Organic Stockless Arable Rotation Experiment - 1999-2007: Review and Analysis Report

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1. Summary

- In 2000 an organic rotation research and demonstration experiment was set up at Oak Park, with an overall aim 'To improve the yield and quality of organic arable crops in Ireland'
- A field scale, long term, stockless seven year rotation experiment was established having three replicates. The single rotation consisted of two years grass / clover pasture followed by five years of cropping, three in cereals, one potato and one legume crop.
- The area was previously in long term silage pasture, which provided a good base from which to convert to organic.
- Within and across the plots a range of 'component research' was undertaken, mainly cultivar comparison and some sowing rate experiments.
- The component research varied and is regarded as being at variance with the long term monitoring of the rotation.
- The experiment would benefit from a re-confirmation of its aims, objectives, experimental design and management.
- Considerable value is placed on the instigation of an 'industry' consultative group consisting primarily of organic farmers as well as members of the organic movement, and other agricultural representatives.
- It is recommended that the experiment continues to be un-certified, as certification is solely a marketing tool which is often at odds with the requirements of research, especially where standards are at odds with organic principles. It is suggested that a stakeholder representative group would give the experiment the credibility that farmers obtain from certification, i.e., it would be peer reviewed by leading organic farmers.
- It is recommended that stakeholders, principally the organic movement but also national farmer representative groups that have an interest in organics, in conjunction with experts / specialists both from within and outside Teagasc, be consulted for their views on the restructuring of the overall experimental program, as well as its aims and objectives and the usefulness / role of a consultative group. This should be completed by July 2008. It is recommended that the process start with as wide a mandate as possible rather than being presented with more narrowly defined options.
- That the revised experimental programme is implemented as far as possible by August 2008 when all crops are harvested and autumn planting of many crops takes place.

2. Introduction

This report provides an overview and analysis of the organic rotation experiment conducted at Teagasc's Oak Park, Crops Research Centre. It is seven years since the rotation was implemented with the first full rotation of the crops completed in 2007. This fact, coupled with the continued interest in organic agriculture, increasing global environmental concerns and political changes in Ireland, one result of which is a Government target of 5% of Irish agricultural land area to be certified organic by 2012, mean that this is an opportune time for such a review.

The report first considers the context and the overall implementation of the experiment before focusing on the details of the scientific work and the overall results it has generated. This is followed by analysis and discussion of nutrient management, participatory research and governance issues, a review of the experiments objectives (also see below), the role of certification, followed by a general discussion and conclusions of potential ways forward.

The trial was originally set up and run by Mr. James Crowley (Agronomist) with Mr. Arnold Mahon and Mr. Eddie Baldwin as project technicians. James retired in 2004 with Mr. Bernard Rice (Engineer) taking over until 2006 and Dr. John J Burke (Agronomist) managing the project for the remainder of 2006. In 2007 there was no researcher in charge and the project continued with Arnold Mahon maintaining it based on previous years protocols. From January 2008 Dr. Tom Kennedy (Entomologist) became the research officer in charge with input from Dr. Charles Merfield (Organic Cropping Research Scientist). This report has primarily been written by Charles Merfield and Tom Kennedy, both of whom have had no prior involvement in the project.

This report focuses on the scientific and agronomic aspects of the Oak Park organic rotation rather than economic issues. This is because markets and input costs are continually changing which results in any financial analysis being out of date soon after it is created, and because the majority of the data that has been collected in the trial is not primarily of an economic nature.

2.1 Context of the organic rotation experiment

Concerns over the lack of organic arable production in Ireland and a desire by Teagasc to better serve the Irish organic sector, led to the establishment of an organic stockless rotation trial at the Oak Park Research Centre, Carlow in 2000. The overall aim of the experiment is summarised as:

'To improve the yield and quality of organic arable crops in Ireland'

Within this overall aim, the experiments objectives, stated in the 2002-2005 report, are:

- To develop and maintain a field facility for research on organic production of arable crops, with particular emphasis on animal feed crops;
- To establish base-line site data against which any long-term changes due to organic production could be evaluated;
- To establish good agronomy practices for the cereal, legume and grass crops included in the rotation;

- To collect input-output data to allow the production costs of organic crops to be established;
- To research key agronomic factors by conducting component trials within the existing rotation.

The above aim and objectives for the organic rotation experiment, in line with Teagasc's overall aims' is clearly focused on researching and demonstrating practical agronomy, i.e., providing solutions to farmers. In terms of scientific endeavour it is at the practical end of the research spectrum. Therefore, if the research is successful, its outputs should be easily and clearly demonstratable. They should also be able to be rapidly transferred to, and implemented by, farmers by a extension / advisory system working in partnership with the scientific system. It is within this concept that the organic rotation experiment has been analysed and reviewed.

3. Establishment, experimental and rotation design

The organic stockless rotation was established in Teagasc Oak Park in 1999, on an eight hectare site in 'Malone Field'.

The soils in Malone field are classified as Knockbeg-Series (Conry, 1987), being deep heavy textured, well drained, Grey/Brown podzolics (Hapludalf) derived from calcareous till, consisting of mainly limestone with a heavy loam surface texture [22 - 26% clay and up to 45% clay in the subsoil (B_2 horizon)]. These soils are capable of high yields of grass and tillage crops (i.e. 10 to 13 t/ha of winter wheat in conventional systems of production). The soil is not un-typical of the soils of many Irish farms, especially organic arable and vegetable farms away from the east coast arable and horticultural areas. The soil in Malone Field can therefore be considered reasonably representative of actual Irish organic farms and therefore the results and techniques should also be representative and transferable.

Prior to organic conversion, the area was under grass monoculture for about ten years with two crops per season of silage removed. It was ploughed in July 1999 and seeded in August with a ryegrass/white clover (*Lolium perenne* / *Trifolium repens*) mixture of Oak Park bread cv Avoca and Susi (4 kg ha^{-1} clover) with good establishment. For the following two summers (2000 and 01) the pasture was mown every 2-3 weeks, leaving cuttings in the sward to 'encourage clover development'.

The original grass pasture, while managed non-organically, is likely to of received few biocides, as it was principally cut for silage. The main inputs would most likely have been soluble fertilisers, which although banned or restricted in organic systems, principally on environmental grounds, are mostly identical to plant nutrients that occur naturally in soil, so are considered to have a low negative impact in terms of the following organic system. If animal manure was spread, it may have contained some synthetic biocidal residues, e.g., anthelmintics. However, application of animal manure is thought to have been limited and so the effects of biocides would also have been limited. In short the soil, which is the main focus of organic production systems, had been managed for a decade prior to conversion in a way that was not too far removed from organic practice and it was under permanent pasture which would be expected to maximise soil structure, organic matter and generally optimise soil properties thereby creating a close-to-optimum precursor for organic conversion.

Significant effort was also put into planting the field margins of the area with mixed hedging species. Field margins were managed to promote biodiversity and the site was generally managed in an ecologically sensitive manner which are key aspects of successful organic production practices. In addition, the whole area is reasonably well separated by woodland, a railway and grass cultivar trials from the intensively managed arable cropping areas of Oak Park which could be the source of pest and disease problems and / or synthetic biocide contamination. Therefore, any problems encountered in the organic system can fairly be attributed to the management of the organic system and/or inherent soil conditions, not what has gone before or the activities of the surrounding area.

In summary, the previous decade of silage pasture, the two year clover pasture conversion phase, good eco-biological management and comparative isolation from the rest of Oak Park is considered among best practice for establishing an organic trial area at a non-organic agricultural research facility.

In autumn 2001 the trial area was laid out with three replicates containing seven plots, one for each year of the rotation with an area of approximately 0.4 ha each (Figure 1). Within each replicate each crop/pasture was randomly allocated to the plots. The rotation design (Table 1) is considered to be typical of an organic mixed cropping/pasture rotation for Ireland and countries with similar climates/farming systems and is therefore considered meaningful to farmers. In addition the trial was originally managed in accordance with the 1992 IOFGA (Irish Organic Farmers and Growers Association) symbol scheme, but not actually certified.

Table 1. Rotation sequence of crops, organic trial, Oak Park.

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Grass/ Clover	Grass/ Clover	Winter Wheat	Potatoes	Winter Oats	Lupins	Spring Barley

Each year a number of experiments, ‘component research’, were undertaken, principally cultivar comparisons and some sowing rate trials within the main rotation experiment (Table 2). In 2002 sowing rate and cultivar trials were also conducted at Johnstown Castle Research Centre.

Table 2. Organic rotation component research. CT = cultivar trial. SRT = sowing rate trial. SC = single cultivar (no trial)

Year	Winter Wheat	Potatoes	Winter Oats	Lupins	Spring Barley
1999 2000	White clover and grass pasture conversion period – no crops grown				
2001	First autumn of crop plantings				
2002	CT & SRT*	CT	CT & SRT	CT	Not sown
2003	CT & SRT Spring W CT Triticale CT	CT	Spring oat CT & SRT	CT & SRT	CT & SRT Undersowing trial
2004	CT	CT	CT	SC	SC
2005	SC	CT	CT	SC	SC
2006	SC	CT	CT	SC	CT
2007	CT	CT	CT Spring oats	CT	CT

*Also undertaken at Johnstown Castle Research Centre

In summary, the organic experimental area at Oak Park uses well designed and managed agro-ecological components (e.g., field margins) that are representative of organic production methods and principles and on which organic research can be conducted with a generally high level of integrity. While it was indicated that both mycorrhiza flora and invertebrate fauna would be monitored within the trial area no arrangements to achieve these aims were made.

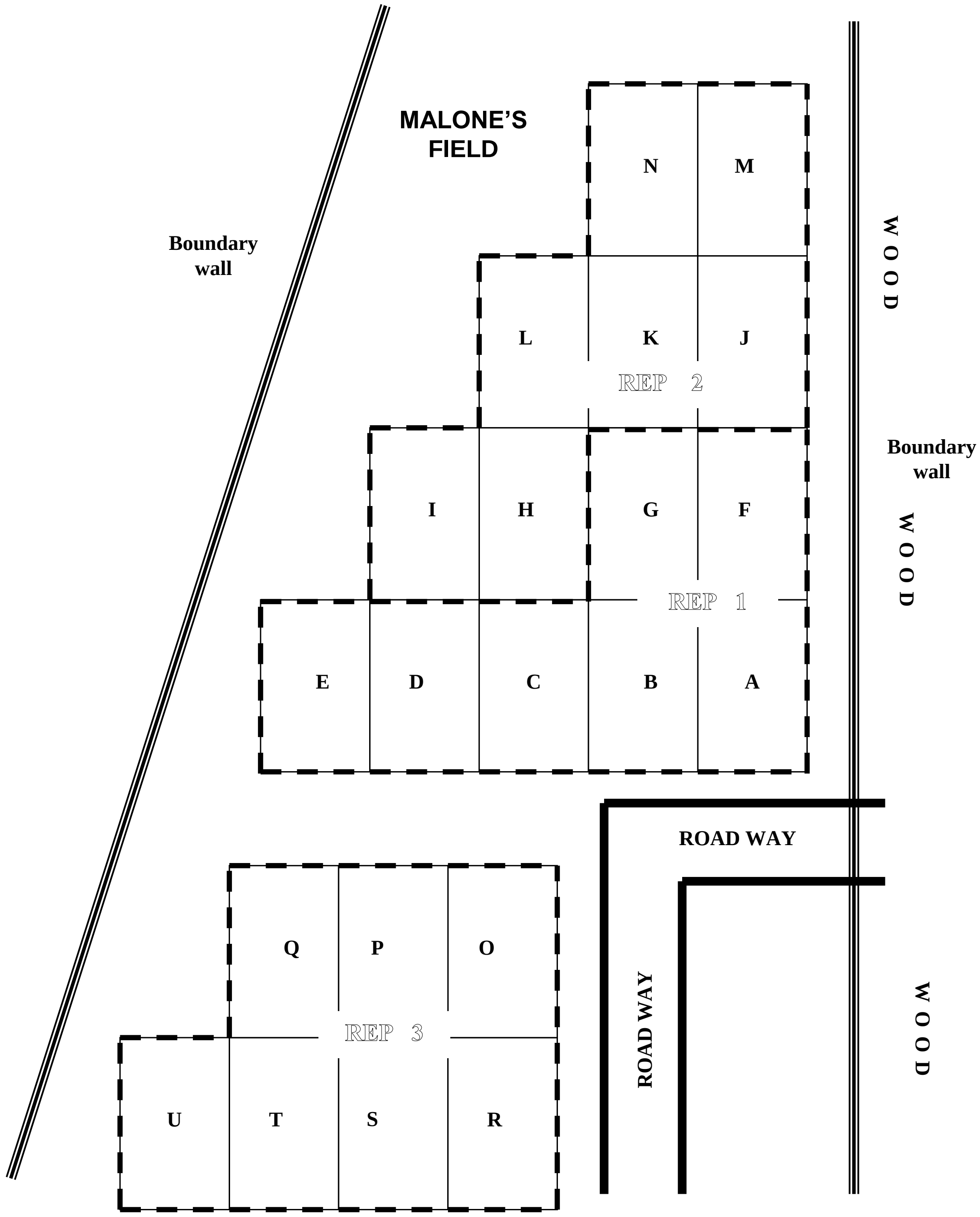

Figure 1. Plan of organic rotation trial, Oak Park

3.1 Experimental design

Despite the excellent eco-biological setup of the research area, the experimental work has used a number of different approaches, some of which follow less common agricultural experimental and statistical methodologies.

