Teagasc
Organic Production Research Conference Proceedings

2008

Contents

Organic versus Conventional Farming:
An environmental comparison review

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Background

Organic agriculture is generally perceived as a form of agriculture that is more favourable for the environment than conventional agriculture. Analyses has shown that consumers are willing to pay for the environmental advantages of organic food. In this paper it is asked where the differences are in environmental terms and whether the available scientific evidence allows for a generalisation.

Sources of Information

A literature search was carried out using Electronic Journals Service®, Web of Science® and Org Prints (http://orgprints.org).

The reviewed literature displays a multitude of references and methodological approaches to the subject both peer-reviewed and non-peer reviewed. A detailed description of the literature and methodological approaches is beyond the scope of this paper but may be found in Stolze *et al* (2000), Kasperczyk and Knickel (2005) and Shepherd (2003).

No research either peer-reviewed or non-peer-reviewed was available for Irish agriculture. This paper focuses primarily on peer-reviewed scientific research from the U.K., northern Europe and New Zealand. Some non-peer reviewed sources of information were also used that in the opinion of the author, were of use due to the lack of available peer-reviewed information for certain subjects.

Fields of Environmental Impact

The assessment presented here is based on the Driver-State-Response (DSR) framework that has been developed by the OECD (OECD, 1997) which separated the environment into 6 sectors: biodiversity, soil, landscape, ground and surface water, climate/air and energy.

Biodiversity

Overall, organic farming supports more farmland wildlife than non-organic farming (Bengstsson *et al*, 2005).

Hole *et al* (2005) in a comprehensive review of 76 peer-reviewed studies from around the world that compared the effects on biodiversity of organic agriculture relative to conventional agriculture, highlighted three broad management practices that are largely intrinsic but not exclusive to organic farming: a ban or a reduced use of chemical pesticides and inorganic fertilizers, sympathetic management of non-cropped habitats, and preservation of mixed farming. While comparing the impacts of organic and conventional farming systems on biodiversity, he identified the following issues:

- It remains unclear whether a ‘holistic’ whole-farm approach (i.e. organic) provides greater benefits to biodiversity than carefully targeted prescriptions applied to relatively small areas of cropped and/or non-cropped habitats within conventional agriculture (i.e. agri-environmental schemes).
- Many comparative studies encounter methodological problems, limiting their ability to draw quantitative conclusions.
- Our knowledge of the impacts of organic farming in pastoral and upland agriculture is limited.
- There remains a pressing need for longitudinal, system-level studies in order to address these issues and to fill the gaps in our knowledge of the impacts of organic farming, before a full appraisal of it’s potential role in biodiversity conservation can be made.

Nevertheless, most studies concluded that species abundance and/or richness across a wide range of taxa tend to be higher on organic farms than locally representative conventional farms (Table 1).

Table 1 Summary of the effects of organic farming on individual taxon, in comparison to conventional farming. Literature review of 76 studies 1981 – 2004 (from Hole *et al*. 2005)

Taxon	**Positive**	**Negative**	**Mixed/no difference**
Birds	7		2
Mammals	2		
Butterflies	1		1
Spiders	7		3
Earthworms	7	2	4
Beetles	13	5	3
Other arthropods	7	1	2
Plants	13		2
Soil Microbes	9		8
Total	66	8	25

(Note: total in table> number of studies in review since it includes multi-taxon studies)

The Soil Association published a report on the biodiversity benefits of organic farming (Anon., 2000). It reviewed all the known studies (both peer and non-peer reviewed) which compared the levels of wildlife on organic and conventional farms. It found clear evidence that overall organic farms support substantially higher levels of wildlife in lowland areas, particularly of those wildlife groups that are declining. Examples include 40% more birds in a three year peer-reviewed study of 44 farms by the British Trust for Ornithology (Chamberlain *et al*., 1998), twice as many butterflies in another peer-reviewed study (Feber *et al*, 1997) and five times as many wild arable plants (Kay and Gregory, 1999).

Semi-natural habitats are extremely valuable habitats in the agricultural landscape with respect to the conservation of biodiversity. Overall, there is little information available to compare habitat diversity in organic and conventional farming systems. Van Mansvelt *et al*. (1998) compared seven organic and eight adjacent conventional farms in the Netherlands, Germany and Sweden in order to evaluate their effect on landscape diversity. They found that areas dedicated to natural elements ranged from

55% to 20% in the mixed organic farms and from 11% to 0.3% in the conventional neighbours.

Semi-natural habitats are intrinsic in organic regimes where their management is central to the philosophy (Stockdale *et al*. 2001; Alföldi *et al*. 2002). Organic farming tends to have a positive impact on habitat diversity but the correlation is not very strong since habitat diversity depends highly on given historic and landscape structures and site-specific aspects (Stolze *et al*. 200; Shepherd *et al*. 2003).

Landscape

Landscapes can be classified according to their beauty, historical features, embodiment of cultural values, past and present impacts of land use, farm practices, composition of farming systems, distribution of habitats and human made features like stone walls or historical buildings (OECD, 1997).

Organic farming generally provides a good potential for landscape diversity (Stolze *et al*. 2000). However, few comparative studies are available in the literature regarding the impact of organic farming on the landscape. In a comparative analysis of organic and conventional farms in two Danish counties, Tess (1999) found generally fewer fallow fields and a larger area of permanent and extensive grassland on organic farms. More fields of smaller size and a significantly larger share of inner and outer hedgerows on organic farms create a more diverse mosaic within the farm. Alföldi *et al.* (2002) found that the diversity of landscapes and production systems was greater in organic farms than on conventional farms. This was in relation to land use, crop type, livestock, plantings, hedges, trees, flora and sensorial information.

Soil

One of the most valuable benefits of organic farming is the improvement in soil quality, which can be expressed in terms of chemical, physical and biological properties and their interactions (Escobar and Hue, 2007).

Soil Organic Matter (SOM) and Soil Acidity: The environmental relevance of organic matter is based on it’s capacity to improve nutrient availability as well as biological activity and to reduce the vulnerability of the soil to physical damage and erosion. SOM and humus are important components in the organic farming philosophy. Several long-term trials that compare organic farming to conventional farming have been performed in various European countries. The research shows that soil organic carbon content is higher in organic systems than in conventional farming (Mader *et al*, 1995; Petersen *et al*, 1997; Clark *et al*, 1998; Stolze *et al*, 2000). As for pastures the difference is less pronounced (Shepherd *et al*. 2003). Gosling and Shepherd (2004) found that soils in England under mixed organic arable rotations maintained concentrations of SOM at similar levels to those under typical conventional systems.

Soil acidity is an important parameter since it can affect the plant's ability to take up nutrients and can effect the microbial activity in the soil that influences the processes required for plant nutrition. Results from the long-term 21 year Swiss trial comparing biodynamic, organic and conventional farming systems (the Swiss FiBL DOK biodynamic- organic-conventional trial), demonstrate that the utilization of composted manure, common in organic systems, has a positive effect on the content of organic matter and helps to avoid soil acidification (Flieβach *et al*. 2001).

Soil Structure: The environmental importance of a favourable soil structure lies in an improved resistance to structural damage, such as compaction and erosion. The maintenance of a favourable soil structure is of significant concern in organic farming. Soil management techniques common in organic farming such as organic fertilization, mulching and cover cropping improve soil structure, increase the water infiltration and retention capacity, and thus reduce the erosion risk substantially (Kasperczyk and Knickel, 2005).

In the literature studies were found that showed increased aggregate stability and significant differences in soil physical parameters (eg, reduced bulk density and soil stability) between organic and/or biodynamic and conventional farms (Gerhardt, 1997; Siergist *et al*. 1998). Reganold (1995) showed significant differences in soil structure when 16 fields sampled from both biodynamic and conventional commercial farms were compared in a paired study in New Zealand. In the long-term DOK-trial (see above) organic soil management improved soil structure by increasing soil microbial activity, thus reducing the risk of erosion. Papadopolos *et al*. (2007) in a study of soil structure on both an organic and conventional farm in North Yorkshire, UK, found that organic soils provided a more stable soil structure than conventionally managed soils. Organically managed soils typically provided spatially well distributed pores of all sizes and of greater roughness, although conventional soils had a higher porosity at the macro-scale.

Stolze *et al* (2000) found that in most relevant long-term trials in Europe no significant differences in soil physical parameters, like micropore volume, bulk density and soil stability could be detected between organic and conventional farming systems (Meuser, 1989; Niggli *et al*., 1995).

Soil Biological Activity: High biological activity within the soil promotes metabolism between soil and plants and is an essential part of sustainable plant production and fertilizer management. The role of soil organisms is central to soil processes and fertility since they render available the elements in plant residues and organic debris entering the soil (Alföldi *et al*. 2002).

Earthworms have many positive direct and indirect effects on soil quality, both in terms of their effects on soil physical properties and nutrient cycling. Pfiffner and Mäder (1997) compared organic and conventional farming systems and concluded that in organically farmed soils, a significantly higher biomass and abundance of earthworms occurred as well as a considerably higher diversity of earthworm species. These results were also reported by Siegrist *et al*. (1998) during a long-term field trial and by others (Gerhardt, 1997; Whalen *et al.* 1998). A possible reason for the abundance of earthworms in organic farming is that organic production depends more on a sustained supply of plant residues and manures than conventional farming, which can rely at least partly on the mineral supply of nutrients.

The soil microbial biomass performs critical functions such as nutrient transformation and pesticide degradation. Additionally, micro-organisms form symbiotic associations with roots, control plant pathogens and participate in soil formation (Shepherd *et al*. 2003). The evidence for increased microbial activity under organic conditions is mixed. Stolze *et al.* (2000) reviewed European research results and found that an improvement of microbial activity correlated with the period soils were farmed organically. Hole *et al.* (2005) reviewed 14 studies that investigated microbial communities under organic and conventional systems and found only limited differences in eight of the studies (Yeates *et al*. 1997; Shannon *et al*. 2002; Girvan *et al*. 2003). However, they detected a general trend towards elevated bacterial (Bossio *et al*. 1998) and fungal (Yeates *et al*. 1997; Shannon *et al*. 2002) abundance/activity under organic systems.

Ground and Surface Water

Nitrate Leaching: High levels of nitrate in ground water can lead to toxic contamination of drinking water for humans and animals as well as eutrophication caused by excessive algal growth. Many organic systems operate at a lower level of N intensity than conventional systems because of lower stocking rates and fertilization levels. Farmyard manure and compost, common in organic farming, reduces the nutrient availability and the risk from run-off in comparison to slurry (Kasperczyk and Knickel, 2005). Other organic farming practices which minimize losses are wide crop rotations, soil cover during Winter, intercrops, underseeds and fallows of several years (Nocquet *et al*. 1996; Shepherd *et al*. 2003). On the other hand, the flush of N mineralization following the ploughing-up of leys is a feature of organic systems that possibly increases the risk of nitrate leaching (Stopes and Phillips, 1992; Scheller and Vogtmann, 1995). Additionally, organic pork production results in larger nitrate leaching loss than conventional production due to the free-range nature of the system (Thorup-Kristensen *et al*. 2008).

Taking all these factors into account, leaching losses from organic farms tend to be less than from conventional farms (Edwards *et al*, 1990; Younie and Watson, 1992; Eltun, 1995). Using a modelling approach, Condron *et al* (2000) found that conventional dairy farms in New Zealand had higher annual losses than organic dairy farms. Farm comparisons presented by Stolze et al (2000) show that nitrate leaching rates in organic farming in most studies are significantly lower than those of conventional systems.

Phosphorus: Although the quantities of P lost from farmland are usually small in agricultural terms, losses of a few kilogrammes of P per hectare are sufficient to be of environmental concern. High levels of P in water can cause excessive algal and plant growth which can lead to eutrophication. Data on P leaching and runoff from organic agriculture are scarce. As nutrient balances for organic farms rarely show a significant surplus of P, losses are assumed to be small (Edwards and Withers, 1998). Organic systems have been criticized for exploiting reserves of P and K in soil. Gosling and Shepherd (2005) have researched long-term (over 15 years) changes in soil fertility in organic farming systems in England. Their results support the argument that organic arable systems are mining reserves of P and K. On the other hand, Watson *et al* (2000) in a review of farm-scale nutrient budgets found that this decline does not always occur where budget deficits of P and K are measured.

Pesticides: In terms of environmental impact, pesticides can impact on surface and groundwater. There is also the risk of air and soil contamination. Most pesticide contamination comes from herbicides used in conventional farming (Kasperczyk and Knickel, 2005). Pesticide use in organic farming is very restricted. Synthetic pesticides are completely banned. The impact of pesticides on water quality in organic systems has rarely been studied (Stockdale *et al*, 2001). Many reviews come to the same conclusion: because synthetic pesticides are not permitted for use in organic agriculture, the risk of contamination of air, soil and water in this respect is avoided (Condron *et al*. 2000, Stolze *et al*. 2000, Hansen *et al*. 2001, Stockdale *et al*. 2001).

Climate/Air

Global climate change (greenhouse effect) is considered on of the most urgent environmental problems of our time. The Kyoto protocol in 1992 set out to stabilize greenhouse gas emissions to the atmosphere so as to prevent human influence on climate change. The gases carbon dioxide (CO_2), nitrous oxide (N_20) and methane (CH_4) mainly contribute to the greenhouse effect and are largely, directly or indirectly, are a result of the burning of non-renewable fossil fuels. On a global scale, agriculture is responsible for roughly 15% of the trace gas emissions associated with climate impact (Stolze *et al*. 2000). However, agriculture also provides a sink for CO_2 because of the fixation of carbon by crops and pasture. A recent report on organic farming and climate change published by the Swiss FiBl (Anon., 2007) reviewed the benefits and weaknesses of organic farming with respect to climate change. While it is agreed that organic farming has considerable potential to reduce emissions of greenhouse gases, there are weaknesses, mainly related to productivity of organic farming which can only be improved through more research.

Carbon Dioxide (CO_2): Carbon Dioxide emissions from the agricultural sector in OECD countries are estimated at less than 1% of overall CO_2 emissions (IPCC, 2001). On a per hectare scale, most studies found lower (up to 40 – 60%) CO_2 emissions in organic systems (Burdick, 1994; Haas and Kopke, 1994; Stolze *et al*, 2000). The main reasons for these positive effects are the omission of the use of mineral N fertilizers with high energy consumption, lower use of high energy consuming feedstuffs and mineral fertilizers as well as the elimination of synthetic pesticides.

Nitrous Oxide (N_20): In OECD countries, the agricultural contribution to N_2O emissions is estimated at 58% (IPCC, 2001). Soils (particularly waterlogged soils) fertilized with inorganic fertilizers and manure stores are seen as the largest sources (Chadwick *et al*. 1999, Brown *et al*. 2002). There is a lack of information in the literature relating to comparative studies between organic and conventional systems. Nitrous oxide emissions are very difficult to measure and therefore have been related to the total N input in the form of fertilizer, manures and crop residues. Consequently, it has been largely assumed that, because organic farming operates at a lower intensity, with lower N inputs and less available mineral N in both manures and soils, N_20 losses will be lower (Stolze *et al*, 2000; Alföldi *et al*, 2002). However, some organic farming systems such as organic pork production may cause higher N_2O losses because of the free range nature of the system (Kristensen *et al*, 2008). Losses per unit of yield is unlikely to differ to that from conventional systems (Stolze *et al*, 2000; Shepherd *et al*, 2003).

Methane (CH_4): Agriculture is believed to account for roughly two-thirds of the total worldwide CH_4 emissions (Watson *et al.* 1996). About 75% of methane on farms is emitted directly from ruminant animals, through digestive processes and excretion (Stolze *et al*. 2000; Alföldi *et al.* 2002; Shepherd *et al*. 2003). Comparative empirical studies on CH_4 emissions in different farming systems are scarce. Flessa *et al* (2002) compared a conventional and an organic beef cattle farming in southern Germany and calculated that CH_4 emissions were about 25% higher on the conventional farm. Overall, it is considered that as a result of lower stocking densities, organic farming has a a lower CH_4 emission potential on a per hectare scale, whereas per unit output, the CH_4 emission potential tends to be higher than in conventional farming (Stolze *et al*, 2000; Shepherd *et al*. 2003). However in the absence of solid data, no significant differences between the two farming systems with respect to CH_4 emissions can be identified.

Energy

The OECD (1997) proposed to use energy intensity and efficiency as appropriate indicators to measure and evaluate energy use. The corresponding parameters are:

- Energy consumption (per hectare and per output)
- Energy efficiency (input/output ratio)

Energy consumption: Inputs of direct energy per unit area in the long-term DOK trial in Switzerland were similar across conventional, biodynamic and organic systems (Alföldi *et al*. 1995). In this case, since basic operations such as ploughing, cultivation, sowing and harvesting are likely to be similar, reduced fuel costs in organic systems due to the absence of most pesticide applications and lower harvesting energy inputs because of lower yields, are more or less balanced by increased fuel use for mechanical weed control.

Inputs of indirect energy tend to be substantially lower in organic farming. The major difference is the greater energy use in conventional systems to produce and transport fertilizer, particularly N fertilizers (Alföldi *et al*. 1995; Cormack, 2000; Stolze *et al*. 2000). If both direct and indirect energy use are considered together, calculations of energy consumption per hectare indicate that organic farms use less energy than conventional farms. Lampkin (1997) calculated that average energy consumption on organic farms amounts to 64% of conventional farmers. Flieβach *et al.* (2001) in Switzerland determined that the energy consumption of organic farms amounts to 30% to 50% of conventional farms. For organic potatoes and apples, energy consumption per output unit is higher relative to conventional production. This is the result of a higher energy input for mechanical measures like weed control and the lower mineral N fertilizer use in conventional production (Alföldi, 2002).

Efficiency of energy use: There are varying results on the energy efficiency of different farming systems in both conventional and organic farming, (eg. meat production is much less energy efficient than cereal or vegetable production). Few peer-reviewed studies were available in the literature concerning energy efficiency of organic farming. Furthermore, no standardized scheme for calculating energy use efficiency exists (Kasperczyk and Knickel, 2005).

Nguyen *et al* (1995) found little difference in overall energy efficiency when they compared mixed sheep and arable farms in New Zealand. However, they noted that the conventional farms relied more on legumes for N supply, and therefore were more energy efficient than European equivalents. In Poland, Kus and Stalenga (2000) calculated a 35% higher energy efficiency in organic compared to conventional farming.

Energy efficiency was found to be greater in organic milk and rye production compared to conventional production in Finland (Gronroos *et al*. 2006). In this study, it was concluded that in milk production, energy use efficiency can be increased by favouring organic production, with organic milk production being over 31% more energy efficient. For rye bread, organic production was 13.5% more energy efficient.

A DEFRA desk-study comparing organic and non-organic systems found that organic farming is more energy efficient than non-organic farming both on an area and yield basis. In the study all direct and indirect energy inputs and outputs for a range of farming systems were taken into account. It was found that organic arable production is about 35% more energy efficient and organic dairy production about 74% more efficient per unit of output than non-conventional production (Cormack, 2000). However, the author stated that in practice, energy inputs for cultivations and weed control will vary with soil type, weather, weed spectrum and population, irrespective of whether a farm is organic or conventional.

In another desk study carried out by Azeez and Hewlett (2008), 15 crop and livestock sectors in the UK were compared in terms of organic and conventional energy efficiency. It was found that organic farming uses around 26% less energy per tonne of agricultural output on average. The main energy saving is from the non-use of industrially produced inorganic nitrogen fertilizer. Organic farming is more energy efficient for wheat (16%), an array of common field vegetables-carrots, cabbage, onions, calabrese and leeks (44% average), beef production (41%), sheep production (57%), and milk production (28%). However organic farming was found to be less efficient for egg production (10%), poultry meat production (11%) and potatoes (14%).

Conclusion – Is organic farming more environmentally friendly?

The evidence as found in the literature indicates that there is wide agreement that organic farming comes closest to an environmentally friendly agriculture. Particularly pronounced is the significant difference in pesticide use between conventional and organic farming. A second major area where organic farming is more environmentally friendly is in soil conservation. Soil care is a guiding principle in organic agriculture. It is expressed in higher levels of soil organic matter, the active promotion of soil biological activity, more balanced nutrient cycles and in many cases enhanced soil structure. The third main benefit is the goal to enhance biodiversity through enhanced richness of flora and fauna. Organic farming also benefits habitat diversity and landscape value although other site-specific aspects and landscape structures have a great influence.

Less affirmative, though not necessarily less favourable than for conventional farming, is the evidence that has been presented in fields such as pollution of water resources. The same applies to the emission of N_2O (because manure stores are seen as a major source) and both CO_2 and CH_4 (because on an output unit scale the emission potential may be higher in organic farming).

Undoubtedly, organic farming generally uses less energy than conventional farming but a standardized methodology needs to be adopted to determine it’s role in terms of energy efficiency.

In a review of literature related to the environmental impacts of organic farming Kasperczyk and Knickel (2005) summarized the absolute and relative impacts of organic farming. An adaptation of this table which also considers other information sourced by the author and used in this paper, may be found in Table 2.

In terms of research needs, there is a lack of research under Irish conditions and in a more general sense on pastoral and upland agriculture. There is also more research needed on the effect of organic farming on climate change, especially in relation to losses of greenhouse gases per unit of yield and on the energy use efficiency of organic farming.

While it is considered that the beneficial effects of organic farming outweigh the adverse, there is a clear need for further scientific research into the complex relationships between organic farming and the environment in order to provide sound advice to policy makers, advisors and farmers.

Table 2 Overview of the relative impacts of organic farming compared with conventional farming (adapted from Kasperczyk and Knickel, 2005).

Area	**Aspect**	**Relative Environmental Impact***
Biodiversity	Floral diversity Faunal diversity Habitat diversity	+++ ++ +
Landscape	Landscape structure and aesthetic value	+
Soil	Soil organic matter and acidity Soil structure Soil biological activity	++ +? ++
Ground and Surface Water	Nitrate leaching Phosphorus Pesticides	++/- +? +++
Climate and Air	Carbon dioxide (CO_2) Nitrous oxide (N_20) Methane (CH_4)	+? +/-? +?
Energy	Intensity of energy use Efficiency of energy use	++/- +?

* + = Slightly better; ++ = better; +++ = substantially better; ++/- =better with some aspects that are negative; +?=better with some uncertainties; +/-? = partly better and partly worse with some uncertainties.

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Managing the conversion process successfully

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The increase in numbers of farmers considering organic farming as a viable option will lead to an increase in the number of conversion plans to be prepared in the near future. Good conversion planning can help minimise the risks associated with conversion by identifying potential problems, in particular feed requirements and stocking rates, animal health, soil fertility and nutrient management.

Techniques for conversion planning were developed as student projects in the early eighties and were subsequently adopted by organic farming advisors in the UK (Lampkin, 1992). Conversion plans are now a perquisite for applying for an organic licence from one of the certification bodies but are also a useful tool for assessing the technical feasibility of the conversion and a roadmap through the difficulties of the conversion process (MacRae *et al,* 1989).

There are three steps in the process of planning an organic conversion:

1. Current Management Practices – identify the resource limitations to be faced during conversion. This would include soil type, farm infrastructure and quotas.
2. Organic vision- what the target is for the farm to be producing when full organic symbol is achieved.
3. Future management practices – this will outline changes that have to be made to comply with organic standards, the plan will need to demonstrate how sufficient forage will be provided, how soil fertility and good animal health and welfare will be maintained.

Provision of sufficient high quality forage

Clover is the key to successful grassland management on organic farms (Barry, 2002). Assuming reasonable soil fertility levels, nitrogen supply to the plant is the key to sustainable levels of grass growth (Culleton *et al*, 2002). White clover through its ability to fix atmospheric nitrogen, can transfer nitrogen to the plant and thereby encourage grass growth. The quantity of nitrogen supplied can be as much as 150kg N/ha (Humphreys & Lawless, 2007).

Clover content in pastures can be increased by:

- Encouraging the spread of indigenous varieties
- Direct Reseeding
- Undersowing with a cereal crop
- Oversowing into permanent grassland (Culleton et al, 1999; Humphreys & Lawless 2007).

Maintenance of High Animal Health and Welfare

The maintenance of a high animal welfare status is enshrined as one of the principles of organic farming and good health is obviously a major element in the overall welfare status of the animal (IFOAM, 1998). Good livestock health is not seen simply as the absence of disease, but a high level of vigour and vitality, thus enhancing the animal's ability to resist infection, parasitic attack, metabolic disorder and recovery from injury (Younie, 2000).

Because the organic system minimises the use of veterinary treatments, a positive approach to livestock husbandry is required (Boehncke, 1997). Every decision that is made regarding grassland management, housing, reproductive patterns have the potential to impact on livestock health. Preventative health strategies include:

- Closed herds
- Breed choice – breeding for disease resistance
- Adequate feed supplies
- Establishment of clean grazing system
- Adequate winter accommodation.

Soil Fertility

Nutrient management is one of the main challenges facing the organic farmer. In the short term, the challenge is to supply sufficient nutrients to the crop at the correct time in its development to achieve economically viable yields. In the longer term, the challenge is to balance inputs and off-takes of nutrients to avoid reduction in soil fertility or environmental pollution (Briggs, 2008).

