total maize area (National Institute of Agricultural Botany, 2013). The UK Descriptive List of forage maize cultivars nominated as having potential suitability for AD use includes separate lists for favourable and less favourable sites, with details for each cultivar of concentrations of dry matter (DM) and metabolisable energy (ME) together with yield of DM and ME, early vigour and standing power at harvest or root lodging (NIAB 2015). These characteristics are similar to those assessed for maize cultivars in the UK Descriptive List of forage maize cultivars for animal feed (NIAB, 2015).

Feedstock and feed inputs comprise the major variable costs of biogas and livestock production. For example, cost of feedstock was estimated to comprise 0.49 to 0.83 of total variable costs of farm-scale AD (Redman, 2010) and the cost of animal feed comprised 0.76 of the total variable costs of milk production (DairyCo, 2014). Since forage has a lower unit cost than concentrate feed (DairyCo, 2012), optimum output of livestock product from forage is a key performance objective. For example, a target for milk production is for forage energy intake to comprise 0.50 of total annual energy intake (Wilkinson, 2013).

Two major operational objectives in AD are maximisation of specific methane ($CH_4$) yield (litres of $CH_4$ per kg volatile solids, VS) and maximum methane yield per hectare of land (Amon *et al*., 2007b). In contrast, a major objective of most livestock production is the optimisation of daily output of milk or live weight gain per animal within the constraints of input costs, especially when factors other than land such as labour or animal accommodation are the primary limiting resources.

The development of methane biogas production on a farm-scale using ensiled whole-plant maize as the sole or primary feedstock raises the question: Are maize cultivars developed for ensiling as animal feed equally well-suited for use as feedstock for AD and if not what phenotype of maize should be selected specifically for AD? It could be argued that maximising energy yield per hectare is an important objective in the production of both biogas and animal feed. This may be correct, provided specific methane yield per kg volatile solids and the concentration of ME per kg DM are not compromised by choosing a variety of maize of high DM yield but low methane yield or ME per kg VS or DM, or harvesting at a late stage of crop maturity so

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that daily output of methane or voluntary intake of ME and animal output are reduced by more than the increase in yield of DM.

In this review factors affecting methane production are discussed, the main features of fermentation in the anaerobic digester and rumen are compared, and phenotypic traits of whole-plant maize for AD are compared with those for animal nutrition.

## 2. Methane production

Maximum methane production is the main objective in operating a digester. However, methane is a greenhouse gas (GHG) and emissions of methane from enteric fermentations comprise 0.39 of global livestock GHG emissions (Opio, 2013). Minimising methane production is therefore an important environmental objective in ruminant animal nutrition.

Methane is the final product of a multi-stage process. The methanogenic organisms responsible for the production of methane, the *Archaea*, do not ferment carbohydrates, proteins or lipids, but gain energy by reducing the end products of the fermentation process such as carbon dioxide, acetic acid, formic acid and methanol with methane being produced as a by-product of the reduction process (Moss, 1993). The A*rchaea* are strict anaerobes and both digester and rumen are ideal environments for their development with excess hydrogen from microbial digestion of feed producing highly reduced conditions (Eh -350 mV). Hydrogen is potentially poisonous to the microbial population and must therefore be removed. Several hydrogen sinks exist, of which methane is by far the most important. Other hydrogen sinks include the production of ammonia from the degradation of amino acids and the saturation of unsaturated fatty acids (Moss, 1993).

Typically 0.60 of total DM in ruminant diets is carbohydrate, 0.15 to 0.20 crude protein, 0.10 ash and 0.10 lipid (McDonald *et al*., 1995). The digestion of carbohydrate (mainly cellulose, hemicellulose, starch and fructans) by the microbial population results in the production of simple sugars, mainly hexoses, which are rapidly fermented to steam-volatile fatty acids (VFA) such as acetic, propionic, butyric and valeric. At pH 6 and above VFA are present as their dissociated salts - acetate, propionate and butyrate (Penner, 2014). Protein and other nitrogenous compounds such as amides and amines are reduced to ammonia, some of which is incorporated into microbial protein (McDonald *et al*., 1995). A key intermediate in the digestion of carbohydrate is pyruvate, which is fermented to VFA and formate. The formate is converted to carbon dioxide and hydrogen, probably by enzymes produced by methanogens.

Importantly, excess hydrogen is produced with the production of acetate and butyrate but not with the production of propionate and valerate (Moss, 1993). Feeds containing lower levels of fibre and higher proportions of starch tend to result in higher proportions of propionic and lower proportions of acetic acid than higher fibre feeds and feeds (Table 1). The proportions of different VFA vary with the relative proportions of different bacterial species - those producing acetate predominating with feeds higher in fibre and at higher fermentation pH (above pH 6.0). Thus the pattern of VFA production affects the amount of excess hydrogen and hence the amount of methane produced per mole of hexose sugar fermented (Table 1).

**Table 1:** Production of methane from hexose sugar fermentation in the rumen

| Molar ratio of acetate: propionate: butyrate in rumen fluid | Moles of methane produced per mole of hexose fermented in rumen |
|---|---|
| 70:20:10 (forage diet) | 0.64 |
| 55:30:15 (concentrate diet) | 0.48 |

Source: Moss, 1993.

Methane has a gross energy value of 55 MJ/kg DM, compared to 17.5 MJ/kg DM for cellulose and 17.7 MJ/kg DM for starch - the two major fermentable substrates in maize (McDonald *et al*., 1995). Methane energy loss in ruminants generally accounts for about 0.05 of gross energy intake but can vary widely from 0.02 to 0.12 of gross energy intake (Holter and Young, 1992; Johnson and Johnson, 1995) - more for fibrous feeds and less for concentrate and previously fermented feeds such as brewers' grains (McDonald *et al*., 1995). Research is currently underway to produce a wider range of methane emission factors for livestock because it is recognised that current values do not represent the full range of diets, classes of animal and systems of production currently in use on farms.

Two major factors affect the total amount of methane produced per digester or animal – the amount of feedstock or feed DM consumed daily and its digestibility (Tamminga *et al*., 2007) with the most important factor for the animal being daily DM intake (Mills *et al*., 2008). Early research demonstrated that the digestible energy concentration of the diet (reflecting fibre concentration and fibre digestibility) had a major influence on methane energy produced per unit of gross energy eaten (Blaxter and Clapperton, 1965). Energy balance studies with dairy cows given a wide range of diets showed that daily methane production per animal was positively related to DM intake and diet NDF concentration, and negatively related to diet concentrate proportion (Yates *et al*., 2000). Studies with dairy cows have also shown that substitution of grass silage by maize silage reduces methane emissions (Tamminga *et al*., 2007: Garnsworthy *et al*., 2012), although this mitigation of methane emissions may be offset by soil carbon loss following the ploughing of grassland for maize cultivation (Vellinga and Hoving, 2011).

In AD, type of feedstock can have a major impact on specific methane yield. Typical specific methane yields for a range of feedstock are shown in Table 2. Maize silage is intermediate between manure and food waste. Crude fat (total oil) concentration in maize is related positively to specific methane yield (Rath *et al*., 2013) and, in contrast to the rumen, feedstocks with higher concentrations of oil such as rapeseed meal and waste cooking oil yield more methane per kg volatile solids than feedstock with lower oil concentration such as maize silage (Table 2). Addition of long-chain fatty acids to the diet depresses methane production in the ruminant (Blaxter and Czerkawski, 1966), often with associated decreases in DM intake, NDF digestibility and milk production (Tamminga *et al*., 2007).

**Table 2:** Specific methane yields from a range of feedstock

| Feedstock | Specific methane yield (litres $CH_4$/kg volatile solids) |
|---|---|
| Cow manure | 190 |
| Rye | 300 |
| Maize silage | 320 |
| Wheat grain | 370 |
| Waste vegetables | 380 |
| Food waste | 400 |
| Rapeseed meal | 410 |
| Waste cooking oil | 540 |

Source: Al Seadi *et al*, 2008.

The extent to which methane production is decreased in the animal depends on fatty acid chain length and degree of unsaturation (Giger-Reverdin *et al*., 2003), with longer chain and unsaturated fatty acids possibly having a toxic effect on gram-positive bacteria in a similar way to the action of the gram-positive antibiotic monensin, which also reduces methane and acetate but not propionate production in the rumen (Russell and Strobel, 1987). A possible explanation for the positive relationship between feedstock oil concentration and specific methane yield in AD is that the microbial population adapts to higher fatty acid feedstock during the relatively long residence time in the digester.

## 3. Anaerobic digester compared to rumen

To answer the question of phenotypic suitability of whole plant maize for AD or rumen digestion, it is essential to know to what extent the anaerobic digester and rumen are similar in terms of optimal operational parameters and in what respects they differ. Of fundamental importance in both AD fermentation vessel and rumen is optimisation of both physiological and biochemical conditions for microbial digestion of crop components. Typical optimal operating parameters for AD and rumen are shown in Table 3. Common features include concentration of total volatile solids in feedstock or dry matter (DM) in animal diet, optimal fermentation temperature, pH and concentration of ammonia-N.

The most important difference between digester and rumen is in residence time – on average several weeks for AD but less than 2 days for rumen, with potential consequences for optimal speed of digestion, which may be different for AD compared to animal diet. Speed of degradation of plant substrates by microbial enzymes, with production of volatile fatty acids (VFA), carbon dioxide and methane as principal fermentation end-products, determines rate of fermentation in both AD digester and rumen. Maintenance of pH above 6 is essential for maintaining fibre digestion in the rumen (Ørskov, 1998; Offer *et al*., 2004) and also for growth of methanogenic microorganisms in the digester (Weiland, 2010). Rapidly digested substrates such as starch and water-soluble carbohydrates (sugars) can result in the production of VFA at a rate that exceeds the buffering effects of salts or saliva with the result that the pH of the digester or rumen can fall. Lower rumen pH due to rapid production of VFA can predispose the animal to sub-acute acidosis (Kleen *et al*., 2003). In this situation the microbial population changes and the mix of VFA shifts from acetate towards propionate. In situations of excess ruminal acidity (below pH 5.5) the microbial population can change further with the production of lactic acid (Chamberlain and Wilkinson, 1996) with continued reduction in pH because lactate-producing bacteria are more tolerant of low pH conditions than acetogenic bacteria (McDonald *et al*., 1991).

Adequate buffering of fermentation acids is therefore vital in both digester and rumen. Offer *et al*. (2004) ascribed rumen stability values to different feeds according to concentration of neutral detergent fibre (NDF) and potential acid load (PAL), determined *in vitro* by incubating a feed for 24 hours with rumen liquor and measuring the amount of alkali required to raise the pH of the incubation mixture back to pH 7.25 (i.e. the total free acid produced by the fermentation). PAL is now estimated in grass silages routinely by near infra-red reflectance spectroscopy (NIRS) to identify silages that may increase the risk of sub-acute ruminal acidosis in the animal (Walker, 2014). It is assumed that feeds like hay with a relatively low PAL (800 meq/kg DM) effectively have a neutral effect on rumen pH in terms of their buffering capacity and fermentation acid production because the rate of acid production from their fermentation can be balanced by plant buffering constituents, salivary bicarbonate and rumen ammonia. Feeds with higher PAL such as maize silage (1000 meq/kg DM) or wheat grain (1250 meq/kg DM) tend to lower rumen pH and need more salivary bicarbonate, produced

**Table 3:** Typical optimal operating parameters for anaerobic digestion and rumen digestion

| | Digester | Rumen |
|---|---|---|
| *Feedstock or feed* | | |
| Total volatile solids or DM (g/kg fresh weight) | 100 to 300 | 400 to 500 |
| Carbon: Nitrogen | 25:1 | 15:1 |
| *Fermentation* | | |
| Temperature (°C) | 25 to 40 | 38 to 40 |
| pH* | 7 to 8 | 6 to 7 |
| Ammonia-N (mg/litre) | 50 to 70 | 50 to 80 |
| Average residence time (days) | 21 to 65 | 1 to 2 |
| *Biogas* | | |
| Methane (% of total gas) | 50 to 60 | 30 to 40 |
| Methane energy (% of total energy intake) | 55 to 80 | 3 to 15 |

*Optimal conditions
Source: Satter and Slyter, 1974; McDonald *et al*., 1995; Chamberlain and Wilkinson, 1996; Holter and Young, 1992; Ørskov, 1998; Amon *et al*., 2007b; Al Seadi *et al*., 2008 and Weiland, 2010.

 

during rumination and stimulated by fibrous feeds of relatively high NDF concentration (Schultze *et al*., 2014), to balance this effect (Offer *et al*., 2004). In the absence of such information for different feedstocks destined for use in AD, evaluation of their potential effects on the pH of digestate in terms of PAL would be a valuable aid to feedstock formulation. However, the variation in PAL and NDF between different varieties of forage maize is likely to be relatively small compared to that between different crop species and by-products used as feedstock sources for AD.

Ammonia nitrogen (N) can accumulate in digestate and rumen when the supply of feed protein or non-protein nitrogen (e.g. urea) exceeds its assimilation into protein by the microbial population. Elevated concentrations of ammonia N (>80 mg $NH_3$-N/litre) can be toxic to methanogens (Al Seadi *et al*., 2008) and give rise to raised concentrations of $NH_3$ in biogas (Strick *et al*., 2006). Higher concentrations of ammonia in the rumen can lead to elevated concentrations of ammonia in blood, with increased risk of reduced livestock fertility (McEvoy *et al*., 1997). The optimal concentration of $NH_3$-N in rumen fluid is 50 to 80 mg/litre (Satter and Slyter, 1974), similar to that for AD (Table 1). Forage maize has a relatively low concentration of crude protein (N x 6.25) compared to other forage crops and by-products (Thomas, 2004) and would normally be balanced by additional supplementary protein or NPN to meet requirements for degradable N (Chamberlain and Wilkinson, 1996). The risk of excess ammonia in digestate and rumen fluid is low provided supplementary N is included at the correct level, mixed uniformly with other ingredients and there are no other factors (e.g. toxins or deficiencies in essential minerals) that might reduce microbial growth and reduce the rate of synthesis of ammonia into microbial protein.

Diet formulation for the dairy cow involves balancing the composition of one ingredient with that of others so that the total diet meets the requirement of the animal for nutrients within constraints, of which the most significant is daily DM intake. Thus the relatively low protein concentration of maize silage is balanced with feeds of relatively high protein concentration such as lucerne, soyabean meal or urea. Similarly, adding complementary components to the digester can mitigate variation in individual feedstock composition. Phenotypic variance in whole-plant maize feedstock may therefore be of lesser importance than crop yield *per se* in determining choice of cultivar provided alternative sources of feedstock are available at competitive cost.

## 4. Desirable traits of whole-plant maize

Compared to other crops, forage maize has three important characteristics that contribute to making well-preserved silage - relatively high concentrations of DM and water-soluble carbohydrates and a relatively low buffering capacity or resistance to acidification. Thus the risk of secondary (clostridial) fermentation in maize silage is low, even at relatively low DM concentration (Weissbach *et al*., 1974; Wilkinson, 2005). However, excessive loss of water-soluble carbohydrates, high silage acidity and elevated concentrations of soluble nitrogen are features of whole-plant maize ensiled at low concentrations of DM (Wilkinson and Phipps, 1979; Wilkinson *et al*., 1998). It is therefore advisable to harvest the crop at DM concentrations above 275g/kg fresh weight to minimise fermentation losses.

Barrière *et al*. (1997) reviewed the phenotypic attributes of forage maize for silage and stressed the importance of a well-developed rooting system to aid resistance to lodging and drought, and also to increase efficiency of nitrogen utilisation by the crop. They suggested a target grain concentration at harvest of 0.46, corresponding to 0.30 starch, as optimal in maize silage for dairy and beef cattle. The target stage of maturity at harvest for optimal utilisation by the dairy cow is 300 to 350g DM/kg fresh weight (Browne *et al*., 1995; Wilkinson *et al*., 1998). At this stage of plant maturity starch comprises about 0.67 of the grain endosperm (Bal *et al*., 1997).