3.1.1 Whole rotation experimental design

From the perspective of the rotation as a whole, the trial is to a reasonable extent laid out in a randomised complete block design (RCB) (Figure 1). However, RCB designs are used where there is a known or suspected environmental gradient, e.g., a slope, which is considered likely to influence results, e.g., due to variations in soil moisture. In such designs blocks are normally rectangular and laid across the environmental gradient with each block placed under the previous one to form a rectangular shape. The organic rotation is blocked, but the blocks are staggered both horizontally and vertically, (due to field layout constrictions) yet there is no clear environmental gradient in the field, especially one that relates to the triangular blocking pattern. This is not an ideal situation from a statistical perspective.

In most agricultural field trials two or more treatments are normally compared to determine what differs between/among them. However, there is only one treatment (rotation sequence / type) at the organic rotation experiment so there is nothing to compare. Despite a lack of different treatments, the replication means that it is possible to establish the statistical variation of the individual crops within a year [e.g., standard deviations or errors (SD / SE) of crop yield]. In addition, the long duration of the trial (seven years), coupled with measurement of intra-year variability, means that long term averages can be calculated (although not directly statistically comparable) and potential trends, e.g., increasing weed biomass, higher earthworm populations, could be identified.

While uncommon in agricultural research, such long term monitoring is a common approach in ecological science, especially where the ‘classical’ manipulation of variables is not possible. For example, forest ‘health’ is measured before, during and after, a pest control exercise from which the effect of the pest control treatment is inferred, even though it could be due to some other effect that was / cannot be controlled for, e.g., weather. So while there is only one treatment in the organic trial, the intra-year replication and long duration mean dependable and biologically valuable data could be produced.

For such data to be reliable it requires that the same crop species, cropping systems and ideally cultivars, are used every year and across all replicates. However, instead of each year’s rotation being identical, different component research experiments have taken place among years and within and across plots of the rotation experiment. The component research therefore complicates the requirement for intra- and inter-year consistency of the whole rotation experiment. It is therefore problematical for statistically reliable analysis of crop and soil performance over the duration of the rotation to be produced.

Fortunately, the component research has not changed the placement of individual species within the rotation sequence, e.g., for any one year, while all three barley plots may have different experiments in each one (e.g., cultivar, sowing rate and under-sowing), they have always, and only, grown barley, i.e., ultimate rotational integrity has been preserved. This means that while analysis of previous years data is problematic, future research at whole plot level is reasonably secure, i.e., future work has probably not been overly compromised by the previous component research, although considerable care may be required to ensure that this is in fact true. As a precaution the first one to three years results from an area of land after a piece of component research has taken place on it should be treated with caution unless experimental design takes the likely within-plot variation due to the previous component research into account.

3.1.2 Demonstration value

Positively, the trial as a whole is considered a very valuable demonstration facility for farmers. Such 'whole farm simulation' approaches are considered to be highly beneficial for convincing farmers of the merits of particular farm systems as they can readily visualise and work out how to implement the system being demonstrated on their own farm, as the scale of the demonstration work is one they have empathy with. This is in comparison with small plot experiments which farmers often consider to have limited credibility as they are far removed from their day to day practical farming experience (Liepins & Campbell, 1997).

3.1.3 Component research

The component research experiments, of which the majority have been cultivar and sowing rate comparison trials (Table 2) have taken a number of forms, for example, having a replicated trial within a single plot or replicating the trials using the main rotation blocks. Cultivar, sowing rate and similar agronomic experiments need to be consistently repeated across multiple sites and years to be able to produce biologically reliable data. This means the organic rotation component research has two issues:

- with the exception of one years research at Johnstown Castle, it has mainly occurred at Oak Park. Cereal cultivars have been evaluated at other organic sites as well as at Oak Park by The Department of Agriculture and Food.
- there is inter-year variation in the experimental methodology, for example, layout, design, cultivars tested, measurements taken, etc.

This means that while the design and methods of some of the individual experiments are statistically valid it would be hard to extrapolate the results to be applicable to other locations. Unfortunately, this means that the value of the component research is not be as strong as it could have been.

An further issue is the use of the same land area (i.e., plot) for year-on-year field trials. A fundamental methodological and statistical assumption of field trials is that the land on which the trial is sited is reasonably homogeneous / background variation is random, or at least inherent site properties, e.g., soil drainage, occur in relatively smooth gradients which can be accommodated by the method of analysis, e.g., blocking. However, research trials produce very non-homogeneous conditions, i.e., the differences in treatment from previous years experiments will leave a legacy in the soil, which can significantly effect following crops. If the following crop is an experiment, then the plot differences of the following experiment may not be due to treatment difference but due to plot / treatment differences from the previous year's experiment. Therefore best practice is that for any given piece of ground, trials should only be conducted once every two to four years (depending on the type of research), with a uniform treatment (crop) grown on the area in the time between trials to reduce any legacy variation to background or sufficiently low levels that they do not compromise future experiments. This means that one to three pieces of component research should be carried out each year / rotation cycle with the rest of the plots / rotation sequences growing a uniform crop / pasture. A proportion of the component research in the organic rotation experiment has been conducted on the same plot in more than one year, which it is suggested is not ideal.

3.1.4 Whole-rotation and component research priorities

Based on the analysis and discussion in sections 3.1.1 and 3.1.3 above, there is a clash between the whole-rotation experiment and the component research, i.e., it is problematic to do both on the same piece(s) of land. This is not to say that the rotation plots cannot be sub-divided into split plots or other statistically valid system to study long term sub-treatment effects. However, it is hard to see how the annual component experiments can continue to be conducted within and among whole-rotation plots.

There is one statement in an early presentation that the experiment is “Not a rotation or systems comparisons trial” and that the aim was to have “only one rotation” and to “carry out component research projects on each crop each year”. It would therefore appear that the approach chosen was deliberate. However, other presentations state different aims / objectives, e.g.,

- Develop field organic research facility;
- Establish good agronomy practices;
- Monitor site soil and fauna changes;
- Provide basis for organic crop costing;
- Fit in agronomy trials where necessary.

In retrospect it appears that the aims and objectives of the research were possibly slightly fluid. Which, coupled with the difficulty of monitoring the whole rotation system and conducting component research on the same pieces of land has created a number of analytical challenges.

However, both the whole rotation and future component research are valuable in their own right and it would be a potentially significant loss if one were sacrificed for the other. Therefore, considerable thought and deliberation, with expert statistical advice, is required to unambiguously unpick the current situation, and work out a statistically and scientifically rigorous means of proceeding in the future.

3.1.5 Dept. of Agriculture Fisheries and Food (DAFF)

The DAFF have also used the organic rotation in 2007 and 2008 as one site for their organic cultivar trials. In 2007 the DAFF had trials of triticale in plot C, spring barley in plots D and U and spring oats in plot G. In 2008 there is winter triticale in plot F, winter oats in plot A, spring barley varieties in plots B and P, and spring oat in plot H. Leaving aside the direct benefits of the DAFF’s work in terms of cultivar trial research, the presence of these trials is effectively an extension of the component research conducted by Teagasc and therefore contributes to the analytical and methodological problems discussed above.

3.1.6 Data storage and analysis

For long term trials, it is essential that long term and rigorous data collection and statistical analysis techniques are established at the outset and scrupulously adhered to, to ensure that stored data is accurate and can be correctly analysed.

The organic rotation data which forms the basis for this report, is in the form of spreadsheets which vary in how and what data are recorded. There is incomplete information on the methodologies used and some of the spread sheets are difficult to audit. Some the experimental methodologies use unusual designs that have presented difficulties in statistical analysis. Therefore, in most cases, only the means (averages), as found in the data, have been compiled into the inter-year results Tables presented in section 4, i.e., the data has not be re-analysed.

3.2 Experimental design conclusions.

Due to the challenges, discussed above, it is uncertain that the research would meet the requirements of a peer-reviewed journal. Due to the analytical challenges, statistical analysis has not been completed so the level of variance of the data is unknown. However, with the area now having been managed organically for nearly a decade and under near-organic conditions for the previous ten years, the site has almost immeasurable future value as a location to conduct scientifically and statistically rigorous organic research to address the needs and aspirations of Irelands organic farmers.

4. Crop production experiment results

4.1 Introduction

Previous reports on the rotation trial have mostly been chronologically based, e.g., annual reports. The results presented here are grouped by crop then date, with the aim of giving an overall impression of the full five years performance of each crop.

The data reported are also not a comprehensive listing of all data collected. In early experiments a considerable range of measurements were often made, e.g., straw length, weight etc., that were not collected in later years. Therefore, only the more standard agronomic measurements are presented and/or those that were made in most years. Brief notes are also given on the experimental designs.

Each section starts with a general introduction to the crop, then the experiment methods, then results followed by a brief discussion of the results.

4.2 General agronomy

The general crop production agronomy has been to shallow plough (15 to 20 cm) followed by secondary cultivation, ideally three to four weeks before planting to create a false seed bed to allow weeds to germinate. Winter cereals are generally sown late to avoid the autumn weed flush and minimise barley yellow dwarf virus (BYDV) and take all infestation. In spring, early sowing is attempted so the crop is ahead of the spring weed flush and also to reduce BYDV infection.

In-crop weed control is by spring tine weeder or light harrow. No interrow hoe is available nor has one been used.

Immediately following cereal crops that are not to be replanted in winter cereals harvests straw has been chopped and spread over the plots and then lightly cultivated with disks or tines to encourage volunteer and weed germination to create winter green cover (cover crop) to retain soil nitrogen. A number of cover crops have also been sown, particularly after potatoes as volunteers are not desirable and do not have the same level of nutrient retention as of cereals. Phacelia (*Phacelia tanacetifolia*) was initially trialled but had poor establishment and also produced seed which became weedy. Legumes have also been trialled as overwinter cover crops including black medic (*Medicago lupulina*) and clover with varied success. Various cereals have also been used including rye (*Secale cereale*) for late sowings. Other species include mustard (unknown genera) and ryegrass. Cover crops, both sown and volunteer are mown and ploughed under in the spring.

4.3 Barley (*Hordeum vulgare*)

1.1 Introduction

Spring barley is the last crop in the rotational sequence before its return to the two year restorative pasture phase. Therefore, it is expected that soil nitrogen will be at its lowest point and that other production aspects, e.g., soil structure, drainage and particularly weed populations will also be at their most challenging. The decision to plant barley at this point is not considered ideal. It has lower overall nutrient demands than some of the other crops in the rotation, especially wheat and potatoes, but has a higher demand in early spring when biological nutrient release is slow. However, it is one of the least competitive crops, especially against weeds, mainly due to its short height, which makes it one of the less suitable crops to place at the end of an arable rotation where weed seed banks are likely to be at their largest. In traditional rotations it was placed after wheat or a root crop due to the lower weed populations after such crops. It is considered such a challenging crop to grow organically under Irish climatic conditions that many experienced organic arable producers will not grow it unless there is a significant price premium.