Nutrient supply to crops depends on the use of legumes to add nitrogen to the system and limited amounts of supplementary nutrients, in acceptable forms. Manures and crop residues must be carefully managed to recycle nutrients around the farm. Crop rotation is the central tool that integrates the maintenance and development of soil fertility with different aspects of crop and livestock production in organic systems. Short term leys help ensure good soil structure and biodiversity in crop systems as well as improving weed control (Watson *et al.*, 2002). As a result of the long term interactions between different components, soil fertility management needs to be a long term integrated approach rather than the short term very targeted solutions common in conventional agriculture.

Organic farming adopts many practices that minimises fertility losses such as:

- Maximising green covers – short term leys, cover crops
- Use of straw based manures or compost applications
- Lower stocking rates.

Manure management within the rotation has been shown to have large effects on both yield and product quality including protein levels in cereals (Stein – Bachinger, 1996; Frederiksson *et al*, 1997). The quality of nutrients in manures varies with type of animal, feed composition, quality and quantity of bedding material, length of storage and storage conditions (Dewes & Hunsche, 1998; Shepard *et al*, 1999).
Animal manures are an important means of re-distributing nutrients as it is important to ensure that excessive fertility is not built up in some fields at the expense of others (Berry *et al*, 2002). Manure use should be planned with regard to both farm system and field nutrient budgets (Briggs, 2008).

While the certification bodies accept conversion plans from both farmers and professional advisors, it is important to research the topic well, a good solid conversion plan will provide a roadmap for the farmer and will help ease the transition from conventional methods of farming.

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Reproductive Management of Dairy Cows with Particular Reference to Organic Systems

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Introduction

Reproductive efficiency is a major factor affecting production and economic efficiency in dairy herds. In seasonally calving herds the requirement of good reproductive performance is of greater importance than in other production systems in order to maximally exploit the use of grazed grass in the diet of the cow. Reproductive performance of lactating dairy cows worldwide has declined over the past 30 years in association with selection for milk yield. There is increasing and consistent evidence to suggest that at least some part of the decline in cow reproductive performance is related to underlying changes in reproductive physiology caused by high milk production and or negative energy balance (NEB) in early lactation. Organic systems of milk production demand high tight seasonal calving patterns, maximal production from grazed grass, low involuntary culling rates and the continuous genetic improvement of the herd for commercially important traits. Organic milk production systems should also allow for replacement rates of 25% - 30% to ensure a young herd age structure and low somatic cell counts (SCC). The objective of this paper is to review the role of management factors in herd reproductive performance with particular reference to organic herds.

Factors affecting overall herd reproductive efficiency.

While there are numerous factors that affect the reproductive performance of individual cows and consequently herd reproductive performance they can be categorised under the following three broad headings: (i) the interval from calving to resumption of ovulation and regular oestrous cycles, (ii) oestrous detection efficiency and submission rate and (iii) conception rate following service.

The interval from calving to resumption of ovulation and regular oestrous cycles

The number of ovulatory oestrous cycles preceding insemination has been shown to beneficially influence subsequent conception rate. Consequently, it is desirable that dairy cows resume ovulation in the first 4 weeks after calving. The objective with dairy cows in early lactation is to achieve high dry mater intakes (DMI) as this would be expected not only to hasten the onset of oestrous cycles post calving but also increase conception rates (see later) and shorten calving to conception intervals. Increasing dietary intake is restricted by the requirement for inclusion of fibre in the diet to maintain rumen function as well as by the variability in voluntary feed intake by cows during this period. Increasing feed allowance does not necessarily result in increased feed intake and energy balance (EB) is likely to be limited by the inherent voluntary capacity of the cow. Generally about 90% of dairy cows should be observed in heat by 42 days post calving.

Relative importance of heat detection efficiency and conception rates

Once regular oestrous cycles have been established and, in the absence of pregnancy, cows should continue to return to oestrus every 17-24 days. The subsequent overall reproductive performance of a herd, measured in terms of the pregnancy rate at the end of a 14-week breeding period, is a function of the product of heat detection rate (HDR) x conception rate (CR) (Table 1.). From Table 1 it can be seen that a pregnancy rate of 91%, at the end of a 14-week breeding period, can be obtained either by HDR of 90% and a CR of 50% or by a HDR of 70% and a CR of 60%. It is clear from numerous studies that there is much greater variation in heat detection efficiency at farm level than there is in conception rate. From management point of view heat detection efficiency is much more under management control than is conception rate and, consequently, individual producers using AI should concentrate on improving heat detection and therefore submission rates.

Table 1

The effect of different heat detection and conception rates on the % of the dairy herd that is pregnant at the end of a 14-week breeding period.

		Conception Rate %			
		60	**50**	**40**	**30**
Heat Detection Rate %	**90**	96	91	83	71
	70	91	82	73	61
	50	76	68	59	48
	40	67	59	50	40

Duration of oestrus

Published estimates show that the average duration of standing heat was 8.1 hours with 9.1 standing events or mounts recorded during standing heat. This represents on average one standing event occurring every 53 minutes with an average duration of each standing event lasting about 2.5 seconds. This clearly illustrates the difficulty that detecting standing heat presents particularly when "standing to be mounted" is definitive criteria required and in the absence of a bull or other technologies aids to assist with detection. Breaks or quiescent interludes in standing activity have also been observed. O'Farrell observed that breaks in standing activity occurred in 30% of dairy cows at pasture while Stevenson et al., (1998), using HeatWatch, recorded breaks with an average duration of 2.6 hours in 67% in beef heifers.

Pattern of heat onset

Recent data from a comprehensive US study that utilized HeatWatch system to provide 24 hours a day surveillance of cows showed that the pattern of onset and end of heat was evenly distributed throughout the day.

Table 2

Percentage of dairy cows first observed in standing heat at specific times of the day.

Hours	07:00	10:00	13:00	16:00	22:00
Percent detected	40	5	7	18	30

Source: Diskin & Sreenan, 2000

Data from this laboratory for dairy cows at pasture (Table 2) shows that careful checking for heat in the early morning and late evening minimises the night interval and results in the detection of at least 70% of cows in heat. Three further checks during the day, at about 4-5 hour intervals, are required to detect 90% of cows in heat.

Factors affecting the expression of heat

Numerous factors affect the expression of heat, the more important of those are briefly discussed.

Housing arrangement: For satisfactory expression of heat cows must have adequate space to allow cow-to-cow interaction. If the stocking density is too high the expression of the signs of heat are reduced, consequently making detection more difficult as well as increasing the likelihood of wrongly identifying cows in heat. Checking cows in holding pens or collecting yards is not to be recommended.

Milk yield: Recent US data recorded a strong negative relationship between milk yield near the time of oestrus and the duration of standing heat that was independent of parity

Floor surface: Cows dislike being mounted while standing on concrete and have a preference for softer underfoot surfaces such as grass, dirt or straw bedded yards. Mounting activity was reduced by almost one half when cows were kept on concrete as opposed to softer underfoot conditions while the duration of oestrus activity was reduced by about 25%. Cows distinctly dislike being mounted by herd mates if the floor surface is either slippery or very coarse. Studies from this laboratory show that expression of oestrus, in terms of the number of mounts recorded and the duration of the standing period were both reduced in heifers on concrete slats compared with heifers at pasture or on rubber covered slats or on straw-bedded pens..

Feet and leg problems: Cows with sore feet or legs or that have poor structural conformation exhibit less mounting activity and have fewer “stands”. Furthermore, such cows may well stand to be mounted when not in heat because it is too painful to escape from the mounting cow. Consequently, lame cows have significantly longer calving to service and calving to conception intervals.

Status of herd mates: The number of cows in heat simultaneously has a major impact on overall heat activity in the herd and on the average number of mounts per cow (Table 3.). The number of mounts per cow increased with the number of cows that are in heat simultaneously up to about 3-4 cows in heat.

Table 3 Effect of number of cows in heat simultaneously on the average number of mounts and on the average duration of heat

No. of cows in heat simultaneously	No. of mounts	Duration (h)
1	17	8.6
2	29	12.4
3+	40	14.1

Thus, in smaller herds and as more cows become pregnant the likelihood of more than one cow being in heat on any given day becomes less, consequently, making heat detection more difficult. To be detected in standing heat a cow she must engage the attention of a herd mate willing to mount her. Generally cows that are themselves in heat, coming into heat or were recently in heat are most likely to mount a cow that is in heat. Cows that are at the mid-stages of their cycles (day 5 to about day 16) are least likely to mount a cow that is in heat and consequently could be termed “poor heat detectors”. Similarly, cows that are pregnant show less interest in mounting other cows that are in heat. Consequently, as more cows in a herd become pregnant it becomes increasingly difficult to identify the few remaining open cyclic and repeating cows. .

Signs of heat

To optimise heat detection a number of the signs of heat, both primary and secondary, must be clearly understood.

Primary signs of heat: Standing to be mounted by herd mate or bull is the most definite and accurate sign that a cow is in heat. During the period of standing heat, cows stand to be mounted by other cows or move forward slightly with the weight of the mounting cow. Cows that move away quickly when a mount is attempted are not in true heat.

Secondary signs of heat: Because standing heat may not always be observed, stockmen must frequently use other signs of heat in arriving at a decision as to whether or not to inseminate a cow. These secondary signs of heat may indicate that a cow is coming into heat, in which case closer attention should be given to her over the following 48 hours, or they may be indicative of a recent heat in which case she should be given closer attention 17-20 days later. Secondary signs of heat include: discharge of clear mucus, chin pressing mounting other cows, restlessness, swelling and reddening of vulva, hair loss and dirt marks, blood stains on the tail or vulval area (metoestrous bleeding) and decreased feed intake and milk yield. A schematic representation of the relative timing of primary and secondary signs of heat relative to ovulation and probability of conception are presented in Fig 1.

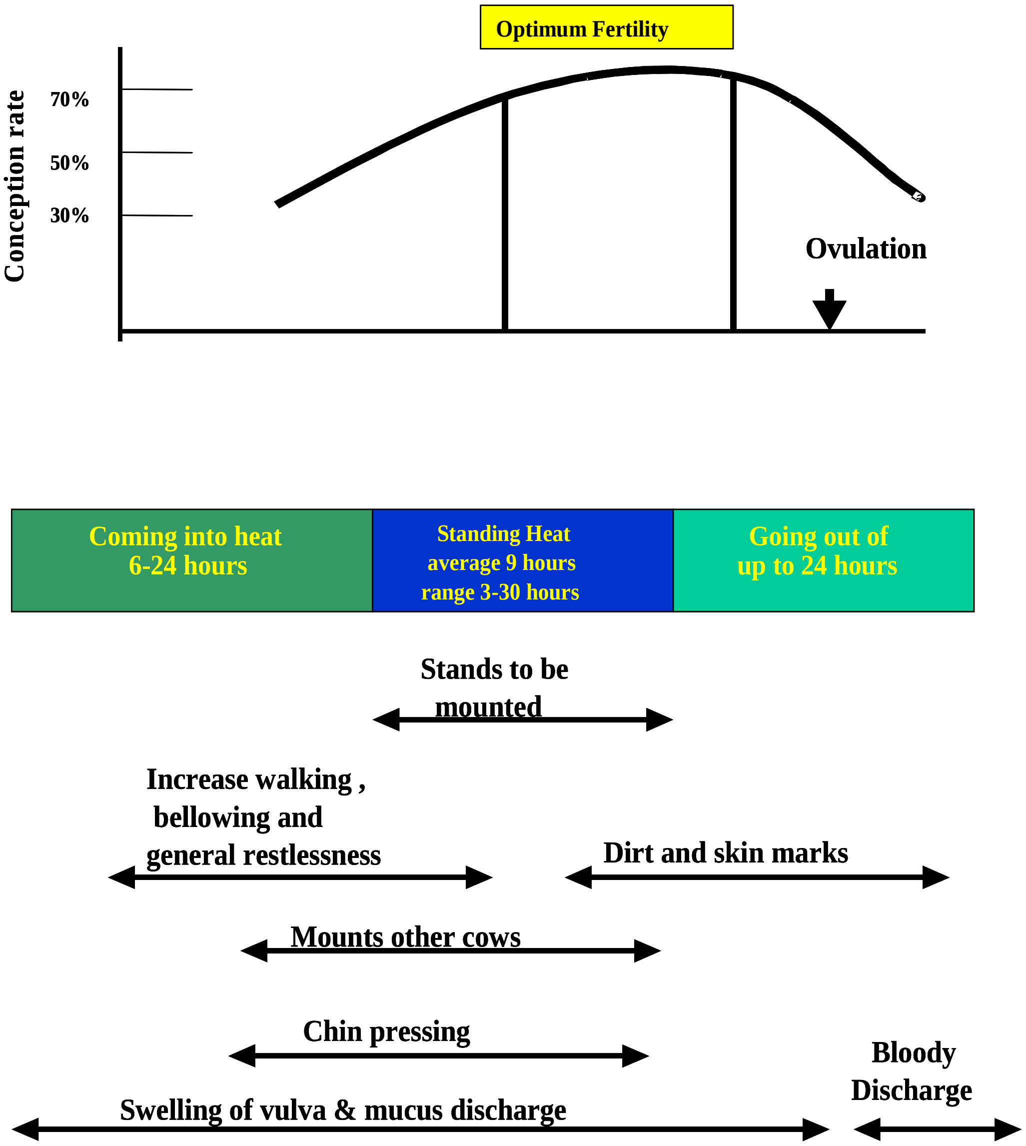

Fig 1. Schematic representation of the relative timing of primary and secondary signs of heat relative to ovulation and probability of conception rate

Improving heat detection

The single most important factor affecting heat detection efficiency is that those responsible for checking for heat should fully understand the signs of heat and be fully committed to heat detection for as long as is planned to use AI. About 10% of the reasons

for failure to detect heats can be attributed to cow problems and 90% to "management" problems. The latter would include too few observations per day for checking for heat activity; too little time spent observing the cows or observing the cows at the wrong times or in the wrong place such as feeding time or in the collecting yard at milking time. Another major reason for failure to detect heat is that those involved in heat detection do not understand the signs of heat.

Records: Individual animal records are an essential part of good breeding management. All animals must be clearly and permanently identified by one of several methods, such as plastic ear tags, neckbands or freeze branding. Whichever system is preferred, it is essential that the animal number be clearly legible from a reasonable distance. Breeding records should include (i) animal number (ii) calving date, and other information relevant to the calving (iii) pre-breeding heat dates (iv) first and repeat service dates and sire used on each date and inseminator code (v) date and result of pregnancy diagnosis and, (vi) date of expected calving. Good records are not only part of good farm management practice but are the first essential step in all infertility investigations.

Monitoring submission rate: This is calculated as the proportion of cows calved at the beginning of the breeding season, that are intended for re-breeding and that are submitted for insemination. A submission rate of at least 80% should be achieved in the first 21 days of the breeding period. Submission rate, which is easily calculated, is an excellent measure of heat detection rate and should be calculated at the end of the first 21 day period of the breeding season. A submission rate of less then 80% indicates a problem with heat detection and diagnosis of this problem at an early stage allows corrective action be taken before much of the breeding period has elapsed.

Technological aids to improve heat detection

The low to moderate heat detection efficiencies achieved on most farms reflect the difficulty of detecting heat in cows. A number of both inexpensive to expensive aids and technologies are available to meet some but not all of these criteria. In any case, use of various technologies to identify symptoms associated with oestrus, ovulation, or both will require judgment of herd management to verify whether or not the cow seems to be in oestrus based on common husbandry experience.

Tail-painting: Research from a number of laboratories has shown that applying paint or chalk to the tailhead of cows is effective in indicating standing activity. When such "tail painted" cows are mounted from the rear some or all of the chalk or paint is rubbed off indicating that the painted cows possibly stood in oestrus while mounted by a herd mate. When combined with early morning and late evening observations, checks for paint loss at milking times should result in a heat detection rate of close to 90%.

Vasectomised bulls with chin-ball marking harness: Active vasectomised teaser or detector bulls are useful in identifying cows either coming into or on heat. Vasectomy should be carried out 40-60 days prior to introduction to the herd. Many herds are now finding that teaser bulls are particularly useful after the first 3 weeks of the breeding season when fewer cows are in heat each day and when the level of heat-related activity in the herd is reduced as more cows become pregnant. However, considerable variation in libido exists among bulls and they require the same management as full bulls without conferring any of the advantages.

Pressure activated heat mount detectors*:* These devices including these marketed as Kamars, Bovine Beacon and Mate Master are affixed to the tail head of the cow and change colour when pressure is applied by the weight of the mounting animal. Reported efficiencies of heat detection using such heat mount detectors vary from 56 to 94% while the accuracy of heat detection is reported to vary from 36 to 80%. The relatively low accuracy of heat detection combined with difficulties in keeping the devices affixed to the tail head limit the potential of this approach.

Pedometers: Oestrus in cattle is accompanied by increased physical activity. Cows that are in heat do 2-4 times more walking than a non-oestrous cow. Pedometers can be attached to the leg of the cow to measure the amount of her activity over a unit time span. Early pedometric-aided heat detection systems operated with a reported heat detection efficiency of 60-100% and with accuracy in the range of 22 to 100%. The low level of accuracy was related to a high proportion of false positives and to technical problems that led to breakage, malfunction, or loss of the pedometers. New improved pedometric technology has now led to improved information storage systems, improved analytical capabilities to allow comparison of current with previous physical activity, incorporation of internal power supply to operate the electronics, the development of self-contained devices to interrogate the pedometers in milking parlour and relay or store information in a personal computer. Some systems have an inbuilt alert system such as a bleeper or flashing light which alerts the farmer when a cow is deemed to be in heat. A number of pedometric systems are commercially available in the US and Europe. While scientific information on their operating efficiencies is not yet available these systems would appear to have significant commercial potential particularly when cows are housed.

Heat detection patches: Recently a number of “scratch card-type” patches have come on the market including Estrus Alert ® and ESTROTECT™. These are affixed to the cow’s tail head. Friction from mounting activity rubs off the silver coating to reveal a bright colored patch underneath. These devises, while not yet comprehensively evaluated under Irish conditions, do show promise.

Conception rate

This is the 3rd major factor affecting reproductive efficiency. The main factors implicated in causing conception rate failure or embryo death are normally categorised as those of genetic, physiological, endocrine and environmental origin. Only some possible environmental factors are considered here.

Fertilisation rate and early embryo loss rates in cattle: When adequate numbers of spermatozoa are used from bulls of high fertility, cows correctly inseminated during or shortly after the end of standing oestrus fertilization rates of 90+% should be expected. While fertilisation rate is apparently similar in high- and moderate-producing cows and unlikely to be affected by whether cows are on pasture or high input total mixed ration (TMR) diets, nevertheless the average calving rate to a single service is significantly lower in high- than in either low-producing cows or in heifers. We calculate an embryonic and foetal mortality rate (excluding fertilisation failure) of about 40% for moderate-producing cows based on a fertilisation rate of 90% and an average calving rate of about 55% with an estimated 70 to 80% of the loss sustained between day 8 and 16 after insemination. The comparative figure (see Fig 2) for high producing dairy cows, based on a fertilisation rate of 90% and a calving rate of 40%, would be 56%.

Late embryo and foetal loss

Over the past decade there has been significant interest in the problem of late embryo and early foetal mortality, which has generally been defined as the death of the embryo after about day 24 of gestation. With the advent of ultrasound scanning it has been comparatively easy to accurately establish the extent and timing of late embryo/foetal mortality. A recent study from this laboratory quantified the extent and pattern of embryo/foetal loss from days 28 to 84 of gestation in 1046 lactating dairy cows and 162 dairy heifers managed on pasture-based systems of milk production. The overall loss rate between days 28 and 84 of gestation were similar for cows (7.2%) producing on average 7247 kg of milk and heifers (6.1%) and the pattern of loss over this period was also similar for cows and heifers. Almost half (47.5%) of the total recorded loss occurred between days 28 and 42 of gestation. There was no significant association between level of milk production or milk energy output measured to day 120 of lactation, milk fat concentration, milk protein concentration, or milk lactose concentration and embryo/foetal loss rate.

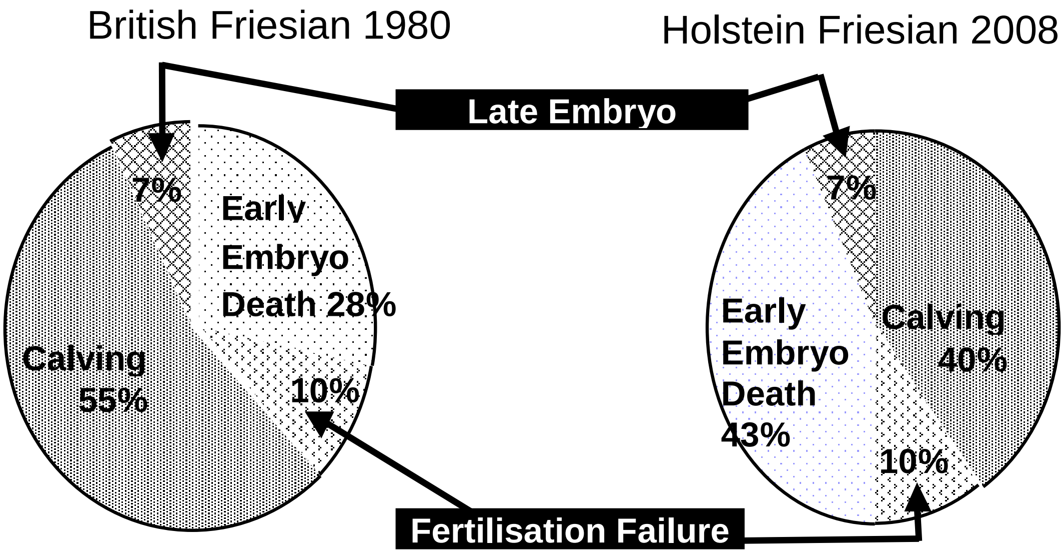

Fig 2 Reproductive outcomes in British-Friesian versus Holstein-Friesian cows

Nutrition -Energy balance

Over the past 3 decades intensive genetic selection for milk yield has increased the differences between feed intake potential and milk yield potential. This has resulted in dairy cows that have a greater predisposition for mobilising body reserves and for NEB. It is also clear that even under optimal grazing condition total dry matter intake is less than when cows are fed maize-based TMRs. It is clear that even under optimal grazing conditions the actual DM intakes of cows are significantly less than the cows' potential intake and this is likely to have implications for EB status and subsequent fertility in early lactation. Furthermore, it is apparent that the consequences are greater when high genetic merit dairy cows are grazed.

Energy balance during the early postpartum period and subsequent conception rate: Recently, Moorepark studies explored the relationships between energy balance, DM intake during the first 28 days of lactation and subsequent conception rate. Both variables were positively associated with 1st service conception rate. This is a particularly interesting observation and suggests that there may be long-term carryover effects of nutrition / EB on conception rate. The results of this study strongly emphasize the importance of maximising feed intake and minimising negative energy balance in the immediate post-calving period.

Energy balance at around the time of insemination and subsequent conception rate: It has frequently been hypothesised that improving the energy balance of the dairy cow at around the time of insemination would improve conception rate. However, there is a lack of data supporting this hypothesis with few if any studies supporting it. The reason for this is that only a small proportion (<20%) of the additional feed intake achieved by the additional concentrate supplementation is partitioned towards an improvement in energy balance with >80% going to supporting increased milk production. This clearly highlights the difficulty that improving the energy balance of the modern dairy cow presents at this stage of lactation where grazed grass is the predominant component of the diet. Furthermore, the increased milk production as a result of the concentrate supplementation may well be associated with increased hepatic blood flow resulting in increased metabolism of progesterone and consequently lowering of peripheral concentrations of progesterone and pre-disposing to greater risk of embryo death.

Sudden reductions in feed intake and conception rate: Studies from this laboratory show that sudden reductions in DM intake at around the time of insemination adversely affect embryo survival in heifers. When energy intake was reduced from a high level of twice their maintenance requirement to 0.8 times maintenance for two weeks immediately after AI, embryo survival rate in heifers was consistently less than 40%. When heifers were provided with either a constant level of feed intake or when they were changed from a low to a higher level feed intake embryo survival was consistently high at 65-71%. In that study, where heifers were used, there was no indication of any association between energy intake and systemic progesterone concentration

Protein nutrition and conception rate: Dairy cows at pasture frequently ingest high quantities of protein, often with a high proportion of the ingested protein being rapidly degradable in the rumen. The effects of high intakes of crude protein on conception rate are equivocal. However, in an extensive range of studies from this laboratory, using beef heifers in positive energy balance, there was no effect of a high crude protein intake on conception in heifers, irrespective of whether the crude protein was derived from high nitrogen-fertilized grazed grass or from added urea to a silage-based diet. Furthermore, a retrospective analysis of both experiments failed to record any association between peripheral concentrations of urea and embryo survival, notwithstanding peripheral concentrations of urea having been elevated up to 25mmol/l. From these two studies, from this laboratory, it is possible to conclude that elevated peripheral concentrations of urea per se are not detrimental to embryo survival. However, it needs to be clarified whether the observed adverse effects of urea on embryo survival are dependent on the energy status of the animal.