Optimal maize plant maturity for AD is probably similar to that for the animal, though the decrease in plant cell wall (NDF) digestibility with advancing plant maturity may be relatively less important for AD than for the animal in view of the longer residence time in the digester than in the cow (Table 1). Nevertheless, rate of fibre digestion and residence time in the digester determine rate of methane production. Enhanced digestibility of maize silage allows average residence time in the digester to be reduced or, for new digesters, the same amount of methane may be produced from a digester with a smaller volume. Weissbach (2009) found that gas yield from a range of silages was related to digestible (i.e. fermentable) organic matter (FOM), which in turn could be predicted from concentrations of ash and acid detergent fibre. Average potential biogas yield from silages was 800 litres/kg FOM and methane yield was 420 litres/kg FOM. Frei (2013) reviewed the different roles of lignin, a complex carbohydrate polymer cross-linked to cell wall hemicelluloses that confers structural strength to the plant, in plant stress, animal nutrition and bio-energy production. He concluded that low concentrations of lignin are desirable for both animal feeding and biogas production. In the ruminant, lignin concentration and NDF digestibility are inversely related (Van Soest, 1994). Oba and Allen (1999a) found that a one unit increase in forage NDF digestibility *in vitro* was reflected in 0.17 kg increase in DM intake and 0.25 kg increase in fat-corrected milk yield in dairy cows. The lower lignin brown midrib (*bm3*) mutant (Cherney *et al*., 1991) has higher NDF digestibility and supports greater milk production and feed conversion efficiency than conventional hybrids (Oba and Allen, 1999b; Kung *et al*., 2008). The *sfe* maize mutants with reduced ferulate lignin–arabinoxylan cross linkage also have higher cell wall digestibility and intake than conventional hybrids, resulting in higher milk production (Jung *et al*., 2011). Barrier and Argiller (1993) highlighted the lower yield and susceptibility to lodging of brown midrib hybrids and suggested that genetic variation could lead to the selection of brown midrib hybrids of high agronomic value. Lauer and Coors (1997) reviewed 18 agronomic and dairy cattle feeding trials comparing brown midrib and conventional maize hybrids. They concluded that although NDF was lower for *bm3* than for conventional maize (by an average of 2%) and milk output per tonne of crop was higher (by 4%), yield per acre was lower for the bm3 hybrids by 6% and milk per acre was reduced by 2%.

**Table 4:** Effect of stage of forage maize harvest on AD specific methane yield and on methane yield per hectare

| | Harvest 1 | Harvest 2 | Harvest 3 |
|---|---|---|---|
| Harvest (days after sowing) | 97 | 122 | 151 |
| Stage of grain maturity | Milk ripeness | Wax ripeness | Full ripeness |
| Dry matter (g/kg fresh weight)[1] | 187 | 293 | 468 |
| Volatile solids (g/kg fresh weight)[1] | 178 | 278 | 452 |
| Specific methane yield (litres $CH_4$/kg volatile solids)[1] | 338 | 308 | 278 |
| Methane yield per hectare ($m^3$ $CH_4$)[2,3] | 6350 | 7270 | 7930 |

[1]Means of three years and four late-maturing cultivars (FAO 290 to FAO 600).
[2]Means of three years and three late-maturing cultivars.
[3]$m^3$ = cubic metres at normal temperature and pressure.
Source: Amon *et al*., 2007b.

A very important attribute of maize for biogas is output per hectare of land, so yield of biomass (as DM or volatile solids) may be an overriding criterion in selection of species, cultivar and stage of plant maturity at harvest. Amon *et al*. (2007a) studied biomass and methane yields of a range of ensiled crops - maize, wheat, triticale, rye, sunflower and grass. They found that the highest methane yield per hectare was from maize harvested at the "wax ripeness" stage of maturity (300 to 350 g DM/kg fresh weight).

The effect of stage of maize plant maturity at harvest on specific methane yield and on methane yield per hectare is shown in Table 4. Specific methane yield decreased with advancing plant maturity. The decrease in specific methane yield with increased plant maturity reflected reduced concentration of fibre and increased concentration of starch in the whole plant DM, consistent with the reduction in methane production in the rumen with reduced proportion of acetate in the rumen VFA associated with increased concentrate in the diet (Yates, *et al*., 2000 and Table 1). However, despite reduced specific methane yield, the large increase in crop yield with advancing grain ripeness was reflected in an increase in methane output per hectare. Schittenhelm (2008) concluded that the ideal maize hybrid for biogas was a later-maturing hybrid that can be harvested at a DM concentration consistent with the production of good quality silage i.e. around 300 g DM/kg fresh weight.

Amon *et al*. (2004, 2007b) found that ensiling increased the specific methane yield of whole-crop maize by 0.25 compared to the fresh crop, presumably because the products of the silage fermentation were reduced compounds and more suitable substrates for utilisation by *Archaea* than the original water-soluble carbohydrate substrates. The possibility of directing fermentation in the silo by inoculating the crop at harvest was explored by Vervaeren *et al*. (2010) who added a range of inoculants to whole-plant maize ensiled at 26% DM. They found that specific methane yields after a 21-day incubation were higher from additive-treated than from untreated silage, and tended to be higher from silages treated with additives containing heterofermentative lactic acid bacteria (that produced lactic and acetic acids) together with cell wall degrading enzymes, than from silage treated with predominantly homofermentative lactic acid bacteria that produced lactic acid as the sole end product of fermentation (McDonald *et al*., 1991). The storage period may influence the efficacy of additive since Herrmann *et al*, (2011) found little effect of additive treatment on methane yield after an ensiling period of one year. They also noted a decrease in lactic acid and increases in acetic acid and in methane yield with increased length of storage period.

Several phenotypic characters of the maize plant have been found to exert a significant influence on methane production; namely crude protein, crude fat, cellulose and hemicellulose (Amon *et al*., 2004, 2007b). Calculation of theoretical biogas potential (gas yield and methane concentration) is possible from pre-determined concentrations of crude fibre, crude protein, crude fat, ash and moisture (Allison, 2011). Rath *et al*. (2013) found that concentrations of crude fat and hemicellulose in maize were positively related to biogas yield whilst acid detergent lignin and water-soluble carbohydrates were negatively related to biogas yield. In view of the positive relationship between crude fat concentration of maize and specific methane yield, cultivars with elevated concentrations of oil may be worth exploiting for AD, provided their biomass yield is competitive with conventional hybrids.

Grieder *et al*. (2012a, b, c) made a comprehensive study of genetic parameters of maize hybrids for biogas involving 570 testcross progenies of 285 inbred dent lines. Heritability estimates were high but genotypic variance and hence heritability in specific methane yield decreased towards the end of the 35-day fermentation, reflecting almost complete degradation of potentially digestible components during the relatively long residence period. Variation in total methane yield per hectare was mainly attributable to variation in DM yield. They concluded that introgression of later maturing or exotic material may be productive, with selection for higher DM yield and less focus on ear proportion for biogas maize compared to forage maize for animal feed.

In situations where large distances have to be travelled between field and farm, the cost of transportation of the crop is likely to be affected significantly by crop DM concentration. This cost should be taken into account in determining the optimal stage of plant maturity for harvesting for biogas production and supports full ripeness as the optimal stage of harvest for maximum methane yield per hectare (Table 4).

A challenge for the future is to optimise AD methane yield, ideally via in-line real-time analysis of feedstock composition using near infrared reflectance spectroscopy

 

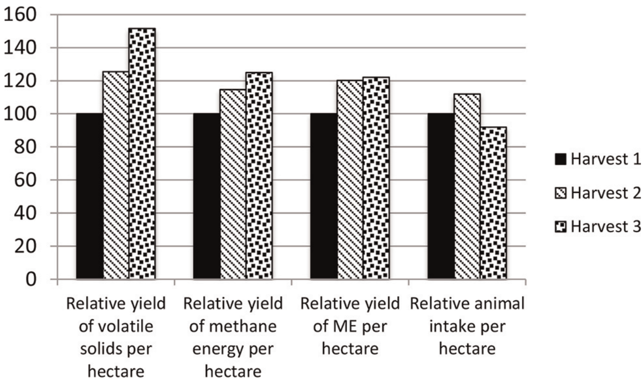


**Figure 1:** Effect of stage of maize crop harvest on relative yield of biomass, methane energy, ME and animal intake per hectare (Harvest 1 = 100). **Source:** Based on data in Table 4.

(Jacobi *et al.*, 2011), and also by determining factors in the ensiling process that impact significantly on methanogenesis.

In an attempt to integrate the effects of maize crop maturity on both biogas and animal nutrition, the data of Amon *et al.* (2007b, Table 4) and Oba and Allen (1999) were used to compare three dates of harvest in terms of biomass yield, methane energy yield, ME yield and animal intake per hectare of land. The results (Figure 1) are to be treated with caution since ME concentration and NDF digestibility were estimated for the purposes of the comparison. Nevertheless, the trends were similar for biomass, methane energy yield and ME yield, with yields increasing progressively with advancing crop maturity. Relative animal intake was highest at the medium crop maturity.

## 5. Conclusions

Yield of whole-plant maize biomass per hectare should be the main criterion of maize cultivar performance assessment for AD. Selection of cultivars for use in AD with elevated concentrations of oil or reduced concentrations of lignin may be desirable. Maize cultivars for use as animal feed should contain i) a relatively high proportion of ear in the total plant DM to give a high concentration of starch and ii) high NDF digestibility, to meet animal requirement for readily available rumen-fermentable forage energy. Selection of forage maize and other forage crop cultivars for both AD and animal feed should include evaluation of NDF concentration and NDF digestibility.

## About the author

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REFEREED ARTICLE

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# The role of differing farming motivations on the adoption of nutrient management practices

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**ABSTRACT**

This study examined nutrient management practice adoption across a cohort of farmers in the Republic of Ireland with particular emphasis on the role played by different farming motivations. Results of a count data model indicated a number of distinct farming motivations are positively related to farmers' behaviour in the adoption of nutrient management best practices. Specifically farmers more motivated by classifications of 'farm stewardship', 'ecocentric' and 'productivist' considerations were more likely to adopt a greater number of the nutrient management best practices under review. Conversely, the results also indicated that 'anthropocentric' considerations were important to some farmers and this had a negative effect on adoption. A number of demographic and structural variables such as age, off-farm employment status, contact with extension services were found to be significantly related to the probability of adoption of nutrient management practices examined. This analysis highlights important considerations for targeting farmer cohorts for forward land-use planning with regard to tailoring policy measures and incentives in onward reviews of environmental directives and schemes.

**KEYWORDS:** Nutrient management; practice adoption; farmer motivations

## 1. Introduction

Farm and field level nutrient management best practice have been shown to significantly improve both farm level profitability (Buckley and Carney, 2013) as well as end of catchment water quality outcomes (Rao *et al.*, 2009). Best practice in the area of nutrient management promotes strict management of nutrients (nitrogen (N) and phosphorus (P) mainly) on land to reduce the risk of nutrient mobilisation in runoff pathways to water bodies. The risk to water bodies from excessive N and P supply is over nourishment, or eutrophication, and this can cause biodiversity and amenity impairment (Van Grinsven *et al.*, 2013). According to the European Environment Agency (2012), despite some progress, diffuse pollution from agriculture is still significant in more than 40% of Europe's water bodies in rivers and coastal waters, and in one third of the water bodies in lakes and transitional waters.

As a mitigation measure for managing diffuse pollution from agricultural land, farm and field level nutrient management is considered one of the most cost-effective and is embedded in good agricultural guidelines and regulations (Zhang *et al.*, 2012). Indeed, Wright *et al.*, (2011) found that in Denmark half of the reduction in N leaching for achievement of Water Framework Directive objectives (deemed necessary from agriculture) could be achieved by low cost win-win good agricultural practices at farm level.

However, much like participation in wider agri-environmental and conservation schemes, policymakers often express frustration at the observed levels of adoption of nutrient management practices (Pannell *et al.*, 2006). This frustration is even more apparent when increased adoption rates have the potential to lead to a double dividend of increased economic returns to agricultural production while reducing the risk of nutrient transfer to the aquatic environment.

Ideally, policymakers would have a complete understanding of what motivates farmers to adopt desirable nutrient management practices (NMPs) and could then deliver the appropriate set of incentives and messages to amendable individual producers (Prokopy *et al*, 2008). There is a large and increasing literature which suggests farmers' behaviours result from complex processes influenced by a range of socio-economic, psychological and social variables (Willock *et al*. 1999a; 1999b; Pannell *et al.*, 2006; Rehman *et al.*, 2007; Greiner *et al.*, 2009). To-date the literature has focused on the role of environmental attitudes in farmers' decision to adopt best practices in the area of the environment; this paper

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is an exploratory analysis and builds on this literature by specifically exploring other positive and negative motivations underlying nutrient management practice adoption. This paper has the following objectives i) to examine the effect of different underlying farming attitude based motivations on NMP adoption and ii) examine farmer personal and farm structural factors on NMP adoption. The paper proceeds as follows, firstly a review of the practice adoption literature and farmer motivations in this area is presented then the methodology for this study is outlined, results are then presented and some conclusions and discussion is offered.

## 2. Background

### Best practice adoption

There is a growing literature surrounding best practice adoption by farmers and the factors that affect their management behaviour. A variety of socio-demographic factors such as age, education, off-farm employment or identification of a successor have been found to be significantly related to the probability of adopting best management practices (Rahelizatovo and Gillespie 2004; Prokopy *et al*., 2008; Ghazalian *et al*., 2009; Gedikoglu *et al*., 2011; Genskow, 2012). Farm structural and business variables identified to be important include farm size, production intensity, level of diversification and compatibility with current systems (Monaghan *et al*., 2007; Isgin *et al*., 2008; Prokopy *et al*., 2008; Ghazalian *et al*., 2009; Lapple and Van Rensburg, 2011). A number of studies have also highlighted the importance of various factors related to the provision of relevant information needed for nutrient best management such as contact with extension or government agents and or participation in a farmer network or watershed groups as influential in best management practice adoption (Rahelizatovo and Gillespie 2004; Paudel *et al*., 2008; Lemke *et al*., 2010; Baumart-Gertz *et al*., 2012).

The characteristics of the best management practice itself can also affect the probability of adoption as issues such as complexity, familiarity, trialability, cost effectiveness, uncertainty or perceived usefulness have been found to influence technology adoption (Kaiser *et al*., 1999; Flett *et al*., 2004; Pannell *et al*., 2006; Gillespie *et al*., 2007; Monaghan *et al*., 2007; Rehman *et al*., 2007; Ingram, 2008; Vermeire *et al*., 2009; Lemke *et al*., 2010). Finally, positive environmental attitudes and or environmental awareness have been found to influence best management practice adoption (Prokopy *et al*., 2008; Lemke *et al*., 2010).

A limited number of studies have focused exclusively on adoption of NMPs or associated technology adoption. Monaghan *et al*. (2007) found the issue of cost, complexity, compatibility with the current farm system and a perceived uncertainty of actual environmental benefits were key barriers to adoption of some NM technologies in New Zealand. Gedikoglu *et al*. (2011) found that adoption of injecting manure into the soil is positively and significantly impacted by off-farm employment of the farm operator, but off-farm employment had no effect on adoption of record keeping. Ghazalian *et al*. (2009) found that farms with larger animal production enterprises are more apt to implement manure management practices as were those belonging to an agro-environment club. Genskow (2012) found that nutrient management planning courses can lead to changes in farmer nutrient management behaviours but not always toward reducing nutrients. Vermeire *et al*. (2009) found that the successful implementation of desirable animal manure measures was influenced by uncertainty and/or the absorptive capacity of farmers towards new ways of nutrient management in general.

### Farmer Motivations

While farmers' production strategies are influenced by technical aspects related to agricultural production and farm structure, differences in farming motivations also play an important role in farmer decision making (Darnhofer *et al*., 2005). Specifically, while business related motivations such as maximising profits will be important to farmers, it may not in many instances be their core motivation for farming. Social scientists have increasingly identified typologies of farmers based on different farming motivations and there is strong evidence from a wide range of studies that there are distinct behavioural categories, some driven more by business and economic motives and others more by environmental or productivist objectives. Pannell *et al*., (2006) suggested that farmers will adopt a new technology/farm practice when he/she perceives that the innovation in question will enhance the achievement of their personal goals. Farmers in turn are influenced by a multiplicity of goals and a myopic view of the profit maximisation goal as driving farm decisions may misrepresent farmers behaviour (Basarir and Gillespie, 2006; Pannell *et al*., 2006; Gillespie and Mishra, 2011, Lokhorst *et al*., 2011).