1.2 Design

No crop was grown in 2002 (the first year of the rotation) due to the extremely wet spring preventing field access until it was too late to plant.

In 2003 cultivar (cv.), sowing rate and undersowing trials were established. The cultivar trial included cv. Fractel, Feltwell, Lux, Optic, Prestige, Saloon, Spike, Tavern, Newgrange and an unknown mixture, sown in plot A (Replicate 1) using a RCB, 4 replicate design at 300 seeds m^{-2}, on 20 March 2003. A considerable range of measurements as well as yield were taken e.g., straw properties and weed biomass. The sowing rate trial used rates of 200, 250, 300, 350, 400, 450 seeds m^{-2}, grown in plot R (Replicate 3) using a semi-RCB design with four replicates, the cv Newgrange with a TGW of 40.7 g sown on 14 March 2003. The undersowing experiment was in plot H (replicate 2) using cv Newgrange sown at 300 seed m^{-2} on 14 March 2003 and harvested at 8 August 2002. Technically it consists of two side by side single factorial experiments with four replicates, but the intention appears to of been for a two factorial design of undersowing mixture and application time.

The mixtures applied by broadcasting were:

1. control of no undersown mixture (i.e., barley only);
2. 7.5 kg ha^{-1} of 50:50 mix of white clover cv Avoca and Aran;
3. 7.5 kg ha^{-1} of 50:50 mix of white clover cv Avoca/ Aran plus 15 kg ha^{-1} of 50:50 mix of ryegrass cv Cashel and Magician;
4. 13 kg ha^{-1} undefined proprietary mixture.

Application times were:

A. 13 days post barley drilling (27 March)
B. 45 days post barley drilling (28 April) aimed to be at 4 leaf development stage of the barley.

In 2004 the cv Tavern with a TGW of 43.9 g was sown on 29 March 2004 on plots C, I and S. In 2005 Tavern was sown again in plots F and Q and in 2006 plots O and J. Mostly standard yield measurements were taken from these sowings.

Multiplication rate for sowing rate trials has been calculated from the data using the formula ((yield - sowing weight) / sowing weight) ha^{-1}.

1.3 Results

The results for investigations on spring barley are given in Tables 3 to 6.

Table 3. Barley sowing rate experiment results, 2003.

Sowing rate Seed m^{-2}	Sowing rate kg ha^{-1}	TGW	MC %	*Grain yield t ha^{-1}	Protein %	kg/hl	Multiplication Rate (wt)	Weeds (kg/plot)	Straw t ha^{-1}
200	**82**	49.63	30.37	4.10	10.0	62.39	4900%	12.93	1.44
250	**102**	48.83	27.43	4.39	9.8	61.40	4204%	8.00	1.57
300	**122**	47.40	29.07	4.94	9.3	63.35	3949%	7.88	1.68
350	**142**	45.93	25.27	5.07	9.9	62.21	3470%	10.32	1.78
400	**163**	45.57	19.97	5.40	9.6	62.85	3213%	8.17	1.87
450	**183**	44.90	30.47	4.74	9.3	60.25	2490%	6.34	1.75
Mean		**47.04**	**27.10**	**4.77**	**9.7**	**62.08**	**3704%**	**8.94**	**1.68**

*At 80% dry matter

Table 4. Barley cultivar experiment results 2003 to 2006.

Year	Cultivar	MC %	*Grain yield t ha^{-1}	TGW (g)	kg/hl	Protein %	Straw t ha^{-1}	Crop height cm
2003	**Fractal**	19.08	5.12	43.97	61.14	8.60	1.85	61
2003	**Feltwell**	20.45	5.52	36.47	61.05	8.40	2.00	49
2003	**Lux**	20.60	5.63	38.30	58.88	8.00	2.15	49
2003	**Optic**	20.53	5.60	37.63	59.44	8.90	2.11	56
2003	**Prestige**	19.38	5.83	42.50	62.79	8.90	2.02	54
2003	**Saloon**	20.05	5.80	34.70	62.84	8.40	2.01	47
2003	**Spike**	19.68	5.72	42.30	61.67	8.60	2.04	60
2003	**Newgrange**	19.23	5.70	44.33	57.59	9.10	2.25	59
2003	**Mixture**	19.53	5.71	46.17	58.82	8.80	2.19	68
2003	**Mean**	**19.84**	**5.63**	**40.71**	**60.47**	**8.63**	**2.07**	**56**
2003	**Tavern**	18.83	6.17	37.93	58.75	8.60	2.37	53
2004	**Tavern**	14.60	4.62	41.20	68.30	7.95	1.47	55
2005	**Tavern**	17.70	3.30	48.70	61.10	9.70	3.90	48
2006	**Tavern**	19.20	4.78	50.05	67.90	8.45	4.10	61
Tavern mean		**17.58**	**4.72**	**44.47**	**64.01**	**8.68**	**2.96**	**54**
Overall mean		**19.14**	**5.35**	**41.87**	**61.56**	**8.65**	**2.34**	**55**

*At 80% dry matter

Table 5. Grain yield and quality and straw yield, barley undersowing experiment, 2003.

Days post Barley sowing	Treatments	MC %	*Grain yield t ha^{-1}	TGW (g)	kg/hl	Protein %	Straw t ha^{-1}
13	**Control**	18.80	4.30	42.60	65.0	8.60	1.70
13	**Clover**	20.20	3.91	41.50	64.3	8.70	1.54
13	**Clover/grass**	19.75	4.20	42.20	64.9	9.00	1.66
13	**Mixture**	19.90	3.92	43.60	64.3	8.90	1.55
13	**Mean**	**19.66**	**4.08**	**42.48**	**64.6**	**8.80**	**1.61**
24	**Control**	20.38	4.37	42.60	65.0	8.60	1.72
24	**Clover**	23.43	3.78	42.00	64.3	8.90	1.49
24	**Clover/grass**	20.98	4.06	44.40	65.0	9.20	1.60
24	**Mixture**	20.30	4.07	42.80	64.9	9.00	1.61
24	**Mean**	**21.27**	**4.07**	**42.95**	**64.8**	**8.93**	**1.61**
Overall Mean		**20.47**	**4.08**	**42.71**	**64.7**	**8.86**	**1.61**

*At 80% dry matter

Table 6. Yield of vegetation from barley undersowing experiment, harvested 26 November 2003.

Days post Barley sowing	Treatments	Moisture Content %	Dry matter yield t ha^{-1}
13	Control	n/a	n/a
13	Clover	16.85	383
13	Clover/grass	16.70	417
13	Mixture	16.43	444
13	**Mean**	**16.66**	**415**
24	Control	n/a	n/a
24	Clover	18.35	312
24	Clover/grass	18.80	288
24	Mixture	19.25	262
24	**Mean**	**18.80**	**287**
Overall Mean		**17.73**	**351**

1.4 Discussion

The experimental design of each of the three 2003 experiments, while not statistically ideal, are sufficiently randomised that the figures can be considered reliable for the purposes of comparison among themselves. The two undersowing experiments are correctly blocked, but it is disappointing they were not laid out as a single trial as this would have permitted a two factorial analysis with its greater statistical power and the potential to detect interactions, so no statistical analysis was undertaken.

The sowing rate trial shows a trend for increasing yield with increased sowing density except at the highest value, which could be an indication of intra-species competition starting to occur, although comments in one report indicate it may be due to disease.

However, the difference between maximum and minimum yields is 1.3 tonne ha^{-1} which is less than half the 2.87 tonne ha^{-1} inter-year variation for Tavern. The variation among other measures is biologically small with the exception of multiplication rate which clearly show diminishing returns.

For the 2003 cultivar trial the most striking result is the lack of variation among cultivars. In contrast, the most striking result of the four year cv Tavern yields is their very large variation. This is a good example of why it is essential for cultivar comparisons to be conducted over multiple years and sites, if the data is to be reliable.

For the undersowing experiment there is little variation among the data, there are no clear trends, and differences are biologically small.

4.4 Lupin (*Lupinus angustifolius)*

4.4.1 Introduction

At the outset of the experiment a primary concern was the provision of sufficient soil N for good crop yields. It was therefore considered essential that a leguminous crop be included to help replenish N partway through the cropping phase.

Early reports state that spring lupin (blue lupin) was used in all experiments as this was considered the most suitable for Irish conditions based on UK trial results, although it is not stated which trials these were. There are two forms of lupin, single-stem and multi-branching types. The branching types are considered to be better from a production perspective as they are considerably more competitive against weeds than the single-stem type. However, the branching type mature later which means they may not reach sufficient maturity and dry matter content at harvest, negating their production advantages.

Lupins are always spring sown.

4.4.2 Design

The lupin cultivars grown in the organic trial, at Oak Park, included the multi-branch types Barlenna, Bordako, Erantis, Galant, Kompolit, SNS and V6-1. The single stem cultivars were Borweta, Prima and Viol.

The 2002 cultivar trial was grown over the three blocks in plots A, H and R. Cultivars were Bordako (sowing rate 125 kg ha^{-1}) and Prima (sowing rate 185 kg ha^{-1}).

The 2003 cultivar trial was conducted within a single plot ‘C’ (Replicate 1) with cultivars: Prima, Borweta, Barlenna (sowing rate 163 kg ha^{-1}) and Bordako (sowing rate 125 kg ha^{-1}). The trial design is not randomised in that cv Barlenna is on the outside and the remaining cultivars were not randomly distributed. The experiment was sown on 30 April.

The 2003 sowing rate trial was conducted within the single plot ‘I’ (Replicate 2) using a two factorial split plot type design with two cultivars (main plots) and four sowing rates (sub plots), although the layout does not strictly follow a standard split-plot design it is probably sufficiently randomised to have good confidence in the results. Cultivars were Prima and Borweta, sowing rates were 100, 125, 150, 175 kg ha^{-1}, sown on 30 April.

In 2004 rotation trial the cultivar Prima was grown across the three blocks in plots F, K and Q; the sowing rate was 168 kg ha^{-1} and the date of sowing 13 April. In 2005

Bordako was grown across the three blocks in plots E, J and O; seeding rate 164 kg ha^{-1}, sown on 27 April. In 2006 Bordako was grown over three blocks D, L and U; sowing rate 165.6 kg ha^{-1}, sown on 28 April. In 2007 Kompolit, SNS, Erantis, V6-1, Galant, and Viol, were grown on plots B, N and P. The respective seeding rates were 171, 188, 153, 176, 164 and 188 kg ha^{-1} (based on 1000 kernel weight) sown on 19 April.

Multiplication rate for sowing rate trials has been calculated from the data using the formula ((yield - sowing weight) / sowing weight) ha^{-1}.

4.4.3 Results

The results for investigations on lupins are given in Tables 7 to 9. In 2006 plot L had a large infestation of wild oats resulting from which no produce was harvested from this plot. Similarly in 2007 plot N was not harvested due weed infestation.

Table 7. Lupin cultivar experiments' results: yield t ha^{-1} at 80% dry matter.

Cultivar	2002	2003	2004	2005	2006	2007	**Cultivar Mean**
Barlenna		5.36					**5.36**
Bordako	3.17	4.25		2.97	2.09		**3.12**
Borweta		3.60					**3.60**
Erantis						0.79	**0.79**
Galant						2.13	**2.13**
Kompolit						2.29	**2.29**
Prima	2.87	2.95	1.24				**2.35**
SNS						2.89	**2.89**
V6-1						2.35	**2.35**
Viol						0.99	**0.99**
Year Mean	3.02	4.04	1.24	2.97	2.09	1.91	**2.59**

Table 8. Lupin cultivar experiments' results: moisture content at harvest.

Cultivar	2002	2003	2004	2005	2006	2007	**Cultivar Mean**
Barlenna		25.22					**25.22**
Bordako	40.27	31.86		23.40	19.60		**28.78**
Borweta		15.84					**15.84**
Erantis						34.56	**34.56**
Galant						39.09	**39.09**
Kompolit						41.90	**41.90**
Prima	21.92	17.76	20.30				**19.99**
SNS						33.35	**33.35**
V6-1						40.18	**40.18**
Viol						34.88	**34.88**
Year Mean	31.10	22.67	20.30	23.40	19.60	37.33	**31.38**

Table 9. Lupin sowing rate and cultivar experiments' results 2003: percent moisture content at harvest and yield, t ha^{-1}.

