Organic Stockless Arable Rotation Experiment - 1999-2007: Results 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 overall results of this research is presented here. However, the results are only from the Oak Park site and cannot be considered representative of the rest of Ireland, so should not be considered indicative of all Irish organic agriculture.
- This report only considers the activities of the research trial to-date. It avoids making recommendations as to what future research should be undertaken but instead recommends a participatory research model be used with wide consultation before settling on the future direction of the research.

2. Introduction

This report provides an overview of the organic rotation experiment conducted at Teagasc’s Oak Park, Crops Research Centre.

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.

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 1999. 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.

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 particularly in regard to their heavy clay nature. The soil in Malone Field can therefore be considered reasonably representative of actual Irish organic farms and therefore the techniques should also be representative and transferable, even if crop performance will vary compared with other climatic areas.

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 (see figure below). Within each replicate each crop/pasture was randomly allocated to the plots. The rotation design is considered to be generally typical of an organic mixed cropping/pasture rotation for Ireland and countries with similar climates/farming systems and is therefore considered meaningful to farmers. Although the cropping phase is longer than most Irish organic farms, it is also a stockless system which requires that the maximum amount of cropping is undertaken. 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.

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. In 2002 sowing rate and cultivar trials were also conducted at Johnstown Castle Research Centre.

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.