In this study, through presenting farmers with various attitude based statements different sets of farming motivations are identified which, it is hypothesised, will affect the probability of farmers adopting the nutrient management practices examined. First, in line with much previous research which suggests that productivist motivations are important to famers, a distinction is made between the goals of profit and output maximisation. While agricultural policy may have shifted from production oriented to more decoupled forms of payment, farmers still tend to overwhelmingly obtain a productivist mind set (Gorton *et al*., 2008).

The potential role of environmental values has previously received considerable attention in explaining farmers' environmental related farm practices (Kantola *et al*., 1983; Lynne and Rola, 1988; Beedell and Rehman, 2000; Greiner *et al*., 2009). While some studies have found a discrepancy between environmental attitudes and conservation-oriented management (see for example Plieninger *et al*., 2012), the general finding is that farm operators with more positive environmental attitudes are more likely to engage in conservation behaviour. However, adoption of NM best practices has resource use efficiency and agronomic benefits in addition to environmental ones. These motivations for NM best practice adoption have not received anything like the same attention and are a primary focus of this research.

## 3. Methodology

### Data

The data for this analysis were derived from a survey of farmers within twelve river catchments located throughout the Republic of Ireland and across a range of soils and land use gradient. Geographic Information Systems multi-criteria decision analysis was employed to select these case study catchments, ten of which ranged mostly from 4 $km^2$ to 12 $km^2$ and two were approximately 30 $km^2$. The criteria used for selection included maximisation of agricultural intensity (based on percentage arable or forage area and livestock grazing intensity), minimisation of non-agricultural land uses (forestry, residential housing density) and the selection of a range of soil and geology types that were indicative of high N or P transport risk. The method for catchment selection is further described in detail by Fealy *et al.* (2010). These catchments were selected to represent the range of intensive grassland and arable agricultural interests in the Republic of Ireland across a soil and physiographic gradient that defines potential risk of P and / or N transfers. Consequently, they tend to represent more intensive areas of agricultural production.

A questionnaire was designed to collect data from farmers across a range of topics including attitudes to farming and the environment, farm structures and profile, socio-demographics, contact with extension services and adoption of a range of nutrient management best practices. This questionnaire aimed to establish a baseline in terms of nutrient management practices, assess farmer willingness to provide ecosystem services and explore farmer opinion on regulations post EU Nitrates Directive implementation across the Republic of Ireland. The questionnaire was administered by a team of professional recorders to a total of 402 farmers across the 12 catchments in 2010 with a base year of 2009. For the purposes of this analysis the sample size is restricted to systems which generate and store organic manures so the effective sample size for this analysis is 271 farmers. Table 1 outlines the farm profile of the sample.

In consultation with farm extension agents ten nutrient management practices were selected for investigation. These encompassed the nutrient management planning, application and recording best practice continuum (Beegle *et al.*, 2000). The criteria for each practice is outlined in Table 2 and each practice takes a binary yes/no form, hence a farmer undertaking all would achieve a score of 10. Other NM practices were not considered in this analysis as a higher level of data resolution would be necessary for exploration then was available through the questionnaire instrument.

It should be noted here that elements of NMPs 1 and 2 are mandatory in the Republic Ireland for some farmers. If a farmer is allowed a derogation to farm at a higher stocking rate under Nitrates Directive regulations, then it is mandatory to perform a periodic soil test and develop a nutrient management plan (Wall *et al.*, 2012). Additionally, soil testing is part of CAP funded agri-environment based scheme(s) in the Republic of Ireland. However, there is evidence from the sample that farmers were undertaking these actions for regulatory compliance and not actually consulting when making nutrients management decisions. So only where farmers expressly indicated referring to a soil test result or a nutrient management plan were they deemed to have engaged with best practices.

## Modelling the intensity of practices adoption

As the number of practices adopted is a non-negative integer, the application of standard ordinary least-squares regression (based on an assumption of a continuous dependent variable) is not appropriate. Given that the dependent variable is a non-negative integer, a count data model was used to assess intensity of practice adoption. A count data model predicts the number of times an event occurs (Cameron and Trevedi, 1998) where the dependant variable is measured by the number of nutrient management practices undertaken by a farmer in the survey year which is a discrete non-negative integer value count. It is common in the literature to use the Poisson regression model as a starting point (Lord and Mannering, 2010). As outlined by Cameron and Trevedi (1998) the Poisson model can be defined as follows:

$$f(y_i - x_i) = \frac{e^{-\mu_i}\mu_i^{yi}}{y_i!},\ y_i = 0,1,2,\ldots, \quad (1)$$

where $y_i$ are the number of nutrient management practices adopted by the farmer and $x_i$ are a vector of explanatory variables that affect practice adoption. The $\mu_i$ parameter represents the mean number of expected events and can be expressed as:

**Table 1:** Farm profile of the sample

| | Mean | Range |
|---|---|---|
| Farm Size (utilizable hectares) | 62.2 | 6.1 – 412.8 |
| Crops (hectares): | | |
| Grassland | 50.2 | 0 – 230.0 |
| Arable | 12.0 | 0 – 363.8 |
| Livestock: | | |
| Dairy cows LU's | 25.8 | 0 – 275.0 |
| Cattle LU's | 53.5 | 0 – 230.0 |
| Sheep flock (ewes) | 27.1 | 0 – 700.0 |
| Main Farm Enterprise* | **% Sample** | |
| Dairying | 33% | |
| Livestock rearing | 62% | |
| Arable | 5% | |

*Typology based on EU Farm Accountancy Data Network methodology classification (A complete description of the Farm Typology system is given in Commission Regulation (EC) No 1242/2008)

 

**Table 2:** Description of nutrient management best practices

| **Nutrient Management Practices** |
|---|
| 1. *Soil testing* - This variable takes a value of 1 if a farmer has soil tested at least once in the previous 5 years and indicated using the results for nutrient management. |
| 2. *Nutrient management plan* – This variable takes a value of 1 if a farmer has a de-facto nutrient management plan based on soil testing and indicated using this plan for nutrient management. |
| 3. *Estimation of nutrient content of organic manures* - This variable takes a value of 1 if the farmer indicated using scientific guidelines to estimate the N and P content of organic manure pre-application. |
| 4. *Chemical fertiliser calibration* – This variable takes a value of 1 if the chemical fertiliser spreader is calibrated to apply specific quantities at the field level. This variable is constraint to 0 in the absence of reference to a soil test or nutrient management plan. |
| 5. *Organic manure calibration* – This variable takes a value of 1 if the organic manure spreader is calibrated to apply specific quantities at the field level. This variable is constraint to 0 in the absence of reference to a soil test or a nutrient management plan. |
| 6. *Springtime manure application* – This variable takes a value of 1 if at least 50 per cent of organic manure is applied in the spring season. |
| 7. *Organic manure application method* – This variable takes a value of 1 if the farmer indicates using a trailing shoe, band or injection method of application. |
| 8. *Liming* – This variable takes a value of 1 if the farmer indicates applying lime to land on a regular basis. This variable is constrained to 0 in the absence of reference to a soil test. |
| 9. *Chemical fertiliser recording* - This variable takes a value of 1 if chemical fertiliser applications at the field level are being recorded. |
| 10. *Organic manure recording* - This variable takes a value of 1 if organic manure applications at the field level are being recorded. |

$$\mu_i = E[y_i|x_i] = \exp\left(x_i^{'}\beta\right) \qquad (2)$$

Where the logarithm of the conditional mean is linear in the parameters In $E[y_i|x_i] = x_i^{'}\beta$. Assuming independent observations the log-likelihood can be expressed as:

$$In\ L(\beta) = \sum_{i=1}^{n} y_i x_i^{'}\beta - \exp\left(x_i^{'}\beta\right) - In\ y_i! \qquad (3)$$

The Poisson model properties require the mean and variance of $y_i$ to be equal. Often in count data this assumption is violated as there often tends to be over/under dispersion leading to underestimation of standard errors, overestimation of chi-squared statistics and inefficiency of estimates (Cameron and Trevedi, 1998). Where the mean variance condition is not satisfied a more flexible modelling of the variance such as the negative binomial model which allows for the presence of over dispersion maybe necessary. The Poisson model is generally easy to estimate but in addition to over/under dispersion it can be adversely affected by low sample means and can produce biased results in small samples (Lord and Mannering, 2010). This will be examined in greater detail below in the context of this research.

## Farmer Motivations

In the survey questionnaire, respondents were read out a list of statements and asked to state how much they agreed or disagreed with these set of statements on a scale from 1 (completely disagree) to 8 (completely agree) as recommended by Garforth *et al.*, (2006). The statements drew on a variety of previous work where attitudinal statements were used to capture diverse farming motivations (Duram 1997; Willock, 1999b; Ryan 2003; Maybery, 2005; Brodt *et al.*, 2006; Barnes *et al.*, 2007; Davis and Hodge, 2007; Lapelle and Kelly, 2013). Using principal component analysis (PCA), these data was reduced to a number of latent constructs reflecting diverse farming motivations.

PCA was employed to extract underlying latent constructs. Factor analysis involves data reduction and operates by examining the pattern of correlations (or covariances) among a number of variables. PCA transforms a set of correlated variables into a smaller number of uncorrelated factors or variables (Kline and Wichelns, 1998). Factor loading coefficients were used to derive standardized factors for the sample population. Factor scores are advantageous as they can be employed in regression analysis in place of the original attitudinal statements, with the knowledge that the meaningful variation in the original data has not been lost but that the derived variables are uncorrelated thus preventing any potential multi-collinearity problems.

## Explanatory variables

A number of different underlying farming motivations as well as farmer personal and farm structural factors were hypothesized to influence the uptake of nutrient management practices examined. Table 3 provides an overview of the explanatory variables included in the regression analysis.

It is hypothesized that information and knowledge transfer around the adoption of the prescribed practices is most likely to come from contact with an agricultural advisor and participation in a network such as a farmer discussion group. Farmer discussion groups are facilitated by an agricultural advisor; hence farmers in these groups would also by definition have regular contact with an agricultural advisor. Consequently, two dummy variables were included in the analysis, the variable ‘contact with an advisor’ took a value of 1 if a farmer had engaged an agricultural advisor in the previous 12 months and the variable ‘advisor & discussion group’ took a value of 1 if the respondent is a participant in a farmer discussion group.

**Table 3:** Explanatory variables that were included in the model

| Variable | Variable Description | Mean | Min | Max |
|---|---|---|---|---|
| Farm Stewardship motivations | Derived factor score (see Table 4) | 0 | −3.2 | 0.9 |
| Eco-centric motivations | Derived factor score (see Table 4) | 0 | −4.3 | 2.0 |
| Productivist motivations | Derived factor score (see Table 4) | 0 | −5.9 | 1.6 |
| Anthropocentric motivations | Derived factor score (see Table 4) | 0 | −2.3 | 3.0 |
| Contact with farm advisor | 0=No contact with an advisor or discussion group. 1=Engaged with an agricultural advisor in the previous 12 months. | 0.45 | 0 | 1 |
| Contact with farm advisor & discussion group | 0=No contact with an advisor or discussion group. 1=Participant in a farmer discussion group facilitated by an agricultural advisor. | 0.23 | 0 | 1 |
| Age | 1=under 36 years; 2=36-65; 3=+65 years. | 2.0 | 1 | 3 |
| Partial farmyard manure system | 0=No FYM was generated on farm. 1=Some FYM generated on farm. | 0.18 | 0 | 1 |
| Full farmyard manure system | 0=No FYM was generated on farm. 1= Only FYM generated on farm. | 0.09 | 0 | 1 |
| Off-farm employment | 0=Not employed off-farm 1=Employed off-farm | 0.25 | 0 | 1 |
| Total organic N kgs $Ha^{-1}$ | Kilogrammes of organic nitrogen per hectare. | 124.5 | 11.6 | 322.0 |
| Farm size | Area farmed in hectares | 62.1 | 6.1 | 412.8 |

Demographic and farm structural variables included in the analysis were age of the farmer, off-farm employment status, type of organic manure storage system, livestock production intensity and farm size. Older farmers tend to be more conservative and farmers engaged in off-farm employment may have less time to dedicate to on-farm management activities. Animal waste is stored in either liquid (slurry) or more solid forms (farmyard manure based on straw bedding). Farmyard manure (FYM) is more difficult to apply evenly, it takes longer to breakdown and to be absorbed into the soil and the nutrient content also tends to be more variable. This variable tends to be reflective of livestock housing facilities as older facilities would generally tend to hold animal waste as FYM. More solid based FYM storage systems do not as readily lend themselves to some of the practices under review given that FYM is not as easy to handle and apply as liquid slurry based systems. Consequently two dummy variables were included in the analysis, one named 'partial-FYM' took a value of 1 if FYM and slurry were generated and a second variable 'FYM' took a value of 1 if only FYM was generated.

Production intensity has been shown to influence best practices adoption (Lapple and Van Rensburg, 2011). Hence, a variable labelled organic N (ON) production is included in the analysis; this is an indicator of livestock farming intensity and is measured in kg ON $ha^{-1}$. This is estimated based on average numbers and type of animal held on farm and applying standard coefficients (e.g. 1 dairy cow is equivalent to 85 kg ON) for different livestock types (as set out in Nitrates Directive regulations (Government of Ireland, S.I. 601 of 2010). Finally, farm size in hectares was included in the analysis.

## 4. Results

### Farmer Motivations

Following a PCA a total of four factors emerged. The explained proportion of the total variation of the original variables was 65%. A Kaiser-Meyer-Olkin measure of factor suitability was 0.81, indicating the use of factor analysis on this dataset to be appropriate (Kaiser, 1974). Using Bartlett's measure of Sphericity the null hypothesis was rejected that the correlation matrix is an identity matrix and the alternative hypothesis was accepted that there is a significant relationship between the variables ($p < 0.0001$). A reliability test using Cronbach's alpha was applied to assess the internal consistency and reliability of the derived factor variables. Values above 0.5 are considered acceptable as evidence of a relationship (Nunnally, 1967), whereas values above 0.7 are more definitive (Peterson, 1994). The factor loadings in Table 4 represent correlations between all respondents' answers to each attitudinal statement with the derived component scores. There is a high degree of consistency in responses to the attitudinal statements used to derive the factor variables as indicated by a Cronbach's Alpha of 0.95 and 0.75 for factors 1 and 2 and just over 0.5 for factors 3 and 4.

The PCA resulted in four factors with an eigenvalue greater than one and as such were chosen for further analysis. These four latent constructs (factors) reflect diverse farming motivations.

The statements that had high loadings for factor 1 were strongly associated with general principles of good farm management such as making best use of farm resources, maximising yields and farm profits and minimizing risk in the area of the environment. This factor included statements indicating the importance of managing and storing manure correctly and avoiding a cross compliance violation – both involve risk management and have financial consequences under EU Nitrates based regulations if found in breach. As such, this factor variable representing good farm business management and was labelled '*farm stewardship*'. The statements that had high loadings on factor 2 were related to farming in a manner that protects the environment and was hence labelled as '*ecocentric*'. The third factor variable reflects productivist motivations and statements that were important here reflect the importance to which farmers place on maximising farm

 

**Table 4:** Farmer attitude factors and component statements

| Statements | Farm Stewardship | Ecocentric | Productivist | Anthro-pocentric |
|---|---|---|---|---|
| Maximizing and making best use of my farm resources is important to me. | **0.96** | −0.05 | 0.02 | −0.00 |
| Storing and using slurry and manures correctly is important to me. | **0.93** | −0.06 | 0.00 | 0.01 |
| Achieving the highest yield possible from my livestock/ crops is important to me. | **0.92** | −0.06 | 0.03 | 0.02 |
| Avoiding a cross compliance violation is important to me. | **0.88** | 0.08 | −0.04 | −0.01 |
| Maximising farm profits is important to me. | **0.85** | −0.12 | 0.12 | −0.00 |
| If it reduces pollution a farmer should change or adapt his/her farm practices. | −0.05 | **0.84** | 0.05 | −0.05 |
| It is important to take the environment into consideration, even if it lowers farm profits. | −0.13 | **0.77** | −0.15 | −0.05 |
| Farmers have to play their part in reducing environmental pollution. | −0.04 | **0.75** | 0.25 | −0.11 |
| It is appropriate that farmers should be held responsible for agricultural related water pollution. | 0.05 | **0.64** | 0.21 | −0.12 |
| Monitoring farm production levels is important. | 0.09 | 0.21 | **0.75** | −0.14 |
| A farmer must be oriented towards production to survive and be successful. | 0.03 | −0.04 | **0.73** | 0.06 |
| Good quality farmland not in production is being wasted. | −0.02 | 0.11 | **0.60** | 0.13 |
| Maximizing farm profits is more important than protecting the environment. | −0.05 | −0.20 | 0.15 | **0.73** |
| Any increase in pollution is insignificant compared to the benefits of increasing production. | −0.09 | −0.09 | −0.07 | **0.71** |
| Damage to the environment is beyond a farmer's control. | 0.20 | −0.11 | 0.19 | **0.60** |
| Eigen values | 4.3 | 2.7 | 1.6 | 1.3 |

output. Therefore this factor was labelled '*productivist*' motivations. The final factor was labelled *anthropocentric* as it consisted of statements that place the farmer's needs ahead of those of the environment. The higher a farmer's score on each of these factor variables, then the higher their overall level of agreement with the statements that make up that factor.