Cultivar	Sowing rate kg ha $^{-1}$	Moisture content (%)	Yield, t ha^{-1} @ 80% dry matter	Multiplication rate (wt)
Borweta	100	20.2	2.77	2670%
	125	18.8	3.31	2548%
	150	17.1	3.86	2473%
	175	16.8	4.33	2374%
	Mean	**18.2**	**3.57**	**2516%**
Prima	100	24.3	2.09	1990%
	125	21.6	2.50	1900%
	150	22.3	3.17	2013%
	175	19.1	3.28	1774%
	Mean	**21.8**	**2.76**	**1919%**

4.4.4 Discussion

It is difficult to draw conclusions from the cultivar trial as only Prima and Bordako were grown in more than two years. The only clear result is there are large variations in both yield and moisture content (MC), which is typical of agricultural crops.

The sowing rate trial showed a consistent and agronomically significant increase in yield and a decline in MC with increased sowing rate. The data give no indication of the causal relationship, e.g., if increased sowing rate reduced weed biomass / competition, or if it was a straightforward yield response to increased populations. The multiplication rate show a steady decrease for Borweta with increasing sowing rate but little significant change for Prima until the highest sowing rate. These data indicate there are potentially important sowing rate effects, particularly regarding MC. As MC is a critical issue for lupins due to late harvest then increased sowing rate could be an important production technique, however, there are far to few results on which to base firm conclusions, and further research is essential.

4.5 Oats (*Avena sativa*)

1.5 Introduction

Oats are considered to be good nutrient scavengers and have a useful place as a second cereal crop in organic arable rotation or even as the last crop before return to pasture. Oats are also reasonable to good competitors against weeds and suffer from less pests and diseases than wheat unless grown continually and are considered a reasonably straight forward crop to grow in organic systems.

1.6 Design

Winter oats (WO) have been the predominant crop with spring oats (SO) trialled in 2007. In 2002 and 2003 both cultivar and sowing rate experiments were undertaken. From 2004 onwards only more limited cultivar trials have been completed.

In 2002 Barra oats was sown on 2 November 2001, with a TGW of 32.2. The sowing rate trial (plot I) also used cv Barra with sowing rates of 145, 160, 174, 189, 203, 218 and 232 kg ha^{-1}.

The 2003 sowing rate trial again used cv Barra (TSW of 38.5 g) with sowing rates of 156, 173, 190, 208, 225, 242 and 259 kg ha^{-1} in plot K (Replicate 2) sown 18 February. The cultivar trial compared Barra, Freddy, Evita and a mixture, TGW were 38.5, 34.5, 33.0 and 30.8 g respectively, all sown at 539 seeds m^{-2} on the 20 March 2003 in plot F (Replicate 1) in a RCB design.

The 2004 cultivar trial compared Barra and Jalna, each grown in plots E, J and O, i.e., replication by plot, sown on 29 October 2003. The 2005 cultivar trial was again Barra and Jalna on plots B, N and P. The 2007 spring oat cultivar trial included Corrib, Evita, Freddy, Husky and Nord, with three Replicates per cultivar in plot M (Replicate 2) and two replicates in plot T (Replicate 3).

1.7 Results

Results for investigations on oats are given in Tables 10 and 11.

Table 10. Oat sowing rate experiments' results: using cv Barra, 2002 and 2003

Year	Sowing rate kg ha^{-1}	TWG	MC %	Yield t ha^{-1}	kg/hl	Multiplication rate (wt)
2002	145	33.8	19.5	7.39	58.9	4997%
	160	32.4	19.0	7.75	60.9	4744%
	174	33.6	18.6	7.86	61.4	4417%
	189	30.4	18.5	7.84	59.8	4048%
	203	33.2	18.9	7.84	61.0	3762%
	218	34.3	19.1	7.54	60.7	3359%
	232	32.0	18.3	7.60	59.9	3176%
2002 mean		**32.8**	**18.8**	**7.69**	**60.4**	**4072%**
2003	156	32.1	15.9	4.65	57.4	2915%
	173	32.8	15.6	4.57	59.2	2590%
	190	34.8	16.6	4.85	59.3	2303%
	208	34.5	16.6	4.85	58.2	2237%
	225	34.2	16.2	4.74	58.5	2057%
	242	32.1	16.4	4.82	58.6	1857%
	259	34.0	16.0	4.69	58.6	1757%
2003 mean		**33.5**	**16.2**	**4.74**	**58.5**	**2245%**
Overall mean		**33.1**	**17.5**	**6.21**	**59.5**	**3159%**

Table 11. Oat cultivar comparison experiments' results 2002 to 2007, Oak Park. WO = winter oats, SO = spring oats.

Year	Crop	Cultivar	M C %	*Yield t ha^{-1}	TGW (g)	kg/hl	Straw t ha^{-1}	Height (cm)
2002	WO	Barra	16.8	6.90	33.9			
2003	WO	Barra	16.4	2.41	33.6	54.8		77
		Freddy	15.5	2.63	36.4	54.5		70
		Evita	15.6	2.03	35.5	54.0		68
		Mixture	20.7	1.91	32.5	52.5		69
2004	WO	Barra	14.5	6.10				
		Jalna	14.0	7.11				
2005	WO	Barra	17.6	5.30	33.8	56.2	12.30	132
		Jalna	17.4	6.00	34.6	54.7	13.70	120
2006	WO	Barra	12.5	6.20	44.3	52.4	12.50	132
		Jalna	12.8	4.80	40.1	57.2	11.80	133
	WO	**Mean**	**15.8**	**4.67**	**36.08**	**54.5**	**12.58**	**100.1**
2007	SO	Corrib	9.5	4.46	42.6	49.1	4.05	97
		Evita	9.3	4.34	40.8	48.5	5.45	90
		Freddy	9.7	4.46	43.4	50.4	4.45	89
		Husky	9.2	4.55	40.1	50.1	4.85	87
		Nord	9.5	5.18	45.3	50.1	4.00	90
	SO	**Mean**	**9.4**	**4.6**	**42.44**	**49.6**	**4.56**	**91**
SO + WO		**Mean**	**12.6**	**4.64**	**39.26**	**52.05**	**8.57**	**95.6**

*80 % dry matter

1.8 Discussion

Increasing sowing rate has very little effect on any measure of yield or quality in either year apart from multiplication rate which declines considerably. The almost complete lack of yield variation is perhaps the most interesting aspect of this result, as this indicates that yield was almost totally determined by other factors, e.g., weather, and/or soil conditions. The declining multiplication rate is therefore almost entirely due to the change in sowing rate. This is considered unusual and in need of further research.

For the cultivar comparison trials there is obvious inter-year and inter-cultivar variation. The difference in MC between the WO and SO is very obvious, but as this is largely dependent on weather at harvest undue emphasis should not be placed on this one years results.

4.6 Potatoes (*Solanum tuberosum*)

1.9 Introduction

Potatoes are considered agronomically valuable as they are a weed 'cleaning crop' and in cereal dominated rotations they also have a major benefit as a pest and disease 'break crop'. The downside of potato production in organic systems is that they are susceptible to potato blight (*Phytophthora infestans*) for which there are limited management options, principally growing early potatoes, chitting and using the small number of resistant cultivars. Control options are almost totally dependent on copper and sulphur based fungicidal sprays which generally have moderate effectiveness, and foliage destruction if these fail. Potatoes are also a ‘hungry’ crop with high nutrient demands and so need to be placed close to the start of the rotation to make the most of the residual nitrogen from the pasture. However, due ‘wire worms’ (the larvae of click beetles *Agriotes* and *Athous* spp.) it is not recommended to grow potatoes directly after pasture. In the Oak Park organic rotation sheep manure at a rate of 50 tonne ha^{-1} was applied to potato plots prior to tillage to help ensure that there were sufficient nutrients for the potatoes. For more information on nutrient management and manure nutrient analysis see section 5.

1.10 Design

In 2002, a cultivar trial planted on 10 April 2002 compared Orla, Cara and T1823/10, grown in plots K, F and Q using a number of sub-plots.

In 2003 the cultivar trials compared Orla, Cara, as in 2002 and Setanta in place of T1823/10. Within the three plots E J and O sub-plots were used to determine the efficacy of copper for the control of blight.

From 2004 to 2007, Orla, Sante, and Setanta were the only cultivars grown. These cultivars were grown in all three plots due for potatoes as part of the rotation, i.e., they are properly replicated within the main rotation experiment but there are often sub-plots within the main plots. The multi-year arithmetic means, especially for Orla, Sante, and Setanta, are felt to be sufficiently robust as to give a reliable indication of the relative performance of the cultivars for locations with similar soils and climate as Oak Park.

The means in the three yield analysis tables differ slightly due to rounding.

1.11 Results

The results of investigations on potatoes are given in Tables 12 to 15.

Table 12. 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^{-1}
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 13. Potato cultivar experiments 2002 to 2007: results by cultivar including percentage breakdown of size grades by weight.

CV	< 40 cm	40-50 cm	45-60 cm	60-80 cm	> 80 cm	Discards	DM %	Yield t ha^{-1}
Cara	13%	14%	56%	15%		4%	22.8	26.2
Orla	7%	15%	57%	18%	0%	4%	20.8	31.4
Sante	6%	22%	58%	11%	0%	2%	23.4	35.4
Setanta	4%	12%	49%	31%	3%	2%	24.1	34.3
T1823/10	5%	5%	63%	27%			26.8	33.9
Mean	**7%**	**14%**	**57%**	**20%**	**1%**	**3%**	**23.6**	**32.2**

Table 14. 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^{-1}
2002	**Cara**	10%	9%	59%	22%			25.1	28.2
	Orla	14%	15%	61%	10%			21.3	22.9
	T1823/10	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**

Table 15. The effect of copper fungicide on size and yield of potato cultivars, organic trial Oak Park, 2003.

Cultivar	Copper	< 40 cm	40-50 cm	45-60 cm	60-80 cm	Discards	DM %	Yield t ha^{-1}
Cara	**+ Cu**	15%	17%	55%	10%	4%	20.5	24.1
Cara	**- Cu**	15%	17%	57%	7%	4%	21.1	23.7
Orla	**+ Cu**	13%	14%	61%	9%	3%	20.9	28.1
Orla	**- Cu**	13%	14%	61%	9%	3%	21.4	28.1
Setanta	**+ Cu**	9%	13%	58%	17%	3%	27.3	25.8
Setanta	**- Cu**	8%	12%	58%	20%	2%	27.7	27.7
Mean	**+ Cu**	**12%**	**15%**	**58%**	**12%**	**3%**	**22.9**	**26.0**
Mean	**- Cu**	**12%**	**14%**	**59%**	**12%**	**3%**	**23.4**	**26.5**

1.12 Discussion

There is a clear and agronomically large yield difference between years, although the yield difference among Orla, Sante and Setanta grown over a minimum of four years is much smaller than the yearly yield variation. There are also some clear effects of year on tuber sizes although what caused the effect cannot be ascertained from the data. Orla and Setanta have very good resistance to blight with that for Sante being somewhat lower. In the case of Orla and Sante tuber “bulking” occurs earlier than that for Setanta. This earlier bulking can in some seasons result in greater yields for the earlier maturing cultivars. The 2003 copper fungicide trial shows practically no difference between the treated and untreated crop. However, this is just one years results and fungal infestations vary considerably among years depending on the weather.

4.7 Wheat (*Triticum spp. inc. × Triticosecale*)

4.7.1 Introduction

Both winter and spring wheat as well as triticale have been grown in the Oak Park rotation, although winter wheat is the dominant crop.