Insemination technique: The reported effect of site placement of semen within the uterus on conception rate are equivocal. In a recent study from Teagasc, Athenry, involving 3546 dairy cows in 51 herds and 8 inseminators, we recorded a significant effect of insemination site x inseminator on conception rate. For some inseminators there was a significant increase (up to +11 percentage point increase) on conception rates following cornual while for others there was no effect. A retrospective analysis of all the data showed that there was an inverse relationship between the improvement in conception rate and conception rate following uterine body insemination. The largest improvements in conception rates were recorded by inseminators with the lowest conception rate following body insemination. These results suggests that conception rates could be improved for individual inseminators by adopting the practice of placing half of the inseminate beyond the curvature of each uterine horn as opposed to body insemination which is the normal practice. It is clear from many studies that placement of the inseminate in the cervix result in significantly lower conception rates. Therefore it is critical to at least ensure that the inseminate is placed in uterine body and for skilled experienced inseminators it would appear beneficial to place half of the inseminate in each uterine horn.

Time of insemination: Results from a recent large scale US study concluded that conception rates were optimum when dairy cows were inseminated 4-16 hours after heat onset. Insemination later than 16 hours after heat onset results in significantly lower conception rates. However, in most instances the time of heat onset is not accurately determined and in this situation once daily AI for cows observed in standing heat is equally as effective as inseminating cows in accordance with long-established the am.-pm. guidelines.

Calving difficulty: Calving difficulty, besides its effect on calf and cow mortality and on milk yield, also decreases cow rebreeding performance. Teagasc data clearly shows that as the severity of calving difficulty increases, conception rate to the first and to all services combined also decreases (Fig 2). This reduction in conception rate is due to abnormalities directly arising from the calving difficulty including delayed uterine involution and increased uterine infection, damage to the reproductive tract and the development of uterine and ovarian adhesions. Furthermore, the interval to first heat is often extended after a difficult calving. For optimal reproductive performance calving difficulty must be minimised.

Two factors that greatly influence the incidence of calving difficulty are cow age and sire breed. The incidence of calving difficulty is 4 to 8 times higher in first calving heifers than in mature cows and about twice as high in second calvers as in mature cows. Breed of sire and indeed the individual sire within a breed should be carefully selected for use on heifers and on young cows to minimise the risk of calving difficulty and therefore of subsequent infertility.

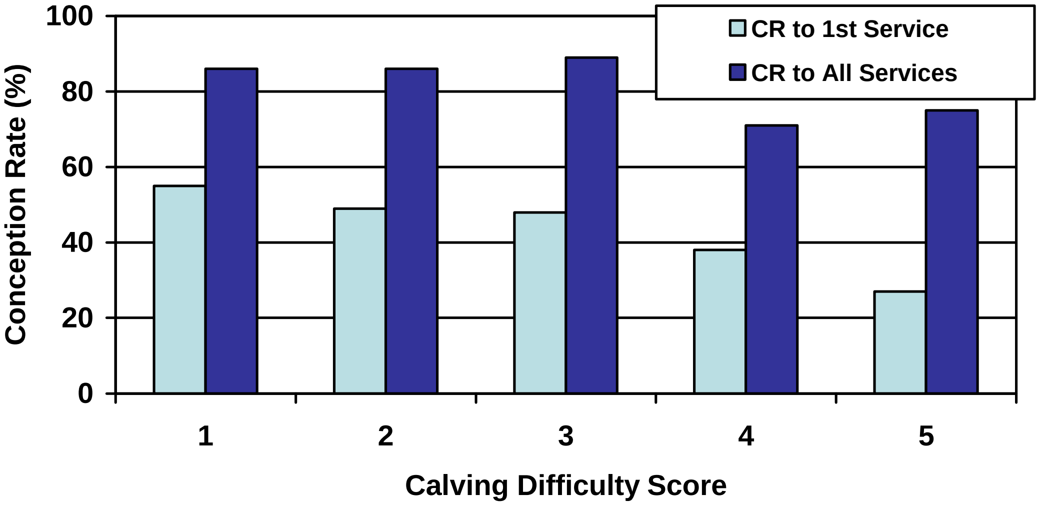

Fig 2. Relation ship between calving difficulty score and conception rate to 1st services and to all services combined. Score 1 = unassisted birth to score 5= severe difficulty requiring mechanical extraction of the calf.

While it is an increasing practice to breed late calving dairy cows to beef breed sires the combined effects of the longer gestation and the increased incidence of calving difficulty make it even more difficult to achieve a 365-day calving interval in such cows. The wisdom of this practice, especially if the objective is to optimise reproductive performance, is therefore questionable.

Bull fertility: Bull reproductive performance is influenced by several factors including, testicular development, semen quality, libido, mating ability and physical soundness. On farms using natural service the level of bull fertility can have a major impact on pregnancy rate and calving spread. Published data from abroad suggests that up to 5% of bulls in natural service may be completely infertile while a further 30% may be sub fertile. Unfortunately if a bull is infertile this is not usually discovered until at least one repeat interval has elapsed since joining the herd. While a veterinary examination combined with a semen evaluation one month before the start of the breeding season will help to identify the majority of infertile bulls it will not identify sub fertile bulls. Furthermore, it should be realised that a bull may not remain fertile for all of his working life or indeed throughout a single mating season. For example, a bull that is ill with a raised temperature for a number of days may have a period of temporary infertility about 40 to 60 days later. Similarly, injury to the penis, sheath or prepuce while not necessarily affecting mounting behaviour, can prevent mating. Therefore, the bull should be observed regularly for serving ability and all mating dates recorded. Such recording will help identify infertile or sub fertile bulls at an early stage.

A.I. vs natural service: Artificial insemination is often criticised on the grounds that conception rate is lower than following natural service. Apparent improvement in conception rate often arises following the introduction of a bull. This improvement is likely to be due to cows being mated at a longer post-partum interval and or, because inaccuracies in heat detection are now eliminated. Where heat detection is accurate, insemination is timed and carried out correctly; conception rate is similar following A.I. or natural service.

Breeding of Replacement Heifers.

For Holstein-Friesian heifers the target weight for breeding at 15 months is 350 kg. The breeding of heifers should commence at the beginning of the breeding season and be bred to easy calving sires to minimise the risk of calving difficulty. Late calving heifers, on average, produce late calving cows which have a lower probability of being retained in the herd.

Sire Selection

Organic milk producers should carefully examine the Economic Breeding Index (EBI) of any potential sire to be used in their herd and in particular the sub-indices that make up the EBI. Producers should select sires that have positive sub-index for milk production and that have fertility sub-index of >€60. Consistent use of sires with strongly positive fertility sub-indices will, overtime, result in more fertile cows. Recent results from Teagasc Moorepark show that cross bred dairy cows are more fertile while maintaining or improving milk solid production. Norwegian Red crossbred dairy cows are similar in size to Holstein-Friesian, are more fertile and have lower somatic cell counts. Jersey cross Holstein –Friesian are smaller than the Holstein-Friesian and, therefore, will have a lower maintenance requirements while still maintaining milk solid production but have superior fertility. Irrespective of which breeding plan is chosen it is important that producers select a panel of 4 sires each year as well as minimising the risk of inbreeding.

Conclusion

Reproductive performance is critically important particularly in seasonally calving herds in order to maintain compact calving close to the onset of the grazing season. While the modern high genetic merit Holstein-type dairy cow selected solely for milk production is biologically more efficient at converting forage, irrespective of source, to milk their sustainability in predominately pasture-based systems of production is questionable given their low fertility. It is now becoming increasingly clear that energy balance during the immediate post-calving period affects both the onset of oestrous cycles post calving and subsequent conception rates. Paying more attention to other factors that are predominately under management control, particularly heat detection can significantly offset some consequences of inherently low fertility traits that exist with the modern dairy cow. We have clearly shown that improving heat detection efficiency by 12-15% has the equivalent effect of increasing conception rate by 10 percentage points. From numerous published reports there is scope in most herds to improve heat detection efficiency by at least 15 percentage points by adopting well-described practices. Conception rate is affected by a range of both cow and management factors. Producers should ensure cows presented for insemination are in heat, are properly inseminated with high fertility semen. Sudden reductions in feed intake during the breeding season should be avoided.

The role of clover in organic milk production

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Introduction

Grazed pasture makes up between 60 and 75% of the diet of dairy cows on conventional farms in Ireland. This reliance on grazed pasture results in lower milk production costs compared with other countries in Europe. On organic dairy farms, the very high cost of concentrates, relatively high cost of making silage and relatively low stocking densities create a strong incentive to maximise the proportion of grazed pasture in the diet of cows. White clover is a key component of organic pastures because swards that contain white clover have twice the productivity of swards that don't (Figure 1). The reason for this is that clover forms a symbiotic relationship with N-fixing *Rhizobium* bacteria that can supply up to 150 kg N per ha per year under Irish conditions.

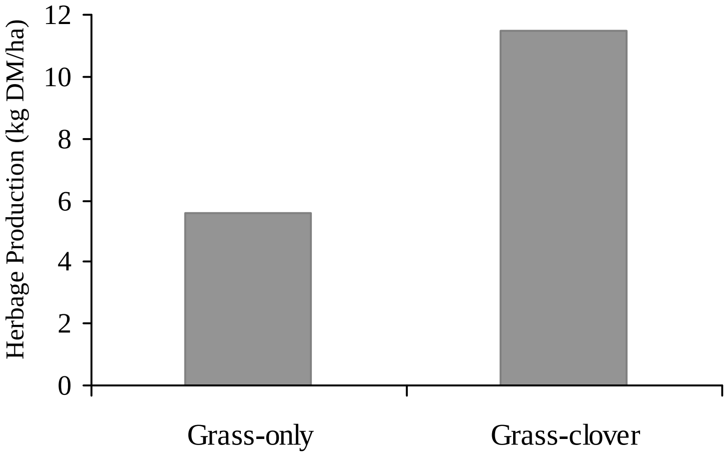

Figure 1. Herbage dry matter (DM) production of grass-only and grass-clover swards receiving no inputs of synthetic fertilizer N

An important difference between grass-clover swards on conventional and organic farms is that, on conventional farms, fertilizer N can be used to increase pasture production in spring. On organic farms, the growing season is curtailed in spring unless slurry or farmyard manure (FYM) is used to increase spring growth, although the availability of FYM is unlikely be sufficient to entirely meet this requirement on organic farms. Slower pasture production in spring raises the question of calving date. Should calving date be delayed in spring to better match pasture supply? Another important question influencing calving date is milk price. There is a price premium for organic milk when 55% of annual production is supplied between 1 September and 1 March. Hence, milk production during the winter is important and this has an important bearing on calving dates on organic dairy farms.

Pasture supply during the year

The pattern of pasture supply from grass-white clover swards receiving no inputs of fertilizer N is shown in Figure 2. Growth rates are quite low until late March and this is associated with a low clover content of swards. In general clover likes warm temperatures and does not begin to grow and fix N until soil temperatures reach around 9°C in April. However, the grass component of the sward will start growing from early March onwards and where early spring growth is required FYM should be applied during February to meet this requirement. The clover makes a small direct contribution to pasture production in spring accounting for 5% or 15% of sward DM during February and March. Clover makes and increasing contribution to pasture production during April and May. There is usually a peak in grass production during late May followed by a sharp reduction due to the death of reproductive grass tillers during this time of year. During this mid-summer depression of grass growth clover becomes prominent in the sward because (i) high soil temperatures during this time of the year favours clover growth and (ii) the dip in grass growth rates means that it is less competitive with the clover. From mid-summer onwards, approximately 50% of the sward is composed of clover and it is during this time of the year that most N fixation takes place. Some of this fixed N becomes directly available for pasture production and the remainder is tied up in the clover stolons at the base of the sward. During the summer and early autumn there can be a four-fold increase in the amount of clover stolon per ha. During the winter much of this clover stolon dies back releasing the N for pasture production when soil temperatures rise during the following spring and early summer. Hence, some N fixed in one year is carried over the winter and released for growth during the early part of the following year.

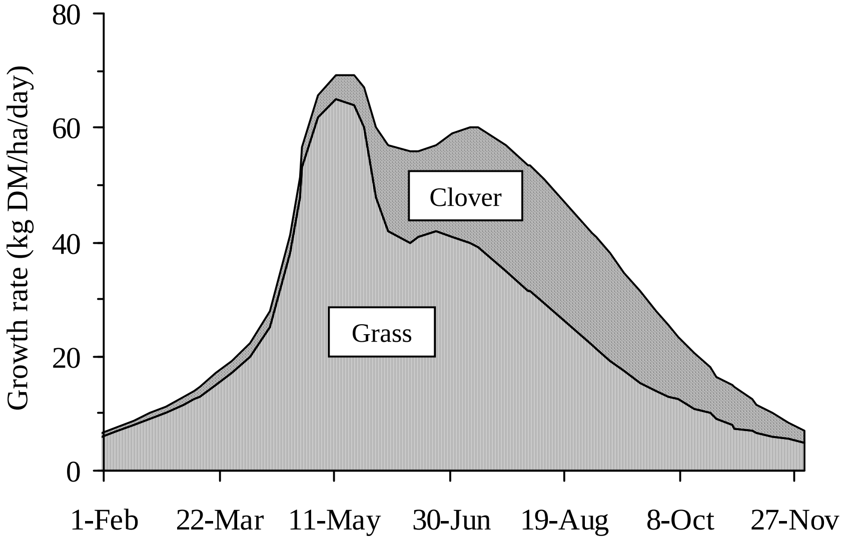

Figure 2. Changes in the grass and white clover content of swards during the year

While the rate of pasture accumulation of grass-clover swards is relatively low in spring, high soil temperatures and a high clover content of the sward means that rates of pasture production from grass-clover swards can be very high during the summer and autumn, matching the production of perennial ryegrass swards receiving high inputs of fertilizer N. These grass-clover swards also have high nutritive value because white clover has the highest nutritive value of any grassland species, having a high crude protein content and high digestibility. Furthermore, research has shown that a grass-clover sward being grazed on a 42-day rotation had similar nutritive value to a grass-only sward on a 28-day rotation during the autumn. The clover content of the sward is at its highest during the autumn and this contributes to maintaining sward nutritive value under long rotations. Progressively increasing rotation lengths in a planned way during the late summer and autumn facilitates extending the grazing season into the winter. Hence, while growth of organic grass-clover swards during the spring is relatively low, there is substantial potential to extend the grazing season into the winter by extending out rotation lengths from the late summer onwards. This combined with intermediate stocking densities (1.6 LU per ha) on organic dairy farms means that long grazing seasons can be achieved on grass-clover swards despite relatively low growth rates on spring.

Experimental systems at Solohead

At Solohead we are examining the potential of grass-clover swards receiving no inputs of fertilizer N (NFN) to meet the feed requirements of dairy cows during the year. A description of these systems is shown in Table 1.

Table 1. Comparison of the levels of production on the average dairy farm from the National Farm Survey and clover-based systems at Solohead (i) early spring calving receiving no inputs of fertilizer N (ii) late spring calving receiving no inputs of fertilizer N and (iii) Standard clover system receiving 90 kg per ha of fertilizer N in spring

	Average Dairy Farm	Early-calving Solohead NFN	Late calving Solohead NFN	Standard Solohead system
Stocking density (cows per ha)	1.9	1.6	1.6	2.15
Fertilizer N (kg per ha)	170	0	0	90
Mean calving date	mid-March	15 February	15 April	15 February
Milk yield (litres per cow)	4,700	6,400	6,400	6,400
Milk Fat (%)	3.75	4.15	4.15	4.15
Milk protein (%)	3.30	3.55	3.55	3.55
Milk solids (kg per cow)	342	493	493	493
Milk solids (kg per ha)	650	788	788	1,060
Concentrate (kg per cow)	715	400	750	400

The stocking density on two systems being examined is 1.6 LU per ha. The mean calving date of the early-NFN system is 15 February and cows were turned out to grass from late January onwards as they calved. On this system pasture supply was tight until the end of April. Concentrate supplementation during the spring was 250 kg per cow. Compared with the standard Solohead grass-clover system receiving fertilizer N in spring, first-cut silage production was greatly curtailed on the early-NFN system because the entire area was needed for grazing until late April, even at the lower stocking density, and no silage ground was closed off until late April. The late-NFN system had a mean calving date of 15 April. Cows started calving in March and went straight to pasture and received no concentrate supplementation during the spring and summer. The plan was to keep grass in the diet of these cows through to drying off in late February. This was facilitated by housing replacement heifers and calves in late September and making the entire area of the system available for grazing by the cows during the late-autumn and winter, hence, the stocking density of dairy cows during the winter was 1.2 cows per ha.

By extending the rotation length from mid-July onwards 1,200 kg DM per ha was accumulated on the late-NFN system on 1 November. Experience at Solohead has shown that grass-clover swards receiving no fertilizer N during the summer, autumn and winter grow at an average daily rate of 10 kg DM per ha during the winter. From 1 November to drying off on 28 February is 120 days. Hence growth during the late autumn and winter supplies a further 1,200 kg DM per ha. Accumulated pasture and winter growth gives total pasture availability of 2,400 kg DM per ha or 2,000 kg DM per cow (at a winter stocking density of 1.2 cows per ha). This equates to a pasture allowance of 16.7 kg DM per cow per day. Along with this daily allowance of pasture, the cows receive 4 kg concentrate per day from mid-September through to drying off in late February. Assuming the cows consume 14 kg pasture DM per day and a daily allowance of 4 kg concentrate gives total intake of 18 kg DM per cow per day, which is sufficient to meet the requirements of the cows. Silage is only fed when grazing conditions are very difficult and during these days, concentrate supplementation is increased to 5 kg DM per cow. Total concentrate input to this system is 750 kg per cow compared with 400 kg per cow on the system with a mean calving date of 15 February. The cost of this additional concentrate is compensated by the higher milk price on the later calving herd that produces 55% of the milk between 1 September and 1 March each year. The cows in the late-NFN system are dried off during February and housed until the commencement of calving in late-March.

It can also be seen in Table 1 that the levels of milk production per ha, in terms of milk solids per ha, is higher on the clover-based swards receiving no fertilizer N. This demonstrates that clover- based swards place no limitation on milk output per cow from cows with potential for high milk output and also can also support moderately high output per ha.

Maintaining the clover content and productivity of swards

Maintaining the clover content of swards is a key component of maintaining productivity from year to year. Experience at Solohead has shown that there are two key components in achieving this objective:

(i) Tight grazing during the year and particularly during the autumn and winter;

(ii) Regular renovation of the clover plants in the sward

Tight grazing during the year

Clover does not compete as aggressively and can be shaded out by the grass component of the sward. Clover is most vulnerable to shading during the winter and early spring because, as pointed out above, it needs higher soil temperatures for growth than grass. At Solohead, cows graze down to a post-grazing height (PGH) of 4 cm from turnout in spring. It is important that cows start grazing to 4 cm and that this is maintained to ensure that the cows are presented with a leafy highly nutritive sward throughout the grazing season. Lax grazing in spring followed by tighter grazing later in the growing season will depress milk yield and constituents. Tight grazing during the late autumn and winter allows light down to the clover stolons at the base of the sward. The amount of light penetrating to the base of the sward directly influences the survival of stolon over the winter and the more stolon that survives the winter the higher will be the clover content of the sward during the following growing season. In the late-NFN system described above, tight grazing throughout the winter should promote very high clover contents in the following year. This is an issue that we are investigating in the experiment described above.

Regular renovation of the clover plants in the sward

White clover has a reputation for inconsistent production from year to year. Part of the reason for this is differences in weather conditions from year to year. Fixation of

N is a biological process dependent on conditions such as soil temperature and moisture availability. Cold soil conditions and too little or an excess of water can impede N fixation and these are factors that vary from year to year. Nevertheless, the main reason for inconsistent production is the interaction between grass and clover. In newly established re-seeded swards receiving no fertilizer N the clover usually has an advantage because it can fix its own independent supply of N. However, over time the N content of the soil builds up as clover stolon increases and dies back from year to year. Greater availability of N in the soil favours the grass, which increasingly shades out the clover. The clover goes into decline and the rate of N fixation drops off. This is often seen happening after a period of four or five years. In the next year the productivity of the sward can be relatively high although the clover content of the sward is quite low because grass growth is fuelled by the residual N in the soil. However, in the following year pasture production can be very low because the residual N has been used up and there is little clover remaining in the sward. Freed from competition from the grass due to declining grass growth the clover content of the sward will again increase during the following year or two and remain productive for another couple of years before competition from the grass again drives the clover into decline and the cycle is repeated. Often it is adverse weather conditions in a particular year that can trigger the decline in the clover content of the sward across the farm and this has consequences for maintaining pasture supply. Hoof damage by grazing cows is another factor that can lead to the sudden loss of clover from a sward. Hooves penetrating down thought the soil surface can bury and break up stolons and this is detrimental to clover survival. This inconsistency of pasture production can make it very difficult to operate an efficient dairy production system maintaining consistent milk output from year to year.

At Solohead we have been investigating methods of maintaining consistent supply of clover from year to year. Tight grazing is important as pointed out above. Over-sowing 20% of the farm each year is also an important component. On organic farms clover seed can be over-sown using a slug pellet applicator, or mixed with lime or granulated rock-phosphate. 20% of the farm is over-sown each year on a five-year rotation to ensure that there are swards of different ages distributed across the farm. Each sward is in a different stage of development which acts as a hedge against swards with declining clover contents. Swards with low clover contents due to competition from grass or due to hoof damage are identified and then over-sown in the following year. Hence, these swards are brought quickly back into production. When managing clover swards it is necessary to accept that not all parts of the farm will be fully productive all the time; some will have declining clover contents whereas others will be recently over-sown and these swards generally take around a year to become fully productive again. On the other hand, using a planned approach to maintaining the clover content of swards avoids the boom and bust cycles usually associated with clover swards.

Although 20% of the farm is over-sown each year it is not always the same paddocks that are over-sown every five years. This is because the clover content of some swards can go into decline after three years whereas it can be as long as seven years in other paddocks, with an average of five years across all paddocks. Therefore, the clover content of swards are examined and recorded each year and paddocks with declining clover contents are identified for over-sowing in the following year.

Summary and Conclusions

Relatively high levels of milk output are possible from organic clover-based grassland compared with average production on conventional dairy farms in Ireland. Although clover-based swards receiving no fertilizer have relatively low growth in spring, a long grazing season can be achieved by extending the grazing season during the autumn and winter. High growth rates during the summer and autumn and relatively low stocking densities on organic dairy farms facilitate this. Maintaining the clover content of swards is important to maintain productivity. Tight grazing to 4 cm throughout the year and particularly during the late autumn and winter is important. Identifying swards with declining clover contents due to competition from the grass component of the sward or due to hoof damage is also important. These swards need to be over- sown the following year with the target of over-sowing or re-seeding no less than 20% of the farm each year.

Organic Beef Production – Sire breed comparison

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Introduction

The Department of Agriculture, Fisheries and Food Organic Farming Action Plan 2008-2012 stated that it is imperative that growth in the organic sector is market driven. The report also stated that the UK imports 4,000 tonnes of organic beef per year, this translates to a requirement of 14,000 animals. For Ireland to supply the home and UK market it would need 3 times the amount of beef currently produced. Against a background of a shortage of organic beef it is understandable that organic beef currently commands a premium of 20% to 25% over conventional beef.

The opportunity to achieve premium price for organic beef was the driving force behind the decision to constitute an organic suckler herd in Johnstown Castle with the objective of producing quality organic beef and at the same time evaluating the impact of early or late-maturing sire breeds on beef output.

The current experiment location at Johnstown Castle Environmental Research Centre is to determine the effects of sire breed type (Charolais and Aberdeen Angus) on production and meat quality in organic beef production. A 44-cow continental-cross spring-calving herd has been established to produce cross-bred calves. This herd is principally made up of Limousin x and Simmental x cows. This herd is maintained by bringing in mature cow replacements of the same breed type. Using a representative group of bulls from each breed 50% of the cows were bred to Aberdeen Angus and 50% to Charolais. AI was used to the greatest extent possible with two natural service bulls used to ‘mop up’.

The overall plan is to slaughter the progeny of the herd on three dates. In year 1 the first date half the Charolais and half the Aberdeen Angus heifers were slaughtered. At the middle date the remaining heifers were slaughtered as well as half the steers from each breed group and at the final date the remainder of the steers were slaughtered.

The cow/calf herd followed a rotational grazing pattern in a designated area of the farm. The yearling heifers and steers also had a rotational grazing programme on a different land area section of the 60 ha land unit.

The animals were accommodated on straw according to Organic Standards.

Results

Calf and weaning weights

Calf liveweight: In years 1, 2 and 3 the Charolais calves were approximately 8 kg heavier at birth than the Aberdeen Angus calves (Table 1).

Weaning Weight: Performance from birth to weaning was consistent over the three years. In years 1, 2 and 3 the performance of both sire breeds and male and female from birth to weaning was satisfactory, averaging 1.20 kg/day in year 1, 1.00 kg/day in year 2 and 1.05 kg/day in year 3 (Table 1). The growth advantage of the steers over the heifers and that of Charolais over Aberdeen Angus (Table 1) was comparable to that achieved in conventional production systems.

Table 1: Effect of sire breed on calf performance to weaning (kg)

	AA		CH	
	Male	Female	Male	Female
Year 1 (2006)				
Birth wt. (kg)	49	43	54	50
Weaning wt. (kg)	292	275	326	298
Liveweight gain (kg/d)	1.17	1.17	1.31	1.12
Year 2 (2007)				
Birth wt. (kg)	44	39	52	49
Weaning wt. (kg)	264	226	269	264
Liveweight gain (kg/d)	1.02	0.91	1.06	1.04
Year 3 (2008)				
Birth wt. (kg)	46	41	51	49
Weaning wt. (kg)	269	242	289	280
Liveweight gain (kg/d)	1.04	0.94	1.14	1.12

End of 2nd grazing season weight

The liveweight performance of the Aberdeen Angus and Charolais steers and heifers was 535, 534, 512 and 543 kg respectively at the end of the grazing season (October 2007). The corresponding values for 2008 were 514, 519, 453 and 513 kg (Table 2).