## Intensity of NMP adoption

Table 5 reports on the adoption of the ten nutrient management practices under review. Results indicate that recording of chemical fertiliser applications (74%) and majority springtime application of organic manures (70%) were the most popular practices across the sample, while use of a nutrient management plan (27%) and newer organic manure application methods (5%) were the least popular.

Table 6 reports on the intensity of NMP adoption. A total of 1% of the sample (3 farmers) didn't undertake any of the practices while the same proportion undertook all 10 practices. The mean number of practices undertaken across the sample was 5.26 with a variance of 5.67. This satisfies the mean variance and low-sample mean conditions necessary for the Poisson model as outlined in section 3.2 (Lord and Mannering, 2010). The Poisson model was hence adopted in this analysis to explore intensity of practice adoption.

Table 7 reports the results of a Poisson count data model on the number of practices adopted. Results indicate that all the derived factor variables significantly

**Table 5:** Type of nutrient management practices undertaken by farmers

| Nutrient Management Practice | Numbers adopting | Percent Adopting |
|---|---|---|
| Chemical fertiliser recording | 201 | 74% |
| Springtime organic manure application | 191 | 70% |
| Soil testing | 180 | 66% |
| Chemical fertiliser field calibration | 170 | 63% |
| Organic manure recording | 156 | 58% |
| Liming | 140 | 52% |
| Organic manure field calibration | 130 | 48% |
| Estimation of nutrient content of organic manures | 128 | 47% |
| Nutrient management plan | 72 | 27% |
| Organic manure application – Trailing shoe, band or injection. | 14 | 5% |

(N=271)

**Table 6:** Number of nutrient management practices undertaken by farmers

| Number of practice | Number of farmers undertaking practice(s) | Percent of farmers undertaking practices |
|---|---|---|
| 0 | 3 | 1% |
| 1 | 14 | 5% |
| 2 | 21 | 8% |
| 3 | 29 | 11% |
| 4 | 41 | 15% |
| 5 | 43 | 16% |
| 6 | 30 | 11% |
| 7 | 23 | 8% |
| 8 | 47 | 17% |
| 9 | 18 | 7% |
| 10 | 3 | 1% |
| Mean | 5.26 | |
| Standard deviation | 2.38 | |

affect the number of best management practices adopted by farmers. Specifically, there is a significant and positive association between both *farm stewardship* and *productivist* motivations with the number of nutrient management practices adopted. Environmental values also appear to be important when it comes to explaining adoption practices. Farmers with an *ecocentric* value orientation were likely to adopt a higher number of nutrient management practices. On the other hand, farmers identified as having *anthropocentric* orientations were more likely to place greater importance on economic over environmental issues and were less likely to adopt the nutrient management practices under review.

Contact with an agricultural advisor and advisor contact plus participation in a farmer discussion group had a positive effect on the overall number of NMPs adopted. Farm structural variables were also found to influence intensity of practice adoption. Age (5% level), off-farm employment (5% level) and FYM storage systems were all negatively and significantly related to intensity of NMP adoption. Farm size and livestock production intensity were associated with higher adoption rates, but the effect was not found to be significant in this instance. The Wald chi-squared statistic for the model shows that, taken jointly, the coefficients for this model specification are significant at the 1% level. The model predicts the mean number of practices

**Table 7:** Results of Poisson regression for nutrient management practice adoption

| | Parametric estimates | Marginal effects |
|---|---|---|
| Farm stewardship | 0.08** (0.03) | 0.38 |
| Ecocentric | 0.08*** (0.03) | 0.42 |
| Productivist | 0.07** (0.03) | 0.37 |
| Antropocentric | −0.04* (0.02) | −0.21 |
| Advisor contact | 0.20*** (0.06) | 1.01 |
| Advisor contact & discussion group | 0.20*** (0.07) | 1.09 |
| Age | −0.116** (0.05) | −0.59 |
| Partial FYM system | −0.13* (0.07) | −0.63 |
| Full FYM system | −0.26** (0.12) | −1.17 |
| Off-farm employment | −0.17** (0.07) | −0.85 |
| Total Organic N $Ha^{-1}$ | 0.001 (0.00) | 0.003 |
| Farm size | 0.001 (0.00) | 0.003 |
| Constant | 1.72*** (0.14) | |
| Log pseudolikelihood = −578.2 | | |
| Wald chi-squared = 117.5 | | |

***1% level, **5% level, *10% level, †Discrete changes (from 0 to 1) for these variables adopted to be 5.26 which is the same as the mean number of actual practices adopted (Table 6). The model predicts the actual number of practices adopted for 20 per cent of the sample and within +/- 1 practices for a further 35 per cent of the sample. Hence the model predicts accurately or within +/- 1 practice for 55 per cent of the total sample. Additionally, the model predicts within +/- 2 practices for a further 22 per cent of the sample.

Table 7 also reports marginal effects for each independent variable with all other variables held at their means. Results indicated that farmers with off-farm employment were likely to adopt just under 1 (0.85) less NMPs on average. Age also had a negative impact on adoption rates with NMPs undertaken on average declining by 0.59 per increasing age category. Fewer of the NMPs under review were adopted where farmyard manure was the more dominant method of organic manure storage. Where all organic manure was stored in the more solid FYM form the number of NMPs adopted declined by 1.17 compared to fully liquid slurry storage systems. Contact with an agricultural advisor and advisor contact plus participation in a farmer discussion group had a positive overall relationship with NMP uptake as respectively each class of contact increased the number of practices adopted by circa 1-1.1.

## 5. Discussion and conclusions

Demographics and farm structures have long been established to influence best practice adoption in the literature, yet solutions to increasing best practice adoption rates among farmers remain elusive. In keeping with the substantive body of previous work on practice adoption a number of farm structural variables in this study were found to affect the number of NMPs adopted by farmers. Age and off-farm employment were found to constrain best practice adoption. The effect of off-farm employment status could be due to time constraints of the individual farmer in that the use of certain NMPs can be relatively labour intensive. This means that irrespective of any potential economic benefits, some farmers may simply not have the time to implement certain nutrient management practices. Older farmers tend to be more conservative in relation to the uptake of new management practices and results from this study are consistent with this. Common Agricultural Policy pillar two co-funded based incentives for installation of young farmer and a retirement scheme for older farmer have existed in the Republic of Ireland since the MacSharry reform in 1992 until a suspension in 2008. Yet the average age of farmers across the Republic of Ireland has increased from 51 years in 2000 to 54 years in 2010 (CSO 2002; 2012). Recent CAP reforms have included additional direct payments for young farmers and potentially more could be done in this area given that 28% of single farm payment recipients were 65 years or older while only 5% were 35 or under at the end of this period (Murphy, 2012). FYM systems of organic manure storage were negatively associated with the number of NMPs adopted in this study. These less fluid systems of organic manure storage tend to be associated with older housing facilities and do not lend themselves as readily to the practices examined. Significant capital investment would be required to convert to more liquid systems of manure storage and policymakers could offer incentives in this area to promote substitution towards more liquid based systems of organic manure storage.

Results from this study indicate higher adoption rates were associated with contact with an agricultural advisor or advisor contact plus participation in a farmer discussion group network. The causality of this relationship is unclear as more progressive farmers maybe more likely to engage with these extension based contacts in the first instances. However, there is an information burden associated with some of the practices under review and these extension contacts maybe assisting to address the information burden associated with implementation of some of the NMPs examined. Additionally, peer influence from agricultural advisors or other farmers may influence adoption rates. Policymakers in the Republic of Ireland have acknowledged this by providing incentives for farmers to join farmer discussion groups where adoption of new techniques is a requirement for incentive based payments (DAFM, 2013; 2014). A longer term analysis of adoption outcomes and persistence of practice adoption of discussion group participant will attest to the success of these incentives.

To date much of the focus has been on the role of *ecocentric* motivations on farmers' conservation behaviour and results here also indicate this motivation is an important factor in explaining the number of nutrient management practices adopted. However, findings from this study introduce other motivations that drive NMP adoption. All of the practices under review have potential positive profitability and production potential in addition to environmental benefits and results here indicate that farm stewardship (or business) as well as productivist motivations significantly affect the probability of farmers adopting NMPs. Underlining the business, productivist and environmental benefits of NMPs can potentially play an important role in farmer decision making processes as highlighting these specific benefits can assist farmer to identify with the one that is in keeping with their own motivations and self-identity. Promoting and re-enforcing the multi-functional benefit of these practices among farmers with either farm stewardship, ecocentric or productivist motivations could increase adoption rates and embed these practices into farmer routines. Conversely, farmers with anthropocentric based motivations were likely to adopt a lower number of practices and are less likely to be open to this message – suggesting a different policy approach based more on regulation or compulsion. Research in other jurisdictions has shown that low cost win-win type nutrient management practices as mainly examined in this study can greatly assist in achieving environmental policy objectives in the area of water quality (Wright *et al.*, 2011). Appealing to farmers' farm stewardship, productivist or ecocentric motivation could assist adoption in this area as could incentives through agri-environment schemes (regulatory based approaches are also open to policymakers). However, exclusively relying on adoption of these practices is unlikely to be enough to sufficiently reduce diffuse pollution from agriculture in certain catchment areas for achievement of objectives under the EU Water Framework Directive. It maybe that in addition of NM best practices adoption, critical source areas, where the risk of nutrient transfers from agricultural production to the aquatic environment is greatest, need to be identified and adaptive land management strategies implemented on these land parcels to better manage this risk maybe necessary. However, policymakers ought to be guided by a better understanding of farmer motivations and the constraints faced by farmers in adopting NMP and be able to tailor policy measures for maximum effectiveness on this basis.

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# REFEREED ARTICLE

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# Rural livelihood adoption framework: A conceptual and analytical framework for studying adoption of new activities by small farmers

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**ABSTRACT**

The adoption of new income generating activities is a critical livelihood diversification strategy for many small farming households in developing countries. However, innovation adoption in a rural context typically involves complex processes and complicating factors, and rates of discontinuation can be high, with consequent wastage of public and private resources. This paper describes (1) the development of a new conceptual framework with which to analyse the complexity of adoption of new livelihood strategies, and then (2) describes its application in a case study involving mushroom cultivation by smallholder farmers in Vietnam. The new conceptual framework, termed Rural Livelihood Adoption Framework (RLAF), is based on a combination of DFID's Sustainable Livelihoods Framework, Ellis' Rural Livelihood Framework and Rogers' Diffusion of Innovations theory, to capture multi-dimensional factors including livelihood assets, innovation attributes, livelihood outcomes, livelihood systems, vulnerability, and policy and institutional contexts. The application of RLAF to the selected case study of adoption of mushroom cultivation in rural Vietnam enabled systematic and comprehensive description of the livelihood trajectories of the innovation adopters, and identification of critical factors and ways in which those factors influenced adoption behaviours at each stage. It also provided the basis for developing strategies to overcome sustained adoption constraints and barriers. The RLAF is thus an analytical tool with considerable utility for identification of systemic problems impacting on rural livelihoods in developing countries, and for devising effective and relevant solutions.

**KEYWORDS:** innovation adoption; rural livelihood; livelihood diversification; mushroom cultivation

## 1. Introduction

Although causes and consequences of livelihood diversification are differentiated in practice by location, assets, income, opportunity and social relations (Ellis, 1998), it has been long recognized as an efficient risk management mechanism to spread risks, and/or earn additional income to supplement that from the main agricultural activities, and thus sustain livelihoods in a risk-prone and uncertain world (Misha *et al*., 2004; McNamara and Weiss, 2005; Hussein and Nelson, 1998). On-farm diversification appears particularly to suit poor rural producers as it helps restructure their production mix more easily than investment in non-farm businesses (Hussein and Nelson, 1998), as well as enhance efficiency of the use of the existing livelihood assets such as natural resources, labour, and skills (Misha *et al*., 2004).

The process of diversifying livelihood activities for the individual farmer is to identify, learn about, implement, adopt and ultimately integrate new income generating activities or innovations into the existing livelihood system. Schipmann and Qaim (2010) argue that innovation adoption can be an important avenue for smallholder farmers to improve their situations. At the macro-scale, innovations, particularly those involving sustainable technologies, are believed to be able to contribute to achievement of regional and national sustainable development goals (Guerin, 2001). Therefore, innovation adoption in agriculture has attracted significant attention among governments, development agencies and their agents, scientists, practitioners, and the public.

In studies of agricultural innovation adoption processes, identifying enabling factors and reducing constraints to adoption has become a priority (Doss, 2006). Research aimed at identifying those factors needs to be based on an understanding of the adoption experiences of adopters, from their first exposure to the innovation,

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through persuading themselves to trial it, followed by a confirming decision to continue or discontinue after a period of implementation. This five-stage innovation adoption process (Rogers 1983) has been widely acknowledged in the literature as effectively describing the innovation adoption process (Feder *et al.*, 1985; Frank, 1995a; Frank, 1995b; Girsang, 2005; Moreland, 2011).

We are especially interested in learning how rural communities in the developing world diversify livelihoods by adopting new activities into their farming system(s). To do this, we developed a conceptual framework in a study designed to explore, in one district of Vietnam, the experiences of subsistence farmers who attempted to adopt mushroom culture into their farming system. The conceptual framework we developed - Rural Livelihood Adoption Framework (RLAF) - integrates several widely accepted research concepts: the Sustainable Livelihoods Framework (DFID, 1999); the Rural Livelihood Framework (Ellis, 2000); and the Innovation Adoption Process (Rogers, 1983).

There are two aims for this paper. The first is to develop the RLAF, and the second is to use the adoption of mushroom cultivation as a case-study with which to critique the utility of RLAF. We explore its capability in enabling systematic and full description of the livelihood trajectories of the innovation adopters, understanding critical factors influencing adoption behaviours at each stage of the adoption process, and then identifying constraints and adopters' strategies to overcome them. Through a combination of different methods including deep interviews and household surveys, the research methodology combines qualitative and quantitative approaches to describing, analysing and evaluating the adoption experiences of respondents.

The remainder of this paper consists of five main sections and a conclusion. First, we briefly review selected literature on rural livelihood study frameworks (Section 2) and on innovation adoption theory (Section 3). In Section 4 we present the conceptualization of RLAF, and in Section 5 the application of RLAF will be illustrated via the case study on the mushroom cultivation adopters in Giao Thuy district, Nam Dinh province, Vietnam. The utility of RLAF is discussed in Section 6, with concluding comments in Section 7.

## 2. Frameworks for rural livelihood study

The contemporary origin of livelihoods research is the Sustainable Livelihoods Framework (SLF) advocated by the Department for International Development of the U.K (DFID, 1999). The framework defines five components of livelihood assets: human (H), natural (N), financial (F), physical (P) and social (S). The capacity of people to pursue a livelihood strategy, and the success or otherwise of those strategies, is affected not only by their access to these assets, but also by different aspects of their vulnerability, which is largely a function of social, political and economic structures and processes (DFID, 1999; Prowse, 2010). SLF does not prescribe the exact methods to be used for research (Tang *et al.*, 2013), but it could be seen as a set of principles, an analytical framework and an objective (Small, 2007; Morse *et al.*, 2009). However, operationalizing the entire SLF appeared to become an overwhelming task for practitioners to complete (Morse *et al.*, 2009; Prowse, 2010), such that 'livelihoods analysis became an end in itself, without contributing to evidence-based policy' (Prowse, 2010, p. 220).