Wheat is an important crop globally and is also a common crop in organic arable systems. However, compared with other cereals, particularly in Ireland, it is average in its ease of production because the wetter climate is conducive to a fungal pathogens, of which wheat is more susceptible than other cereals. However, practical organic farmer experience in Ireland indicates that fungi are not as significant an issue as non-organic crops indicate. This may be due to the prohibition of water soluble synthetic N fertilisers in organic production with a consequential reliance on biologically fixed N stored in soil organic matter. This means N is released more slowly to crops which helps prevent excessive N uptake which is associated with increased levels of pests and diseases. However, disease levels are still sufficient that alternatives such as triticale attract considerable interest. Wheat is also a heavy feeder yet it is considered to have a weaker root system than other cereal species which means that it is essential it is placed close to, or at the start, of the rotation, (as is done at Oak Park) to ensure sufficient yield. Wheat is also reasonably competitive with weeds, especially the longer strawed cultivars, which are also thought to have stronger root systems than shorter strawed cultivars (Long strawed cv are often ‘older’ having been bred at times when soluble N fertiliser use was a lot lower and more akin to current organic systems, while short strawed cv have been bred to maximise yield under high N fertilisation systems).

Triticale is a wheat and cereal rye hybrid so is not a ‘true’ wheat. However, in the Oak Park rotation it has been placed in the wheat rotation as there was no specific rotational place for it, as its other parent, rye, is not grown at all, and on commercial farms triticale is often grown as an alternative to wheat. Triticale is considered the easiest to grow of all the cereals, both organically and non-organically. Its hybrid nature means that it is very vigorous and is resistant to fungal pathogens and pests that are problematic on it’s parents, especially wheat. The hybrid vigour and rye parentage also means that it is a very tall and quick growing crop that out-competes weeds. Anecdotal observations of cereal trials at Oak Park and practical farm experience often find low to practically no weed biomass under triticale, medium levels under oats and wheat and barley often struggling in a significant weed understory.

4.7.2 Design

In 2002 winter wheat (WW) cultivar trials were conducted at Oak Park and Johnstown Castle. The Oak park work was conducted over two plots (E and J, Replicates 1 and 2) with each plot having internal four replicates. Seed rate was 450 seeds m^{-2} and within each plot an RCB design was used. The experiment at Johnstown had an RBC design with four replicates.

WW sowing rate trials were also conducted at Oak Park in 2002 in plot O using cv Soissons, with a TGW of 45 g, with sowing rates of 300, 350, 400, 450, 500 seed m^{-2} sown on 1 November 2001. A similar trial was sown at Johnstown Castle, Co. Wexford on 15 November 2001.

In 2003 triticale (TC) planted 14 February and spring wheat (SW) planted on 14 March cultivar trials were established on plot L in two separate RCB designs with four reps. Sowing rate was 450 seeds m^{-2}. TC cv were Taurus, Fidelio, Lupus, Bienvenue, Cylus, Versus, Deben and Exsept and SW cv were Alexandria, Baldus, Raffles and an unspecified proprietary organic mixture.

In 2004 the WW cultivars Claire and Deben were grown on plots B, N and P, sown 28 October 2003 at 192 plants m^{-2}. In 2005 WW cultivars Deben and Fidelio, were grown on plots G, M and T. 2006 cv Deben and Fidelio were grown again on plots A, H and R, except there is no data for Fidelio for plot R. In 2007 a much larger number of cultivars Alceste, Alchemy, Claire, Cordial, Cordial + Alceste mixture, Einstein, Glasgow, Gulliver, Hyperion, Lion, Robigus, Savannah, Soltice and Timber were compared using plots S (two reps per cv) and I (three reps per cv). As for the lupin experiments, the amount of methodological detail recorded decreases each year.

4.7.3 Results

The results of investigations are presented in Tables 16 to 20.

Table 16. The effect of seeding rate on yield, t ha^{-1}, of winter wheat, cv Soissons, organic rotation trial, Oak Park, 2003

Seeding rate seed m^{-2}	Seeding rate kg ha^{-1}	Moisture content %	Yield, t ha^{-1}, 80% DM	Multiplication rate (wt)
300	135	18.8	6.13	4441%
350	157.5	18.5	6.36	3938%
400	180	19.2	6.42	3467%
450	202.5	18.4	6.48	3100%
500	225	18.9	6.78	2913%
Mean		**18.8**	**6.43**	**3572%**

Table 17. The effect of seeding rate on yield, t ha^{-1}, of winter wheat, cv Soissons, organic rotation trial, Johnstown, 2003

Seeding rate seed m^{-2}	Seeding rate kg ha^{-1}	Moisture content %	Yield, t ha^{-1}, 80% DM	Multiplication rate (wt)
300	135	19.68	3.75	2678
350	157.5	19.70	3.79	2306
400	180	19.40	3.79	2006
450	202.5	19.48	4.11	1930
500	225	19.60	4.58	1936
Mean		**19.57**	**4.01**	**2171**

Table 18. Summary of winter wheat cultivar comparison trials, 2002 to 2007

Cultivar	Crop	Year	M C %	*Yield t ha^{-1}	TGW g	Height cm
Carlton	**winter wheat**	**2002**	15.40	5.35	32.5	75
Claire	**winter wheat**	**2002**	15.80	5.84	33.1	81
Deben	**winter wheat**	**2002**	15.70	6.27	35.1	85
Equinox	**winter wheat**	**2002**	16.90	4.56	26.5	83
Exsept	**winter wheat**	**2002**	17.20	8.76	49.6	94
Falstaff	**winter wheat**	**2002**	16.10	4.99	31.8	95
Fidelio	**winter wheat**	**2002**	28.80	6.65	53.0	108
Goodwood	**winter wheat**	**2002**	16.00	5.61	31.1	80
Ld 91-59-1	**winter wheat**	**2002**	15.80	4.80	33.6	72
Madrigal	**winter wheat**	**2002**	15.60	5.91	33.6	78
Marshall	**winter wheat**	**2002**	16.50	5.59	31.5	91
Milestone	**winter wheat**	**2002**	16.60	6.35	32.3	95
Savannah	**winter wheat**	**2002**	16.20	5.52	33.0	79
Tanker	**winter wheat**	**2002**	16.50	4.38	29.0	83
Trust	**winter wheat**	**2002**	15.70	5.95	35.5	87
Xi 19	**winter wheat**	**2002**	15.60	6.14	35.8	90
Access	**winter wheat**	**2003**	14.80	6.52	33.3	74
Deben	**winter-wheat**	**2003**	15.33	7.78	35.9	87
Dick	**winter wheat**	**2003**	14.80	6.85	N/a	78
Except	**winter wheat**	**2003**	13.80	5.93	N/a	80
Fidelio	**winter-wheat**	**2003**	24.55	8.45	52.0	108
Marshall	**winter wheat**	**2003**	14.50	7.45	36.9	82
Option	**winter wheat**	**2003**	14.40	6.84	35.8	79
Robigus	**winter wheat**	**2003**	14.50	8.50	35.8	79
Victor	**winter wheat**	**2003**	14.50	7.83	39.7	73
Welford	**winter wheat**	**2003**	14.80	7.36	31.2	74
Xi 19	**winter wheat**	**2003**	14.30	7.16	42.3	83
Claire	**winter wheat**	**2004**	14.80	8.37	46.3	N/a
Deben	**winter wheat**	**2004**	14.50	8.27	51.5	N/a
Deben	**winter wheat**	**2005**	16.70	6.40	42.1	98
Fidelio	**winter-wheat**	**2005**	16.50	6.70	47.4	108
Deben	**winter wheat**	**2006**	15.80	7.30	50.3	90
Fidelio	**winter-wheat**	**2006**	15.80	7.30	50.3	90
Alceste	**winter wheat**	**2007**	15.41	3.46	49.0	49
Alchemy	**winter wheat**	**2007**	16.08	6.73	53.6	54
Claire	**winter wheat**	**2007**	16.92	7.46	51.1	51
Cordial	**winter wheat**	**2007**	14.63	3.42	47.4	47
Cordial + Alceste	**winter wheat**	**2007**	15.93	5.10	54.8	55
Einstein	**winter wheat**	**2007**	15.64	6.12	52.9	53
Glasgow	**winter wheat**	**2007**	15.96	6.50	44.6	45
Gulliver	**winter wheat**	**2007**	16.26	4.88	50.5	51
Hyperion	**winter wheat**	**2007**	15.93	6.01	48.5	49
Lion	**winter wheat**	**2007**	15.74	7.09	48.5	49
Robigus	**winter wheat**	**2007**	15.93	5.26	47.4	47
Savannah	**winter wheat**	**2007**	16.82	6.51	49.9	50
Soltice	**winter wheat**	**2007**	16.91	6.20	49.3	49
Timber	**winter wheat**	**2007**	16.34	7.63	52.0	52
	Minimum		**13.8**	**3.42**	**26.5**	**45**
	Maximum		**28.8**	**8.76**	**54.8**	**108**
	Mean		**16.15**	**6.38**	**41.94**	**74.67**

*80 % dry matter

Table 19. Summary of spring wheat cultivar comparison trials, 2003.

Cultivar	Crop	Year	M C %	*Yield t ha^{-1}	TGW g	Height cm
Alexandria	**spring wheat**	**2003**	15.93	6.15	37.7	54
Baldus	**spring wheat**	**2003**	15.43	6.00	32.2	56
Mixture	**spring wheat**	**2003**	16.48	4.40	29.4	51
Raffels	**spring wheat**	**2003**	15.38	5.77	35.8	57
	Minimum		**15.38**	**4.4**	**29.4**	**51**
	Maximum		**16.48**	**6.15**	**37.7**	**57**
	Mean		**15.81**	**5.58**	**33.78**	**54.50**

*80 % dry matter

Table 20. Summary of triticale cultivar comparison trials, 2003

Cultivar	Crop	Year	M C %	*Yield t ha^{-1}	TGW g	Height cm
Bienvenue	**triticale**	**2003**	14.78	7.73	44.8	100
Cylus	**triticale**	**2003**	15.70	9.20	42.4	117
Taurus	**triticale**	**2002**	19.10	9.40	44.4	123
Taurus	**triticale**	**2003**	19.10	7.13	44.8	114
Lupus	**triticale**	**2003**	17.93	7.48	41.0	126
Versus	**triticale**	**2003**	16.50	8.19	45.0	115
	Minimum		**14.78**	**7.13**	**41**	**100**
	Maximum		**19.1**	**9.4**	**45**	**126**
	Mean		**17.19**	**8.19**	**43.73**	**115.83**

*80 % dry matter

4.7.4 Discussion

The seeding rate trial shows a consistent trend of increasing yield with increasing seeding rate and the multiplication rate has a similar but opposite trend while MC is unaffected. The design of the trial and the clear data trends mean the data can be considered reliable, however, it is only one experiment in one year at one site so the results cannot be generalised.

A considerable number of wheat and triticale cv were grown over the 2002 to 2007 period, however, most of them were only grown for one season, and the experimental designs have varied greatly. Therefore the data can only be considered to be a general indication of crop and cv performance, the most obvious of which is there are large variations in all measurements, which is typical of crop yield among years and cultivars for any particular field or farm, and why multi year and site experiments are essential for this type of empirical research.

4.8 Crop experiment general discussion and conclusions

As discussed in section 3.1, the analytical challenges mean that statistical measures of variation have not been calculated. There has also been a reduction in the amount and detail of work conducted over the years which also complicates interpretation of long term data.

5. Nutrient management: Data and analysis

5.1 Introduction

Good nutrient management is essential in organic systems, principally because of the prohibition on synthetic nitrogen (N) fertiliser, and restriction of phosphorous (P) and potassium (K) fertiliser to raw, or minimally processed, mined 'rock' fertiliser. N can only effectively be imported into organic rotations to replace losses via legumes. Rock P and K fertilisers are uncommon and therefore often considerably more expensive and/or difficult to obtain than the processed fertilisers that are made from them. This means that nutrients have had much higher value within organic than non-organic systems, and therefore, considerable effort is put into cycling nutrients around the farm and minimising losses, e.g., N leaching, to reduce the need to purchase fertilisers and also minimise environmental pollution.

There is a lingering debate in the organic movement about the need to import nutrients onto farms and whether they should be 'self-sufficient' for nutrients. The analysis presented here is based on the 'balanced nutrient budget' approach whereby all nutrients removed from a farm, i.e., in produce or lost e.g., via leaching, must be replaced if the farm is not to deplete (mine) soil nutrient levels. This is fundamentally the same approach used in non-organic agriculture where nutrients are replaced according to soil tests. The key difference is that organic aims to 'feed the soil to feed the crop' while non-organic will target soluble fertiliser application to crops with known ability to take up such nutrients to produce yield increases.