Table 2: Effect of sire breed on calf performance to yearling (kg)

	AA		CH	
	Male	Female	Male	Female
Year 1 (2006)				
Birth wt. (kg)	49	43	54	50
Mid-April 2007 wt. (kg)	348	314	353	359
23rd October 2007	535	512	534	543
Year 2 (2007)				
Birth wt. (kg)	44	39	52	49
Mid-April 2008 wt. (kg)	357	314	362	345
23rd October 2008	514	453	519	513

Performance of the progeny to the end of the 2nd grazing season was consistent over both years. In both years the liveweight of the steers was in excess of 500 kg for both Aberdeen Angus and Charolais. The key production values achieved for animals born in year 1 are presented in Table 3 and the corresponding values for animals born in year 2 are presented in Table 4.

Table 3: Effect of sire breed and sex on performance of calves born in spring 2006 (year 1)

	AA		**CH**	
	Male	Female	Male	Female
No. of animals	13	9	12	10
Birth wt.	50	43	54	50
06 June 06	152	124	155	157
21 Nov. 06	338	305	342	344
19 April 07	348	314	353	359
24 Aug 07	492	461	477	496
23 Oct 07	535	512	534	543

Table 4: Effect of sire breed and sex on performance of calves born in spring 2007 (year 2)

	AA		CH	
	Male	Female	Male	Female
No. of animals	11	8	12	13
Birth wt.	44	39	52	49
18 June 07	159	130	151	159
08 Nov. 07	282	240	290	271
19 April 08	357	314	362	345
14 Aug 08	470	410	475	454
23 Oct 08	513	453	519	502

Carcass data

The slaughter data generated from year 1 of the study (Table 5) shows a 67 kg increase in carcass weight between the early and late slaughter dates for the heifers. The corresponding value for the steers was 44 kg. The data when complete is expected to confirm the expected difference between Aberdeen Angus and Charolais sires.

The late groups of heifers slaughtered responded very well to the additional feeding from October to January when the cold carcass weight increased from 276 kg to 343 kg (Table 5). Similarly, the late groups of steers slaughtered responded well to the additional feeding from January to March when cold carcass weight increased from 344 to 388 kg (Table 5).

Table 5: Effect of different slaughter dates on the performance (kg) of male and female calves born in spring 2006 (year 1)

	Heifers		Steers	
	Early	Late	Early	Late
Slaughter date	24 Oct	22 Jan	22 Jan	11 Mar
No. of animals	10	9	13	12
Birth wt.	44	50	50	54
21 Nov 06	321	330	334	346
24 Oct 07	522	532	534	535
Final wt. (kg)	522	609	615	688
Carcass wt. (kg)	276	343	344	388
KO %	53.0	55.8	55.9	56.4
Conformation score	3.1	3.4	2.9	2.7
Fat score	3.3	3.3	2.9	3.3

[1] Conformation score: E = 5, U = 4, R = 3, O = 2 and P = 1

Data from the early slaughter heifers groups show consistency between in year 1 and year 2 (Table 6). The Ch x had heavier carcasses compared the Aberdeen Angus x when both were finished off grass. The Ch x also indicate better carcass conformation.

Table 6: Effect of sire breed on carcass characteristics of early slaughtered heifers for year 1 and year 2

	AA		CH	
	2006	2007	2006	2007
No. of animals	5	4	5	6
Final wt.	505	478	539	530
Carcass wt.	266	252	287	279
KO%	52.8	52.8	53.2	52.8
Conformation score	3.2	3.0	3.0	3.2
Fat score	3.6	3.2	3.0	2.9

Conclusion

The results to date, from this sire breed comparison study indicate that with the contrasting Aberdeen Angus and Charolais sire breeds that is possible to achieve animal performance data comparable to well managed conventional suckler calf to beef systems (300 kg carcass for heifers in Nov and 400 kg carcass for steers in March). Similarly the responses to sire breed type, sex and date of slaughter for the organic beef animals are biologically compatible. Organic beef is produced under organic rules in response to consumer demand for organic product. The organic system contributes to the protection of the environment and animal welfare. “We have not inherited the world from our forefathers ……. we have borrowed it from our children” (Kashmiri proverb).

Lamb production:
grazing management, breeding policy and parasite control

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Introduction

Internal parasitic infection can pose major health problems in young livestock and this is particularly so in the context of lambs in organic production systems. In the context of sheep production on an organic farm the challenge to control parasite infection is especially difficult in situations where crop production is absent or a minor element of the whole farm system. Our investigations, to date at Athenry, have concerned an exploration of lamb production in an all-grass farming setting with particular attention being paid to the breeds employed and the seasonal patterns of gastrointestinal parasite challenge. This flock (about 110 ewes plus replacements) is wintered indoors and lambs in early March each year.

Breeding policy

One of the major determinants of production efficiency from a sheep enterprise is the annual output of lamb meat per ewe carried. This is true whether the production system is conventional or organic. Consequently in developing the flock of ewes in the organic system in Athenry we took into account available evidence for breed differences in inherent prolificacy and parasite resistance. The policy established involved converting the foundation ewe flock to Belclare-cross ewes because our evidence shows that the Belclare crosses have a high level of resistance to parasites as well as having been developed for high prolificacy. The second part of our breeding policy was to use Texel rams to sire all lambs produced except those required to generate flock replacements. The reason for this is that we have very clearly shown over the years that the Texel breed is the most resistant to intestinal parasites across the range of terminal sire breeds used in this country. What this policy means is that about one third of the ewes are joined with Belclare rams each season to generate female replacements and the remainder of the flock is put out with Texel rams. This is expected to generate something of the order of 28 female lambs reared per ewe put to the ram and hence leave some scope for culling a small proportion when selecting the necessary replacements.

Grazing management

The grazing management system that has operated over the last 3 seasons is that ewes are put out with their lambs on grassland that had not been grazed by sheep in the previous year. The primary objective of this policy to ensure that the risk to lambs from *Nematodirus* spring challenge is absolutely minimised; the second objective is to contain the normal season build up of larvae of other roundworm parasites. Our early experience with the organic flock at Athenry and evidence from larval build up studies under conventional systems that we have undertaken highlighted the need to dose ewes before turn out to the pasture to achieve the following objectives:

1. To ensure the season build up of larval challenge on pasture is delayed as long as possible.
2. That the level of challenge is reduced as much as possible.

The objective of this is to minimize the likelihood that the lambs are exposed to a significant roundworm larval challenge at any stage during the main grazing season and thus to obviate the need for anthelminthic intervention and retarded lamb growth performance. The combination of these management strategies with the use of breeds that have a high level of parasite resistance are key elements in the overall management of the flock.

Flock monitoring

Ewe reproductive performance and lamb growth are recorded using standard procedures. Roundworm parasite infection levels are monitored throughout the grazing season on a weekly basis. This involves using a DIY kit (Fecpak©) to determine the faecal egg count (FEC) on pooled faecal material from at least 20 lambs or 20 adults. The eggs are classified as Nematodirus or “other Trichostrongyles” as the development cycle of Nematodirus is annual whereas the others hatch to yield infective larvae within the season.

Results

The number of lambs reared per ewe put to the ram was 1.44 over the seasons 2006 & 2007 and this that is well above the average (1.3) achieved in conventional mid-season lamb production systems.   Lamb birth weight and weight at weaning (at 14 weeks of age on average) are summarised in Table 1. The mean values recorded are below what we would expect from a similar flock under conventional management system- especially for the period between 10 weeks of age and weaning. The low average values shown in the table conceal the fact that there was a large divergence between 2006 and 2007 for growth during this period --- 250 g/day in 2006 compared with 169 g/day in 2007. The value for 2006 would be considered quite acceptable whereas the performance in 2007 was well below the norm.

Table 1. Lamb performance (± s.e.) **– 2006 & 2007 seasons**

Birth type	Birth weight (kg)	Growth rate birth to 5 weeks (g/day)	Growth rate 10 to 14 weeks (g/day)	Weaning weight (kg)
Single	5.0 ± 0.16	334 ± 17.1	228 ± 20.7	35.1 ± 1.14
Twin	4.0 ± 0.12	250 ± 14.2	208 ± 17.4	29.0 ± 0.95
Triplet	3.0 ± 0.14	224 ± 16.8	193 ± 19.9	26.9 ±1.12

The pattern of parasitic infection in lambs for the 2006 and 2007 grazing seasons is shown in Figure 1. These results show a pronounced rise in FEC in mid June and the infection which was responsible for this occurred from late May and this coincides with the low growth rate in the period from 10 to 14 weeks of age. It is evident from the results in Figure 1 that while the strategy of providing grazing area for ewes and lambs that had not been grazed by sheep in the previous season gave effective control of Nematodirus- at least in 2006- it cannot be relied upon to prevent a significant build up of infective larvae on herbage during the grazing season.

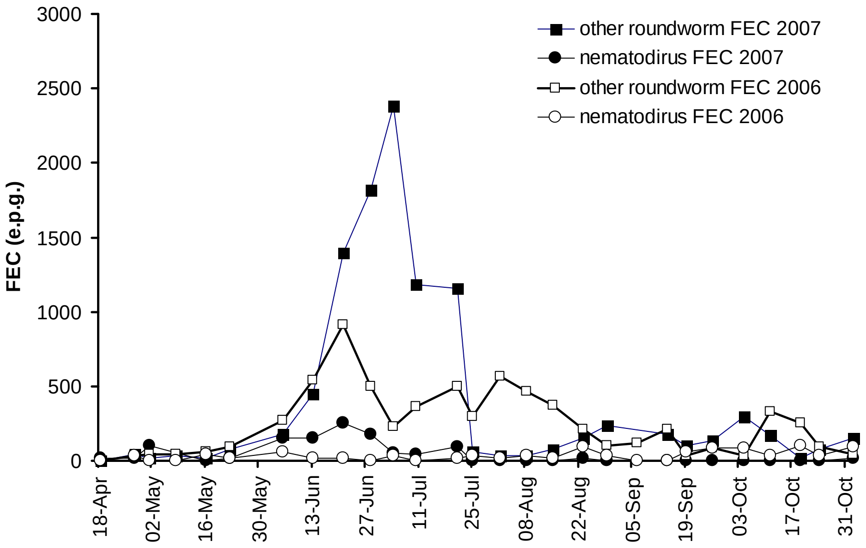

Figure 1 . Weekly faecal egg counts for lambs in the organic system at Athenry

The evidence also shows that Nematodirus was also present in early June in the 2007 season and so the adequacy of a 1-year break from sheep for the elimination of Nematodirus challenge is evidently not sufficient. The evidence also highlights the build up of challenge from “other Trichostrongyles” during the grazing season and our conclusion is that ewes should be receive an anthelmintic treatment before turnout with lambs onto pasture after lambing

Results from an arable crop rotation study at Oak Park 2000 - 2007

Study was undertaken by J. G. Crowley, A. Mahon and E. Baldwin

Report prepared by T. Kennedy[1], C. Merfield[2] and A. Mahon[1]
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Summary

An organic rotation trial was established at Oak Park in 2000. The crop sequence in the seven year rotation was**:** two years grass-clover, winter wheat, potatoes, winter oats, lupins and spring barley. The grass-clover, which supplies nitrogen to the system, also provides vegetation which of late is cut and mixed with cereal straw to produce compost. The compost replaced sheep manure which was available up to 2007. Manure was applied to potato plots prior to cultivation for the period 2002 to 2007 and to barley plots from 2005 to 2007. The average yield of crops over the period of the rotation was**:** winter wheat 5.9 t/ha, potatoes 32.7 t/ha, winter oats 5.8 t/ha, lupins 2.4 t/ha and spring barley 4.5 t/ha. Triticale, which was grown in one of the plots designated for winter wheat, had an average yield of 7.5 t/ha. Lupins have been unsatisfactory due to uncompetitiveness with weeds and lateness of maturity.

Introduction

An organic crop rotation experiment was established at Oak Park Carlow in July 2000. The selected rotation which did not include livestock completed one full cycle in 2007. The overall objective of the experiment was ‘to improve the yield and quality of organic arable crops in Ireland’.

Methods

The site: The trial site soil is a deep heavy textured, well drained, Grey-Brown podzolic (22-25% clay) capable of producing high crop yields. Prior to organic conversion, the area was under grass for about 10 years.

Rotation: The seven year rotation had the following crops; two years grass-clover, winter wheat, potatoes, winter oats, lupins and spring barley. The seven plots, one for each year/crop of the rotation, were randomly positioned within a block. There were three blocks (replicates), two of which had plots of size 0.32 ha with plots of the remaining replicate of size 0.2 ha. Triticale was grown in one of the plots designated for winter wheat each season with the exception of 2004. In 2003 winter wheat failed to establish in one plot and was replaced with spring wheat. From autumn 2006, the trial site was used by DAFF as one of four country wide organic sites for cereal cultivar evaluation. Cultivars of either wheat/triticale, oats or barley were evaluated by DAFF in small plots (3.3 x 12 m, having five-fold replication) within a single large plot of the same cereal. The cultivar data from the Oak Park site together with data from other sites contributes to a more comprehensive and reliable assessment of individual cultivars.

Results

Grass-Clover

The grass-clover seed mixture sown in the period 2000 to 2003 is given in Table 1. In general, the establishment of grass-clover plants when under-sown into barley was considered poor and in 2005 the grass-clover failed to produce adequate plant populations. After 2005, grass-clover was sown directly into freshly cultivated soil during early autumn following harvesting of the barley. The white clover was replaced by red clover (cv Merviot) in autumn 2006 because establishment of the white clover crop had been poor. In the period 2000 to 2006 the grass-clover was mulched into the plots by frequent cutting, thereafter it was cut twice per year and mixed with straw from the cereal plots to produce compost for subsequent application to soil prior to sowing the potato and barley crops.

Table 1 The grass-clover seed mix, kg/ha, 2000 to 2003.

Crop	Cultivar	Heading date	kg/ha
Grass (perennial)	Greengold (tetraploid)	Mid-season	9.8
Grass (perennial)	Tivoli (tetraploid)	Late-season	9.8
Grass (perennial)	Spelga (diploid)	Mid-season	5.2
Clover (white)	Avoca	-	2.6
Clover (white)	Aran	-	1.6

The mixture used from 2004 to 2006 is given in Table 2.

Table 2 Grass-clover seed mix, 2004 to 2006.

Crop	Cultivar	kg/ha
Grass (perennial)	Magician	6.2
Grass (perennial)	Cashel	10.4
Clover (white)	Avoca	5.2
Clover (white)	Aran	5.2

Winter wheat and triticale

A number of wheat cultivars (varieties) were evaluated in the period 2002 to 2007. In general, yields were good for the top yielding cultivars which, over the rotation cycle, had an average yield of 7.37 t/ha and a range of 6.02 to 8.24 t/ha (15% moisture content), Table 3 and Appendix 1. The seasonal minimum yields for the lowest yielding cultivars over the six year period ranged from 3.22 to 7.78 t/ha. The average seasonal yield for all winter wheat cultivars investigated was 5.93 t/ha. Best yielding cultivar per season, 2002 to 2007, respectively, were Exsept, Robigus, Claire, Deben, Deben and Timber. In the case where cultivars were evaluated for more than one season there was surprising variation in yield; for example the cultivar Exsept yielded best in 2002 but had the lowest yield for the cultivars evaluated in 2003.

The results of a seeding rate trial, 2001/2002, showed that yields increased with increasing seeding rate. The maximum seed rate of 225 kg/ha (14.5 st/ac) yielded 6.38 t/ha, Table 4. Three cultivars of spring wheat were evaluated in 2003. Grain yields ranged from 5.43 to 5.79 t/ha, Table 5.

The results of grain yields for six cultivars of triticale grown in 2003 are given in Table 6. Yields ranged from 6.71 to 8.66 t/ha. The top yielding cultivar was Cylus. Fidelio was grown in four seasons, 2002, 2003, 2005 and 2006 and had an average yield of 6.85 t/ha. Results of DAFF evaluation of twelve triticale cultivars at the site in 2007 showed an average yield for cultivars of 4.14 t/ha. The best yielding cultivars were: Versus, Tremplin, Bienvenu and Amarillo which yielded 5.06, 4.69, 4.61 and 4.57 t/ha, respectively.

Table 3 Grain yields, t/ha, and plant heights of winter wheat cultivars organic rotation trial Oak Park, 2002 – 2007.

		[1]Yield, t/ha			Plant height (cm)
Year	No cultivars	Minimum	Maximum	Mean	Range
2002	15	4.12	8.24	5.40	72 - 95
2003	10	5.58	8.00	6.80	73 - 87
2004	2	7.78	7.88	7.83	-
2005	1	6.02	6.02	6.02	98
2006	1	6.87	6.87	6.87	90
2007	14	3.22	7.18	5.53	45 - 55

[1] 15% moisture content (MC)

Table 4 The effect of seeding rate on yield, t/ha, of winter wheat, cv Soissons, organic rotation trial, Oak Park, 2001/2002

Seeding rate		(Stone/acre)	Yield, t/ha, 15% MC
seed/m^2	kg/ha		
300	135	(8½)	5.77
350	157.5	(10)	5.99
400	180	(11½)	6.04
450	202.5	(13)	6.10
500	225	(14½)	6.38

Table 5 Spring wheat yield, t/ha, and plant heights (cm) 2003.

Cultivar	**[1]Yield t/ha**	**Height cm**
Alexandria	5.79	54
Baldus	5.65	56
Raffels	5.43	57
Mean	**5.62**	**55.7**

[1] 15% moisture content.

Table 6 Triticale cultivars, yield, t/ha, and plant heights (cm) 2003.

Cultivar	[1]Yield t/ha	Height cm
Cylus	8.66	117
Fidelio	7.95	108
Versus	7.71	115
Bienvenue	7.28	100
Lupus	7.04	126
Taurus	6.71	114
Minimum - Maximum	**6.71 – 8.66**	**100 - 126**
Mean	**7.56**	**113.3**

[1] 15% moisture content.

Potatoes

In the period 2003 to 2007 sheep manure (F.Y.M.) was applied to potato plots prior to tilling at the rate of 50 t/ha. Potatoes were sown at a tuber spacing of 30 cm. Three potato cultivars were sown each season between 2002 and 2007. These were Cara, Orla, and Setanta in 2002 and 2003, thereafter Cara was replaced with Sante. Orla, which is a 'second-early' has good tuber blight resistance. Setanta, a 'main-crop' cultivar also has good blight resistance. The cultivar Sante is an early 'main-crop' and is considered suited for organic growing since in addition to blight resistance it also has resistance to eelworm (PCN) and powdery scab. Weed control during the crop establishment phase of growth was achieved by hoeing and mould-ploughing. In general, weeds were not a problem. The average yield of tubers over the six seasons was 32.7 t/ha (Table 7) ranging from 26 to 45.7 t/ha, Table 8. The seasonal yields for each of the three cultivars are given in Table 8. Sante was found to have considerably greater resistance to slug damage when compared with either of the other two cultivars.

Table 7 Potato cultivar experiments 2002 to 2007: results by year including percentage breakdown of size grades by weight.

Year	< 40 cm	40-50 cm	45-60 cm	60-80 cm	> 80 cm	Discards	DM %	Yield t/ha
2002	9%	10%	61%	20%			24.4	28.3
2003	14%	16%	57%	10%		3%	23.1	26.0
2004	5%	7%	53%	32%	2%	1%	23.1	45.7
2005	2%	32%	37%	27%	1%	2%	23.2	37.3
2006	7%	8%	51%	29%	2%	5%	22.3	27.8
2007	2%	18%	73%	3%	0%	4%	21.0	30.9
Mean	**7%**	**15%**	**55%**	**20%**	**1%**	**3%**	**22.9**	**32.7**

Table 8 Potato cultivar experiments 2002 to 2007: overall yield results including percentage breakdown of size grades by weight.

Year	CV	< 40 cm	40-50 cm	45-60 cm	60-80 cm	> 80 cm	Discards	DM %	Yield t/ha
2002	**Cara**	10%	9%	59%	22%			25.1	28.2
	Orla	14%	15%	61%	10%			21.3	22.9
	Setanta	5%	5%	63%	27%			26.8	33.9
2003	**Cara**	17%	18%	54%	7%		4%	20.5	24.1
	Orla	15%	15%	59%	9%		3%	21	27.8
	Setanta	10%	14%	58%	15%		2%	27.6	26.2
2004	**Orla**	5%	7%	53%	34%	1%	1%	21.8	44.9
	Sante	8%	11%	63%	16%	0%	1%	24.7	42.5
	Setanta	2%	3%	44%	47%	4%	1%	22.9	49.6
2005	**Orla**	1%	24%	39%	33%	0%	1%	21.3	41.4
	Sante	4%	50%	33%	9%	0%	2%	23.7	35.9
	Setanta	1%	21%	38%	38%	2%	2%	24.6	34.5
2006	**Orla**	6%	8%	60%	17%	0%	8%	20.9	22.1
	Sante	10%	12%	62%	13%	0%	4%	24.2	26.3
	Setanta	3%	2%	31%	56%	5%	2%	21.8	35.0
2007	**Orla**	2%	19%	71%	3%	0%	6%	18.6	29.5
	Sante	2%	16%	73%	6%	0%	3%	20.8	37.0
	Setanta	2%	19%	75%	1%	0%	3%	23.5	26.3
	Overall mean	**7%**	**15%**	**55%**	**20%**	**1%**	**3%**	**22.8**	**32.7**

Oats

In 2002 and 2003 both cultivar and seeding rate trials were undertaken, thereafter only cultivar trials were conducted. The results of oat cultivar trials are given in Table 9. The low yields obtained in 2003 were as a consequence of the crop being sown on 20 March 2003; the delay resulting from unsuitable sowing conditions during the preceding season. The crop sown 13 November 2006 had extremely poor plant establishment due to various factors including crow damage. These plots were ploughed-up in spring and sown with spring oat cultivars. The average grain yield of winter oats was 5.81 t/ha when the data for 2003 is omitted. The yield range was 4.52 to 7.24 t/ha (Table 9). The cultivar Jalna out-yielded Barra in the three seasons for which comparisons were made. Increasing the seeding rate of winter oats in the range 145 to 232 kg/ha, in 2002, did not produce commensurate grain yields, Table 10. A similar result was recorded in 2003. Spring oats, grown in 2007, had an average yield of 4.64 t/ha. Of the ten spring oat cultivars evaluated by DAFF at the site in 2007 Kaplan and Corrib were best.

Table 9 Oat cultivar comparison trials' results 2002 to 2007, Oak Park. WO = winter oats, SO = oats sown in spring.

Year	Crop	Cultivar	[b]Yield t/ha	Height (cm)
2002	WO	Barra	7.24	-
2003[a]	SO	Barra	2.27	77
	SO	Freddy	2.48	70
	SO	Evita	1.91	68
	SO	Mixture	1.80	69
2004	WO	Barra	5.74	
	WO	Jalna	6.69	
2005	WO	Barra	4.99	132
	WO	Jalna	5.65	120
2006	WO	Barra	4.52	133
	WO	Jalna	5.84	132
	WO	**Mean**	**4.46**	**100.1**
2007	SO	Corrib	4.53	97
	SO	Evita	4.34	90
	SO	Freddy	4.52	89
	SO	Husky	4.68	87
	SO	Nord	5.12	90
	SO	**Mean**	**4.64**	**91**

[a] Sown 20 March 2003. [1] 15% moisture content.

Oat seeding rate trial results, cv Barra, Oak Park, 2002.

Table 10

Seeding rate kg/ha	Stone/acre	[1]Yield t/ha
145	9.2	6.55
160	10.2	6.86
174	11.1	6.96
189	12.0	6.95
203	12.9	6.68
218	13.9	6.73
232	14.8	7.15

[1] 15% moisture content (MC)

Lupins

Lupins are a leguminous crop grown for its high protein content and nitrogen fixing ability. The main cultivars grown included the multi-branched types Borlenna, Bordako, Erantis, Galant, Kompolit, SNS and V6-1. The single stem cultivars were Borweta, Prima and Viol. Seeding rate was determined by 1000 kernel weight but commonly was in the region of 168 kg/ha. A seeding rate trial with the cultivars Prima and Borweta was sown 30 April 2003.

The results of investigations on lupin cultivars are given in Table 11. The mean yield of lupin grain was 2.43 t/ha and a range of 0.74 to 5.04 t/ha. The mean moisture content of grain at harvest was 31.4% (range 15.8% to 41.9%). The seeding rate trial showed that increased seeding rate resulted in increased grain yield and decreased moisture content of grain, Table 12. The relationship (regression value) between seeding rate and yield for the cultivars Borweta and Prima was R^2 = 0.99 and 0.94, respectively, while that for moisture content was R^2 = 0.94 and 0.80. Lupins are now considered an unsuitable crop for inclusion in an organic rotation in Ireland. The main problems encountered were uncompetitiveness of the crop with weeds and the lateness of maturity of grain resulting in late-autumn harvesting of the crop.

Table 11 Lupin cultivar experiments' results: yield t/ha at 15% dry matter.