In an attempt to overcome shortcomings of SLF, Ellis (2000) developed the Rural Livelihood Framework (RLF), which has been demonstrated as being flexible enough to be applied at all scales, from micro, meso to macro (Murray, 2002; Prowse, 2010). More importantly, RLF is more suitable than SLF when studying how poor households in low-income countries combine activities and straddle spaces (Prowse, 2010). RLF also starts with the five livelihood assets accessible by individuals or households, operating within a context of multiple vulnerabilities, to achieve their livelihood strategies through the mediating processes of social relations, institutions, and organizations (Ellis, 2000).

Both frameworks use the same core components of assets, livelihood activities or strategies, outcomes, vulnerability context, and policy and institutional context. However, what is missing from both these frameworks is specific attention to the process of livelihood strategy selection, incorporation and review. For insights into this process we turn to the literature on adoption of innovations.

## 3. Innovation adoption for rural households

To adopt an innovation, the unit of adoption (individual, household or organisation) will go through a multi-stage process over time (Frank, 1995b; Moreland, 2011) from knowledge, persuasion, decision, implementation, to confirmation (Rogers, 1983; Rogers, 1995). Recent scholars may consolidate these five stages into two phases of initiation and implementation, but they still clearly reflect the stages that Rogers describes (Moreland, 2011).

The adoption process begins when a unit of adoption is exposed to a new idea and gains some understanding about it. Based on the obtained knowledge, the potential adopter will form a favourable or unfavourable attitude toward the innovation at the persuasion stage. Subsequently, there will be engagement in activities to make a decision to adopt or reject that innovation. Implementation occurs when the innovation is put in practice. Ultimately, results from the implementation and other sources of information will help either to reinforce or to reverse the previous decision (Rogers, 1983; Rogers, 1995).

It is important to note that adoption is a complex process (Guerin, 2001), whose outcomes at each stage cannot be certain due to various factors. Some of the key explanatory factors affecting adoption of agricultural innovations, with particular reference to developing countries, have been comprehensively analysed and found to include: farm size, tenure, human assets or capital (such as education, age, labour availability, gender, and farmers' innovative attitudes, goals and behaviours), alternative income sources, credit constraints, supply constraints, information accessibility, infrastructure conditions, risk and uncertainty, extension service, price changes and exposure year (Carletto *et al.*, 2010; Schipmann and Qaim, 2010; Willock *et al.*, 1999; Lin, 1991; Feder *et al.*, 1985). In addition, agricultural innovation adoption researchers in other Asian countries have proved the importance of informal social networks, especially at the individual level, for farmers to obtain information and make an adoption decision during the early stages (Maertens and Barrett, 2013; Schipmann and Qaim, 2010; Matuschke and Qaim, 2009).

 

Those factors affecting the adoption decision and adoption sustainability can be categorized in three groups of intrinsic, extrinsic and innovation characteristics (Girsang, 2005). Intrinsic characteristics are those of the innovation adopters, while extrinsic factors are those of the external environment impacting on livelihood vulnerability. Innovation characteristics include the five attributes of relative advantage, compatibility, complexity, observability, and trialability (Rogers, 1983; Girsang, 2005).

## 4. Rural livelihood adoption framework

As stated above, the current livelihood frameworks appear to not reflect explicitly the dynamic process of livelihood adoption and/or rejection strategies among rural communities. Therefore, we propose the Rural Livelihood Adoption Framework (RLAF) to combine the livelihood frameworks (DFID, 1999; Ellis, 2000) and the innovation-decision process (Rogers, 1983) in order to describe and analyse how a unit of adoption (i.e. individual, household or organization) can use livelihood assets to assess an innovation's attributes, and subsequently go through stages in the innovation adoption process within specific circumstances in order to obtain outcomes, and adopt or reject the inclusion of the innovation into the existing farming livelihood system.

The combination of these two frameworks, illustrated in Figure 1, is possible due to the fact that both are closely linked, especially for subsistence farmers seeking to diversify their income sources. In addition, both are related to and influenced by the common factors such as livelihood assets (intrinsic characteristics of the decision making unit), vulnerability context, and also the political and institutional context (extrinsic factors).

RLAF captures seven elements to describe a dynamic picture, in that an adoption unit uses the lens of existing activities, experiences ***(existing livelihood system)*** and ***outcomes*** (i.e. income, increased wellbeing, reduced vulnerability, improved food security, and more sustainable use of natural resources) through which to view and consider adopting a new livelihood activity. The unit is characterized with a specific set of ***livelihood assets*** (human, natural, physical, financial and social). Upon exposure to a ***new livelihood activity*** (innovation), the unit will consider its stocks of the five livelihood assets or capitals to study the innovation attributes of that new activity (relative advantage, compatibility, complexity, trialability and observability) throughout the ***innovation adoption process*** (from awareness, evaluation, decision, implementation, to confirmation (acceptance or rejection).

At the outermost layer, vulnerability and policy and institutional contexts are critical extrinsic factors influencing all the components in the framework. ***Vulnerability context*** encompasses trends, shocks and seasonality (DFID, 1999; Ellis, 2000). Needless to say, livelihood strategies, activities, and outcomes are strongly influenced by and also exert feedback effects on both perceived and actual vulnerability (Tang *et al.*, 2013). However, 'vulnerability is not a measurable concept' (Ellis, 2003a, pp. 5), and thus requires indirect indicators to assess the direction in which vulnerability is moving. In addition, the '***policy and institutional context***' is defined by structures associated with government (national and local), authority, laws and rights, democracy and participation (Ellis, 2003b). Scoones (1998) emphasizes

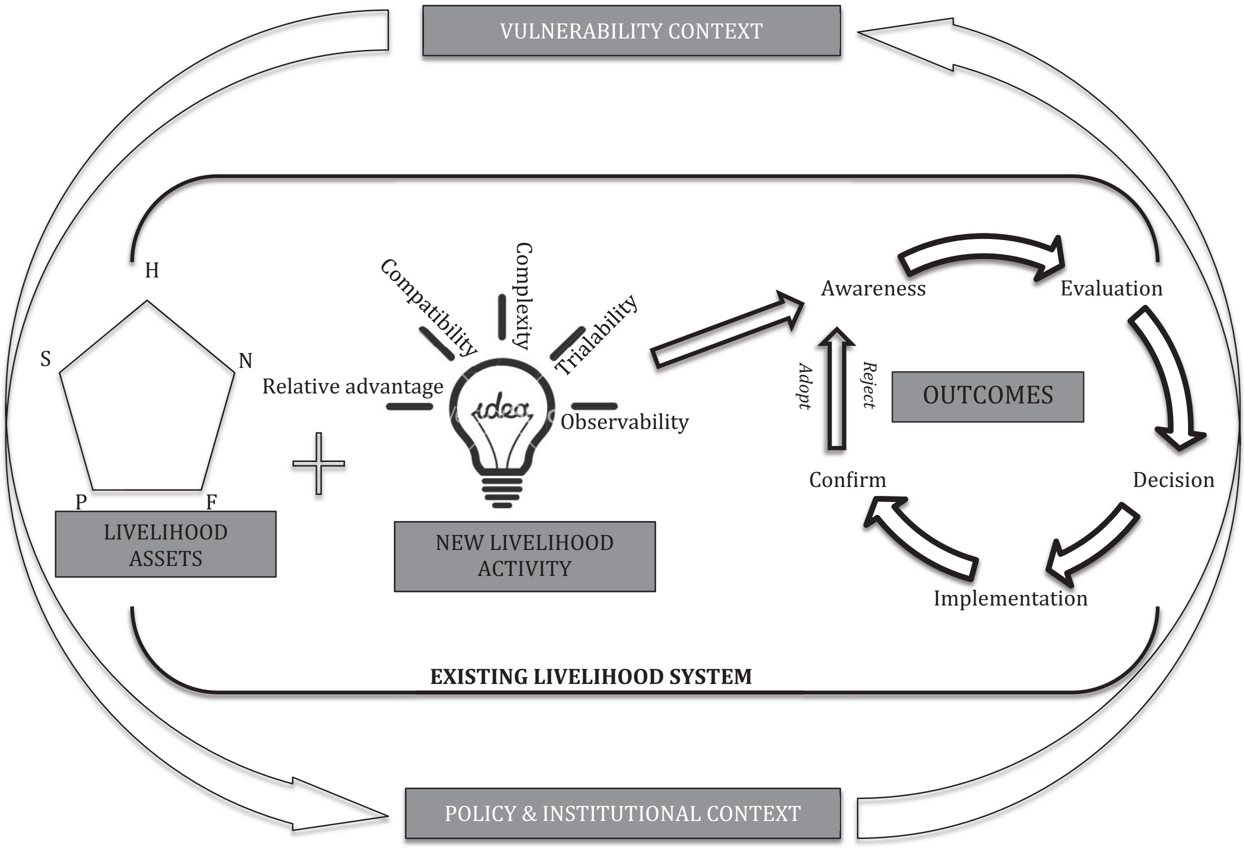


**Figure 1:** Rural Livelihood Adoption Framework (RLAF). **Source:** Adapted from DFID (1999), Ellis (2000) and Rogers (1983).

that institutions (laws, rules and cultural practices) may be formal and informal, and more importantly often ambiguous and fluid, which means institutions are continually being shaped and reshaped over time. Policy and institutional context is critical in the sense that it mediates access to livelihood resources and influences the portfolios of livelihood strategies or activities (Scoones, 1998; Ellis, 2000). Consequently, institutional context can either block / disable, or encourage / enable, and thereby improve livelihoods (Ellis, 2003a).

The '***innovation adoption process***' in the framework consists of the same five stages as Rogers' theory of innovation diffusion (Rogers, 1983). However, instead of considering five stages in a linear sequence, *the adoption process in RLAF is considered as a circle with an exit point at every single stage*, because innovation adoption at the micro-level should be seen from a dynamic perspective as an acquisition of information and a learning process (Feder *et al*., 1985; Marra *et al*., 2003) due to continuous changes in household and environmental conditions (Carletto *et al*., 2010). Consequently, the unit of adoption at each stage must seek and process information from its own and others' experiences, to reduce uncertainty about advantages and disadvantages of a specific innovation (Rogers, 1983, Warner, 1974 cited in Marra *et al*., 2003).

During the process, especially at the implementation stage, Rogers notes a common phenomenon of 're-invention' of the original innovation (Rogers, 1983). In other words, the innovation itself and thus perceived knowledge and awareness of adopters about the innovation are likely to evolve over time. Thus, adopters must continue to consider benefits and costs in implementing the new activity in order to modify their inter-temporal decision to adopt or withdraw (Carletto *et al*., 2010), which explains late adoption decisions after rejection, or discontinuance of an innovation after previous adoption (Rogers, 1983). In short, the innovation adoption process could be seen as a continuous process, without an end, like a cycle, in which adopters always need appropriate reasons to maintain and sustain a new livelihood activity in changeable contexts.

The preceding material establishes seven components in RLAF: livelihood assets, new livelihood activity or innovation, adoption process, outcomes, existing livelihood system, vulnerability context and policy and institutional context. Each component has a number of dimensions and indicators that help analyse and assess the corresponding component. While the dimensions are principal items, the indicators for each dimension need to be flexible or numerous in order to suit different types of livelihoods applications. For example, the livelihood assets pentagon elegantly and comprehensively represents the five dimensions at a conceptual level (Morse *et al*., 2009), but in reality it is not simple to analyse and measure livelihood assets because each form may contain many elements that are subject to context specificity i.e. likely to change from household to household, with geography and over time. In addition, Morse *et al*., (2009) argue that some assets, such as social networks, knowledge and good health, are not straightforward to measure. 'These asset categories are admittedly a little contrived, and not all resources that people draw upon in constructing livelihoods fit neatly within them' (Ellis, 2003b, p. 3). As a result, researchers can work according to the components or principal dimensions, but employ recommended indicators based on their own experiences and literature reviews to identify indicators to suit research topics and purposes.

## 5. RLAF application: Influential factors and barriers in the adoption of mushroom cultivation

### Research subject

To investigate farmers' livelihood adoption experiences, the research chose the farming activity of mushroom cultivation being adopted by farmers in Giao Thuy district, Nam Dinh province, Vietnam. If agricultural innovations can be classified into three broad types of institutional, technological, and social innovations (French *et al*., 2014), mushroom cultivation belongs to the second type, which refers to the application of new technological practices to produce and market new goods.

Many communities in Vietnam have tried growing mushrooms. Amongst these, Giao Thuy was an interesting case for study, for several reasons. Firstly, this district has favourable conditions for growing mushrooms, and with production output of 270 tons in 2012, was the third biggest mushroom producer in Nam Dinh province, which is among the main mushroom production areas in the country (*Center for Advanced Science and Technology Application*, 2010). Furthermore, the district is home to Xuan Thuy national park, and many community development and livelihood projects including mushroom culture have been particularly designed for the local people here with the aim of reducing development pressures on the natural resources in the park. As a result, Giao Thuy farmers have far more financial, technical and institutional advantages to adopt new farming technologies, including to produce mushrooms, than many other communities. However, despite these natural and policy advantages, the sustained adoption of the practice has been low. Many farmers decided to discontinue the practice not long after adoption, others continued for only a few years, and relatively few have persisted to the present. Consequently, the adoption of mushroom culture as a livelihood diversification remains relatively infrequent and predominantly at a small production scale. Reasons for the limited success of the policy initiative are unclear. Based on these conditions, Giao Thuy is an appropriate site where livelihood adoption research can easily approach, identify and analyse the livelihood adoption process and influencing factors, especially constraints limiting long-term incorporation into livelihoods.

### Research method

To investigate and analyse factors working both for and against the adoption and sustainability of mushroom cultivation in the area, the research was mainly about the *retrospective* and *circumspective* (Murray, 2002) to understand past experiences of households growing mushrooms in Giao Thuy. A dichotomous variable approach (Feder *et al*., 1985) was used to define the research population, which includes all the households or adoption units that had been farming any kind of mushroom species on various substrate materials in the research site, since initial introduction.

Tools to collect both qualitative and quantitative data in the research were purposive sampling combined with interactive semi-structured interviews, and a random sample survey (Kanbur, 2005). Data collected in 2013 from the key informants indicated 84 households in twelve communes had adopted mushroom cultivation since the mid-1990s. To obtain representative and non-biased data from the survey, stratified sampling was employed to divide households into two groups based on their current status of mushroom cultivation: (1) currently inactive households which used to grow mushrooms, and (2) currently active mushroom farms. At the time of the study, there were 42 households in each group, reflecting a discontinuation rate of 50%.

Two phases of semi-structured interviews with key institutional (government and NGO) informants were also conducted in order to triangulate farm household findings, and gather enriching contextual information regarding policy, societal and commercial trends impacting farmers in the region.

The research conceptual model – RLAF – was the basis for exploring the livelihood adoption experiences among the mushroom farmers and the factors influencing their decisions at every stage. An array of indicators was assembled that reflected all components of the model. Many were adopted or adapted from previous studies, and others were devised specifically for this study. These indicators (Table 1) then informed development of comprehensive questionnaires and interview guides, and analysis of socio-economic and ecological information obtained in the research.

## Livelihood adoption findings

Through the household survey, all the adoption factors and experiences of the mushroom farmers in Giao Thuy were identified and summarized in Table 2. At the early stage of the adoption process, farmers were attracted to mushroom cultivation because they perceived their assets endowment was sufficient for growing mushrooms, when combined with other supportive conditions including project funds availability. In order for a favourable attitude towards this new livelihood activity to persist, farmers needed to be able to perceive its relative advantages, in particular its potential for good income generation, and to estimate its compatibility with respect to requirements for skills and capital, through observation of neighbourhood successes. These findings reinforced the likelihood that each stage of the innovation decision process is impacted by certain sets of factors, particularly the characteristics of the decision-making unit at the knowledge stage, and perceived characteristics of the innovation (new farming practice) at the persuasion stage (Rogers, 1983; Rogers, 1995; Girsang, 2005).