Stockless organic rotations have often been criticised within the organic movement for their inability to transfer nutrients around the rotation due to the lack of animal manure, which has been perceived to result in nutrient depletion. However, mixed or livestock only organic farming systems, while having the benefit of manure based intra-farm nutrient transfer, have exactly the same nutrient depletion issues as stockless or any other production systems that sells produce off farm, i.e., that nutrients are removed in the produce, whether it be livestock or crops, which must be replaced. The Oak Park organic rotation trial should therefore be well placed to bring valuable scientific data to this debate and demonstrate what is required for effective nutrient management in a stockless organic system.

5.2 Nutrient management data / results

In 2003 and 2004 a nutrient analysis of the sheep manure was taken, the averaged results of which are presented in Table 21. Manure was applied annually at a rate of 50 tonne ha^{-1} to the potato crop prior to tillage as it was considered that it would be this crop that would make the greatest benefit of the increased nutrient levels and it was also a suitable point into the cropping phase of the rotation so that following crops would also benefit from the additional nutrients.

Table 21. The mean nutrient content of sheep manure and amount applied per hectare from analysis of 2003 and 2004 samples.

Nutrient	N %	P %	K %	Mg %	D M %
Percent	0.71	0.24	1.66	0.20	21.98
kg @ 50 t ha^{-1}	352	116	827	100	N/a

Soil analysis has been undertaken in all years, however, not all tests have always been completed leaving gaps in the data, as shown in Table 22. Final means are presented, by both year and crop / rotational sequence (Table 22 and Table 23), which despite the lack of some tests in some years, is based on data from 21 plots over five years so it can be considered to be accurate and reliable.

Table 22. Soil nutrient analysis by year, mg kg^{-1}

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	**6.87**	**5.71**	**11.82**	**128**	**199**	**3.99**	**3.71**	**390**	**12.76**

Table 23. Soil nutrient analysis by crop sorted by rotational position (year) mg kg^{-1}

Crop	Year	pH	OM%	P	K	Mg	Cu	Zn	Mn	S
Grass	**1**	6.76	5.50	9.90	134	198	3.73	3.13	433	14.00
	2	6.79	5.72	12.05	141	198	3.80	4.16	420	12.33
Wheat	**3**	6.90	5.89	9.38	117	204	3.44	3.37	402	13.00
Potatoes	**4**	6.88	5.78	11.04	113	194	4.53	3.50	379	13.67
Oats	**5**	7.02	5.76	15.63	138	203	4.31	3.64	363	13.00
Lupins	**6**	6.83	5.60	12.37	132	205	4.41	4.02	383	12.33
Barley	**7**	6.88	5.68	12.40	119	192	3.76	4.22	359	11.00
Mean		**6.87**	**5.70**	**11.82**	**128**	**199**	**4.00**	**3.72**	**391**	**12.76**

NB. The small differences in the means presented in Table 22 and Table 23 are due to rounding.

5.3 Discussion

Effective nutrient management is a key practical issue for organic farmers and this was reflected in the particular interest in N during the design and implementation of the rotation.

In an experimental situation such as the Oak Park organic rotation, it is considered valuable to have detailed measurement and analysis, on an annual basis, of all nutrient inputs and off takes, ideally on a plot by plot basis, i.e., an analysis of all batches of manure and an analysis of the nutrient content of the crop from each experimental plot should be taken or a bulked sample from the three replicates at a minimum. This data, when combined with crop yield and amount of manure applied would allow an accurate calculation of the nutrient balances of the whole rotation system on a year-by-year / plot-by-plot basis. This should then be reconciled with the soil nutrient levels to give an indication of losses or gains from the system due to nutrient movement other than in manure or produce, e.g., sulphur deposition or P loss.

For most of the soil properties, there are no clear trends in the data and that year-to-year and crop-to-crop variations are as large as variation over longer intervals, which indicates that much of the variation is probably random or at least not significant. The lack of clear trends in the data over time is a strong indication that for most nutrients the system is generally in balance, i.e., off takes (in crops) and replacements (in sheep manure) have been approximately equal.

The change to a red-clover and composting system has the potential to alter this situation. While the red clover and composting system probably imports enough N via fixation to meet crop needs, the importation of P, K and other soil nutrients has effectively dropped to zero with the end of manure importation so there is now a need to import these in mineral form to replace those removed in produce when soil nutrient levels drop to levels where a crop response would be expected.

5.3.1 Use of imported sheep manure and alternatives

The nutrient management strategy used for 2002 to 2006 was based on white clover pastures and importing 50 tonne ha year^{-1} of sheep manure from the Teagasc farm at Knockbeg and applying it to the potatoes plots prior to tillage. In 2006 the sheep farm closed and therefore the manure supply stopped. Based on expert organic advice from Ireland and the UK, the white clover swards were changed to red clover (*Trifolium pratense*) to boost nitrogen fixation and DM production and a system of composting the harvested fresh pasture and cereal straw was initiated with the aim of using the compost as a replacement for the sheep manure.

The use of imported sheep manure as a key part of the nutrient management strategy as been questioned as to its appropriateness by members of the organic community and others. Importing nutrients onto a farm is definitely not prohibited by organic standards or principles. There is a general aim that imported material should ideally be of a biological (organic) form rather than mineral (inorganic) forms where possible. Further, the material should ideally originate from a certified organic source where possible, but where un-certified material is used then it should be aerobically (hot) composted prior to use, for the principle aim of minimising the risk of bringing in veterinary medicines and other biocides, e.g., anthelmintics, that are prohibited or restricted in organic systems. It is unclear if the sheep manure had been truly aerobically composted to a final humic condition. The description is that the sheep manure was brought in January to February each year, stored under cover and turned two to three times before spreading in March on the potato ground before ploughing under. Unless the turning process and subsequent heating was carefully controlled it is unlikely that full and complete aerobic composting would of occurred and that the result is more likely to be only partially composted and retaining many or most of the original attributes of the starting material. In this context such material is considered to be un-composted, i.e., it has not been reduced to principally humus (recalcitrant organic matter). The use of manure from an non-organic certified source without full aerobic composting would be a breach of certification rules. While this situation was not ideal, from the perspective of a research facility that is not selling its produce as organic, it could be argued that this is not a major deviation from the perspective of organic principles as opposed to certification rules. However, it is considered a very significant issue at a practical level in terms of the rotation mirroring real farm practice. This is because there are very few organic farms that would be able to find such large supplies of off-farm manure or other biological fertiliser, and if they could they would almost certainly have to fully aerobically compost it before use. To put it another way, in a straight comparison between the use of the un-composted sheep manure compared with sole reliance on legumes for N and rock fertilisers for P and K, the sheep manure based system would have a significant advantage. This aspect of the rotation was therefore considerably at odds with commercial practice and from the perspective of a demonstration facility it was a significant weakness. The loss of the sheep manure source has therefore forced the experiment to face the same practical difficulties faced by real organic farmers and is therefore a welcome, if challenging, change.

5.3.2 Nitrogen management

As noted earlier, at the outset of the experiment, N was viewed as a key limiting factor in the productivity of organic systems and therefore considerable emphasis was placed on ensuring its sufficient supply. The lack of analysis of N in the system is a deficiency that was and remains difficult to rectify. It is acknowledged that there is no agreed method of measuring soil N despite the vast amount of time and resources dedicated to the issue worldwide. This is partly because N exists in multiple forms in soil, many of which rapidly change from one form to another, often under the control of biological processes (Figure 2). These forms include a range of mineral (inorganic) forms as well as biological forms (organic matter) both living and dead.

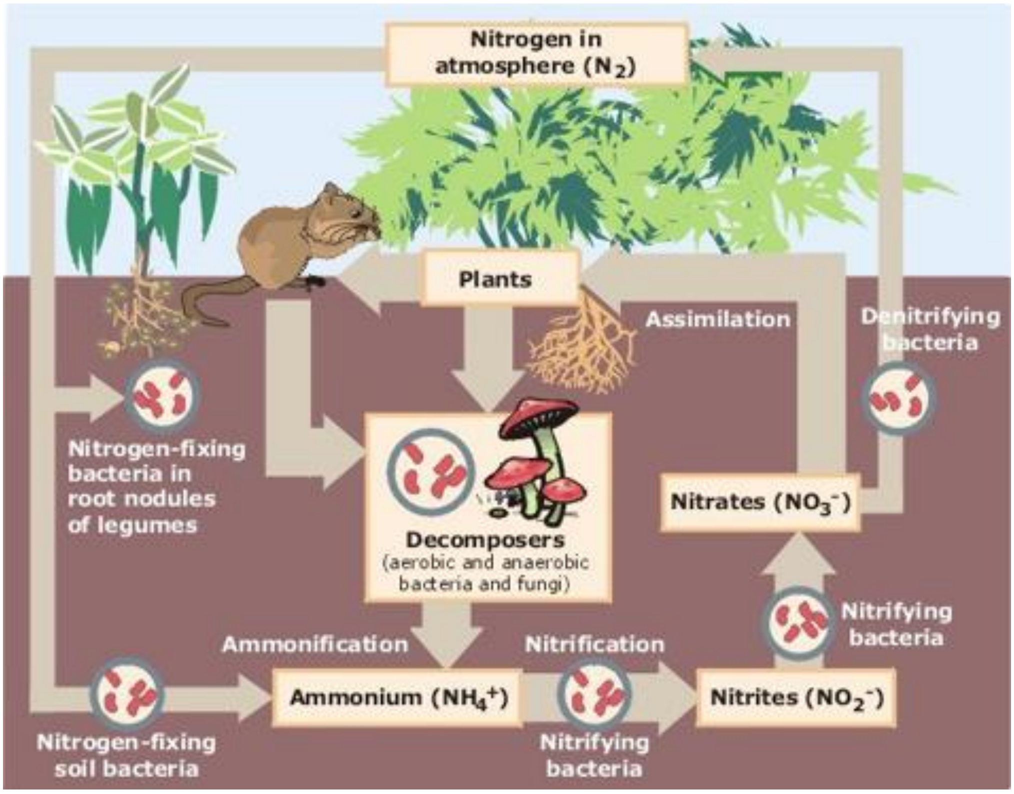

Figure 2. Simple nitrogen cycle.

The levels in the soil of any particular form of N, especially nitrates (which is the predominant form plants assimilate along with ammonium), can fluctuate considerably over short time scales. In practical farming terms this is referred to as the nitrogen flush associated with soil tillage, even minimal disturbance methods such as hoeing. Therefore, determining which forms of N to measure is dependent on the question(s) being asked. With much of the nitrogen destined for crop uptake in organic systems being held in the soil in the form of organic matter, compared with the application of soluble mineral forms in non-organic systems, N analysis approaches optimised for non-organic systems may not be ideal for measuring N in organic systems.

Expert advice from within Teagasc on the issue of measuring N in the organic rotation experiment was briefly taken from Drs. Noel Culleton, Brian Coulter and James Humphreys. The advice given clearly indicated that the resolution of the most appropriate method of monitoring N in the organic rotation requires considerable, possibly extensive advice and consideration, and should not therefore be rushed.

5.3.2.1 The role of leguminous cash crops

As part of the belief that N would be a key factor limiting crop yields it was decided that a leguminous crop should be grown midway through the rotation to supplement the N fixed by the clover in the pasture phase and from the sheep manure. The other key reason for interest in a leguminous crop is that they generally produce a high protein seed which could be valuable as livestock feed.

Internationally there is still considerable scientific debate over the amount of residual nitrogen from leguminous cash crops. This is not helped by the lack of an accurate or even effective means of measuring nitrogen fixation by legumes or other species and the difficulties discussed above regarding measuring soil N. The general concern about the levels of residual N after a legume crop is because although cash crop legumes often fix considerable amounts of N, much this is removed in the harvested seed as these are high in protein which in turn is ‘high’ in N (compared with carbohydrates and lipids). Figures from UK consultants Abacus Organic indicate that between 110 - 280 kg N ha^{-1} can be fixed by lupins while 80 to 150 kg N ha^{-1} remains after harvest. However, these are composite figures from the international literature so could be completely unrepresentative of Irish conditions. Without an analysis of N having been completed for the organic rotation experiment it is not possible to determine the contribution lupins have made to soil N.