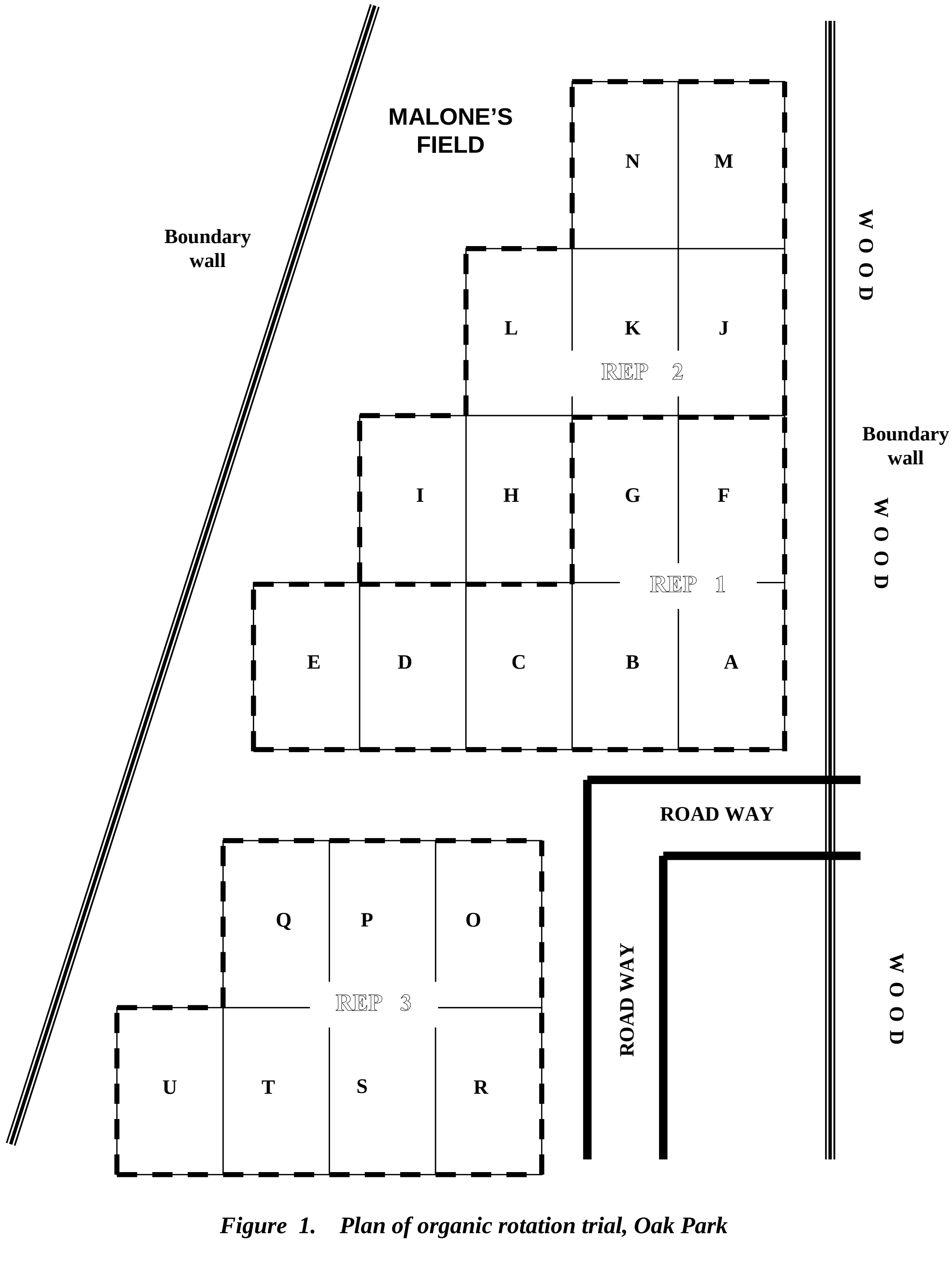


Figure 1. Plan of organic rotation trial, Oak Park

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. Each section starts with a general introduction to the crop, information on the experimental design, then results followed by a brief discussion.

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 has been by spring tine weeder or light harrow when required. 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.

The mixtures used in the undersowing experiment 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.

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.

Barley sowing rate experiment results, 2003.

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

*At 80% dry matter

Barley cultivar experiment results 2003 to 2006.

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

*At 80% dry matter

Grain yield and quality, barley undersowing experiment, 2003.

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

*At 80% dry matter

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 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.

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

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.

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**

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**

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 required.

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.

1.7 Results

Results for investigations on oats.

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%**

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	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	132
		Jalna	17.4	6.00	34.6	54.7	120
2006	WO	Barra	12.5	6.20	44.3	52.4	132
		Jalna	12.8	4.80	40.1	57.2	133
	WO	**Mean**	**15.8**	**4.67**	**36.08**	**54.5**	**100.1**
2007	SO	Corrib	9.5	4.46	42.6	49.1	97
		Evita	9.3	4.34	40.8	48.5	90
		Freddy	9.7	4.46	43.4	50.4	89
		Husky	9.2	4.55	40.1	50.1	87
		Nord	9.5	5.18	45.3	50.1	90
	SO	**Mean**	**9.4**	**4.6**	**42.44**	**49.6**	**91**
SO + WO		**Mean**	**12.6**	**4.64**	**39.26**	**52.05**	**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'. They are also a high value crop so potentially financially lucrative. However, 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

From Orla, Sante, and Setanta were the main cultivars grown with a few others tested occasionally. The multi-year arithmetic means 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.

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**

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**

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**

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 on non-organic crops. This is probably mostly due to the prohibition of water soluble, synthetic, mineral 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. However, there are concerns about sprouting in triticale which may well vary among cultivars.

4.7.2 Design

A considerable range of different cultivars were trialled, however, few were grown on a regular basis so much of the variation could be due to seasonal (inter-year) effects.

4.7.3 Results

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}	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%**

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}	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**

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

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

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. 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, using different experimental designs. 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.

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. Therefore, N can only effectively be imported into organic rotations to replace losses via legumes. Rock P and K fertilisers are less commonly available and therefore often considerably more expensive and 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 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.

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 below. 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.

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. Final means are presented, by both year and crop / rotational sequence.

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**

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 these tables are due to rounding.