An impression through responses of the local farmers was that there has been quite a number of livelihood development projects of NGOs, research and development institutions, vocational training centres, and Government extension organizations to stimulate this livelihood in Giao Thuy (Center for Advanced Science and Technology Application, 2010; Q. H. Dinh 2013 pers. comm., 16 July; X. T. Nguyen 2013 pers. comm., 20 October). Many famers (43%) adopted as a direct result of such projects and spillover effects. However, they received little follow-up extension support, even when they had been funded by such projects. Consequently, many farmers eventually dropped the new activity, pushing the cumulative discontinuance rate to 50%.

Following adoption of mushroom cultivation, all farmers reported developing concerns over the suitability of the innovation as they experienced problems with one or several farming stages from input acquisition, through nurturing and harvesting, to marketing of the products. They also began to realise their lack of various livelihood assets, such as finance (70% of respondents), knowledge, skills, physical facilities, and a reliable and adequate water source. Socio-economic data showed that the mushroom growing households in Giao Thuy were among the vulnerable groups that are characterized with low socio-economic status, low education level, and low change agent contact. In other words, they had all three critical characteristics of high discontinuers as described by Rogers (1995). Additional to the intrinsic constraints were the contextual factors of unstable markets (47%), unreliable input supply (30%), variable natural conditions (30%), and crop diseases (10%).

In terms of innovation attributes, the profit potential for mushroom cultivation was quite observable to the repondents, and thus attracted them to trial it. People can havest and sell mushrooms after only 1 to 3 months, and income is much higher than other conventional farming activities like rice growing (P. T. Vu 2013 pers. comm., 09 October). However, other characteristics were subsequently percieved to be incompatible with the farmers' limited assets, including a high labour requirement, high capital investment, and demanding physical and technical work. In addition, the local farming experience provided little support for the novel activity of growing mushrooms. This incompatibility was explained by a senior mushroom grower that ''our conventional farming activities are all outdoors, whereas mushroom cultivation is indoors and extremely sensitive to weather conditions and infections, and requires lots of attention just like taking care of a child'' (P. T. Vu 2013 pers. comm., 09 October). By that statement, the key informant emphasized that the mushroom farmers must change their habits, and apply a much stricter management regime to successfully grow mushrooms than required by other crops. These findings agree with Rogers' observation that difficulties at the implemenation stage, in institutionalising and routinising a new activity into the ongoing practice and way of life of adopters, affect subsequent sustained adoption. These dificulties are typically derived from the low compatibility of innovation characteristics with people's beliefs and past experiences, and negative perception about relative advantage (Rogers, 1995). Thus, mushroom cultivation to many farmers is a relatively high risk business, which requires high levels of investment of money, time, farm resources, labour and management attention, yet contains much uncertainty not only in the production process, but throughout the supply chain from input supply to fair market access, receiving an adequate price and earning a reliable income.

In short, the intrinsic and extrinsic constraints as well as the non-supportive innovation attributes identified in the research clearly explain the high rate of discontinuation among the mushroom growers in Giao Thuy district. These explanatory factors and their interactions all fit neatly into the components of RLAF to vividly tell a story about the major challenges in continuing growing mushrooms in this area (Figure 2).

**Table 1:** Research indicators based on the components and dimensions of the Rural Livelihoods Adoption Framework included in survey instruments

| RLAF component | Dimension | Scale/Indicator | Characteristic | Adapted from: |
|---|---|---|---|---|
| Livelihood assets | Human (H) | Labour<br>Skills<br>Education<br>Mushroom training | Intrinsic | Ellis, 2000<br>DFID, 1999<br>Lin, 1991 |
| | Natural (N) | Rice field<br>Rice straw<br>Water access | Extrinsic | Ellis, 2000<br>DFID, 1999 |
| | Financial (F) | Family wealth ranking<br>Access to credit/cash (borrowed money for growing mushrooms) | Intrinsic | Doss, 2006 |
| | Physical (P) | Mushroom tent (size & materials)<br>Machinery (straw cutter, sterilization, drying)<br>Storage<br>Package<br>Transportation means<br>Road system | Intrinsic<br><br><br><br><br>Extrinsic | Aguilar et al., 2002 |
| | Social (S) | Member of organization(s)<br>Member of mutual group(s)<br>Relationship with marketing unit(s) | Intrinsic | Ellis, 2000<br>DFID, 1999 |
| Livelihood attributes (Innovation) | Relative advantage | Profit<br>Reduced cost<br>Reduced risk<br>Improved market access<br>Speediness of reward<br>Convenience | Innovation | Rogers, 1983<br>Rogers, 1995 |
| | Complexity | Software: Knowledge/Information to do the livelihood<br>=Suit knowledge/education<br>Hardware: physical attributes<br>=Suit labour and skills | Innovation | |
| | Compatibility | Fit into existing livelihood system<br>Suit past experiences<br>Fit into values/needs<br>Fit into lifestyle<br>Fit into social system | Innovation | |
| | Trialability | Implement at small scale | Innovation | |
| | Observability | Observable degree | Innovation | |
| Outcomes from new livelihood | Livelihood security | Income level<br>Income stability<br>Seasonality<br>Degrees of risk | Innovation | Ellis, 2000 |
| | Environment sustainability | Reduce straw burning<br>Improve soil quality | Innovation | |
| Adoption process | Awareness | Initial source of information | | Rogers, 1983<br>Rogers, 1995 |
| | Evaluation | Information source for clarity | | |
| | Decision | Scale trial | | |
| | Implementation | Farmers seek information to reduce uncertainty<br>Problems and solutions | | |
| | Confirmation | Adopt or reject?<br>Future plan | | |
| Existing livelihood system | On-farm activities | Existence of on-farm activities | Intrinsic | Ellis, 2000 |
| | Off-farm activities | Existence of off-farm activities | Intrinsic | |
| Vulnerability context | Shocks | Diseases<br>Weather fluctuations | Extrinsic | Ellis, 2000<br>Ellis, 2003 |
| | Trends | Regional economic trends<br>Food (mushroom) consumption habits | Extrinsic | |
| | Supply chain system (SC) | Buyers (wholesale, end consumers)<br>Market types (local, cities)<br>Distance from market<br>Price instability<br>Input suppliers (spawn) | Extrinsic | |
| Policy & institutional (P&I) context | Policies | Policies to support mushroom cultivation | Extrinsic | Ellis, 2000 |
| | Intermediary | Local groups<br>Extension services<br>NGOs<br>Private companies<br>Communication sources and channels | Extrinsic | Rogers, 1983 |

 

**Table 2:** Factors influencing the adoption process of mushroom cultivation

| Prior conditions | Awareness | Persuasion | Decision | Implementation | Confirmation | |
|---|---|---|---|---|---|---|
| Desire to create jobs and increase household income | 1st awareness /impressions about mushroom cultivation to enable people to acknowledge it could be a relevant new livelihood | To encourage the livelihood adoption, people considered possibility to grow at least one specific mushroom species first | People decided to firstly try only one species at a suitable scale. After trial, people decided to either maintain the same or increase production scale. | Different stages in mushroom production:<br>• Input acquition (substrates and spawn)<br>• Mushroom nurturing<br>• Harvesting<br>• Proce ssing (could be omitted)<br>• Selling | ***For discontinuers***<br>(people confirmed to discontinue mushroom cultivation) | ***For continuers***<br>(they could confirm to maintain the same production size (0), or plan to increase production (+) to suit their capacity) |
| **Main Factors** (ranked from the most to least important) | **Assets:**<br>• H: labor, experience<br>• F: financial capacity<br>• N: available substrates<br>• S: network (relatives'/ friends' supports)<br>**P&I context:**<br>• Project support<br>• Spillover effect (Follow others)<br>• Media<br>**Vulnerability context:**<br>• Good market | **Innovation characteristics:**<br>• High profit<br>• Simple technology<br>• Easy product processing & storage<br>**Assets:**<br>• H: knowledge, skills<br>• N: available substrates<br>**Vulnerability context:**<br>• Weather<br>• Market | | **Assets:**<br>• F: low capital investment<br>• H: limited knowledge, skills<br>• P: poor/lack of physical facilities<br>• N: lack of fresh water<br>**Vulnerability context:**<br>• SC: Market (unstable, unfair prices); supplier (insufficient, low quality)<br>• Weather: storms, rain, humidity<br>• Diseases: infection with mold<br>**Micro-context:**<br>• H: lack of labor (engage in other livelihood activities) | **Assets:**<br>• H: lack of labor<br>• P: degraded facilities<br>• F: Low capital<br>**Vulnerability context:**<br>• SC: Market (unstable, unfair prices); supplier (insufficient, low quality)<br>• Diseases: often at 2nd and subsequent crops<br>• Livelihood replacement<br>**Innovation characteristics:**<br>• Relatively low income<br>• Intensive physical work | **Assets:**<br>• N: land (0/+)<br>• H: labor, knowledge, skills (0/+)<br>• F: finance (0)<br>**Innovation characteristics:**<br>• Compatible with current capacity (0)<br>**Vulnerability context:**<br>• SC: stable market (+)<br>**Micro-context:**<br>• No alternative livelihoods (+) |

## 6. Discussion on the utility of RLAF as a research framework

The Rural Livelihood Adoption Framework (RLAF) is an attempt to integrate innovation adoption concepts into rural livelihoods study. RLAF was based on the well-studied frameworks of DFID's Sustainable Livelihood Framework and Ellis's Rural Livelihood Framework, which have been commonly applied in different rural contexts, especially in developing countries by the development agencies and institutes like DFID, UNDP, FAO, CARE, Oxfam, SIDA etc. (Neely *et al.*, 2004; DFID, 1999). We believe RLAF has advantages over other approaches in the sense that the theories and operations behind this integrative framework would be familiar to rural livelihood researchers and community development practitioners around the world, and thus it would anticipate fairly quick responses and/or applications.

The integrative framework contains seven components including livelihood assets, livelihood attributes, livelihood outcomes, adoption process, existing livelihood system of the research unit (i.e. household), vulnerability context, and political and institutional context. These components combine attributes of the sustainable livelihood concept and frameworks (Ellis, 2000; DFID, 1999; Chamber and Conway, 1991) and the diffusion of innovation theory (Rogers, 1983), which have been rigorously proved in research over decades. In order to test the comprehensiveness of the integration of these components and the utility of the expanded framework, the research on mushroom cultivation incorporated a significant number of open-ended questions to facilitate comprehensive information gathering. Respondents freely described their individual livelihood adoption experiences, including reasons for initial adoption or rejection, and for subsequent continuation or discontinuation. They described difficulties experienced during mushroom nurture, harvesting, processing and marketing, and in capital and technical aspects of their investments. All the provided information was analysed and found to fit neatly into the seven components and their dimensions. In other words, RLAF has demonstrated in this study its capability of capturing all the important aspects when a rural community adopted mushroom culture. This finding therefore helped confirm the relevance and comprehensiveness of RLAF in rural livelihood adoption research.

During the development and application of RLAF, we observed that while the dimensions of each component are principal and have been reconfirmed in many studies over decades (i.e. five types of livelihood assets, five attributes of innovations), indicators for each dimension must be rather flexibly developed to describe the uniqueness and complexity of different livelihood activities, as well as socio-economic and ecological contexts in which the livelihood activities are conducted. This emphasises the flexibility or openness of RLAF, thereby allowing researchers to apply RLAF for different types of livelihood activities in different situations. Consequently, the list of indicators is rather case specific, and based on literature reviews, researchers' experiences, and pilot study work. Thus, the indicators listed in Table 1 in this study were effective for analysing mushroom cultivation in Giao Thuy district, but may not be sufficient for other livelihood activities, or for the same activity in another location.

Nevertheless, the main components and dimensions of the framework would serve as a comprehensive guideline for researchers to identify indicators and formulate data collection methodology. Subsequently, at the data analysis stage, the collected socio-economic and

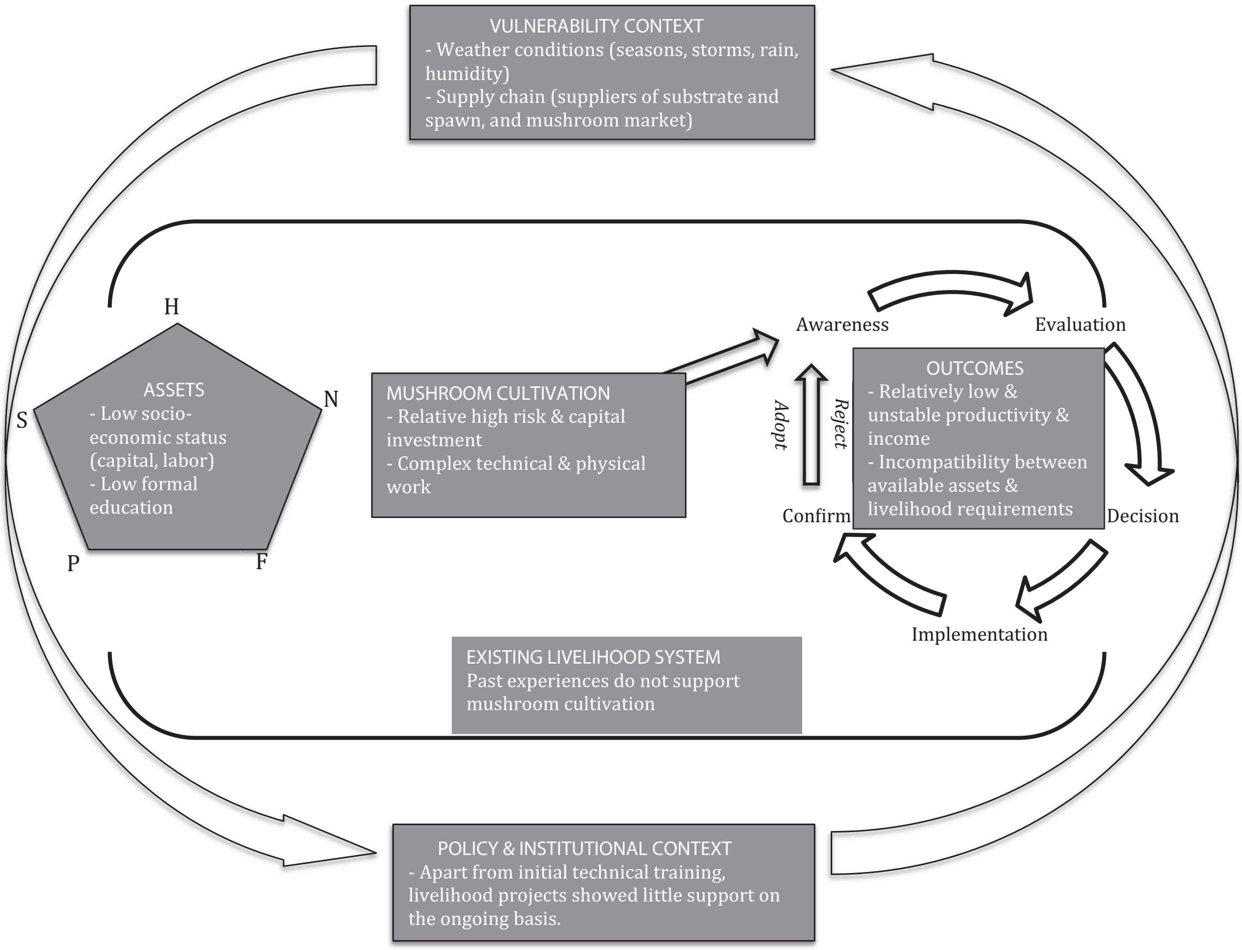


**Figure 2:** Critical barriers and constraints to continuing and developing mushroom cultivation.

ecological data could be conveniently matched with the corresponding indicators and components, which subsequently allow researchers to analyse interactions between livelihood factors, and systematically assess different aspects related to adoption and dis-adoption behaviours. As can be seen in the previous section, Figure 2 concisely illustrates how RLAF can support analysing the adoption barriers to continuing mushroom cultivation in one particular community.