Cultivar	2002	2003	2004	2005	2006	2007	Means **t/ha**	 Moisture %
Barlenna		5.36					**5.04**	25.2
Bordako	3.17	4.25		2.97	2.09		**2.94**	28.8
Borweta		3.60					**3.39**	15.8
Erantis						0.79	**0.74**	34.6
Galant						2.13	**2.00**	39.1
Kompolit						2.29	**2.16**	41.9
Prima	2.87	2.95	1.24				**2.21**	20.0
SNS						2.89	**2.72**	33.4
V6-1						2.35	**2.21**	40.2
Viol						0.99	**0.93**	34.9
Year Mean	**3.02**	**4.04**	**1.24**	**2.97**	**2.09**	**1.91**	**2.43**	**31.4**

Table 12 Lupin seeding rate and cultivar yields, t/ha, 2003.

Cultivar	Seeding rate kg/ha	Yield, t/ha, 15% MC
Borweta	100	2.61
	125	3.12
	150	3.63
	175	4.08
Prima	100	1.97
	125	2.35
	150	2.98
	175	3.09

Spring barley

Spring barley was first planted in the rotation in 2003. Investigations in the first five seasons involved cultivar evaluation and the impact of seeding rates on grain yield. Sheep manure was applied to barley plots, prior to cultivation, at a rate of 25 t/ha in the period 2005 to 2007 inclusive. The average grain yields for spring barley in each season for the period 2003 to 2007 are given in Table 13. The average yield over this period was 4.49 t/ha (range 3.11 to 5.81 t/ha). It is possible yields could have been greater had the preceding crop being other than lupins since the extensive weed infestation in lupins undoubtedly contributed to weed prevalence in the barley crop. Of late, DAFF have conducted cultivar evaluations in barley plots. In 2007, 15 cultivars were evaluated of which the better yielding cultivars were; Cocktail, Sweeney, Frontier, and Publican yielding 5.32, 5.12, 4.81 and 4.81 t/ha, respectively. The yields at Oak Park have been better than at other sites (Appendix 2). The ranking of cultivars, based on yield, at Oak Park is broadly similar to that recorded at other sites. The effects of date of under-sowing grass-clover on barley grain yield and grass vegetation mass post crop harvest were measured in 2003. There was no difference in grain yield between plots sown with grass-clover at either 13 days or 24 days post sowing of barley. However, the mass of vegetation measured three months post crop harvest was greater for that sown at 13 days when compared with that sown at 24 days. The practice of under-sowing grass-clover into barley has been discontinued in favour of sowing in autumn.

Soil Nutrients

The soil nutrient analysis for the period 2002 to 2006 is given in Table 14. The only source of added nutrients was sheep manure (until 2007). No major decline in nutrients has occurred.

New proposals for research on organic arable crops are currently being considered.

Table 13 The grain yield, t/ha, of spring barley, 2003 to 2007, Oak Park.

Year	**Cultivar**	**[1]Grain yield t/ha**
2003	Tavern	5.81
2004	Tavern	4.35
2005	Tavern	3.11
2006	Tavern	4.50
2007	Mean of 15 cultivars	4.71
	Overall mean	**4.49**

[1] 15% moisture content.

Table 14 Soil nutrient analysis by year, mg/kg

Year	**pH**	**OM%**	**P**	**K**	**Mg**	**Cu**	**Zn**	**Mn**	**S**
2002	6.92	5.76	11.61	121	198	3.52	3.25	343	-
2003	6.89	5.97	10.94	124	200	3.56	3.76	366	
2004	6.80	5.40	13.80	154	215	4.08	3.77	403	12.76
2005	7.06	-	10.00	122	215	-	-	-	-
2006	7.07	-	12.76	118	169	4.81	4.05	449	
Mean	**6.95**	**5.71**	**11.82**	**128**	**199**	**3.99**	**3.71**	**390**	**12.76**

Appendix 1 Summary of winter wheat cultivar comparison trials, 2002 to 2007

Cultivar	Year	*Yield t/ha	TGW g	Height cm
Carlton	2002	5.04	32.5	75
Claire	2002	5.50	33.1	81
Deben	2002	5.90	35.1	85
Equinox	2002	4.29	26.5	83
Exsept	2002	8.24	49.6	94
Falstaff	2002	4.70	31.8	95
Goodwood	2002	5.28	31.1	80
Ld 91-59-1	2002	4.52	33.6	72
Madrigal	2002	5.56	33.6	78
Marshall	2002	5.26	31.5	91
Milestone	2002	5.98	32.3	95
Savannah	2002	5.20	33.0	79
Tanker	2002	4.12	29.0	83
Trust	2002	5.60	35.5	87
Xi 19	2002	5.78	35.8	90
Access	2003	6.14	33.3	74
Deben	2003	7.32	35.9	87
Dick	2003	6.45	N/a	78
Exsept	2003	5.58	N/a	80
Marshall	2003	7.01	36.9	82
Option	2003	6.44	35.8	79
Robigus	2003	8.00	35.8	79
Victor	2003	7.37	39.7	73
Welford	2003	6.93	31.2	74
Xi 19	2003	6.74	42.3	83
Claire	2004	7.88	46.3	N/a
Deben	2004	7.78	51.5	N/a
Deben	2005	6.02	42.1	98
Deben	2006	6.87	50.3	90
Alceste	2007	3.26	49.0	49
Alchemy	2007	6.33	53.6	54
Claire	2007	7.02	51.1	51
Cordial	2007	3.22	47.4	47
Cordial + Alceste	2007	4.80	54.8	55
Einstein	2007	5.76	52.9	53
Glasgow	2007	6.12	44.6	45
Gulliver	2007	4.59	50.5	51
Hyperion	2007	5.66	48.5	49
Lion	2007	6.67	48.5	49
Robigus	2007	4.95	47.4	47
Savannah	2007	6.13	49.9	50
Soltice	2007	5.84	49.3	49
Timber	2007	7.18	52.0	52
Minimum		**3.22**	**26.5**	**45**
Maximum		**8.24**	**54.8**	**98**
Mean		**5.93**	**41.09**	**71.85**

*15 % Moisture content.

Appendix 2 The grain yield, t/ha, spring barley cultivars, 2007, Oak Park as well as average yield from sites at Cork, Galway, Carlow and Wexford. Source: DAFF.

	Yield, t/ha	
Cultivar	Oak Park	Average of 4 Sites
Cocktail	5.32	3.91
Sweeney	5.12	3.95
Frontier	4.81	3.91
Publican	4.81	3.91
Sabastian	4.91	3.83
Christina	5.06	3.83
Jolika	4.96	3.72
Wicket	4.76	3.60
Snakebite	5.01	3.79
Eunova	5.27	3.79
Quench	4.96	3.87
Tamise	4.91	3.72
Centurion	5.06	3.68
Doyen	5.12	3.60
Spotlight	4.96	3.68
Mean	**5.00**	**3.78**

Fundamentals of Nutrient Management: Why Nutrient Replacement is Essential in Organic and all Agriculture

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Introduction

There is a belief, going back to the foundation of organic agriculture, that nutrient replacement, i.e., the use of ‘fertilisers’, within organic agriculture is not required. Scientific theories and laws as well as practical farming evidence, now conclusively shows that this belief is incorrect, and nutrient replacement / cycling is essential for all forms of agriculture including organic. This paper is an explanation of why nutrient replacement / cycling is essential, starting at the most fundamental levels of the physical laws of nature, progressively building a holistic / systems based view of the behaviour of nutrients, and also energy, in farm systems and the biosphere as a whole. While such a view may at first appear overly detailed, even irrelevant to agriculture, one of the primary keys to the success of scientific understanding is the ability to create a theoretical understanding with precise predictive power. Much of agriculture is based in the complex sciences of biology and ecology where random processes prevent theoretical explanation and prediction i.e., much of agricultural science is empirical. Nutrient management is one of the few areas of agriculture where fundamental physics, even at the sub-atomic level, can penetrate right through the noise of biological systems to directly inform the actions of farmers. Empowered by such understanding farmers have the ability to fully understand the fundamentals of nutrient management and make better informed decisions about their own practices. Such a holistic perspective also ‘shines a light’ on the unsustainability of nutrient management in ‘industrial’ agriculture and the wider human societies of which it is the foundation, as well as reiterating the solutions that have been known for two centuries.

History and the Schism

The ‘schism’ within organic agriculture regarding nutrient management goes back to its founders. This debate and argument extended over a considerable period of time and has never been fully concluded, with different parts of the organic movement retaining conflicting views to this day. Two sides of the debate can be described by the two terms ‘The Law of Return’ and ‘Closed System’. The former was originally promoted by Sir Albert Howard, indeed the very phrase ‘The Law of Return’ is now intimately associated with his name. The latter was the position Lady Eve Balfour eventually adopted and is continued to this day by her philosophical descendents such as the Soil Association. There were many others involved on both sides of the debate, with some taking significant time to decide where they stood and/or changing sides. However, I have chosen Howard and Balfour to represent the two sides, as they are among the most pivotal founders of organic agriculture, are still very widely known, and therefore best illustrate how profound this split was, and therefore deserving of the title ‘Schism’.

Concisely defining the two sides is not straight forward as the issue of nutrient management is invariably tied up in the wider issue of soil health and its effects on the ecological food chain extending through plants to animals including humankind. The descriptions of the Law of Return and the Closed system given here therefore have to leave out the details, but due to our understanding of the nature of nutrients from the sub-atomic to the system level there are no ‘devils in the details’, i.e., the system as a whole is linear, rather than non-linear and therefore predictable rather than unpredictable.

The Law of Return is defined by Howard in “An Agricultural Testament” (1943) where he says that it is essential to “…adopt farming practices that would follow nature's example of recycling all natural and organic waste products back to the soil” and “When man converts land to agriculture and harvests crops and livestock from the fields, mineral nutrients are removed from the soil. The failure of man to effectively return the waste products of agriculture back to the land results in mineral depletion of soil and represents a lost opportunity to build soil humus.” At first blush, these descriptions could well describe a closed system, however, the position adopted by Balfour and the Closed System proponents is critically different. The Law of Return states that all mineral nutrients removed from a farm, in whatever form, must be returned back to the farm if mineral depletion (soil mining) is to be prevented.

Balfour's position was that the amounts of nutrients removed in farm produce are so small "1/500 of the reserves of the top 9 inches of soil each year" that natural soil formation processes (pedogenesis), especially when speeded up by a biologically active soil, was more than sufficient to ensure that the fertility of soils were maintained or even increased. To be fair to Balfour, the type of farm to which this idea was primarily attached was the ley farming system (alternating grazed pasture with arable crops to feed the livestock) where only animal products were sold off the farm. However, it is clear from her writing and the positions of others promoting the closed system, especially in more recent times, that it is considered possible to have a productive farm that does not import nutrients in any form, e.g., fertiliser, compost, manure or feed, while at the same time exporting produce. This position is reflected in statements such as "To work, as far as possible, within a closed system with regard to organic matter and nutrient elements." From the IFOAM principle aims (that predate the current 'Principles of Organic Agriculture'), "To optimise nutrient cycles and prevent nutrient loss, you must return manure and plant wastes to the soil. You should return enough to increase or at least maintain soil fertility and microbial activity. Together with a sound rotation, this should form the basis of soil fertility management." and "Biological activity is responsible for soil fertility" both Soil Association.

Scientific Knowledge and Organic Agriculture

The above descriptions are considerable simplifications of what was a complex and detailed debate. However, in the first half of the 20th century the amount of scientific knowledge available to Howard, Balfour and other members of the debate was hundreds of orders of magnitude less than is available today. Many of the issues they could only speak of in poetic terms are now well understood and can be framed in precise technical descriptions and quantitative measurement. Science is increasingly in agreement with the fundamental arguments and concepts of organic agriculture, e.g., soil conditions unambiguously affect the quality of food, food quality clearly has an effect on human health and soil is a precious and limited resource that is currently being managed unsustainably. However, to avoid the charge of hypocrisy, if organic agriculture wishes to call on the authority of science to back up its position, it must also listen to and follow science when sufficient information and knowledge has accumulated to be able to decide on issues of debate or where lack of knowledge led the previous generations of organic proponents astray. This is not a radical suggestion, organic agriculture has made use of the scientific method since its earliest beginnings. Howard was a trained scientist and Balfour conducted 'The Haughley Experiment' which pioneered farm scale experiments. Therefore, this paper is also a call for organic agriculture to view this debate through the exceptionally solid foundation of accumulated scientific knowledge and end the 'Nutrient Schism'.

The Nature of Nature

The following explanation and discussions may at first appear an exceptionally long way removed, even irrelevant, to the debate over The Law of Return and Closed Cycles. However, it presents an inclusive and systematic overview of the scientific knowledge on which the debate rests, much, if not most, of which was not known at the time of the organic pioneers. Much of the knowledge is contemporary with the 'second wave' of the organic movement in the 1960s and it is thought unlikely to of been common knowledge among them. However, without such an understanding is not possible to fully comprehend the issue of nutrient management in agriculture.

Matter and Energy

The term 'nutrient' when used in relation to agriculture and food, refers to the chemical elements that are essential for plants and animals to live. The chemical elements are the fundamental parts from which all 'matter' i.e., the material of all physical objects, are composed and only composed.

Energy is the ability to 'do work', which may seem a rather prosaic and simplistic definition, but the science of energy and its transformation 'Thermodynamics' is one of the oldest sciences and has the highest level of certainty within scientific knowledge (it is as unassailable as scientific knowledge gets). Matter and energy are at a fundamental level the same thing, e.g., two sides of the same coin, as discovered by Albert Einstein and defined in the equation $E = MC^2$ with E = energy, M = Matter and C = the speed of light (approx. 300,000 meters per second). Practically all of the energy transformations that occur in the conditions (e.g., temperature and pressures) that humans inhabit, i.e., as found on the earth, are not of Einstein's 'special relativity' but of thermodynamics, i.e., thermal and chemical processes involving only the electron shell of atoms and the exchange of photons. $E = MC^2$ refers to the energy of which matter is ‘made’ i.e., the energy released by processes such as that which power stars (including the sun) and the nuclear reactions harnessed by man, i.e., the nuclear in nuclear power refers to the atomic nucleus and the energy it is ‘made of’. To illustrate, the chemical energy contained within a paper banknote (approx. 1 gram) contains around 16,000 joules of chemical energy while the atomic energy is approx. 90,000,000,000,000 joules.

Neither matter nor energy can be created or destroyed only transformed. Energy/matter was created in the big bang, i.e., the start of the universe, fourteen billion years ago, with the resultant matter being almost entirely hydrogen (H) and helium (He) (4:1). All the heavier elements have been formed since the big bang from the primordial H and He by nucleosynthesis in stars. The solar system including the earth formed 4.5 billion years ago, and is therefore built from the remains of several previous generations of stars, i.e., all the elements on earth heavier than H and He have been, and can only have been, formed within stars. The synthesis of elements (Appendix 1) up to and including iron produces energy and can be formed during the normal life of stars. Heavier elements require energy to synthesise them and therefore are only made at the end of a stars life when it explodes in a supernova (i.e., any gold or silver you are wearing (e.g., jewellery) was created in a supernova and nowhere else).

Matter, Energy and Planet Earth

The fundamental physics of matter and energy completely determine the functioning of life on the earth and everywhere in the universe.

For energy, the earth is an open system. It receives approx. 3.85×10^{24} joules per year of energy from the sun, mostly as visible light, on the daylight side of the planet, and ejects exactly the same amount from the night side of the planet as infrared light (heat). If the amounts were not exactly the same, the planet would increase in temperature. As context the energy captured by photosynthesis is 0.078% of incoming solar energy (3×10^{21} j/yr) while total human energy use is only 0.0057% of solar energy (2.2×10^{20} j/yr).

For matter, the earth is a closed system. There is a minuscule influx of matter from the solar system in the form of meteorites and related material, but the quantity is infinitesimal compared with the mass of the planet as a whole. Therefore, while energy constantly flows through the earth, via the biosphere and atmosphere, matter can only cycle within the planet. This situation is repeated for all the sub-systems that make up the biosphere including agriculture. Failure to maintain this pattern results in decreased biological functioning.

The Elements of Life

Of the 94 naturally occurring chemical elements (Appendix 1) nature has been rather conservative as plants use only 16 essential elements (hydrogen, oxygen, carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, boron, chlorine, iron, manganese, zinc, copper and molybdenum) and five ‘beneficial / optional elements’ (nickel, silicon, sodium, cobalt, and selenium) with animals (depending on species) requiring a handful more. (From here on only plant, nutrients will be discussed for simplicity and because as plants are the first step on the ‘food chain’ / primary trophic level, the concepts equally apply to animal nutrients as well).

The Proportion of Life’s Elements

The common conception of plant nutrients is of NPK (nitrogen, phosphorous and potassium), then Mg (magnesium) and the other micronutrients. However, all these nutrients combined only makeup approximately 4% of plant matter, with the rest being composed of carbon (C) 45%, oxygen (O) 45% and hydrogen (H) 6% (the proportions vary depending on the type of plant material (e.g., wood vs. leaves) and the units of measurement). The key reason C, O and H are not included in standard lists of plant nutrients is because plants absorb them directly from the atmosphere and/or they are obtained from water (H_2O), absorbed from the soil. No action is normally required on the part of the farmer to replace such elements, as they are freely available and a lack of water results in crop death due to dehydration rather than a deficiency of H fertiliser. However, in some special circumstances, for example, within enclosed structures such as glasshouses, growers supply C as CO_2 as the plants can quickly use up all the available CO_2 within the structure and increasing CO_2 from atmospheric concentrations of 0.035% to around 0.09% results in increased yields, i.e., fertilizing plants with carbon increases crop growth just as it does any other fertiliser.

Absorbing Life's Elements

Why do these different nutrient uptake paths, i.e., leaves and roots, exist? The forms the elements occur in varies: some are gases, others as liquids or solids; these are the three 'states of matter'. Some occur in a more than one form, for example, H and O as water occurs in all three forms, others only exist in solid form although they can dissolve in water to become liquids. If a nutrient can never exist in a gaseous form, then it can only occur in the soil, not the atmosphere, so can only be taken up by plants via their roots. If a nutrient exists in multiple forms e.g., oxygen as the gasses O_2 and CO_2 and liquid i.e., water (H_2O) it can be absorbed by plants via both roots and leaves.

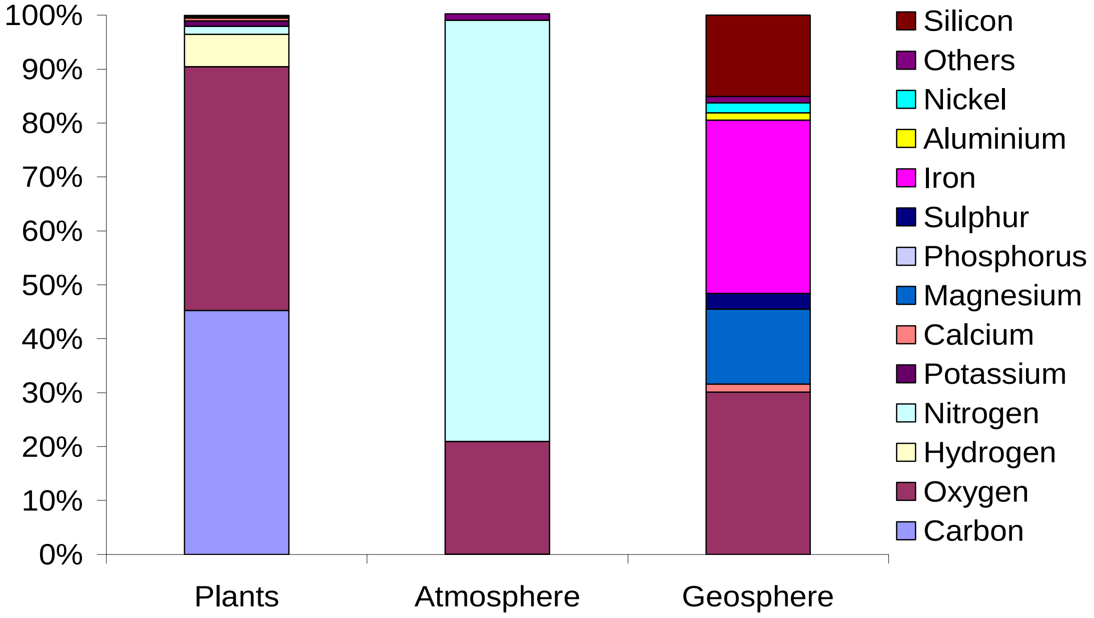

Figure 1. The relative proportions of the 'common' elements in plants, the atmosphere and the geosphere (The order of the elements for each column is identical to the key).

The Uneven Distribution of Elements

The ratio of elements within plants is dramatically different to the atmosphere, soil and the planet on which they live. Figure 1 shows the relative proportions of the common elements in plants, the atmosphere and the geosphere (the rocks, soil and water of the planet). It is clear there is hardly any commonality between all three. For example, carbon, which is considered the foundation element of life i.e., 'carbon based life form', is only 0.035% of the atmosphere and an almost vanishingly small proportion of the planet. The atmosphere consists of 78% N, 21% O, 1.2% chemically inert nobel gasses and 0.035% CO_2 and nothing else. The geosphere consists of a range of metals, mostly in the form of oxides, e.g., silicon dioxide i.e., quartz. Therefore, while plants have been conservative about the number of elements that they need, they accumulate and concentrate a small number, i.e., C, O and H at far greater concentrations than they exist in their surroundings.

Element Cycles

The states of matter that a nutrient occurs in also determine how it will cycle around the planet and farms as well as how plants can absorb them. These cycles are called the biogeochemical cycles, a contraction of biological - geological - chemical, which emphasises that the chemical elements move through both biotic ("bio-") and abiotic ("geo-") spheres. For example, if an element does not exist as a gas in either elemental or compound forms, then it is unable to cycle via the atmosphere as only gasses can cycle via the air. Although an unusual perspective for agriculture, considering how plant nutrients cycle through the biogeochemical cycles gives a holistic and complete description of the movements of plant nutrients on the planet, which is fundamental to understanding how plant nutrients behave at farm level.

The planetary spheres

Within the earth sciences the planet is organised into a number of ‘spheres’ referring to the different parts of the planet as (mostly) concentric spheres starting with the outer atmosphere down the centre of the earth. These spheres are fundamental units in the description of the biogeochemical cycles. There is no formally agreed definition and some terms, e.g., geosphere have changed over time. In this paper:

- the biosphere means all living things what ever their location;
- the atmosphere, refers to the air surrounding the solid part of the earth;
- the hydrosphere, all water on the earth, both fresh and salty;
- the geosphere, the solid parts of the earth, i.e., rocks, including soil but excluding the hydrosphere.

The geosphere is further divided up into:

- the pedosphere better know as soil;
- the lithosphere, the crust and upper mantle but excluding the soil.

The Biogeochemical Cycles of Plant and Animal Nutrients

The biogeochemical cycles are the earth's means of (re)cycling matter including the plant nutrients. If there were no biogeochemical cycles to move and mix planetary matter up then life of earth would be severely diminished as the nutrients of life are often those most easily lost from the biosphere to the depths of the lithosphere. Plate tectonics are therefore considered essential for a diverse biosphere. They are a primary measure of the likelihood of complex life on the other planets and moons of the solar system and extra-solar worlds. Therefore, there is a strong correlation between the fertility of the earth's soils and their age - with new soils being the most fertile and old soils the least.

The Timescale of Sustainability

The importance of specifying the timescale in relations to the biogeochemical cycle's effects on agriculture and the wider human impacts on nutrient management cannot be understated. Time is a fundamental part of the concept of sustainability, regardless of what is being sustained, e.g., a musical note, a farm, economics or a society. The sun has 'only' around five billion years before it 'dies', at which point life on earth will also die, which means that nothing on earth is sustainable as the earth is ultimately unsustainable. Therefore, when discussing sustainability, defining timescales is essential. In this paper the sustainability of nutrient cycles refers to human timescales i.e., years, to decades. These are the same timescales that the more general issue of environmental sustainability is framed in.

Biogeochemical Cycle Timescale

The speed of the biogeochemical cycles varies considerable depending which sphere a nutrient is moving through. Within the same sphere, the rate of movement of individual atoms is not fixed, i.e., they can move at vastly different rates, therefore, the following times are averages. Further, there are considerable overlaps among the cycles and spheres so the following times are qualitative rather than quantitative.

The fastest is the atmosphere; the weather blows gasses around the planet, often at a considerable rate, while constantly mixing its constituents up, cycle times vary from seconds through decades to centuries. Next is the biosphere; living things are highly dynamic physical systems constantly taking in and excreting nutrients and energy. Cycle times are very similar to the atmosphere but slower on average. Third is the pedosphere / soil, which is the primary interface of the atmo- hydro-, geo- and biospheres and where land life starts and ends. Cycle times can be very quick, i.e., seconds but are often much slower taking years to centuries and longer. Fourth is the hydrosphere; the seas and oceans are as dynamic as the atmosphere, in fact the oceans are a fundamental part of the worlds climate, it is just that they move much more slowly and are less visible than the atmosphere simply because they are mostly liquid water and humans are air breathing creatures. Cycle times are rarely quicker than days and weeks to millennia are more common. In a clear last place is the geosphere, or more precisely the lithosphere, which moves far, far slower than a snails pace! A century is a geological blink-of-an-eye, with millennia rated as a sprint and millions of years far more typical of the timescale for rocks.