There is an additional issue regarding lupins; that of the value of legume seeds for organic livestock feed. The issues surrounding feed are discussed in full in section 6, but briefly the assumption that high protein supplement feeds are required in organic systems because they are required in non-organic systems my not be valid due to the higher protein levels of clover based pastures and silage. If this assumption is wrong one of the reasons for growing such crops is also incorrect. As discussed in section 4.4 lupins are a difficult crop to grow, due to late harvest and/or low weed competitiveness. If the assumptions that a legume cash crop is required to produce a high protein livestock feed and to boost soil N levels are not correct, then there is no point growing such an agronomically challenging crop, and easier to grow, and / or more profitable alternatives should be grown instead.

5.3.3 New stockless nutrient management systems

The organic rotation experiment is considered well placed to study new approaches to stockless system nutrient management. The newly adopted approach of composting the red clover pasture with cereal straw and applying this to the potato crop is probably widely viewed in the organic movement as the best option for such a system. This view is probably as much based on standard / traditional organic practice than research or theoretical analysis. The belief in the benefits of composting go back as far as the origins of organics, however, much of the early research compared the application of compost with no application of organic matter at all. In more recent decades other whole farm system approaches such as no-till and cover-cropping, coupled with a very small amount of direct research comparing compost with crop residues indicates that applying fresh organic matter to soils is better for soil 'health' and maximising retention of N and C in the soil than compost. It is suggested that a system level comparison of composting compared with direct transfer of pasture plus straw to cropping land would be world leading research, at practical, empirical and theoretical levels.

5.4 Nutrient management conclusions

The gaps in the nutrient management data should be addressed in future analyses. Although the importation of sheep manure has now ceased, considerable though needs to be given to whether the replacement pasture and straw composting system is the best way forward and if research into alternatives is worthwhile. Alternative sources of P, K and other nutrients which are no longer being imported due to the end of the sheep manure supply also need to be determined and instigated into the nutrient management system. Finally, greater clarity of the actual organic stock feed requirements is required (see section 6) which will then determine if growing a leguminous cash crop is justified.

6. Organic concentrate feeds: What is really required?

An aspect of the context in which the Oak Park organic rotation experiment was established, was the relatively small size of the organic arable sector compared with the livestock sector and the resulting shortage of Irish organic cereals for livestock feed. This issue is probably even more pressing in 2008 than 2000 as the derogations for using non-organic feed have finished, resulting in demand for organic cereals growing even faster than supply and therefore pushing up prices, all at a time when there have been very large increases in non-organic cereal prices as well. However, the analysis and understanding of the problem and possible solutions appears to mirror the non-organic feed situation, rather than being based on a thorough understanding of the organic livestock feed situation and organic systems and philosophy. For example, in non-organic systems pasture is typically a grass monoculture and supplementary feed focuses on the provision of high protein feeds to balance the fodder value of the silage. However, to function effectively, organic livestock farms must have clover based pastures for nitrogen fixation, as this is the only effective (financially and biologically) means of importing nitrogen into the farm system. Clover based pastures are generally higher in protein than pure grass swards. Red clover silage in particular is widely considered to have high levels of protein, and that low sugar content is more of an issue which requires the use of molasses to ensure good fermentation. Therefore organic livestock may not need the same level of protein feed supplements required in non-organic systems, rather they may need higher energy supplements to compliment the high protein silage. In short, extrapolating, or just transferring, the non-organic situation to an organic situation can result in incorrect, or non-existent, issue being addressed.

It is therefore suggested that is essential that the context for the organic rotation experiment is based on a thorough analysis of what organic livestock systems' feed requirements actually are, rather than what they are assumed to be based on the non-organic situation. Such an analysis would need to include a survey of commercial organic farms, both of their actual feeding systems including the feed itself as well as livestock requirements and the farmers attitudes / farming objectives. This would also be a valid and highly beneficial scientific and informative exercise in its own right.

The use of lupins (or any leguminous crop) in the organic rotation is a case in point. One of their key reasons for being included in the rotation was the production of a high protein seed crop for use in organic livestock feed. However, they are a difficult crop to grow, as they are poor weed competitors, and they are late to mature, which increases the risk of harvest failure. If organic livestock supplemental feed needs to be high energy rather than high protein, then the point of growing lupins or other legumes is diminished, especially in light of their production difficulties. See section 5.3.2.1 for more discussions on the role of legume / lupin cash crops.

7. Extension, farmer buy-in and oversight

The Oak Park organic rotation is at heart a 'practical' agronomic demonstration experiment aimed at informing and assisting farmers to understand, convert to, and optimise, their own organic farm systems, i.e., it is aimed at 'real world' farming issues as opposed to more fundamental research. In addition it must produce reliable and ideally detailed data to underpin the advice given to farmers and ensure the research meets acceptable scientific standards.

It is therefore not sufficient to just generate research results. Successfully transferring research results to the farmers and getting them to implement new practices is therefore considered to be as important as the research itself, i.e., such research is of marginal value unless it is successfully translated into permanent changes to current organic farmers' working practices and the conversion of non-organic farms and farmers to organics. This clearly requires as structured a management and planning system as does the research work itself, i.e., to ensure that results are collated in a timely fashion, suitably formatted for farmers and related persons, e.g., advisers, presented at a range of suitable fora and included in general advisory information. Examples of such activities by overseas organic demonstration farms and experiments include websites, regular newsletters of current activities and crops, annual reports with updated conclusions and recommendations, presentations at farm walks and field days and coverage by national farming media.

A key problem of agricultural research, extension and advice systems over much of their existence has been a failure to measure the success rate of information implementation, i.e., just providing farmers with information is only half of the job, ensuring that farmers fully understand the information presented to them and ensuring and measuring its uptake and implementation is just as critical as the research and giving farmers the results. This is clearly moving out of agronomic research into social science, however, there is little point expending considerable resources on practically focused research if it is never taken up by farmers. In the last half century, and particularly over the last decade or two, there has been a fundamental shift, even paradigm change, in agricultural extension and the relationship between 'science' its 'users' and the general public e.g., see (Marks, 1983; Wolpert, 1992; Altieri, 1995; Dunbar, 1995; Dawkins, 1998; Barrow, 1999). Within this context, best-practice practical agricultural science is moving to a much more participatory model whereby farmers, advisers and researchers are increasingly working in a collaborative manner rather than the hierarchal 'top down' structures typical of fifty or even thirty years ago. While there is often reluctance on the part of all parties to use a participatory model, and it often requires more 'up front' work, e.g., in discussions and negotiations, the result is much more targeted research, and greater, more rapid and more successful uptake of research by farmers (Jordan *et al.*, 2006). It is therefore suggested that farmers, both organic and those interested in converting, should be integrated into the Oak Park organic rotation research management cycle. This is not a new idea for Teagasc or even its predecessor An Foras Talúntais which had 'Representative Advisory Committees' to ensure that the research programmes would focus on the real problems of the industry. It is therefore recommended that some form of steering group / advisory committee / or similar body be setup to provide guidance for the research and experiment as a whole.

The benefits of such an arrangement are considered to be many, with benefits to all involved. The group could be a bridge to ensure that the Irish organic movement 'buys in' to the experiment and its outputs, i.e., it would give the experiment credibility in the eyes of the organic movement as it would be overseen by leading organic farmers. Teagasc would gain valuable input into the overall aims and objectives of the experiment and also potentially considerable practical advice based on decades of real farming experience. For the farmers it would boost their standing in both the Irish organic and wider agricultural communities and also act as a form of top level organic agricultural discussion group, which would be of direct benefit to the farmers and indirect benefit to the commercial organic sector, especially if it is cross sectoral (livestock, arable and horticulture should be represented). The farmers would also have first access to the information with the potential to try it out on their own farms - which will produce further information, especially if done scientifically. With the whole experiment strengthened it would also improve its standing and credibility in the non-organic sector of Irish agriculture. This list is not considered extensive by any means.

While such a group could be an effective bridge, it is far from being a complete extension structure to translate research findings to changes in farm practices. It would therefore still be essential for an integrated extension system be created for the experiment which makes full use of the newly established dedicated organic advisory team and the Teagasc advisory system as a whole.

There is also a the issue of scientific validity. It is considered essential that research undertaken as part of the organic rotation experiment must be of sufficient standard to be published in peer reviewed journals. This is not to say that all the science has to be cutting edge or highly novel, but it must be carried out to a sufficient level of quality that other scientists would agree on its rigour. If it fails to reach this standard then is it also not of sufficient standard on which to base advice for farmers. This is also essential for the wider issue of educating farmers as to what constitutes sufficient evidence in scientific terms, i.e., if information is put out that fails scientific quality standards it is suggested that it can only be detrimental to improving the understanding and take-up of science and research information by the farming community.

8. Certification

The Oak Park organic rotation experiment has never been certified, the original reasons for this are now unknown, although it was originally planned to manage the system according to IOFGA standards. This situation has 'raised questions' both within and outside of the organic community about the practices in the experiment.

However, organic certification is principally a marketing device to provide a form of guarantee to consumers who are not directly purchasing from producers, that the goods they are purchasing meet agreed definitions of 'organic'. Over time, standards have also become the practical definition of what is organic and what is not. However, it is perfectly legitimate to farm organically without being certified, the only restriction is that in countries with relevant legislation it is unlawful to claim produce is organic when selling it unless it is certified. Globally many small producers are in this situation, and there has been a shift internationally in the last five years away from equating being organic with being certified to equating being organic as following organic principles and practices, with certification increasingly viewed as a lower level issue and even a 'necessary evil'.

Therefore, there are a number of pros and cons regarding certification of organic research experiments. Certification provides a clear independent statement that the practices meet agreed practical definitions of organic production, i.e., it provides a level of credibility. However, certification is entirely geared towards commercial farmers and growers wishing to provide distant customers with an independent guarantee that their produce is truly organic. Certification is wholly un-geared towards the assessment of experiments and research facilities, especially those that are not selling any produce. Certification can become a significant impediment for researchers wishing to try new approaches, ideas, products etc. that are within organic principles but fall outside or are not covered by certification, i.e., where principles and certification are at odds. There are also many costs, financial, managerial and practical to certification, e.g., certification fees, management time spent on 'paper work', issues regarding part certification of a research facility and contamination from other activities / equipment used at the facility. Such costs in a pure research setting are most unlikely to be recovered as no produce is sold, so therefore only increase total costs without any significant benefits.

It is therefore suggested that certification is essential if a research facility is selling produce to the public with any kind of information as to its origins and especially if claims as to its organic status are made. Certification is considered valuable but not essential where the research facility is being predominantly run as a demonstration unit of commercial farm practices but where produce is not sold or sold as non-organic and without any indications as to its origins. Where the facility is primarily a research unit, especially if the research is exploring the boundaries of organic systems or conflicts between certification rules and organic principles / aims, and produce is not sold at all or sold as non-organic without reference to its origins, then certification is not essential and may well be a hindrance. In such a situation an organic farmer / movement advisory group is considered a valuable means of providing credibility of the 'organicness' of the research, i.e., via 'peer review'.

9. Achievement, and value, of original objectives

9.1 Introduction

The objectives stated at the outset of the Oak Park organic rotation experiment and presented in the introduction of this document were:

- To develop and maintain a field facility for research on organic production of arable crops, with particular emphasis on animal feed crops;

- To establish base-line site data against which any long-term changes due to organic production could be evaluated;
- To establish good agronomy practices for the cereal, legume and grass crops included in the rotation;
- To collect input-output data to allow the production costs of organic crops to be established;
- To research key agronomic factors by conducting component trials within the existing rotation.

From a management perspective, objectives are a tool for setting priorities and determining if they have been achieved. This means that objectives must be specific, concrete and measurable if they are to be an effective management device. This report, coming at the point of the completion of the first full crop rotation, is considered an opportune time at which to review if these objectives have been met and their value in achieving the original experiments broad aim of 'To improve the yield and quality of organic arable crops in Ireland'. This analysis can then be used to modify the objectives if necessary to ensure the continuing relevance of the experiment in the future.

9.2 Analysis and discussion

- To develop and maintain a field facility for research on organic production of arable crops, with particular emphasis on animal feed crops.