RLAF does not take a snapshot of a particular livelihood activity, rather the framework has the capability to tell a story or describe a continuous process of how a livelihood activity was known within a community; subsequently, received favourable or unfavourable attitudes to be adopted or rejected; and if adopted how that livelihood was implemented, then sustainably integrated into household livelihood system or discontinued. The findings in the case-study not only identified factors affecting the adoption of mushroom cultivation in Giao Thuy district, but also enabled the detailed description of the continual changes among local farmers throughout the adoption process (from awareness, to persuasion, decision, implementation and confirmation). For instance, people at first were very confident in growing mushrooms. However, this perception was reversed among many farmers after a short period of implementation as they realized that their previous horticultural experience provided little preparational support for mushroom cultivation. Compared to conventional field-based farming activities, the new indoor livelihood contained higher risks, and required higher investment of financial, physical and technical capital. This clearly showcases the capability of the RLAF approach to capture and analyse the livelihood dynamics or livelihood on-going performance through indicators of the adoption process, and in conjunction with the other components.

Results from this study suggest that using RLAF can assist livelihood practitioners (both change agents and farmers) to analyse existing livelihood systems and constructively seek ways to improve problematic situations related to sustained adoption of innovations. RLAF allows systematic exploration of interactions among the adoption factors. As illustrated for this case study, Figure 2 explicitly indicates how appropriate solutions for the adoption barriers and challenges can be crafted and evaluated systematically. For instance, once external constraints on the mushroom farmers are identified, the change agents' task can be seen to expand to providing not only technical support, but also marketing and business management capacity training programmes. Concurrent changes to institutional and organizational settings are required to support mushroom cultivation on a continual basis (Scoones, 1998). The training programmes should be designed to significantly improve technical knowledge and skills for the mushroom farmers (human assets), thereby reducing the burden of technical and physical complexity of the mushroom growing activities (innovation attributes), and ultimately, increasing the compatibility of the innovation with existing local livelihood experiences. In other words, use of RLAF enables design of an intervention that can target multiple issues simultaneously.

Another suggestion based on the results and illustrated in Figure 2 could be to conduct studies on the mushroom supply chain to identify bottlenecks and weaknesses in the current value stream (Bonney *et al*., 2007; Brown *et al*., 2010). Only a sufficient understanding about the current supply chain will enable the government, change agents, and supply chain partners to propose and implement good policies and actions aimed at improving the current situation of the mushroom producers and encouraging others to return to the activity, and thus promote enhanced livelihood sustainability.

## 7. Conclusion

Through a combination of the sustainable livelihood concept and frameworks (Ellis, 2000; DIFD, 1999) and the diffusion of innovation theory (Rogers, 1983), RLAF suggests an integrative framework with which to capture all the aspects of livelihood adoption research in seven components: assets, innovation attributes, outcomes, innovation adoption process, micro-context (existing livelihood system), vulnerability context, and policy and institutional context. RLAF succeeded in assisting the researchers to comprehensively analyse the adoption experiences, and then identify and assess various constraints in the process of sustained adoption of mushroom cultivation by the local farmers in Giao Thuy district, Vietnam. This case study is evidence of the holistic nature and practicality of this framework for rural livelihood adoption research.

RLAF as an action-oriented research tool has several strong attributes: (1) It is based on the widely recognised livelihood frameworks applied commonly in developing countries. (2) The integrative framework has capacity to assist practitioners to break down livelihood adoption problems into several components, and then measure the problems according to specific indicators. (3) Subsequently, RLAF can guide the collation of all the key findings systematically and their presentation in an explicit and comprehensive conceptual diagram showing interactions among the components. (4) As a consequence, researchers can readily construct a comprehensive understanding of the enabling and constraining factors affecting the adoption of an innovation. (5) This in turn supports crafting and implementing appropriate policies and effective actions to overcome identified constraints to adoption of worthwhile livelihood diversification strategies. It will also allow identification of inappropriate innovations whose promotion should cease.

In summary, the paper suggests RLAF as a practical framework for livelihood-enhancing innovation adoption research and rural development and management work. However, the results reported here can be regarded only as preliminary, as they are based on a single attempt to investigate farmers' behaviours and experiences in relation to a problem of sustained adoption and incorporation of an innovation into an existing farming system, in a small sample from one community in Vietnam. Therefore, further studies are required to examine the effective holism and applicability of the RLAF, not only for on-farm but also for off-farm activities, for other types of innovations, and in different contexts.

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REFEREED ARTICLE

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# Market risk management and the demand for forward contracts among Irish dairy farmers

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**ABSTRACT**

Irish dairy farmers have entered into a period of significant change with the European-wide abolition of the milk quota regime in April 2015. This abolition provides the opportunity for many profitable Irish dairy farms to increase their production levels. Market risk will influence decision-making at the farm level. Dairy farmers have recently acquired more experience of market risk through highly volatile market prices. This has the potential to affect risk attitudes and the farmers' selection of tools available to manage market risk. In this paper, we utilise econometric methods to examine the demand for the forward contracting risk management tool among Irish dairy farmers. Our findings suggest that recency effects are significantly associated with such demand as the recent price history appears to have significant effects on decision-making. 'Within the farm-gate diversification' and the 'number of children' in particular age categories have a positive and significant association with the adoption of forward contracting.

**KEYWORDS:** risk management; price volatility; dairy; forward contracts; risk aversion

## 1. Introduction

Agriculture and the dairy sector in particular have entered into a phase of considerable change. Traditional EU policy supports are now less prevalent due to recent CAP reform and the most significant policy in the dairy sector, the milk quota, was removed in April 2015. One of the consequences of recent shifts in policy is an increased exposure to price volatility both in terms of the milk output and input prices. In the past, the EU employed a suite of policy instruments with the aim of isolating internal EU dairy prices from the greater volatility associated with world prices. Intervention purchasing placed a floor on prices while other measures such as production quotas, export refunds, import tariffs and subsidised consumption measures were used to ensure higher and much less volatile prices than those pertaining in world markets (Jongeneel *et al.* 2010).

In some respects, these recent policy shifts demonstrate a movement away from the management of 'social risks through collective pooling mechanisms' and towards a more 'individualised risk management' approach as described by (Hamilton 2014, p. 453). This places a greater onus on the individual farmer to manage their own market risk situation. As part of an overall risk management strategy, the farmer can potentially transfer risk incidence to professional risk-taking institutions in the form of instruments such as forward contracting (Schaper, Lassen, and Theuvsen 2009).

Given the increase in the incidence of risk at the farm level and the increasing availability of private risk management tools in recent years, it is timely to investigate the factors influencing the potential adoption of the aforementioned tool. Hence, in this paper, the objective is to examine the potential willingness of Irish dairy farmers to adopt forward contracting tools and the factors that are likely to affect adoption in the Irish case.

In the next section of the paper, an overview of the incidence of market risk in Irish dairying is provided along with a background to the incidence of forward contracting in agricultural markets. Following this a description of the data sources used to perform the analysis is provided. The research findings are then outlined focusing on statistical and econometric analysis to identify the factors associated with the demand for forward contracting as a risk management tool. This is finally followed by some conclusions.

## 2. Background

### Overview of market risk in Irish dairying

The degree of milk price variation is likely to be a contributory factor towards the demand for the forward

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contracting tool. In this section an outline is provided on the historic variation in milk and input prices. Milk price variation can be considered desirable in terms of providing price signals that reflect changing market conditions, which lead to changes in resource allocations. Nevertheless, the principles of economics suggest a set of mostly negative consequences of extreme price volatility for producers (Keane and O'Connor 2009). For example, very low prices can threaten the solvency of the farm unit, and lead to damage to productive capacity. Very high prices, however, can also be problematic, in that they can result in product substitution on the consumption side, (consumers forego a product whose price has risen in favour of a cheaper alternative) which can, later on, be difficult or even impossible to reverse.

The exceptional price volatility in several agricultural commodity markets in recent years has created problems for processors, farmers and other food supply chain participants. Figure 1 illustrates the historic variation in monthly farm level milk price in Ireland and on the world market (as illustrated by NZ milk price) from 2001 to 2013. Using New Zealand milk prices as a proxy for world milk prices, there has been a convergence in milk prices in recent years.

Figure 1 not only provides an indication of the level of prices over the recent past, but also provides some indication about the volatility in milk prices over the same time period. Prior to 2007 there was virtually no evidence of extreme price volatility for farm gate milk price in Ireland. Milk prices fell to a small degree between 2000 and 2004. The fluctuations in milk price during these years followed a strong seasonal pattern with milk prices rising in the late autumn and declining early in the following year. However, post-2006 it appears that extreme volatility has become a major feature of the market. A seasonal pattern appears less obvious from the post 2006 data and price changes could therefore be considered to follow a more unpredictable pattern.

## Incidence of forward contracting in agricultural markets

The practice of forward contracting is more closely associated with grain than milk production and this is reflected in the economic literature. In a study of three U.S. states, Davis *et al* (2005) found that more than 65 per cent of corn and soybean producers forward sold during the 1995-1998 period. In a study of Kansas farmers, Goodwin and Schroeder (1994) found that 43 percent of producers forward contracted during the 1990-1992 period. Other recent studies of grain forward contract adoption have included Velandia *et al* (2009), Franken *et al* (2012) and Taylor *et al* (2014). Among the few studies of milk forward contract adoption, Wolf and Widmar (2014) have found a positive association between milk forward contract adoption and the herd size and education level of the farm operator.

Across developed countries, a number of public and private market alternatives have emerged. The Private market alternatives include over the counter contracts (OTC) while publicly subsidized financial instruments have also emerged. Among the most widely researched public programmes is the Livestock Gross Margin for Dairy (LGM-Dairy) programme introduced in 2008 by the Risk Management Agency of the United States Department of Agriculture (USDA).[3] An evaluation of this programme finds that it significantly reduces economic downside risk, with potential to induce modest supply expansion if widely adopted (Burdine *et al.* 2014). The tool locks in a margin between the class III milk price and a weighted average of corn and soybean meal prices with the weights and deductibles chosen by the farmer within certain ranges (Valvekar, Cabrera, and Gould 2010). Bozic *et. al.* (2012, p. 7427) conclude that while 'hedging using nearby futures may help lock in above-average margins when times are good' it is found that 'only the consistent use of contracts with 9 to 12 months to maturity would have sufficed to protect against prolonged periods of very low margins'.

An example of a recently-developed private market measure is the Glanbia (Ireland) milk pricing scheme announced in late 2010. Glanbia is a public limited company with the majority of shares owned by the Glanbia co-operative society (Boland and Cook 2013). The Glanbia initiative was soon followed by the introduction of milk price guarantee certificates in February 2012 by the Dairy Trading Online BV (DTO) venture in the Netherlands[4] (LTO Nederland 2011). We do not examine the specific adoption rates for the Glanbia initiative but our analysis of experimental data will allow us to examine the willingness of Irish dairy farmers to engage in similar milk pricing schemes. Glanbia remains the only milk processor offering forward contracts to Irish dairy farmers and the majority of Irish dairy farmers have therefore no direct access to forward contracting arrangements.

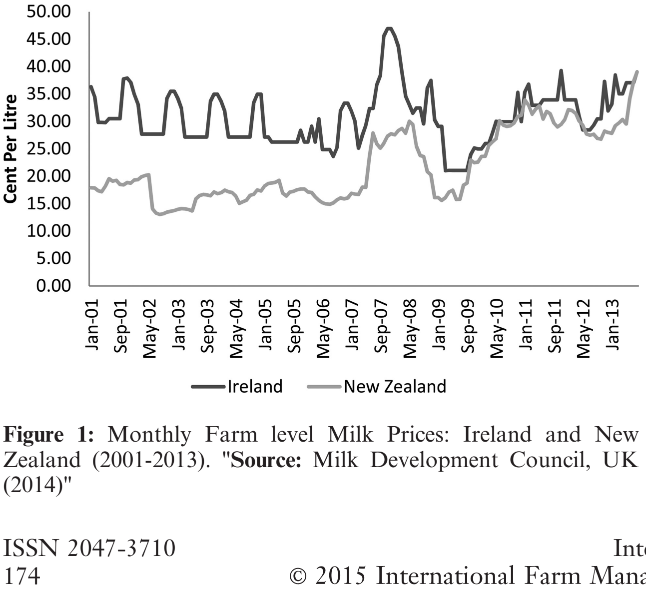


**Figure 1:** Monthly Farm level Milk Prices: Ireland and New Zealand (2001-2013). "**Source:** Milk Development Council, UK (2014)"

## 3. Data

In this section, we describe the data source used to perform the analysis i.e. the Teagasc National Farm Survey. The main part of our analysis relies upon the annual survey for 2011 and the autumn survey of the same year. These are two very distinct surveys in terms of their data content but there is a high degree of

[3] The milk prices for LGM-Dairy agreements are based on simple averages of futures contract daily settlement prices. The indemnities equal the difference between the gross margin guarantee and the actual total gross margin for the insurance period USDA (2011).

[4] Each contract under this guarantee represented a volume of 50,000 kg of milk.

 

overlap in the farms participating in these two surveys. In 2011, a total of 239 specialist dairy farmers participated in both the Autumn survey and the Annual survey. This formed the vast majority of the 270 specialist dairy farms which took part in the 2011 annual survey. The 2011 annual survey contained a total of 1,055 farms, representing 105,535 farms nationally (Hennessy *et al* 2012).

In 2011, the autumn survey interviewed specialist dairy farmers in relation to risk perceptions and risk management including a series of experimental questions with respect to the use of forward contracting. Experimental methods are increasingly viewed by analysts as a superior path towards investigating the relationship between risk preferences and farm management or land use decisions (Herberich, Levitt, and List 2009; Hellerstein, Higgins, and Horowitz 2013). However some experimental methods such as lottery choices are found to be a poor candidate for predicting real-world farming behaviour (Hellerstein, Higgins, and Horowitz 2013).

Each farmer was asked to answer the following questions in relation to milk prices, preferences in the use of forward contracting and the farmer's own expectations for the near future.

**1:** What price do you **currently** receive per litre of milk?

**2:** What do you think will be the **average** price **over 2012**?

**3:** If you could bid to enter a contract to sell **20%** of your milk production at a fixed price over the year 2012 (e.g. forward contract with the co-op) what would be the minimum price per litre you would ask for?

## 4. Methods

The data described above was used to develop an econometric model which examined the preferences of Irish dairy farmers in the demand for forward contracting. In addition to this econometric model, a statistical analysis was conducted of the two groups i.e. a risk averse group of 'expected adopters' and an approximately risk neutral group of 'expected non-adopters'[5].

The classification provides an indication of the likely adoption rates for the forward contracting tool at a particular point in time but it is acknowledged that the classification does not provide a precise measure of risk aversion. For the purposes of classification, the sample average expected price for 2012 *ExpPrice* was used as a proxy for the markets future expected price. The average expected price of the sample was used as the key threshold rather than the individual's own expected price given the tendency for the individuals expected price to be dependent on relative optimism or pessimism for the following year, in this case 2012.[6]

Farmers who were only willing to forward sell milk at or above the samples average expected price were classified as expected non-adopters in the following:

$$Expected\ Non-Adopter\ if\ \left(ExpPrice \leq MinimumFCP_i\right) \quad (1)$$

where ExpPrice refers to the average expected price that the sample of farmers estimate for 2012 and MinimumFCP refers to the minimum price at which the farmer would be willing to forward contract 20 per cent of their milk production. Alternatively those farmers who claim a willingness to forward sell at lower than the average expected price are classified as expected adopters in the following:

$$Expected\ Adopter\ if\ \left(MinimumFCP_i < ExpPrice\right) \quad (2)$$

These groups provide some indication of the degree of risk aversion in the specific domain of forward contracting. In our analysis, we do not use the term risk loving. Many dairy farmers in the sample indicate willingness to forward sell, but only at a price higher than the samples average expected price. This may simply reflect a lack of knowledge about the forward contracting method. It does not necessarily indicate a risk loving response to market price variability.

In the econometric model, the demand is assessed for the forward contracting tool with respect to contract prices for 20 per cent of milk production. A stepwise OLS regression model was used to examine the factors driving the selected forward contract price at which farmers were willing to enter into agreement. While there are theoretical grounds for the inclusion of some variables such as the child-related variables and the farm income, the selection of variables is largely done on an exploratory basis. We therefore begin with a relatively large number of potential variables and use a backward stepwise approach to reach a final model. Variables are only included if the level of significance is below 0.1.