Human Timescale, Land-Based, Biogeochemical Cycles

The land-based, plant nutrient, biogeochemical cycles can be divided up into three ‘classes’ when viewed at human timescales:

- Those that (mostly) cycle through the atmosphere;
- Those that cycle equally through both the air (atmosphere) and soil (pedosphere);
- Those that only cycle through the soil.

It is critical to understand that the above are a special subset of the wider biogeochemical cycles. Plants and animals are the biosphere, i.e., all living things, and the matter / nutrients living things are made of cycle through both the biosphere and the wider abiotic (non-living) spheres, i.e., the atmo-, hydro and geo-spheres. This list therefore excludes all matter that does not cycle through the biosphere (because they are of no relevance to this discussion). The list is also constrained to the human timescale, which automatically eliminates the lithosphere. It also focuses on land-life, so the wider hydrosphere, i.e., the seas and oceans are not part of this subset.

How nutrients enter the biosphere

While there is no true start or end point in a cycle as it is a logical contradiction, there are key points where matter moves from one sphere to another which can be considered metaphorical starting points. For the biosphere, the starting point is plants. A plant in this context is anything that can photosynthesise, and it includes far more than the crops and trees that are normally considered as plants but also much smaller species all the way down to single-celled plants in the soil and seas. Indeed most of the world's plant biomass is in the form of single celled plants. Plants form the basis of the ecological food chain, as they are the only living things that can capture the suns energy. Therefore, when discussing the intersection of the biosphere and abiotic spheres and the cycling of matter / nutrients among them, plants can be reasonably be considered to be the 'start'. Crop plants, including pasture, are also the foundation of agriculture, as all agricultural products are ultimately derived from them.

Therefore, understanding which sphere plants obtain the elements of life from and how those nutrients move within the biosphere and between the biosphere and abiotic spheres is fundamental to understanding nutrient management in agriculture.

The (mostly) Atmospheric Cycles: Carbon and Oxygen

The nutrients that predominately cycle through the atmosphere are carbon and oxygen. The atmosphere contains 21% oxygen and 0.035% carbon dioxide (CO_2), both of which plants take in directly through their leaves. This is the only path by which C can enter a plant because plants cannot take up carbon via their roots as it does not exist in soluble form within the soil (except in miniscule amounts). Further photosynthesis by plants is the only route for C (as CO_2) to be removed from the atmosphere and moved into the soil (as organic matter), i.e., there are no abiotic processes at human time scales that can transport atmospheric carbon into the soil, only photosynthesis in plants. The 'reverse' of photosynthesis is respiration whereby the solar energy trapped by plants in chemical form is released. Respiration also releases some of the nutrients tied up with the plant's chemical energy. Carbon is one such nutrient and it is released as CO_2, which returns to the air completing the cycle. In addition, when the organic matter in the soil decomposes, i.e., is respired, the C is also released back to the atmosphere as CO_2.

Oxygen is more of a 'loose player', as it teams up with C to form CO_2 and H to form water (H_2O). Water is unique in many, many ways, including its behaviour within the biogeochemical cycles. It is the only chemical substance that naturally occurs as solid (ice), liquid ('water') and gas (clouds / water vapour) forms on earth at the same time. It is a planetary sphere in and of itself (hydrosphere) and although it is not technically considered part of the atmosphere, about 2-4% of the atmosphere is made up of water vapour. The hydrosphere also extends into the soil (pedosphere), so it is literally 'water, water, everywhere'. Therefore oxygen can also enter plants as H_2O, mostly via the roots. Therefore, strictly speaking, O cycles through both the air and the soil.

The carbon, oxygen and hydrogen cycles are therefore intimately linked as O continually shuffles between C and H forming CO_2 and H_2O as part of the sublime duet of photosynthesis and respiration - biology's greatest piece of (re)cycling Table 1.

Table 1. Photosynthesis and respiration

Photosynthesis (controlled fuel manufacture) = $CO_2 + H_2O$ + light energy → organic matter* + O_2

Respiration (controlled burning) = organic matter* + $O_2 \rightarrow CO_2 + H_2O$ + chemical energy

* organic matter is hydrocarbon e.g., $C_6H_{12}O_6$

The rapid speed at which photosynthesis and respiration work means that while the soil contains about 50% of the carbon present in the soil, living things and the atmosphere combined (excluding hydro and geospheres) the most rapid turnover is between plants, animals and the atmosphere. Oxygen as carbon's key chemical 'partner' in the cycle also cycles most rapidly through the atmosphere, while still passing through the soil at a more leisurely pace.

Air and Soil Cycles: Oxygen, Hydrogen and Nitrogen

As noted above O cycles through both air and soil, moving from the abiotic spheres to enter plants through both their leaves and roots. In comparison, H mostly enters plants via their roots, although it enters the soil from the atmosphere as rain and other forms of precipitation. This is because H, unlike O, is not found as a 'free' element as it is chemically reactive so very quickly bonds with other elements or chemicals, often the O in the air. A tiny amount of H gets into plants via the leaves as rain or water vapour but it is negligible and does not affect the fundamental fact that the water comes from the sky / atmosphere. Additionally, hydrogen also gets into plants as other chemical compounds e.g., ammonia (NH_3) via the roots. Again, this extra part of the H cycle makes no material difference to this discussion because the critical aspect is that H and O are intimately linked via their mutual product H_2O, which cycles from the oceans to the atmosphere and back down to the land and oceans as rain. While carbon may be the basis of life, water can be considered the heart of life: no water, no life, period.

Therefore, carbon oxygen and hydrogen, which between them make up 95% of plant matter, originate in the atmosphere as far as plants are 'concerned'. This is why, despite them being by far the most important plant nutrients, they are hardly ever discussed as such, i.e., they are provided for free by the workings of the planetary spheres and cycles. From a practical agronomic and economically perspective this is incredibly important, because if these elements did not cycle via the atmosphere, i.e., they were only solid / soil nutrients, the weight of fertilisers applied would be the same as the weight of farm produce removed and therefore require an equal amount of effort to return them to farms. Further, if were C O and H were non-atmospheric nutrients and not replaced nutrient depletion would be extremely rapid.

Therefore understanding the difference between how C, O and H cycle and the rest of the nutrients is fundamental to understanding how soil nutrients must be managed. The first, and odd one out, is Nitrogen.

Nitrogen

Nitrogen is the ‘odd’ nutrient for many reasons. The first is that the main planet-wide reservoir is the atmosphere. For all the other nutrients (including C and O), over 99.9% is tied up in the rocks of the planet. For N 80% is present in the atmosphere, 20% in the rocks of the earth and just 0.004% in the soil, oceans 0.001% and living things 0.0002%. As a proportion of the atmosphere N is 78% (O 21% and CO_2 0.035%) (Figure 1). Further compounding the oddness of N is that despite it being present in the atmosphere in far greater quantities than CO_2 and O, plants have not evolved a means to directly absorb N via their leaves. Were evolution a deliberate process this state of affairs could only be described as a rather major stuff-up! Part of the explanation for this strange situation is that unlike the O and CO_2 in the atmosphere, which can be directly used by plants in their chemical reactions, atmospheric N is ‘un-reactive’ i.e., it is chemically inert. This non-reactive nitrogen is called diatomic nitrogen (di-nitrogen) because it consists of two nitrogen atoms joined to each other and is symbolised as N_2. The process of turning N_2 into forms that plants can use is very difficult to achieve due to the strength of the bonds joining the two nitrogen atoms together, i.e., they are exceptionally difficult to break apart. This can only be accomplished by a small number of primitive bacterial by the process known as ‘biological nitrogen fixation’ and a few abiotic processes, mainly lighting where the immense pressures and temperatures of the lightning bolt provide the energy and extreme conditions required to break di-nitrogen’s chemical bonds. These reactive forms of nitrogen are symbolised by ‘Nr’. In the early years of the 20th century, Fritz Haber discovered how to turn atmospheric N_2 into Nr in the form of ammonia (NH_3). This process, called the Haber or the Haber-Bosch process, as Carl Bosch was instrumental in commercialising the process and both won Nobel Prizes for its discovery and implementation, requires temperatures of 550°C and pressures of 250 atmospheres / bar, an indication of how hard it is to break N_2 apart.

Until the advent of the Haber - Bosch process, the only form of N available to agriculture was via bacterial N fixation or natural deposition from abiotic processes such as lightning. In terms of practical manipulation of N fixation the only option was to grow crops, such as legumes, which have a symbiotic relationship with the Rhizobia bacteria, which live in nodules on the plants roots. The plants themselves cannot fix N_2 to Nr but they provide a home and food for the Rhizobia which in turn fix N and give it up to the plant. There are also free-living bacteria in the soil that are continuously fixing atmospheric N_2 into Nr, as well as a range of other microbes that are doing the exact reverse and turning Nr compounds into N_2, which is returned back to the atmosphere.

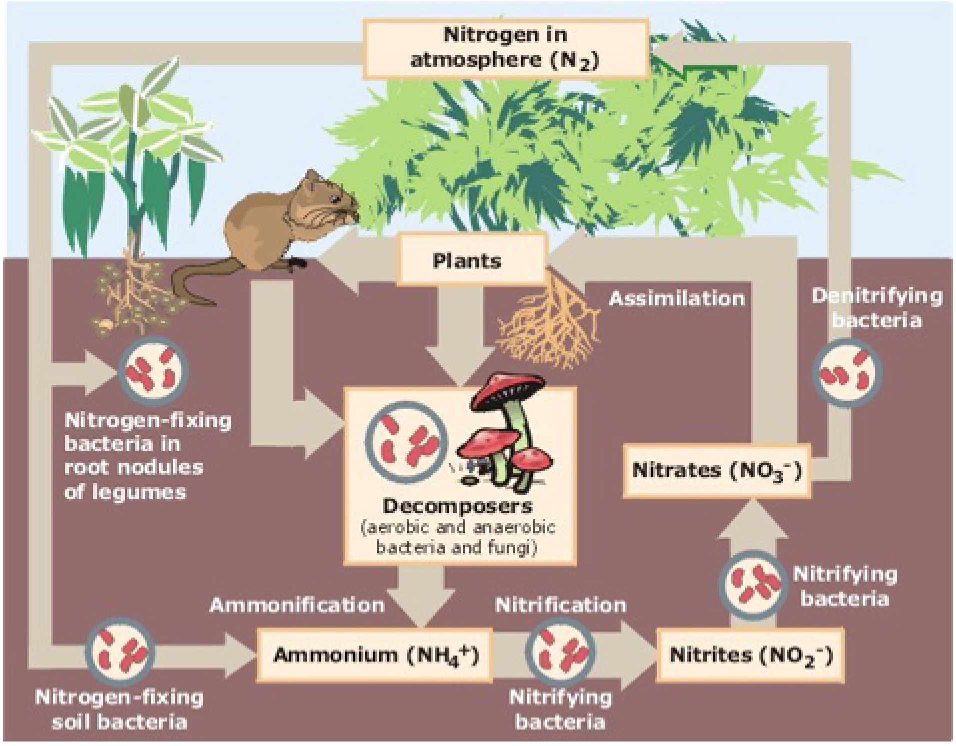

Figure 2. Highly simplified diagram of the nitrogen cycle through the soil, atmosphere and land biosphere (Source USDA).

To sum up, nitrogen is unique because most of it resides in the atmosphere as N_2, which is of no use to living things except a few species of bacteria. These bacteria are responsible for its cycling from the atmosphere into the soil, where it can be taken up by plants or released back to the air by other microbes. Unfortunately, the N cycle is more complicated yet.

Most soil nutrients only come in a small number of different forms, which behave in a relatively straightforward manner within the soil. Nitrogen again stands out due to its highly complex pathways within the soil. Figure 2 shows a highly simplified diagram of the N cycle in the soil, atmosphere and land biosphere. A key point is how much this process is mediated by the biosphere: the majority of Nr in the soil and biosphere has been created by biological processes rather than abiotic processes.

The Soil Nutrients: P, K, Ca, Mg, S, Fe, Cl, Mn, Bo, Zn, Cu, Mo et al.

Compared with the complexity of N and to a lesser extent C, O and H, all the other nutrients cycles are pretty simple. Firstly, none of them exists in the atmosphere unlike N, C, O and H, so none of them can cycle via the atmosphere. This means they can only cycle via the geosphere / lithosphere and liquid and solid states of the hydrosphere, i.e., rivers, seas and oceans. This simplicity is however the undoing of the idea that organic agriculture does not need fertilisers.

As the ‘non-atmospheric’ / ‘soil nutrients’ cannot come from the atmosphere, the only place they can come from is the soil’s parent material, i.e., the rocks from which the soil is formed. For example, if a nutrient is present in low levels in the parent rocks the soil will be deficient, and conversely if there is an ‘excess’ of a nutrient in the parent material it is likely the soil will contain excess, even toxic, amounts.

The formation of soil from the parent rocks is a slow process taking thousands of years. It initially starts as an abiotic physical and chemical process, which is accelerated by the biosphere once it gains a foothold, mainly due to the increased type and speed of chemical reactions. The biosphere also tends to concentrate the nutrients it needs, through the straightforward process that plants mostly absorb only the nutrients they require, so when they die and return the nutrients to the soil surface, those nutrients accumulate. This particularly applies to the ‘atmospheric’ nutrients which accumulate in soil at far higher concentrations that could be achieved had they only originated from the parent rock, i.e., plants ‘pump’ them out of the atmosphere and into the soil. The process of soil formation never stops but it is orders of magnitude slower than the continual and rapid cycling of nutrients from the soil into plants then into animals and back to the soil.

Figure 3 Shows a generalised scheme of the behaviour of the non-atmospheric nutrients in soil. Assuming that the soil is formed in-situ (e.g., its not deposited by rivers on an ongoing basis) the parent material / rocks very slowly release nutrients into the soil as signified by the single tiny arrow from the bottom oval. These nutrients are released as larger pieces of rock break down into smaller pieces, so for example, although there can be a 100 tonnes per hectare of potassium in a soil, most of it is in the form of rock and will not be available to plants for hundreds to thousands of years. Even as the parent rocks weather, the nutrients they release are not instantly available to plants. Many the nutrients move into other unavailable forms, for example, they can become incorporated within the lattice structure of clays where plants are unable to access them. The size of this nutrient pool is much smaller than the parent material but can still be substantial, for example for potassium the range is one to two tonnes per hectare. The longer-term inorganic nutrient pool is in a kind of balance with the much smaller pool of medium term inorganic and organic forms of nutrients, i.e., nutrients can move both ways from more available to less available forms, however, these are still unavailable to plants. The size of this pool is again considerably smaller than the previous pools, continuing the K example, 50 to 100 kilograms per hectare. Finally, there is the soil-solution nutrient-pool. Plants can only take up nutrients is soluble inorganic forms (with a few minuscule exceptions) so this is the only nutrient pool that plants can draw on, but it is very small, for K it is typically 5 to 20 kg /ha and for phosphorous it can be only a few hundred grams per hectare! Fortunately the rate of exchange between the soluble pool and the medium term pool is the fastest of all the exchanges, but it is not infinite - if plants remove nutrients faster than they can be replaced from the medium and longer term pools then the available nutrient pool can shrink to the point that plants cannot get enough and become deficient, even though there are more than enough nutrients in the soil as a whole.

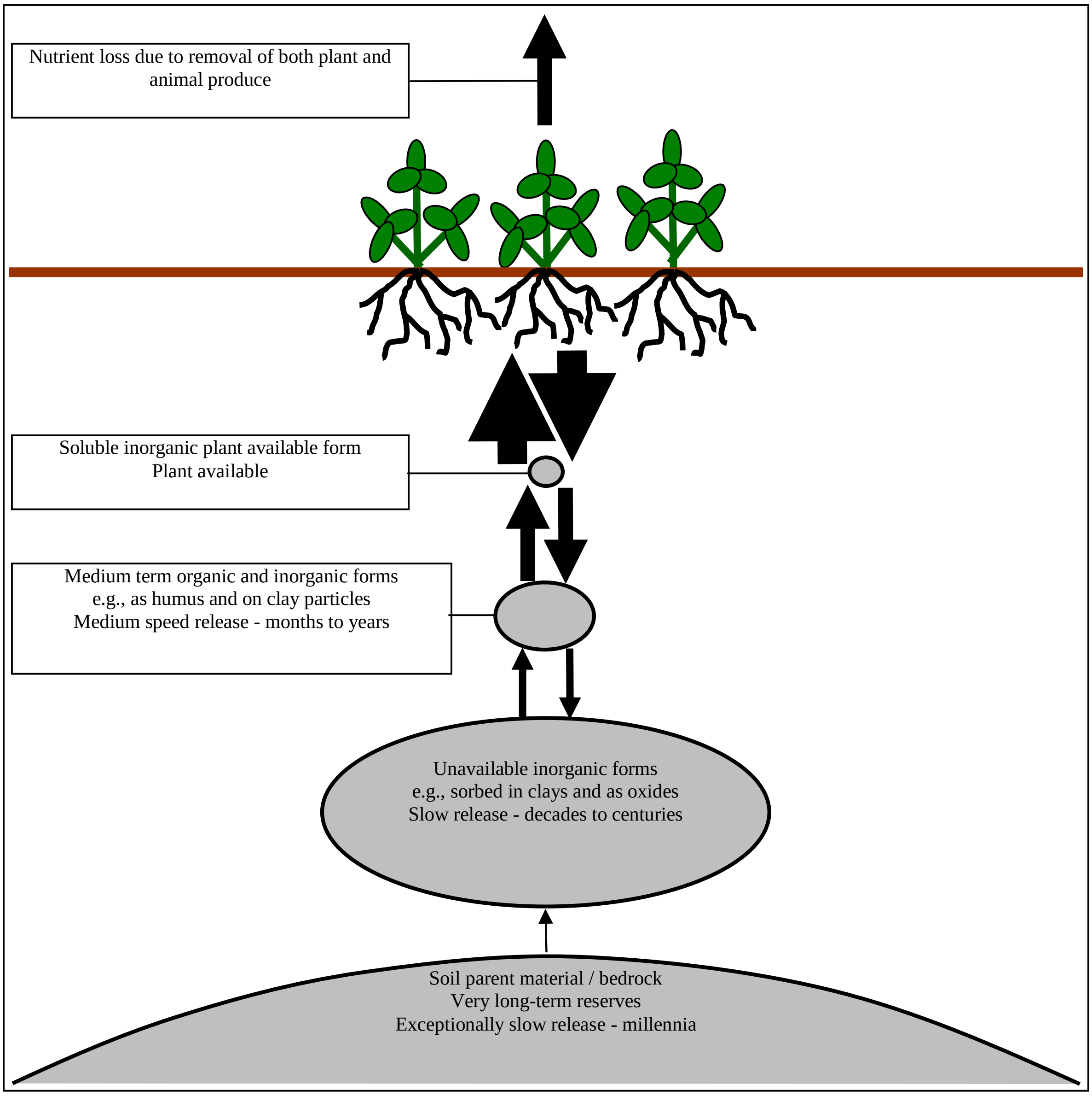

Figure 3. Highly generalised schema of the behaviours in soil of the non-atmospheric / soil plant nutrients. The ovals represent the size of each nutrient pool while the arrows indicate the speed, size and direction of nutrient flows among the pools.

Fertiliser Type and Soil Health

N.B. this paper deliberately ignores the issue of the effects of different forms of fertilisers, e.g., synthetic fertilisers vs. compost, on soil function / biology and the effect on the ecological food chain of plants and animals. While, there is considerable evidence, indeed, it is almost self evident, that different forms of fertiliser will produce different effects on soil biology and that this can have an effect on plant and animal health, such issues are outside this paper's topic and scope.

Why soil nutrients have to be replaced

We are now in a position to understand why the Closed System proponents including Balfour's belief that "In terms of removal from the soil, this works out to infinitesimal amounts of mineral substances (at the most 1/500 of the reserves of the top 9 inches of soil each year)" and therefore nutrients do not have to be replaced and the whole Closed System concept, fails.

Nutrients: Wrong by Degree

While the amount of nutrients removed in produce is small compared with the amount in the soil, (1/500 is small but far from infinitesimal) it is a considerable proportion of the amount of plant available nutrients and a sizeable fraction of the medium term pools. Very simply, if nutrients in produce are removed faster than the conversion rate of parent rock into the smaller pools, they will eventually shrink to the point that the soil is unable to supply sufficient nutrients to plants and they become deficient. A fundamental mistake of the Closed System approach was to believe that all the nutrients in a soil are equally available when they are not. This is not a slur on their abilities, rather a reflection of knowledge at the time: indeed, it was in the Hawley Experiment that it was first noticed that nutrient availability varied over the seasons - a matter of considerable surprise to the experimentalists and the wider soil science community of the time. Another way to conceptualise the situation, is to think of the soil, excluding the parent material, as a bucket (after Liebig's barrel) containing the exchangeable nutrient pools

Figure 4.

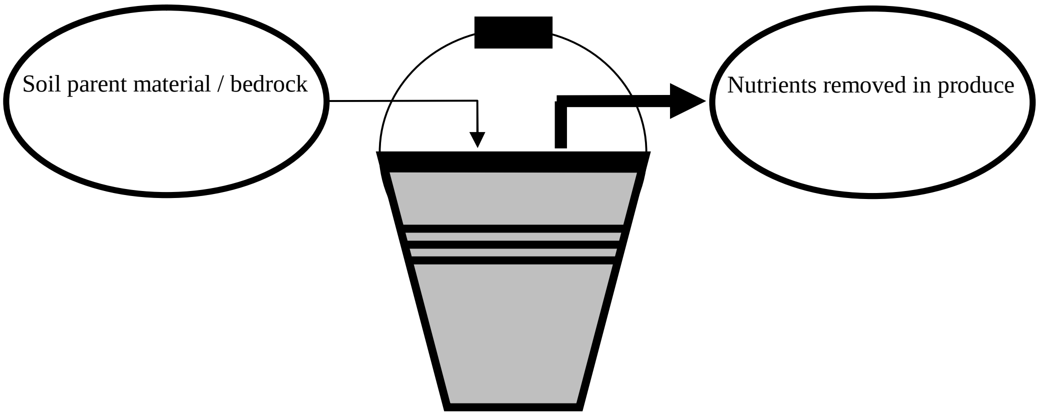

Figure 4. The 'soil nutrient bucket' demonstrating that if nutrient inflows from the parent material are smaller than nutrient outflows (in produce) then eventually the bucket will empty and from that point forward nutrient removal cannot exceed nutrient input due to logical necessity.

The bucket represents the fact that the soil (as far as the soil nutrients are 'concerned') has clearly defined boundaries through which nutrients pass in and out. If the amount going into the bucket is smaller than the amount being removed, then the bucket will at some point become empty and from then on it will be logically impossible to remove more nutrients than are entering.

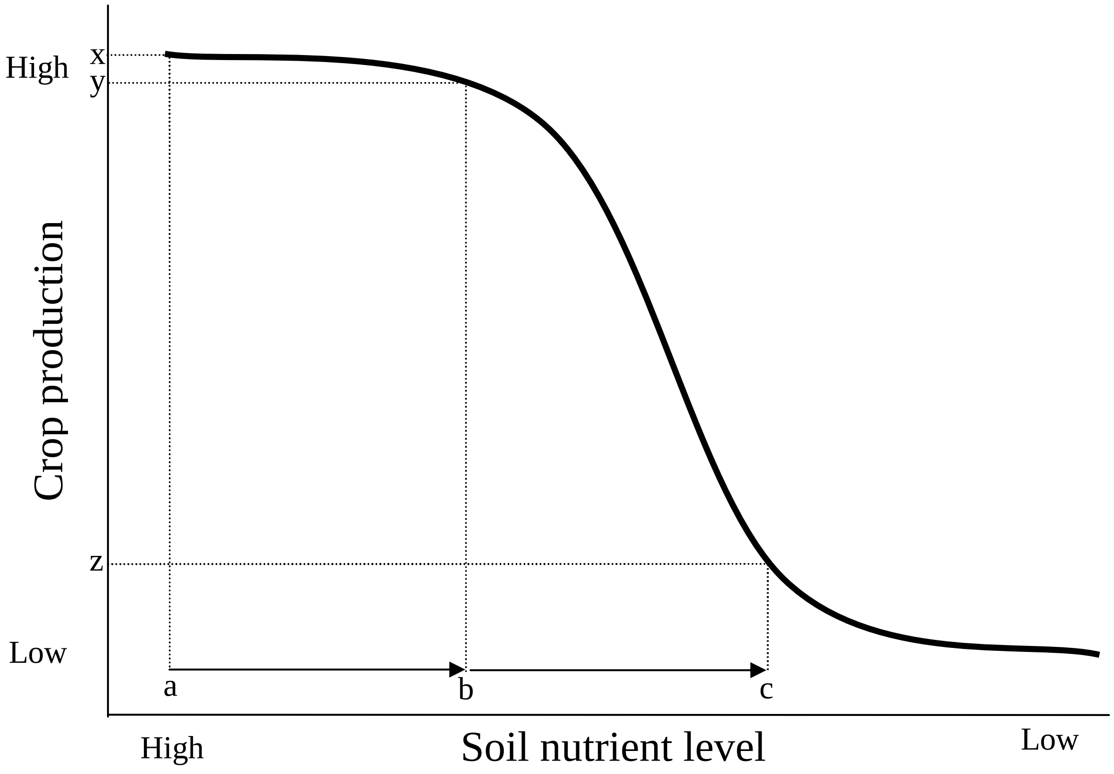

Figure 5. Illustrative sigmoid (S shaped) curve of the relationship between soil nutrient level and crop production.