Achieved: This objective is considered to have been clearly achieved, as discussed in detail section 3. The research area has been designed and maintained according to organic principles and in most cases, with the exception of the un-composted, imported sheep manure, has been mostly managed according to local and international organic certification standards as much as possible for a research experiment. The provision of ecologically managed field margins and previous history under silage pasture mean that the whole area is representative of practicing organic farms.

The crops grown are mostly cereals that can be used for animal feed which the potatoes could also be used for, so this part of the objective has also been met.

Value: The value of this objective is considered very high. There is increasing evidence globally that changes to farm practices at a system level, such as organic, no-till and cover cropping, have significant system levels effects, particularly on soil properties and ecology, that can take several to many years for the effects of changes to stabilise and therefore can only be effectively studied at the system level over multiple years. Further, to be viable, reductionist research, e.g., cultivar comparison trials, must be conducted on land that has been under the relevant management system for sufficient time that it is truly representative of that system. The organic rotation experiment clearly provides that resource for organic systems in Ireland. Further, the time taken to establish such resources are considerable, so few long term agronomic trials of any kind are established and maintained over decades. These 'sunk costs' coupled with the potential future value of the site as a location to conduct truly representative organic research, both system level through to reductionist, is why its value is considered to be very high.

Organic arable crops, both for human and livestock consumption, continue to be in short, or are likely to be in even shorter, supply than when the rotation was established. This could be taken to be a failure of the experiment as it has not 'solved' one of its key aims, however, it is suggested that it is very optimistic for a single long term experiment to 'solve' a national agricultural issue that has multiple causes beyond the agronomy addressed by the trial. It is therefore considered that the value of focusing the rotation experiment on arable, tillage and horticultural crops for livestock and human consumption is also high. (There is also dedicated organic livestock research work being undertaken at other Teagasc research centres (beef - Johnstown Castle, dairy - Athenry) which addresses these systems and complements the Oak Park organic rotation experiment.)

- To establish base-line site data against which any long-term changes due to organic production could be evaluated.

Achieved: This objective has not been achieved, principally due to the component research compromising the long term monitoring of the rotation.

This objective is, however, somewhat unclear and probably unachievable considering the experimental design. To be reliable, base line agronomic and/or ecological data ideally needs to be collected over at least five years. The largest changes to the system on conversion to organic are considered likely to occur over the first three years and to have 'settled down' by year five with later changes relatively small. What duration is meant by 'long-term' in the objective is not clear, but at a minimum it would have to be five years and potentially up to fifteen years or longer. Further, if there was a desire to monitor the change from non-organic to organic, it would be most informative to monitor this where changes in farming practices are minimal, e.g., convert a non-organic mixed cropping or pure arable system to an organic mixed or stockless arable system, rather than long term non-organic pasture to stockless organic arable. In the latter there are changes to both farm type and farm system, so it is impossible to determine whether resulting effects are due to change in farm type, system or an interaction of both. In short, to meet this objective, the conversion of a single farm type from non-organic to organic would have to be monitored over approximately fifteen years - five under non-organic, five under conversion, five under well established organic. This is clearly beyond what was planned for the organic rotation.

Value: Longitudinal studies of the agro-ecological changes caused by conversion to organic, or any other agricultural system, are general considered to be highly valuable as they generate results that cannot be created by other means and the long durations means the data can be considered highly reliable. However, such results tend to have more value for the fundamental scientific analysis and understanding of such systems than immediate practical benefits for farmers, e.g., the effects on soil properties, as opposed to choosing the best weeding machine. However, agricultural science is mostly empirical, so research that makes a noteworthy contribution to a more fundamental / theoretical understanding of agriculture is to be welcomed, and in the longer term (decades) this should create considerable (indirect) benefits for farmers. It is therefore difficult to determine an unambiguous value for this kind of work, however, measurement of agronomic practices and effects are considered essential for long term trials such as the organic rotation at Oak Park so it is vital that they continue and are expanded.

- To establish good agronomy practices for the cereal, legume and grass crops included in the rotation.

Achieved: This objective has on balance been partially achieved. A range of crops have clearly been successfully grown over the full seven years of the rotation and there have been no system level failures, e.g., weeds getting 'out of control' nor does it look like any will occur in the foreseeable future. However, the production practices could be somewhat harshly described as 'neo-organic' in that the production system are run reasonably similarly as non-organic production, and some of the deeper / more radical aspects of organic philosophy have been left to the side. For example, the tillage system has been based on shallow ploughing before each crop which is typical of non-organic practice, while organic principles aim towards minimum, non-inversion tillage. However, it is unusual for farmers converting to organic to try to fully implement organic aims all at once and they typically take a 'walk before running' attitude of getting the basics right before tackling the more challenging aims. Also farmers wishing to convert to organic for financial rather than philosophical reasons are considered highly likely to take a neo-organic approach so the rotation experiment will be directly applicable to them.

However, some of the agronomic practices are starting to look a bit dated, or at least there is little that could be described at cutting edge. In the decade since the idea of the organic rotation experiment was established a wide range of technological and scientific achievements have occurred that should be researched or integrated into the rotation. Weed management is a particular example, with computer vision or RTK GPS (real time kinematic global positioning system) guided interrow hoes now in use which are revolutionising physical weed control/management. The use of imported, un-composted sheep manure could also be questioned if it is a 'realistic organic practice'. Therefore, there is a need for current best organic practice to be implemented and also for more cutting edge approaches to be trialled.

Overall it is suggested that the organic rotation experiment has achieved 'reasonable agronomy practices' that would be of considerable benefit and interest for a non-organic farmer looking to convert, however, it lacks the 'cutting edge' and 'best practice' agronomy that would cause well established organic farmers to consider the experiment to be inspirational and producing the kind of information that would allow them to further refine and improve their farm systems.

Value: The aim of this objective is to provide practical agronomic information that will allow farmers to convert to, and optimise their, organic arable systems and as such is considered of the highest value. It is suggested that most competent to progressive organic farmers should have their fundamental and general production practices well managed, but they are likely to lack the latest information and cutting edge ideas that will help fully optimise their systems. It is suggested that it is essential for research organisations, such as Teagasc, to be continually assessing the latest technologies and researching and developing novel solutions and ideas for farmers to implement. This is also considered an area where Teagasc can quickly gain considerable recognition and support from organic farmers. If the advice coming from the experiment and Teagasc is considered to be of top quality for existing organic farmers it is considered that it will be of equal or even greater benefit to those looking to convert to organics by clearly showing what is possible and how to achieve it.

- To collect input-output data to allow the production costs of organic crops to be established.

Achieved: This objective has not been achieved, primarily due to the data required not being collected and/or produced.

In hindsight, this is a difficult objective to fully achieve, as production costs are highly variable and depend on farm system, e.g., a farmer on 10 ha with limited mechanisation will have radically different production costs to a farmer on 200 ha fully mechanised with the latest technology. It is also very hard to accurately scale up the production costs of field scale trials to 'real' farm costs as the systems are very different.

Perhaps the most valuable information that could be provided is crop yield data. Often the major decider of profitability is crop yield and price, which for agricultural products the latter has always been volatile (2007 being a clear example of this). If farmers have reliable yield data they can then use this information coupled with current and predicted prices in financial calculations based on their own production costs to give a customised prediction of crop gross margins and potential profit/loss. However, as repeatedly pointed out in this report, reliable crop yield data can only be generated by consistent multi-year and site trials which the Oak Park organic rotation cannot supply as it is a single location.

Value: The 'face value' of this objective is considered high, however, it is considered difficult for an experiment such as the Oak Park organic rotation to be able to achieve it. It is suggested that a survey and analysis of commercial farmers financial information would be a more effective and reliable way of determining reliable input and output costs for organic production. For yield data, only cultivar comparison trials following best practices can be considered to be truly reliable for determining crop yields. The DAFF's organic cultivar comparison trails should soon be yielding exactly this kind of information and therefore filling this critical information gap.

- To research key agronomic factors by conducting component trials within the existing rotation.

Achieved: The meaning of this objective is considered somewhat unclear as agronomic factors is such a wide term. However, overall, the component research has generated a range of data that farmers can use to inform the decision making.

Value: For any farming system, there are components / issues / agronomic factors that are easy / simple to manage and others that are highly challenging. Research that focused on identifying the key components in organic cropping systems that are the major obstacles to improving farm productivity / profitability, and finding / testing practical solutions that farmers could implement on their own farms is considered to be of high value because it is likely to gain wide approval and uptake by farmers which will assist in the expansion of organic farm area. Therefore, were the objective reworded to reflect this the value would be considered to be high, to very high.

9.3 Conclusions

A popular management 'tool' for designing clear objectives is the SMART acronym which stands for Specific, Measurable, Achievable, Relevant and Timely. The objectives for the Oak Park organic rotation experiment do not fully meet these requirements, however, considering the time when the objectives were set down, this could be considered a rather harsh test. It is therefore, recommended that the objectives need to undergo revision along with the overall aim and management systems to bring them up to date.

10. General discussion and conclusions

To date the Oak Park organic rotation experiment has been a reasonable success with considerable future opportunity. The site selection, preparation and management is considered among the best for an organic research area at a research institution that is otherwise dedicated to non-organic agriculture. However, this excellent foundation has not always been used to its fullest extent in terms of the component research. Despite this, the status of the site and the whole rotation experiment mean that the potential for future whole system and reductionist research into organic arable systems is substantial. However, extensive analysis, thought, advice and consultation should be undertaken to fully realise this future potential. For example, completely redesigning the rotation would destroy the value of having just completed one full rotation of the crops, i.e., each of the crops have been proceeded by the correct previous sequence of crops and pasture. At the same time it is important not to continue to do something of limited value, e.g., continue with lupins, because making a change, e.g., growing a non-leguminous crop, would destroy the sunk costs, even though there is little or no chance of gaining a return by sticking to the original plan. There are many potential solutions, e.g., division of the plots / split plot designs, however, striking the correct balance will be difficult. It is therefore essential to spend sufficient time and effort appraising and analysing potential ways forward based on wide input from experts / specialists both within and outside Teagasc and even Ireland, and from stakeholder representatives, primarily organic farmers and non-organic farmers interested in converting, but also the wider organic movement and representatives of farmer organisations with a genuine interest in organic agriculture. For this reason this report has focused on examining the Oak Park organic rotation experiment to date, and with minor exceptions has not presented detailed practical experimental ideas to implement. It is suggested that any review group / system that is instigated should be given a reasonable "carte blanche", within the general remit of the experiment, to look at as many options as possible and then narrow these down to the final conclusion. This is considered preferable than this report's authors devising their own list of possible options for a review group to pick and choose among, as the former should ensure that the largest number of possibilities are considered before discarding the sub-optimal ones. This is not to say the authors lack ideas, as the opposite is the case, rather the authors ideas should be put into the review process on a equal footing with ideas from other members.

This is potentially a sizeable exercise, but if undertaken it will be a clear and unambiguous statement by Teagasc of its ongoing commitment to organic agriculture in Ireland. The benefits will also accrue far beyond organic agriculture. The wholesale shift in the CAP (Common Agricultural Policy) over the last decade from a sole focus on production and profit maximisation to integration of environmental sustainability with production agriculture, coupled with increasing awareness of environmental problems, especially climate change, means that new techniques and ideas are required by main-stream agriculture. Organic agriculture is increasingly being shown to have anticipated a considerable number of these problems and issues and has been testing and implementing potential solutions for many decades, e.g., substitution of clover for synthetic N fertilisers. Research into techniques previously described as 'organic' e.g., 'organic weed management' is now paying increasing dividends as such techniques are progressively taken up by non-organic agriculture, often being re-branded to make them more palatable to 'organic sceptical sections of agribusiness', e.g., organic weed management has become 'physical and cultural weed management'.

If this exercise is undertaken, a timeline will be essential. Autumn is considered the best time to instigate system changes as all crops are harvested at this time and most are planted for the next season. This means that it would be valuable to have the majority of the work completed by August 2008. If this is not feasible then spring 2009 should be the target date for completion, even though many of the crops could not be changed until autumn 2009.

Finally, this is regarded as a considerable opportunity for Teagasc to further improve its commitment to Irish organic and non-organic agriculture while making positive contributions to environmental sustainability and therefore benefiting Irelands agricultural sector and the nation as a whole.

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