The OLS regression model is estimated as follows:

$$FCP_i^{min} = \alpha + \beta_1 X_i + \beta_2 MP_i + \varepsilon \quad (3)$$

where

$$\varepsilon \sim N(0, \sigma_t^2) \quad (4)$$

where $FCP_i^{min}$ refers to the selected minimum Forward Contract Price and $X$ refers to a series of farm and non-farm explanatory variables while $MP$ refers to a series of market price variables i.e. recent, current or expected future milk price. These market price variables may be able to capture recency effects or the effects of relative optimism on forward contracting decisions. Basing the econometric analysis solely on the forward contract price avoids the pitfalls associated with classifying farms into risk averse or risk neutral categories. In table 1, the variables that are initially included in the econometric model are outlined. All of these variables relate to individual farm level data from the Teagasc National Farm Survey. Some of these variables will be excluded from the final model due to the stepwise approach. The fat and protein indicators represent proxy variables to account for milk quality. These are important components in the formation of

[5] Previous research on risk aversion has employed terms such as 'risk averse adoption' to describe risk preferences among farmers (Serra, Zilberman, and Gil 2007). For the remainder of the article, we refer to the former group as 'expected adopters' and the latter group as 'expected non-adopters'.

[6] For instance, take a farmer in 2011 with an expected milk price of 40 cent per litre for 2012 and a willingness to enter into a forward contract at 37 cent per litre. This farmer would be classified as an expected adopter if the classification is based on a comparison of the individual's expected milk price and the minimum forward contract price. In addition, the likelihood of a forward contract being offered at 37 cent per litre is very low. We conclude that it is unreasonable to assume that the classification of farmers into these groupings could remain stable over time where the individual expected milk price is used as the key threshold.

**Table 1:** Teagasc National Farm Survey Variables used in the estimation of the models

| Variable Name | Definition |
|---|---|
| Forward Milk Price | The Minimum Forward Contract Price that each respondent is willing to enter into a forward contract for 20% of their milk |
| Log Recent Price Change | The ratio of the Log of the Current 2011 Milk Price to the Log of the Average 2010 Milk Price |
| Log Expected Price Change | The ratio of the Log of the Expected 2012 Milk Price to the Log of the Current 2011 Milk Price |
| Current Price | The Milk Price at the time of interview |
| Diversification | The Share of Farm Gross Output devoted to non-Dairy Output |
| Production (10,000 Litres) | Total Litres of Milk Production in 2011 |
| Costs Per Litre | Average Cost Per Litre of Milk in 2010 expressed as cent per litre |
| Protein Indicator | The Ratio of Kilograms of Protein to the Total Litres of Milk Production |
| Fat Indicator | The Ratio of Kilograms of Fat to the Total Litres of Milk Production |
| Operators Age | Age of the Farm Operator in Years |
| Coupled Income (€10,000) | Farm Income excluding decoupled subsidies |
| Off Farm Job | The Presence of an off-farm job for the farm operator (0 = no off-farm job, 1 = off-farm job) |
| Farm Size | Total Farm Size in number of Hectares |
| Teagasc Advisory | Contact with the Teagasc Advisory Service (0=no, 1 =yes) |
| Formal Training | Farm Operator has formal agricultural training (0 = no, 1=yes) |
| No. Livestock Units Per Hectare | The number of livestock units per Hectare |
| Discussion Group | Participation in a Dairy Discussion Group (0= no, 1 = yes) |
| No. Children 0-5 | Number of Children in the Household Aged 0-5 |
| No. Children 5-15 | Number of Children Aged 5-15 |
| No. Children 16-19 | Number of Children Aged 16-19 |

milk prices within a multiple-component pricing model (Roibas and Alvarez 2012; Geary *et al*. 2010, 2013).

## 5. Results

### Willingness to Adopt

Table 2 outlines the results for a two way sample t-test used to compare the expected adopter and the expected non-adopter groups.[7]

In terms of comparison between these two groups, the main differences appear to be with respect to the current and recent price variables. The significant difference with respect to these variables suggests that recency effects are important and that the recent experience of milk price is an important factor in determining the demand for a forward contract. The result suggests that farmers who are currently experiencing higher than average milk prices are less likely to be categorised as 'expected adopters'. This result can be interpreted in a number of different ways. It could reflect a damaging bias among farmers due to recency effects. It could also however, simply reflect the strong cash flow situation among farmers with the highest prices at a particular point in time.

The expected adopter group has significantly higher average income, levels of milk production and livestock intensity i.e. the number of livestock units per hectare. The number of children in the 5-15 years old age group and the 16-19 age group are both significantly higher among the risk averse expected adopter group. Studies outside of agricultural economics have found a positive relationship between the presence or number of children and risk aversion e.g. (Jianakoplos and Bernasek 1998; Di Mauro and Musumeci 2011).

In the literature on farm succession, Hennessy and Rehman (2007, p.69) found that higher educated potential heirs are less likely to pursue the occupation of full-time farming. Hennessy and Rehman (2007, p.73) also found that the nominated heirs on the "more profitable farms are less likely to pursue tertiary education and therefore more likely to enter full-time farming". Dairy farmers tend to have higher incomes on average relative to the other sectors of Irish agriculture (Hennessy *et al* 2012). In the case of Dairy farming, the result for the 16-19 age group may be related to issues surrounding farm succession and future expansion rather than the desire to fund university education although both may prove to be important factors depending on the family circumstances.

### Factors affecting the willingness to adopt forward contracting

In this section, the findings from the backward stepwise OLS regression model of the forward contract price are outlined. The results are presented separately with the current price variable, the recent price change variable and without price variables. These results reflect a parsimonious model. The results for the entire model are available on request. Our results are the product of a particular sample of farmers at a particular point in time and the findings for this particular research are not necessarily applicable to dairy farmers operating in other countries or under alternative policy environments. The relatively low r-squared value indicates that the explanatory power of the model is quite limited especially with the exclusion of the price variables.

As suggested by the descriptive statistics, between-farm variability in current prices and recent price changes appears to strongly influence risk aversion and adoption of the forward contracting tool. This suggests that farmers place a great amount of weight on recent market price developments in forming risk averse

[7] The sample size is smaller for the recent price change variable as only 170 of the 204 farmers are included in both the 2010 and 2011 annual Teagasc national farm surveys and the 2011 autumn survey. The sample size is smaller for the expected price change variable as there are two farms with no response for this particular variable.

 

**Table 2:** Two Way Sample Mean Comparison t-test

| | Expected Non-Adopters | Expected Adopters | Difference | Sample Average | N |
|---|---|---|---|---|---|
| Forward Milk Price | 35.59 | 31.19 | -4.40*** | 32.93 | 204 |
| Log Recent Price Change | 17.83 | 12.24 | -5.59*** | 14.53 | 170 |
| Log Expected Price Change | -3.38 | -4.78 | -1.40 | -4.22 | 202 |
| Current Price | 35.66 | 34.18 | -1.48*** | 34.76 | 204 |
| Diversification | 18.06 | 19.21 | 1.15 | 18.78 | 204 |
| Milk Protein Indicator | 3.28 | 3.29 | 0.00 | 3.28 | 204 |
| Milk Fat Indicator | 3.80 | 3.80 | 0.00 | 3.80 | 204 |
| Production (10,000 Litres) | 29.91 | 37.61 | 7.70* | 34.44 | 204 |
| Costs Per Litre | 26.37 | 25.03 | -1.34 | 25.58 | 204 |
| Operators Age | 51.74 | 48.19 | -3.55* | 49.58 | 204 |
| Coupled Income (€10,000) | 4.33 | 5.40 | 1.07* | 4.95 | 204 |
| Off Farm Job | 0.08 | 0.08 | 0.01 | 0.08 | 204 |
| Farm Size | 53.02 | 56.52 | 3.49 | 54.96 | 204 |
| Teagasc Advisory | 0.77 | 0.84 | 0.06 | 0.81 | 204 |
| Formal Training | 0.65 | 0.80 | 0.15** | 0.74 | 204 |
| No. Livestock Units Per Hectare | 1.74 | 1.89 | 0.15** | 1.83 | 204 |
| Discussion Group | 0.50 | 0.55 | 0.05 | 0.53 | 204 |
| No. Children 0-5 | 0.13 | 0.27 | 0.14 | 0.22 | 204 |
| No. Children 5-15 | 0.42 | 0.70 | 0.28** | 0.58 | 204 |
| No. Children 16-19 | 0.19 | 0.36 | 0.17** | 0.29 | 204 |
| N-Sample Size | 80 | 124 | | | 204 |

Significance Levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

preferences and their selection of the minimum forward contract price. Farmers who experienced larger than average increases in milk price between 2010 and the autumn of 2011 appear to demand higher forward contract prices for 2012. This could reflect recency bias with possibly negative effects on future decision-making and profitability. This could also however, simply reflect the decision-making of farmers with above normal cash flow surpluses.

One of the added advantages of the OLS regression model is that we can interpret the coefficients as being cents per litre. For instance, it appears from table 3 that a one cent higher milk price is associated with a 0.44 cent increase in the minimum forward contracting price. This is robust to the inclusion of the milk quality indicator relating to milk protein. This suggests that farmers will demand significantly higher fixed contract prices when milk prices are relatively high and conversely will be willing to negotiate at lower fixed milk prices when the milk price is relatively weak. The original format of the Glanbia fixed milk price scheme actually accounted for this sensitivity to the market milk price through the inclusion of a market adjuster.

The inclusion of the milk quality variables for milk protein and milk fat provide some interesting results. We find that higher milk protein is associated with willingness to forward contract at a significantly lower price. The milk fat indicator appears to have the opposite effect but this is only with the inclusion of both the milk quality and milk fat indicators. There are circumstances where the milk fat content can be too high and is therefore a less reliable quality indicator than milk protein. As a result, milk protein tends to have higher rewards per volume in comparison to milk fat (Bailey *et al* 2012). One possible explanation for this apparent relationship between protein levels and the

**Table 3:** Results of stepwise OLS Regressions of Forward Contract Prices

| | (1) | (2) | (3) |
|---|---|---|---|
| Current Price | 0.442*** (0.07) | | |
| Log Recent Price Change | | 0.139*** (0.02) | |
| Diversification | -0.077*** (0.02) | -0.070*** (0.02) | -0.066*** (0.02) |
| Milk Protein Indicator | -5.174*** (1.21) | -2.913** (1.23) | -5.425*** (1.86) |
| Number of Children 16-19 | -0.631** (0.29) | -0.751** (0.31) | -0.610* (0.32) |
| Operators Age | 0.037** (0.02) | | 0.031* (0.02) |
| Milk Fat Indicator | | | 2.471* (1.32) |
| Cost Per Litre (Cent) | 0.087** (0.04) | | |
| Production (10,000 Litres) | -0.044*** (0.01) | | -0.031** (0.01) |
| Farm Size | 0.022** (0.01) | | 0.020** (0.01) |
| Coupled Income (€10,000s) | 0.150* (0.08) | | |
| Constant | 31.81*** (4.35) | 42.21*** (4.11) | 41.26*** (4.33) |
| Sample Size | 204 | 170 | 202 |
| R Squared | 0.285 | 0.263 | 0.124 |
| Adjusted R Squared | 0.252 | 0.245 | 0.093 |

forward price is that farmers are conscious of the desire to protect against declines in milk quality.

We find that price expectations are insignificant in determining the likelihood of forward contracting adoption and the stepwise process is responsible for dropping this variable. This may suggest that over-optimism is not a major issue and that any bias which does exist is better described as a recency bias. We cannot however rule out the possibility of over-optimism being an important factor for some farms. As explained by Couelho (2010), the main concern with relative optimism is whether or not it is grounded in realism or can be considered unrealistic. For example, a superior milk quality at the farm level could be realistic grounds for relative optimism. The concept of 'unrealistic optimism' is examined in a growing literature (see e.g., Coelho 2010; Harris and Hahn 2011; Shepperd *et al*. 2013 on this important subject).

In terms of the non-price variables, it was found that within the farm gate diversification has a positive and significant relationship with risk aversion in the use of forward contracting. A one per cent increase in diversification is associated with a 0.07 per cent decline in the minimum forward contract price. This suggests that farmers who devote a large share to other farm enterprises such as tillage and drystock cattle are more likely to provide a risk averse response to the question on forward contracting and are therefore considered more likely to adopt the forward contracting tool.

In terms of the number of children in particular age categories, it was found that the number of children in the 16-19 age group is highly significant with an additional child in this category being associated with 0.6 to 0.75 cent reduction in the minimum forward contract price. The literature in this area is certainly under-developed although studies such as Wölfel and Heineck (2012) have examined the effect of parental risk aversion on schooling choices finding some differences between the effect of mothers parental risk aversion and the effect due to the risk aversion level of the father. Cameron, DeShazo, and Johnson (2012) find that parents of infants are, on average, more risk averse than other people with respect to net income and that this risk aversion declines as the children become teenagers. This suggests that the age of the child is an important factor in determining parental risk attitudes.

Our result is perhaps due to the fact that our indicator of risk aversion is domain-specific to dairy farming and a particular risk management tool. There is extensive evidence that risky decisions are affected by domain effects (Reynaud and Couture 2012; Vlaev *et al*. 2010; Tversky and Kahneman 1981). Domain-general estimates of risk aversion can however be useful predictors of real-world behaviour (Dohmen *et al*. 2011). We should therefore be careful in the interpretation of the results with respect to age categories as a different measure of risk aversion could be associated more with children in younger age categories. That being said, it is the case that children in the age categories between 16 and 19 are likely to be either entering or participating in third level education or preparing for a larger role within the farm business. In these circumstances, the added risk aversion of the parents would be understandable where income uncertainty exists.

## 6. Summary

In this paper, statistical and econometric techniques were used to estimate the factors associated with the demand for forward contracting as a market risk management tool in Irish dairy farming. Our results show that farm diversification, demographic variables, milk quality and the farmer's individual milk price history are significantly associated with the likelihood of the adoption of forward contracts for milk production. The significance of the farmers recent milk price history indicates that recency effects are strongly influencing preferences in the demand for forward contracting. This could also reflect the behaviour of farmers with superior cashflow positions due to high recent milk prices. We found that the future expected milk price has no statistically significant impact on the demand. Given the dangers of the proof-seeking fallacy (Hansson 2004), we should not rule out the possibility that over-optimism exists for some farm households and that unrealistic optimism can inhibit sound decision-making in market risk management.

The findings can support a better understanding about risk management on Irish dairy farms in the post milk quota era and the expected expansion on many profitable Irish dairy farms. It appears from our results that expansion will involve a heightened concern among dairy farmers towards market risk at the farm level. Farmers are somewhat limited in terms of the number of risk management tools at their disposal. For instance the option of forward contracting is only available to clients of one co-operative in Ireland.

The Irish situation contrasts with dairy farmers in the United States where Wolf (2012) reports that approximately 39 per cent of sampled Michigan Dairy farmers avail of feed price risk management tools such as forward contracting and over the counter contracts. In addition, farmers in the United States can avail of publicly subsidised gross margin insurance through the (LGM-Dairy) programme (Burdine *et al*. 2014).

The degree to which Irish dairy farmers exhibit risk averse behaviour will continue to be important for policymakers to consider both in terms of productivity and inequality (Vollenweider, Di Falco and O'Donoghue 2011). Our analysis suggests that the factors driving the formation of risk averse behaviour are an interesting study in themselves for the case of Irish dairy farmers. Further analysis is required to examine the extent to which these subjective judgements may conform to or depart from the actual decision making. The analysis has sought to examine the risk aversion of farmers through experimental data in the specific domain of forward contracting. We expect that our analysis has provided useful insights into the risk aversion of Irish dairy farmers at this particular point in time and that future research can be devoted towards examining the evolution of risk attitudes and management as more market risk management tools become available to dairy farmers.

Finally, the research findings outlined in this paper have shown that market risk is an inherent part of the dairy farm business. Depending on the individual's inherent attitude to risk, some elements can be considered desirable, but the principles of economics suggest a set of mostly negative consequences of extreme volatility for producers. Consequently, the ever-increasing role which risk is playing in the dairy farm business must be managed at some level. Various instruments, both in the public and private market, which may be utilised to manage price and income volatility, will play an ever-increasing role in the business and financial strategies of the dairy farm business.

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