The actual situation is slightly more complicated than the bucket metaphor indicates because the relationship between soil nutrient levels and plant growth is not linear. Figure 5 shows the sigmoid relationship between soil nutrient level and crop production. When soil nutrient levels are high (point a) crop production is also high (x). If soil nutrient levels are sufficiently high, then they can reduce considerably (from a to b) with only a tiny effect on crop production (the reduction from x to y). However, if nutrient levels continue to drop, the central part of the curve is encountered where small changes in soil nutrient status result in large changes in crop production, i.e., a drop in nutrient levels from b to c of exactly the same size as from a to b results in a very large reduction in crop production from y to z.

Due to the small but continual supply of nutrients from the parent rock of the soil, production rarely ever reaches zero, i.e., the bucket is effectively empty except for a trickle of nutrients in and a trickle out (i.e., very low yielding, nutrient deficient crops). The effect predicted by graph in Figure 5 is exactly what is found in real-world farming practice. When farms stop applying fertilisers often little change is seen in yields for several years even decades (the change due to nutrient levels is often much smaller than the year to year variation due to weather and other factors so is very hard to discern). However, after sufficient time production starts to drop, and then often plunges. This is the actual experience, in Ireland, on organic farms that stop applying fertiliser when they convert. All is well for about six or so years as the ‘fat of the land’ is used up, then production plummets as the farm’s ‘muscles’ start wasting away. The same goes for all long-term agricultural trials studying the effects of lack of nutrient replacement. Often there are no changes for several years, and on exceptionally deep and fertile soils, decades, however, at some point production and quality plunge then level off at very low levels. To completely press the point home, this happened in Ireland as a whole prior to the introduction of fertilisers, as plant and animal produce had been continually removed from the land for many generations without replacement, resulting in widespread soil nutrient depletion and miserable yields of crops and sick animals. Where the opposite is the case, all nutrients removed in produce are returned, e.g., as manure, then soil fertility can slowly increase due to the slow release from the parent rock adding to soil nutrients. Within the organic movement the ‘favourite’ exemplar of this (including by Howard) is the ‘ancient Chinese’ agricultural systems that continued for thousands of years due to the return of all nutrients back to the land, including human manure.

However, while the Closed System proponents including Balfour were incorrect regarding the replenishment of nutrients, it was as more by degree than by kind. If the size of the flows in Figure 4 are reversed, i.e., more nutrients enter the bucket than leave it, the bucket will fill up, but unlike a bucket the total nutrient levels within a soil can keep growing. This is no radical idea, rather it is simply a restatement of how soils form. As described above, plants accumulate the nutrients they need, so these accumulate in the top soil. If there is a continual nutrient input from parent rocks which is greater than losses via crop removal or natural losses such as erosion, then the total amount of nutrients in the soil can increase, and the total amount of soil can also increase, i.e., get deeper, as rock turns to soil, not forgetting that this process that takes millennia, i.e., much slower than human timescales.

For farm systems, this means there is a very simple formula for soil nutrient management - that the difference between the amount of nutrients removed in produce and that supplied by the weathering of the parent material must be returned to the soil to keep nutrient levels static. As the amounts removed in animals and particularly crops, (the annual yield of which per hectare can be order of magnitude greater than animal products so nutrient removal is greater by the same degree) is far, far greater than the input from rock weathering, for practical purposes nutrient supply from parent rocks can be ignored at human time scales.

Suggested alternatives and why they are wrong

As the scientific understanding of soil processes has increased, the Closed System concept has become increasingly shaky. As the evidence has stacked up against the Closed System, a range of alternative sources of nutrients have been suggested as a means to prop-up the theory. While the following may appear far-fetched as a ‘way out’, it has been personally suggested to me in all seriousness by farmers and other members of the organic community.

The creation and transmutation of elements including by radioactive (atomic) decay have been suggested. However, the fundamental physics of the chemical elements (as outlined at the start of this paper) prohibits such sources. Elements cannot be created - only transformed from other elements and/or energy. The temperatures and pressures required to achieve such transformations only exist in stars and nuclear fission and fusion reactors built by humans; therefore such processes are impossible in soils. Radioactive decay cannot be a source of nutrients. First it is far to slow, for example potassium decays to argon, but very slowly with a half-life of 1,260,000,000 years (the universe is only 14,000,000,000 years old). Were it to occur at rates sufficient to replace the quantities of nutrients removed in produce, then the soil would be so radioactive that it would be inhospitable for life. In addition, elements generally decay into the element one place lower than themselves on the periodic table (Appendix 1) and many of the plant nutrients are clustered together in the table so an increase in one can only come at the expense of another.

Simply put, matter cannot be created or transformed in the conditions found in agriculture, if matter is removed from a farm, it simply must be replaced.

Closed Farm System: Wrong by Kind

While the Closed System proponents were wrong more by degree than kind, when it came to nutrients being released from parent rocks at sufficient rates to replace off takes in farm produce, they were wrong by kind rather than degree when it came to their concept of the farm as a closed system. The origin of the word ‘organic’ is not organic matter as is widely, but mistakenly believed, but a contraction of ‘organism’. Some of the organic pioneers used the concept / metaphor of the farm as an organism, i.e., a whole that is also a collection of wholes, or holons to use the term coined by Arthur Koestler. The farm as an organism was believed to be self-contained, i.e., a closed system. While this is a considerable simplification of the argument (for the sake of brevity), it is now very clear that farms are not closed systems for anything.

Farms are not wholes they are holons, i.e., parts of greater wholes, such as ecosystems, countries and all the way up to the ultimate whole, the biosphere to which James Lovelock gave the name Gaia. As the biosphere is the ultimate whole, all other parts of the biosphere must therefore be holons, including farms. The key feature of holons is they constantly exchange matter and energy with their wider environment / larger holons they are part of, i.e., they are open systems, not closed.

The earth is not a closed system for energy, as described at the start of this paper. Energy floods through the planet in literally astronomical quantities. Farms are also just as open to energy as the earth is. Further 96% or so percent of plant nutrients (the atmospheric nutrients, C, O, H and N) come from outside the farms boundaries (the atmosphere), i.e., they are imported, and are eventually returned there. Even soil nutrients are lost from natural systems at slow rates via leaching and erosion, and farming, even pre-industrial, has always accelerated these natural rates of loss. Even without human intervention, soils wear out. As described at the start productive soils are the youngest soils, and the most productive are those that are replenished annually by floods. Most of the earth’s surface is continually replaced over periods of tens to hundreds of millions of years by plate tectonics. Those soils that escape this process become so denuded that they can only support the most meagre vegetation, i.e., even completely natural systems, without human intervention, can result in depleted soils. If nature can destroy soils through the geologically slow process of leaching then humanity can do the same, but much faster, by failing to obey the Law of Return.

To summaries: the whole concept of the farm as a closed system is incorrect. Both matter and energy constantly flow and cycle through its boundaries in large quantities, and even the soil nutrients enter and leave without human intervention and exit far more rapidly with human assistance.

The solution

Close the soil nutrient cycles

The fundamental solution is conceptually very simple: close the nutrient cycles in human time scales and return the nutrients removed from the soil in produce back to the soil as fertiliser. Practically the solution is far, far more complex. Prior to the industrial revolution most food was produced and consumed locally so closing nutrient cycles was practically simple - just return human manure back to the fields. The industrial revolution created urbanisation, which resulted in food being traded, i.e., moved from the countryside to the new urban centres. However, the nutrients in the food were rarely returned, most of it (as sewerage) was dumped into the rivers and from there to the seas and oceans. This created two problems, the eutrophication of the waterways and the removal of nutrients from farm soils at human time scales. By putting the nutrients into the rivers, they moved from the pedosphere and land biosphere, into the hydrosphere which at human time scales is a one way trip, i.e., not a cycle, because as soil nutrients cannot be cycled via the atmosphere, they cannot escape the hydrosphere via the air, the only exit from the hydrosphere is the lithosphere, i.e., the rocks of the planet. As described above these are still cycles, but the timescale moves from the human time scales of years and decades to millions even hundreds of millions of years. This is a very serious problem because the human species is only 200,000 years old, agriculture around 10,000 years and the industrial agricultural system around 200 years old, i.e., humanity is dramatically accelerating a small part of the global nutrient cycles on which it is utterly dependent, i.e., from the pedosphere (farms) to the hydrosphere (oceans) from where there is no known effective, practical or economic means of retrieving them in the required quantities at human time scales.

The history of the solution

The awareness of this situation is not new, in fact it was realised soon after the start of the industrial revolution. Karl Marx writing around 1850 (70 years before Howard) said that “Capitalist production ... disturbs the metabolic interaction between man and the earth, i.e. it prevents the return to the soil of its constituent elements consumed by man in the form of food and clothing; hence it hinders the operation of the eternal natural condition for the fertility of the soil...”[1] Marx was no soil scientist or ecologist, indeed Marx’s writing precedes the full emergence of these sciences by fifty and a hundred years. He was only repackaging the views of others working decades before him. However, farmers did not need the likes of Marx to realise they had a problem, the decline in soil fertility was evident to their own eyes, even if their understanding of the reasons was virtually nil: ‘soil sickness’ was about as good an explanation as was possible. Most farmers realised was the solution was to use the well-known fertiliser effect of animal and human manures, and they were keen to import fertilisers such as manures and pulverised bones, to fertilise their soils. The problem was they were in very short supply, for example “The value of bone imports to Britain increased from [pounds] 14,400 in 1823 to [pounds] 254,600 in 1837. … So desperate were European farmers in this period that they raided the Napoleonic battlefields (Waterloo, Austerlitz) for bones to spread over their fields.”[1]

The first temporary relief came in the form of guano - i.e., the accumulated droppings of sea birds, which is one of the rare, and truly infinitesimal, human timescale return circuits from the hydrosphere to the land. Guano contains a full compliment of plant nutrients, so it proved to be an excellent fertiliser. Indeed, it was so effective it created “guano imperialism”…

> The “United States undertook - first unofficially and then as part of a deliberate state policy - the imperial annexation of any islands thought to be rich in this natural fertilizer. Under the authority of what became the Guano Island Act, passed by Congress in 1856, U.S. capitalists seized ninety-four islands, rocks, and keys around the globe between 1856 and 1903, sixty-six of which were officially recognized by the Department of State as U.S. appurtenances. Nine of these guano islands remain U.S. possessions today.”[1]

However, guano proved to be a finite resource because, although it accumulated each year when the sea birds bred, the rate of removal far exceeded the rate of replenishment. As guano ran out alternatives were needed, and were found, pretty

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[1] Foster, John Bellamy, and Fred Magdoff (1998). "Liebig, Marx, and the Depletion of Soil Fertility: Relevance for Today's Agriculture." Monthly Review. 50: 32-45.

much in the nick of time, in the form of underground reserves of nitrate, potassium and phosphorous ‘rocks’.

At the time, these reserves also seemed inexhaustible / infinite. However, today the lifetime of these fossil nutrient reserves are increasingly well established and their origins are fully understood. They mostly originate from large shallow seas, tens to hundreds of millions of years ago where nutrients such as N, P and K accumulated after being washed from the land and then trapped as the sun evaporated the water, as is happening in the Dead Sea today. These seas and their nutrient rich sediments were then buried by further sediments and uplifted by tectonic activity to their current positions, i.e., these are nutrients concentrated by unusual conditions but that are proceeding through the normal multi-million year geosphere stage of the planetary nutrient cycles. Humans have found a way to short circuit part of the geocycle by mining these nutrients. However, just like fossil fuels and guano, which appeared vast an inexhaustible, they are relatively small, and, just like fossil fuels and guano they have a ‘peak’ of maximum extraction, after which production can only decline. The current estimated reserves of phosphorous are around 70 years and there are some three to four centuries of potassium remaining. While humans have been able to short circuit part of these nutrients geocycles, it is only a very small part. The fundamental problem remains: that humanity is removing soil nutrients from the soil and into the hydrosphere from where the only natural means of return is via the lithosphere.

A comparison with the current ‘energy crisis’ is valuable at this point. Most of the energy that has, and continues to power the industrial revolution has been fossil energy in the form of fossil fuels such as coal and oil. ‘Peak oil’ and ‘peak coal’ are not fundamental physical problems. The amount of energy that flows through the planet compared to what humanity uses is truly vast, in addition to the figures given earlier in this paper, the amount of solar energy reaching the surface of the planet is so immense that in one year it is approximately twice that will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined [2]. While there are no ‘economic substitutes’ for energy, there are plenty of economic substitutes for fossil fuels as energy sources, i.e., renewable energies that directly (e.g., solar panels) or indirectly (e.g., wind and wave power) harness the energy from the sun. However, not only are there no economic substitutes for the

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[2] http://gcep.stanford.edu/research/exergycharts.html

chemical elements, including the plant nutrients, there are no economic substitute sources of plant nutrients left. When they have run out, that is it. The only option at that point is to (re)cycle the soil nutrients from the soil, through society and back to the soil at human time scales.

One of the ‘side effects’ of using fossil fuels is climate change. The Stern Review on the Economics of Climate Change said, “Climate change is the biggest market failure the world has ever seen”. There is no comparison of the many orders of magnitude greater threat that climate change presents to humanity compared to dwindling supplies of fossil nutrients. However, Humanity has understood the nutrient depletion of the soil, at some conceptual level, since the inception of agriculture some 10,000 ago. Humanity started climate change only about 200 years ago and discovered it around 30 years ago. If a problem discovered only 30 years ago is the biggest market failure the world has ever seen, then a problem perceived since the dawn of agriculture, that has been well understood for 200 years including the solution, and which has been to the brink of exhaustion twice before, should be described as…?

The End of the Schism

As described at the start of this paper, the practice of organic agriculture is based on scientific knowledge, i.e., as opposed to belief, although the use of science is guided by clearly defined ethics and a deep understanding of the limits of science (e.g., see[3]). It was also noted how limited the scientific information available to the organic pioneers and even the founders of the organic production standards in the 1960s and 1970s. Most of the scientific knowledge presented in this paper has been discovered, or at least become widely known, since the pioneers time and significant amounts since the fundamental content and structure of standards were created. For example in the 1920s there were 72 known elements, we now know there are 94 naturally occurring ones. In the 1920s, the understanding of the elements was at a mostly empirical, chemical, level. The advent of Einstein’s relativity and the understanding of the sub-atomic quantum ‘worlds’ it helped lay the foundations for, now mean humanity has a fully complete theoretical understanding of the chemical elements at a fundamental physical level (the same as we now have a complete understanding of gravity and space-time). As further illustration, the science of chemistry has its

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[3] Barrow J.D. (1999) Impossibility: The limits of sciences and the science of limits. Vintage, London.

foundations in alchemy (which was practiced by Isaac Newton 1643 - 1727) one aim of which was to find the philosophers stone that could turn base metals into gold. Based on the quantum mechanics, humanity has made a further 22 elements that never have, and never will, exist in nature. The ability to transform elements into each other, and elements into energy and energy back into matter is now routine, making the idea of the philosopher's stone look exceptionally quaint. The origin of the universe, stellar nucleosynthesis, nuclear fusion, fission and radioactivity, plate tectonics and biogeochemical cycles, on which this analysis relies, all postdate, or are highly unlikely to be known by the organic pioneers such as Howard and Balfour and many members of the organic movement since their times.

There is a point when the level of scientific knowledge is such that it is able to act as a final arbiter. I would like to humbly suggest that in terms of the schism in organic agriculture between the Law of Return and Closed Cycles that the case is now closed and that Howards Law of Return has prevailed.

Appendix 1 The periodic table of the naturally occurring chemical elements

1 Hydrogen H																		2 Helium He
3 Lithium Li	4 Beryllium Be												5 Boron B	6 Carbon C	7 Nitrogen N	8 Oxygen O	9 Fluorine F	10 Neon Ne
11 Sodium Na	12 Magnesium Mg												13 Aluminium Al	14 Silicon Si	15 Phosphorous P	16 Sulphur S	17 Chlorine Cl	18 Argon Ar
19 Potassium K	20 Calcium Ca		21 Scandium Sc	22 Titanium Ti	23 Vanadium V	24 Chromium Cr	25 Manganese Mn	26 Iron Fe	27 Cobalt Co	28 Nickel Ni	29 Copper Cu	30 Zinc Zn	31 Galium Ga	32 Germanium Ge	32 Arsenic As	24 Selenium Se	35 Bromine Br	36 Krypton Kr
37 Rubidium Rb	38 Strontium Sr		39 Yttrium Y	40 Zirconium Zr	41 Niobium Nb	42 Molybdenum Mo	43 Technetium Tc	44 Ruthenium Ru	45 Rhodium Rh	46 Palladium Pd	47 Silver Ag	48 Cadmium Cd	49 Indium In	50 Tin Sn	51 Antimony Sb	52 Tellurium Te	53 Iodine I	54 Xenon Xe
55 Caesium Cs	56 Barium Ba	57-70	71 Lutetium Lu	72 Hafnium Hf	73 Tantalum Ta	74 Tungsten W	75 Rhenium Re	76 Osmium Os	77 Iridium Ir	78 Platinum Pt	79 Gold Au	80 Mercury Hg	81 Thallium Tl	82 Lead Pb	83 Bismuth Bi	84 Polonium Po	85 Astatine X	86 Radon X
87 Francium Fr	88 Radium Ra		89 Actinium Ac	90 Thorium Th	91 Protactinium Pa	92 Uranium U	93 Neptunium Np	94 Plutonium Pu										
			57 Lanthanum La	58 Cerium Ce	59 Praseodymium Pr	60 Neodymium Nd	61 Promethium Pm	62 Samarium Sm	63 Europium Eu	64 Gadolinium Gd	65 Terbium Tb	66 Dysprosium Dy	67 Holmium Ho	68 Erbium Er	69 Thulium Tm	70 Ytterbium Yb		

The essential plant nutrients / elements are highlighted by the thick cell border. The non-essential nutrients are nickel, silicon, sodium, cobalt, and selenium.

Financial Performance of Organic Farming

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Introduction

The market for organic food is growing strongly across all international markets, albeit from a low base. Food scares combined with greater health awareness have given rise to greater consumer demand for products that are produced in a natural environment. In Ireland, the growth in demand for organic food continues to outstrip domestic supply resulting in imports of organic food to make up the deficit.

Currently within the EU-25, 3.6% of land farmed or 5.7 million hectares are either organic or in-conversion production. Italy has the largest number of holdings followed by Austria, Spain and Germany. There are 1,230 registered producers in Ireland in 2008 farming 44,600 ha which represents 0.9% of total land farmed. Of the above 31,309 ha is fully organic being farmed by 888 producers and the remainder is in the process of conversion to organic. The growth of organic farming in Ireland over the last decade is shown in Table 1. The data show that organic production grew rapidly in the 1990's, peaked in early 2000 at 30,000 ha and remained static until 2005 when there was further expansion to 1,230 producers 888 organic/342 in conversion farming 44,600 ha (31,709 ha organic/12,891 ha in conversion) by 2008.

Table 1: Irish organic/in conversion farm numbers and area farmed 1995-2008

Year	Farms*	Organic Area (ha)*
1995	300	6,400
2000	852	27,230
2001	918	30,020
2002	923	29,850
2003	889	28,510
2004	897	30,670
2005	978	35,260
2006	1,104	39,940
2007	1,102	39,240
2008	1,230 *(organic 888: in convn 342)*	44,600 *(org 31,709 convn 12,891)*

Source: DAFF *Organic plus in conversion

Organic production in Ireland is located mainly in the west and the southwest with counties Clare and Cork accounting for approximately 30 percent of producers. The proportion of organic producers in the east of the country is significantly lower and as a result the area devoted to organic cereals and tillage is much lower than the national average. In the early years of organic production organic farms were considerably smaller in size than conventional. However, over time this has changed and in 2008 the average organic farm was 36 ha compared to 37 ha for conventional farms. It should be pointed out however that a significant proportion of the larger organic farmers have a part of their land that is of marginal quality.

The majority of Irish organic farms are involved in drystock i.e. cattle or sheep farming and in a number of surveys of the sector, 65 percent of producers were involved with beef and a further 20 percent with sheep production. The majority of producers have more than one enterprise but the above percentages refer to the main or predominant enterprise on the farm. In 2007 there were 93 cereal producers farming 1,283 hectares and a further 274 horticulture producers with 445 hectares. Dairy farming is one of the least represented farming systems involved in organic production due mainly to the lack of an organised organic milk processing and marketing sector. However the number of organic dairy farmers have increased and there are now 19 organic dairy farms farming 1,028 ha.

Financial and Technical Performance on Organic and Conventional Cattle Rearing Farms

Drystock farming is the most prevalent system of production in both the organic and conventional farming sectors in Ireland and in this paper the Cattle Rearing suckler production system is examined. Data on technical and financial performance were collected from a sample of farms involved in the Cattle Rearing System, as defined by the EU Farm Accountancy Data Network (FADN). The method of classifying farms into farming systems, as used in this study is based on the EU farm typology. The methodology assigns a standard gross margin (SGM) to each type of farm animal and each hectare of crop. Farms are then classified into groups called particular types and principal types, according to the proportion of the total SGM of the farm which comes from the main enterprises after which the systems are named. For the purposes of adapting the EU typology to suit Irish conditions more closely, a re-grouping of the farm types has been carried out. The system titles refer to the dominant enterprise in each group and their results should not be confused with those of individual farm enterprises.

The data on organic farms were collected from farms participating in the joint Department of Agriculture, Fisheries and Food (DAFF) and Teagasc Organic Monitor Farm Project. In 2004, a Steering Committee on organic farming proposed the selection of a number of well developed and managed organic farms to be used as demonstration farms in encouraging and promoting new entrants to organic production. Data were analysed on the selected farms using the Teagasc National Farm Survey (NFS) farm recorders and recording and analysis system. Data on the organic cattle rearing farms selected by the steering committee were collected in 2007. It should be emphasised that the NFS farms were randomly selected by the CSO, whilst the organic farms were specially selected due to their level of performance and experience and therefore would represent the more efficient sector of organic cattle production.

Table 2: Land use – organic v conventional cattle rearing 2007

	Organic	**Conventional**
	Ha	
Land farmed (UAA)	34.6	27.8
Pasture	20.3	16.5
Winter forage	6.7	7.2
Tillage crops	0.2	0.2
Rough grazing	3.6	2.8

Source: National Farm Survey - 2007

Organic farms were 24% larger than conventional whilst grassland was the predominant crop with virtually no tillage or root crops on either groups of farms. Tillage has declined on both drystock systems since the previous similar analysis in 2004. Winter forage area was similar on both groups despite a higher stocking rate on conventional farms.

Table 3: Livestock units on organic and conventional cattle rearing farms – 2007

	Organic	Conventional
	Livestock units	
Cattle	16.8	28.2
of which suckler cows	11.1	16.8
Sheep	0.2	1.0
Horses	-	0.2
Total	17.0	29.4

Source: National Farm Survey - 2007

Livestock categories are shown for both systems in Table 3 with the organic farms having less sheep and 42% less livestock than conventional farms despite having 24% more land. The decline in sheep numbers on both organic and conventional farms is another major change compared to the 2004 results. Combining land farmed in Table 2 with livestock units in Table 3 results in a stocking rate of 0.95 livestock units per ha on conventional farms versus 0.50 livestock units per ha on the organic farms. This is a key difference between both systems with organic farms only achieving approximately 50% of the stocking rate pertaining to conventional farms.

Table 4: Selected financial data for organic and conventional cattle rearing farms – 2007

	Organic		Conventional	
	€/farm	€/ha	€/farm	€/ha
Gross Output	23,292	673	25,518	917
of which Direct Payments	17,883	517	12,763	459
Direct costs	3,504	101	7,696	278
Gross margin	19,788	572	17,822	641
Overhead costs	4,813	139	10,120	364
Family Farm Income (FFI)	14,975	433	7,702	277
Cash Income	16,179	467	11,294	406
Net new investments	794	23	5,538	200
Loans (closing balance)	638	18	9,570	344
Total Costs % Gross Output	35%		70%	

Source: National Farm Survey - 2007

Conventional farms had higher output (10%) on a per farm basis and 36% on a per hectare basis. "Market" output i.e. returns from animal sales excluding direct payments was €12,755 per farm on conventional farms compared to €5,409 on the organic farms, which translates to €460/ha and €156/ha on conventional and organic respectively. Total Direct Payments on organic farms was €17,883 per farm (€517/ha) compared to €12,763 per farm (€459/ha) on conventional farms. Total production costs (direct and overhead) were €17,816 per farm (€640/ha) on conventional versus €8,317 per farm (€240/ha) for organic producers resulting in a Family Farm Income (FFI) of €14,975 per farm on the organic farms versus €7,702 on the conventional group. On a per hectare basis FFI at €433/ha on organic farms was 56% higher than on conventional farms. The results shown in Table 4 are similar and confirm findings in a previous studies carried out in 2004 and 2001 on the financial performance on organic drystock farms which also found that organic drystock farmers achieved higher incomes than conventional farms due to a combination of lower production costs and higher direct payments (Moran, B. 2007; Connolly, L. 2005; Conway, A., 2002). This is clearly evident in the data in Table 4, where total costs account for 70% of gross output on conventional farms compared to only 35% on the organic farms. Cash income was also higher on organic farms both on a per hectare and a per farm basis. Conventional farms had a higher level of net new investment at €5,538 per farm compared to only €794 per farm on organic farms.