5.3 Discussion

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

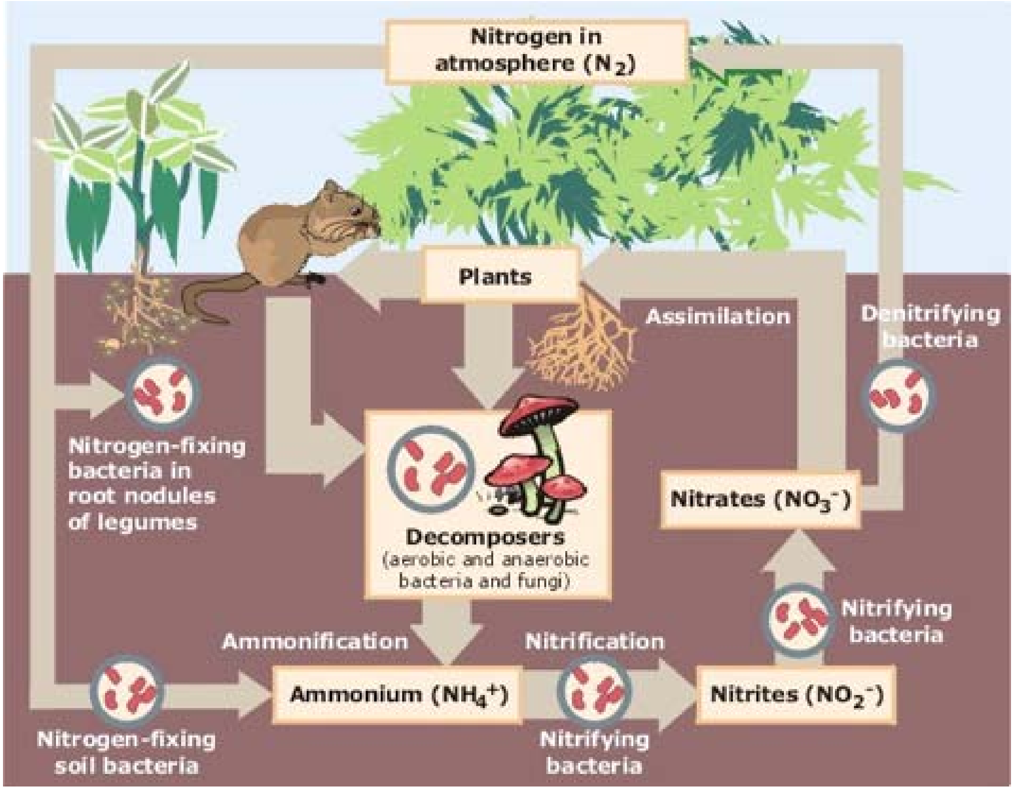
The nutrient management strategy used for 2002 to 2006 was based on white clover pastures and importing 50 tonne ha year^{-1} of sheep manure from the Teagasc farm at Knockbeg and applying it to the potatoes plots prior to tillage. In 2006 the sheep farm closed and therefore the manure supply stopped. 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 has 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. The sheep manure came from another Teagasc farm and was brought in January to February each year, stored under cover and composted before spreading in March on the potato ground before ploughing under.

While such a practice would have been within certification rules, it is, however, considered a significant issue at a practical level, in terms of the rotation mirroring real farm practice. This is because there are very few organic arable farms that would be able to find equivalent (on a tonne / hectare basis) supplies of off-farm manure or other biological fertiliser. This aspect of the rotation was therefore considerably at odds with what is commercially practical 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

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, including in Ireland, 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 (see below). These forms include a range of mineral (inorganic) forms as well as biological forms (organic matter) both living and dead.



Simple nitrogen cycle. (Source EPA, USA)

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 events 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.

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 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

Ensuring that full nutrient management data is recorded in future is essential, i.e., avoiding the gaps in the current data set. Although the importation of sheep manure has now ceased, considerable thought 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 which will then determine if growing a leguminous cash crop is justified.

6. 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 (favourite topics) 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.

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.

7. References

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