The dependence of the cattle rearing system of farming on subsidies and direct payments in both production systems can be clearly seen in Table 4 where they contribute 119% of farm income on the organic farms and 166% of farm income on conventional farms i.e. direct payments/subsidies account for more than 100% of farm income whenever market based output is not sufficient to cover total production costs. The composition of direct payments is shown in Table 5 showing that the decoupled Single Farm Payment (SFP) is the main contributor followed by the REPS payment on conventional farms but REPS is the main contributor on organic cattle rearing farms.

Table 5: Direct payments on organic and conventional cattle rearing farms – 2007

	Organic		Conventional	
	€/farm	**€/ha**	**€/farm**	**€/ha**
Direct Payments	17,883	516	12,763	460
of which SFP	5,740	166	7,990	287
REPS	9,163	264	2,649	95
DAS	2,980	86	2,115	76

Source: National Farm Survey - 2007

SFP = Single Farm Payment; REPS = Rural Environment Protection Scheme;
DAS = Disadvantaged Area Scheme.

Organic farm households were demographically more viable than conventional farms – farm operators were younger, had a higher percentage of farm holders married and had more off-farm employment. In the National Farm Survey demographically viable is defined as the percentage of farm households which have at least one member under 45 years of age and the survey data show that in 2007 there were 92% and 75% of organic and conventional households respectively demographically viable. Finally the amount of farm labour used was higher on the organic farms at 1.14 labour units compared to 0.95 labour units on conventional farms.

Table 6: Socio-economic data on organic and conventional cattle rearing farms – 2007

	Organic	Conventional
Age Farmer	50	54
Married (%)	72	65
Off-farm Income (% Holders/spouse)	65	62
Labour Units	1.14	0.95

Source: National Farm Survey – 2007

Financial Returns to Organic Dairying

There are approximately 20 organic dairy farms in Ireland and expansion has been limited due mainly to limited processing and market outlets. The dairy data shown in Table 7 are based on a relatively small number of organic dairy farms participating in the National Farm Survey and therefore should be read with caution. As in the cattle sector, farms are classified into the dairying system based on EU typology i.e. dairying is the predominant enterprise on the farms shown in Table 7, but these farms can also have other minor enterprises e.g. cattle, sheep or tillage crops. The data are farm level data – not dairying enterprise data – and therefore represent all other enterprises on the farm and it is important that this is taken into consideration when interpreting the data.

Table 7: Financial farm returns to Organic Dairying farms compared to conventional – 2007

	Organic Dairying	**Conventional Dairy Farms**
	€/ha	
Gross output	2,646	2,850
- of which Direct Payments	484	434
Direct costs	708	923
Gross Margin	1,938	1,927
Overhead costs	734	800
Family Farm Income	1,204	1,127

Source: National Farm Survey – 2007

The data shows that whilst output is 8% higher on conventional dairy farms, family farm income is 7% higher on organic dairy farms due to total costs being 16% lower. Direct payments were 12% higher on the organic farms. Organic dairy farms were considerably larger than conventional farms 66 ha versus 45 ha. However as expected stocking rate was lower on the organic farms at 1.22 LU per ha compared to 1.82 LU/ha on conventional farms i.e. almost 50% higher on the conventional farms. Despite lower overall livestock units on the larger organic farms, labour units on organic farms was 42% higher.

Conclusions

FFI/ha on organic cattle rearing farms was 56% higher than on conventional farms due entirely to lower costs of production (€240/ha v €640/ha). However the organic farms were selected as monitor farms and therefore represent the better producers whilst the conventional farms were selected at random. Output and direct payments per ha were higher on conventional farms but not sufficient to cover the additional costs. Organic farms were 24% larger than conventional farms. Organic drystock cattle producers had a more viable socio-economic profile, whilst technical performance was higher on the conventional farms. Organic dairy farms had 7% higher farm income over conventional dairy farmers in 2007. However, these data are based on a small sample and should therefore be interpreted with caution.

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Meat Quality – Using consumers to measure preferences

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Abstract

It is currently difficult to judge beef quality prior to consumption, as there are inconsistencies in beef eating quality that are unrelated to its visual appearance. Consumers need a reliable indication of beef quality at point of purchase. Consumer sensory panels were carried out to test a palatability based grading scheme (the MSA model) and to evaluate consumers' perceptions of eating quality. Information gained may be used in the future during the selection of beef to bridge the gap between consumer expectation and satisfaction. Consumer taste panels were held according to the Meat Standards Australia (MSA) guidelines. Consumers rated beef samples from unidentified cuts according to the palatability attributes of tenderness, juiciness, flavour and overall liking. Results indicated that there is a high degree of variability in the eating quality of the striploin, rump and blade. Consumers were able to distinguish between beef quality from unsatisfactory to premium. This study indicated that the introduction of a consumer led approach to the categorisation of beef according to eating quality is likely to appeal to Irish consumers.

Introduction

Beef palatability can be broken down into 4 main characteristics; tenderness, juiciness, flavour and overall liking. Palatability is a function of production, processing factors and cooking method. As beef palatability is ultimately evaluated by the consumer it is appropriate that the consumer should be the driving force behind any categorisation of beef according to eating quality.

Consumer satisfaction depends on the extent to which the product meets their expectations and a repeat purchase is unlikely if their expectations are not met. However, consumers have difficulty in performing predictive quality expectations for beef. Providing consistent eating quality to guarantee consumer satisfaction is problematic due to inconsistency in palatability and a lack of reliable intrinsic and extrinsic quality cues. It would be beneficial to use a brand or label which would accurately describe the palatability of beef in a way that is easily recognisable before consumption. This would enable consumers to form accurate expectations, which would improve consumer satisfaction as it would reduce the difference between expected quality and experienced quality.

Variation in palatability stems from a wide range of factors along the supply chain from farm to fork. For example breed, sex, age at slaughter, post-slaughter intervention techniques such as electrical stimulation, hanging method and chilling regime all influence palatability. The selection of beef cut by consumers at point of purchase combined with cooking method also has an affect on palatability. Currently in Ireland beef carcasses are classified for conformation and fat cover. These visually assessed characteristics are related to the value of the carcass through their effects on saleable yield and are not strongly related to eating quality. In order to improve the consistency of beef eating quality it would be beneficial to develop a grading system which takes into account consumers attitudes towards eating quality of each cut.

Meat and Livestock Australia has pioneered a key initiative called Meat Standards Australia (MSA). This programme, based on the PACCP (Palatability Assured Critical Control Point) approach, adopted consumer testing to steer a total quality management scheme as a means of controlling the factors (critical control points) which contribute to the incidence of poor beef quality. No such quality management system involving consumer feedback is currently used within the Irish beef Industry. The objective of this research was to conduct large scale consumer taste panels in order to test the MSA model on Irish beef and Irish consumers and to gain insights into the knowledge and perception of beef eating quality by Irish consumers.

Methods

Currently two cooking methods are being assessed at AFRC. One of the cook types are traditional to Irish cooking (grill), while a novel cooking method for Irish consumers called yakiniku or ‘thin slice’ was also introduced in consumer panels. Yakiniku is a form of Korean barbeque whereby thin slices of beef, typically 4 mm thick, are cooked very quickly on a dry hot plate.

In each of the cooking methods consumers were presented with 7 pieces of beef all cooked to medium degree of doneness. Each sample was tested by 10 consumers. In the case of grilled beef, the samples were cooked on a clamshell cooker set at 230 ^{o}C. Using the MSA protocol, consumers were asked to complete a questionnaire rating individual beef samples for the palatability attributes: tenderness, juiciness, flavour and overall acceptability. They were also asked to indicate if they found each sample 'unsatisfactory', 'good everyday eating quality', 'better than everyday eating quality' or 'premium quality'.

Results

Average scores for each sample were compared with the scores predicted by the MSA model. Initial results indicate that the model might be suitable for Irish beef and consumers. Consumers accurately ranked palatability attributes according to the quality of the beef consumed regardless of cooking type. For example 'good everyday eating quality' consistently scored significantly higher ($P \geq 0.05$) for all palatability attributes than 'unsatisfactory'. The fillet was ranked as being of significantly ($P \leq 0.05$) better quality for all palatability attributes when compared to the other cuts. The fillet is the most valuable cut. This further emphasises that consumers have a good knowledge of palatability attributes and can distinguish between cuts with different quality attributes.

Figure 1 illustrates how beef cuts were ranked according to quality category. The striploin, rump and blade were fairly evenly spread across categories indicating a high degree of variability in palatability.

Implications

Consumer feedback has a vital role to play in the development of quality assurance schemes based on palatability as it is ultimately judged by consumption. Consumers have a good knowledge of beef palatability after it has been consumed. This is an excellent basis for the development of an Irish quality assurance scheme based on the PACCP approach which would help to link consumer evaluations before and after the consumption of beef.

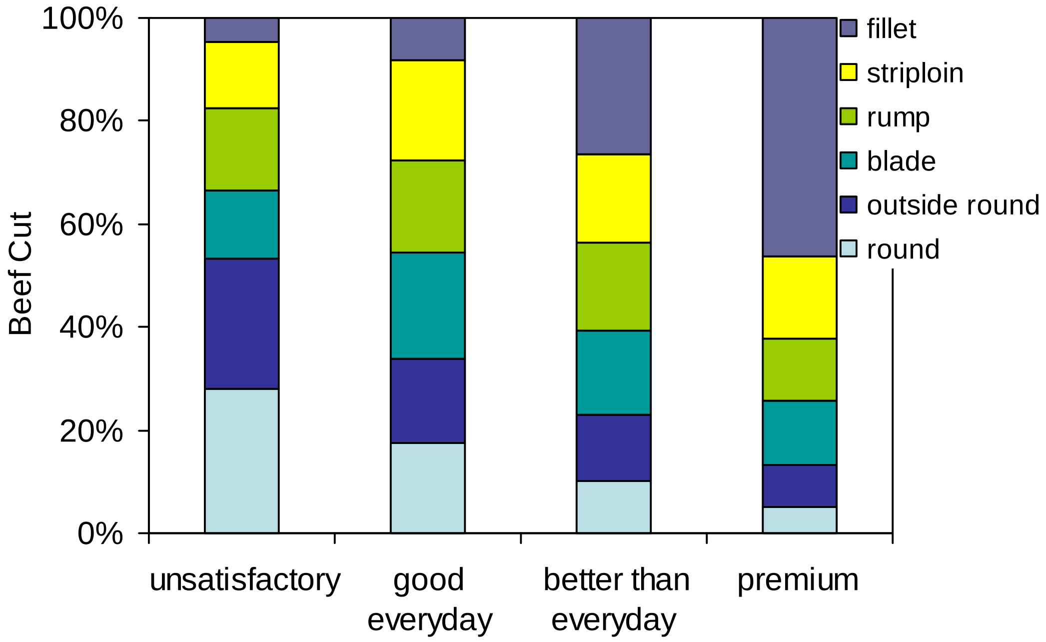

Figure 1: Beef cuts as a percentage of each quality category.

Key market drivers in the organic sector

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The total organic market is valued at more than €100 million. The fresh and chilled category accounts for the majority of this (€77.3m), followed by ambient (€22.6) with a very small amount accounted for by the frozen category (€0.7m). Whilst the sector has grown by 82% in the last 2 years (Bord Bia, 2008), there are signs of a slow down in growth. This paper looks at what is going well from a marketing perspective, identifies some areas requiring attention and suggests a change in positioning to maintain current levels of growth.

There are many things going well for organic food from a marketing perspective, in part due to the sustained efforts of many industry stakeholders including producers and processors. Recent research conducted by Bord Bia (2008) found that almost 100% of consumers are aware of the organic label. (This is the highest level of awareness of all ethical labels, with fairtrade for example reported at 78% awareness). This research also found that consumers' understanding of the word organic relates to no chemicals, natural, environmentally friendly, GM free, etc. In other words, consumers' understanding of the concept relates to how the organic bodies describe organic. A further positive aspect is that there is a strong core group of organic consumers and a significant number of consumers who purchase organic food on an occasional basis.

However the high level of awareness and understanding does not translate into correspondingly high levels of purchases. Across Europe, Ireland has one of the highest levels of awareness but is quite down low in the rankings in relation to purchases. Despite the high levels of awareness, Bord Bia (2008) reported that 17% of consumers purchased organic food in the last 4 weeks, 7% in the last 3 to 6 months and 48% are not organic purchasers.

Results of recent research by Nielsen (2008) suggest cause for concern:

- 38% are not sure about the benefits of organic
- 27% claim it is just a fad
- 25% don't trust the credentials of organic products.

Furthermore when one examines consumers' understanding of the organic concept further and look at what factors most influence consumer choices, some alarm bells may start to ring regarding future growth opportunities.

- In relation to understanding organic, more than 50% of consumers believe that it is expensive and price is the main reason deterring non-purchasers. With price ranking first or second in terms of factors influencing consumer choice with respect to food across European countries, this is cause for concern. This concern is also highlighted by a decline in the number of consumers agreeing with the statement that "Its worth paying extra for organic products" from 27% to 21% between February 2006 and February 2007 (Nielsen, 2008)
- About 20% of consumers associate taste with organic food, yet taste is the word that first comes into consumer's minds when they think about food and it is the 3rd most important factor influencing food choice across Europe.
- "Free from" is a key association for organic, particularly for the core group of consumers. However most Irish consumers associate few risks from food in spontaneous responses and in an EU study it was found that only 34% of consumers are very worried about food. This research also found that the longer people stayed in full-time education, the less they tended to worry about potential health risks. With increasing education levels, this suggests that the fear factor will decline in importance in the future.
- Health is a key driver of consumers purchasing organic food and 52% of consumers view organic food as healthy, however scientific claims in this area require further investigation and validation.

Another issue is the role of discounters in the organic market. German discounters (e.g. Aldi and Lidl) are offering organic food produce. This could have an impact on local organic outlets, e.g. farmers' markets and independent retailers. On the positive side, it will change consumer perceptions on “expensive” organic produce but possibly at the expense of a commodity image.

Thus the message is that the Irish organic market is small but rapidly growing. Awareness of organic is high and the benefits of organic appeal to a core group who can be categorised as “worriers” who focus on the “free from” elements of the organic proposition. It is now time to broaden the organic appeal to include the “less worried” and the “not worried”. This needs to be done by broadening and the appeal of organic products to include consumer needs for quality, taste and pleasure. The organic awards (organised by Bord Bia in conjunction with the Department of Agriculture, Fisheries and Food) within SHOP[4] provide a very appropriate and worthwhile initiative in supporting this development. The price and health claim issues are things that can not be tackled in the short term but they are something the organic sector as a whole needs to take a strategic perspective on.

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[4] annual food and drink retail trade event taking place in the RDS

Farmer attitudes towards converting to organic farming

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Introduction

Despite the considerable interest in organic farming the Irish organic sector remains small. Therefore to target support for the sector it is important to understand why farmers make decisions in favour or against organic farming as well as to identify drivers and barriers affecting that decision. Adoption of organic farming is assumed to be driven by a variety of different reasons such as economic and socio-economic, structural and institutional factors (e.g. Defrancesco et al., 2008; Burton et al, 2003). However, information gathering (e.g. Genius et al, 2006) and attitudes of the farmer (e.g. Willock et al, 1999, Hattam, 2006, Rehman et al, 2007) are also important in that decision.

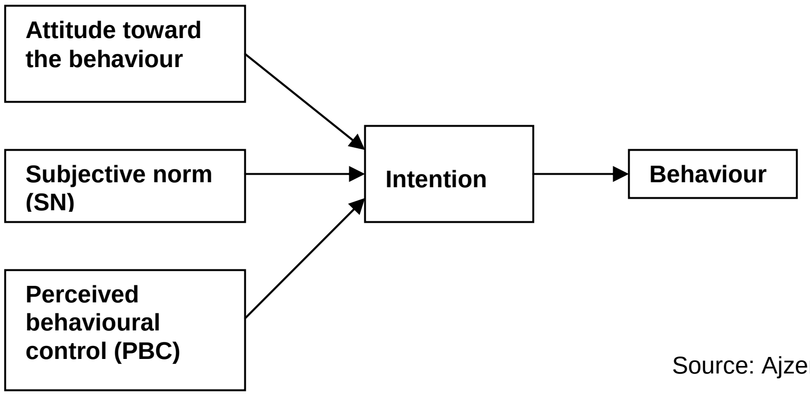
This paper focuses on the role that the attitudes of farmers play in identifying drivers and barriers to the intention to convert to organic farming using the theory of planned behaviour. To set this paper in context, it is part of a larger study which aims to explain the decision to adopt or not to adopt organic farming over time with respect to a variety of factors such as economic, institutional and socio-economic as well as comparing the attitudes and objectives of organic and conventional farmers.

Theory of planned behaviour

In order to gain a better understanding of the decision to adopt organic farming, it is perceived as a human behavioural issue. A model from the social psychology literature named the theory of planned behaviour (TPB) is applied. According to the TPB intention is based on three main constructs, namely attitudes, subjective norm (SN) and perceived behavioural control (PBC) (see Figure 1).

Intention to perform the behaviour is regarded as the most important immediate determinant of that action (Ajzen, 2005). Therefore, the primary objective is to identify the factors that drive the intention to perform the behaviour. However, due to social consequences (SN) and not having full control over the implementation (PBC), attempting to perform the behaviour may not necessarily lead to performing the behaviour.

Figure 1: The theory of planned behaviour (TPB)



Source: Ajzen, 2005.

Each construct is measured in a direct and indirect way. The direct measures are captured by statements which directly assess the opinion of the respondents (e.g. attitude is measured by '*In your opinion how good or bad would it be to produce organic meat on your farm within the next five years?*'; SN investigates the agreement of the farmer to the statement *'most people who are important to you think you should produce organic meat'*, whereas PBC assesses if the farmer thinks it is possible to produce organic meat on the farm). The indirect measures consist of three different types of outcome belief statements, namely (i) behavioural, (ii) normative and (iii) control beliefs (Hattam, 2006); and evaluation of these beliefs. The strength of each belief is multiplied by the subjective evaluation, giving each statement an individual weight (Ajzen, 1991).

Farmer interviews, survey design and method

In order to design the survey of conventional drystock farmers, preliminary work was undertaken to establish suitable survey questions. About 50 personal interviews with conventional farmers and farm advisers were conducted to elicit the true opinion and perceived problems of farmers if farming organically on their farm. The most frequently mentioned beliefs were then included in the survey to elicit conventional farmers' attitudes toward and possible responses to organic farming. The survey also includes questions about the level of farming experience and succession plans, sources of information on farming, as well as attitudes and objectives of the farmer. Since the survey was conducted by the Teagasc National Farm Survey (NFS) no questions on economic, socio-economic and structural data were included, as this type of data is collected as a matter of course in the NFS. As data collection is still ongoing, 181 conventional drystock farmers are included in the data analysis presented here.

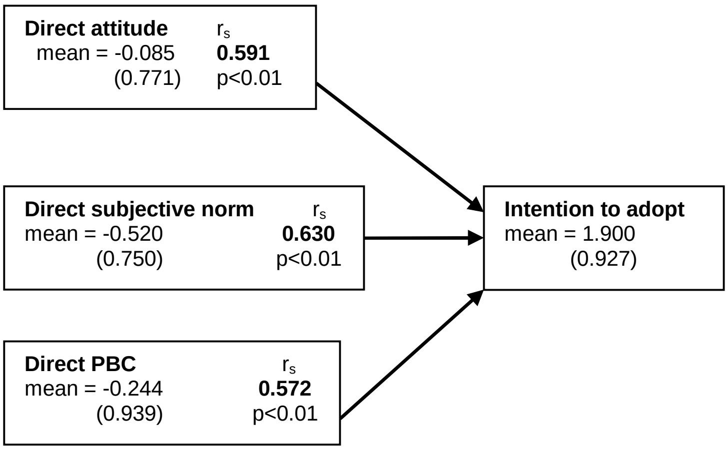
Results and discussion

General influence

Descriptive statistics show that the intentions of farmers to adopt organic farming within the next five years are low with a mean score of 1.9 measured on a scale from 1 to 5 (see Figure 2). Almost three quarters of the respondents express a very low or low intention to go organic. Nevertheless, 6% of respondents indicate considerable interest in going organic within the next five years.

The mean scores of the direct measures of attitude, SN and PBC are generally negative, though not strongly (see Figure 2). These statements are measured from -2 to +2, therefore a mean score close to 0 equals a neutral opinion. This indicates that in general farmers themselves do not have particularly strong opinions about converting to organic farming. Furthermore, they recognise a negative opinion among their ‘important others’ with respect to organic farming and perceive problems when farming organically.

Figure 2: Mean scores and correlation coefficients of attitude, SN and PBC



Intention is scored from 1 – 5, Attitude, SN and PBC are scored from -2 to +2, correlations (r_s) are non-parametric Spearman correlation coefficients; values in brackets are standard deviations.

Source: Authors' work

The differential influence of attitude, SN and PBC measures is determined by comparing the correlations between them and the intention to convert. All factors correlate significantly with the intention to convert and thus are influential (see Figure 2). However, the strongest correlation is found between SN and intention. This suggests that farmers are sensitive to the views of important others regarding conversion to organic farming.

Barriers and drivers of conversion

Barriers and drivers were identified by calculating correlation coefficients between the indirect attitude measures and intention (see Table 1). A perception by farmers that by becoming organic they would *'produce a product only rich people can afford'* appears to be the main barrier. This influence is stronger than the two identified drivers of adoption, which are '*increasing farm income due to higher support payments'* and '*receiving higher prices*'. These results indicate that future uptake of organic farming is likely to be financially driven, but farmers are reluctant to produce a product which they perceive only rich people can afford. The personal interviews also confirmed this result, as most farmers immediately mentioned they felt no one can afford to buy organic food as it is seen as too expensive.

Table 1: Correlations between attitudinal statements and intention

Attitudinal statements	Intention versus attitudinal statements correlations
Saving on fertilizer costs	n.s.
Receiving higher prices	0.247**
Increasing farm income due to higher support payments	0.290**
Leads to farming as it was 50 years ago	-0.182*
Provides a product only rich people can afford	-0.316**

Corrleation coefficients are non-parametric spearman, ** significant at $p<0.01$, * significant at $p<0.05$, n.s. = not significant.

Source: Authors' work

Influence of other people and information sources on the farm operator

Results indicate that farmers are moderately motivated to follow the advice of others or act on information received from sources such as information events or the farming press. Farm advisers appear to be the most influential group with a mean score of 2.59, with the farmer's family seen as the next most important influence (see Table 2). Negative mean scores for normative beliefs indicate that none of these groups or information sources trigger farmers to convert. In the personal interviews, it was particularly noticeable that the father of the farm operator, having a bad opinion about organic farming, was frequently mentioned as a barrier to converting. This finding is supported by a mean score of -1.14 for the farmer's family, the strongest negative value (see Table 2). Correlation coefficients to intention indicate that the farming press and farm advisers have the strongest influence on conversion. Thus, promotion of organic farming by the farming press and by farm advisers may overcome the limited positive sentiment towards going organic.

Table2: Mean values and standard deviation for motivation to comply, normative beliefs, referent subject norm and correlation coefficients to intention.

	Motivation to comply (range 1 to 5)		Normative beliefs (range -2 to +2)		Belief based subjective norm (range -10 to +10)		Correlations to intention
Important others	Mean	St.dev.	Mean	St.dev.	Mean	St.dev.	r_s
1. Family	2.44	1.33	-1.14	0.97	-2.36	3.07	0.380
2. Other farmers	2.10	1.13	-1.09	1.00	-1.93	2.63	0.339
3. Farm advisers	2.59	1.30	-0.78	1.05	-1.57	3.28	0.392
4. Information events	2.35	1.29	-0.71	1.10	-1.08	2.90	0.388
5. Farming press	2.27	1.26	-0.73	1.13	-1.06	2.99	0.440

Correlation coefficients (r_s) are non-parametric spearman and are significant at $p<= 0.01$

Source: Authors' work.

Perceived problems

Maintaining animal health based on prevention shows a negative mean score of -0.61 suggesting that this is a concern for farmers when going organic (see Table 3). Mean scores close to 0 indicate that farmers are uncertain about their organic knowlegde and skills (0.24) and the time involved in farming organically (0.17). These figures suggest that generally conventional farmers believe that they are not particularly well informed about organic farming. Thus promotion and increased information about organic farming could overcome some of these barriers.

Table 3: Mean scores of control belief statements

Control belief statements	**Mean scores** (range -2 to +2)	**St. dev.**
Having the knowledge and the skills	0.24	1.04
Having sufficient time to carry out the work	0.17	1.07
Having suitable farm conditions	0.59	1.09
Producing organic meat without using fertilizer	0.49	1.07
Maintaining good animal health based on prevention	-0.61	1.03

Source: Authors' work.

Conclusion

The results presented here suggest that, under current circumstances, large-scale conversion to organic farming by drystock farmers within the next five years is uncertain, but nevertheless 6% of drystock farmers state considerable interest in going organic. It appears that farmers do not have strong opinions about organic farming but equally the results here suggest that they feel they do not have a good level of knowledge about organic farming. Therefore an increase in information mainly focused on promoting organic farming as a profitable alternative to conventional farming could have a positive impact on the tendency for conversion. Future conversion to organics is most likely to be financially driven, but nevertheless the farmers' perception that only rich people can afford to buy organic food remains a barrier and considerations might be given towards approaches that might alter this mindset.

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