A STUDY OF CULTIVATION AND SOWING SYSTEMS FOR CEREALS

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SUMMARY

Due to the pressure on cereal margins growers are seeking ways of reducing their costs of production. Reduced cultivation may provide cheaper and faster crop establishment, but in the past has been subject to problems with (poor crop establishment) weeds and soil compaction. With modern cultivation and sowing technology and methodology it may be possible to overcome these difficulties. In addition reduced cultivation is considered to be more environmentally friendly and sustainable than the conventional plough-based system. With these considerations in mind it was decided to start an experiment in autumn 2000 to compare the conventional system (PL) with reduced cultivation (RC) for crop establishment, and to examine the effect of incorporating the straw into then soil or baling and removing it. The treatments were assessed on winter wheat, and winter and spring barley. The parameters assessed included – crop establishment, yield and quality effects on disease levels, invertebrate pests and beneficials (aphids, slugs, earthworms, beetles), and soil conditions.

The work reported here was conducted on four trial sites at Oak Park, Carlow and Knockbeg, Co. Laois from 2000 to 2003. the objectives were to establish the efficacy of RC compared with PL and to its effects on the parameters outlined above.

Plant establishment was lower after RC in most of the experiments. Winter wheat yields were good irrespective of the number of plants established and there were no significant differences between cultivation or straw disposal method. The relative yields of the PL and RC treatments in winter barley varied over the three years; in 2001 there was no difference, in 2002 PL yielded 1 t/ha more than RC, while in 2003 the PL area produced 2 t/ha extra. Spring barley yields were similar on the PL and RC treatments.

Broadleaved weeds were not a problem on the PL or RC treatments but there were more annual grass weeds on the RC plots. This was particularly serious in the winter barley experiments where sterile brome (*Bromus sterilis*) had a big effect on yield by 2003. annual meadow grass (*Poa annua*) was a problem in both PL and RC areas if not controlled by timely herbicide application; this was particularly so on the headland areas in the spring barley field.

Disease assessment on the winter wheat trail showed no significant differences in Take-all or Eyespot levels between cultivation or straw disposal methods, although Take-all levels tended to be lower on the RC plots.

Soil strength as measured by cone penetrometer and shear vane was higher on the RC treatments. In the winter wheat there was no difference in slug numbers between any of the treatments. Leaf damage by slugs increased in RC relative to PL but not significantly, in 2003. No below ground slug damage was found.

Earthworm numbers in the winter barley increased significantly on the RC treatment relative to the PL as the study progressed. Straw incorporation increased earthworm numbers on both PL and RC treatments. *Allolobophora chlorotia* was the most common species in 2004. In the winter wheat the RC and straw incorporation increased earthworm numbers.

Cultivation method had a greater effect on ground beetle numbers than method of straw disposal. Large species (e.g. *Pterostichies malanarius*) were favoured by RC while smaller species (e.g. *Bembidon* species) were more numerous in the PL plots.

Molecular studies on virus diseases, vectors and vector-predators are underway in progress.

In the invertebrate pests and beneficials investigations the RC winter barley had 11% fewer aphids and 27% less BYDV than the PL. Incorporating straw reduced aphid numbers and virus incidence by 36% and 32% respectively; the comparable values for the PL + straw treatment were 15% and 15%.

In the winter wheat there was less BYDV in the RC plots than the PL + less were the straw was incorporated than where the straw was removed. Aphid infestation of wheat ears was low in the three years of the experiment.

The insecticide seed treatment imidacloprid significantly reduced aphid numbers and virus incidence in winter barley but was less effective than a single insecticide spray in controlling the disease. The seed treatment was more effective in controlling BYDV in RC than in the PL plots.

Estimations of slug numbers in the winter barley showed that the dominant species was the grey field slug (*Deroceras reticulatum*). Slug numbers increased significantly on all treatments between 2001 and 2004. In November 2004, slugs were significantly more numerous in the RC treatments than in the PL areas. Leaf damage was proportional to slug populations, but the slugs did not damage the barely seed or reduce plant populations in continuous winter barley under RC.

Root and stem diseases (Take-all and Eyespot) were not nay worse under RC than after PL. In fact there was a tendency towards lower disease levels on the RC areas and there was significantly less sharp eyespot on the RC treatment.

INTRODUCTION

There is considerable pressure on cereal margins due to lower prices and increasing costs. Conventional seedbed preparation and sowing are relatively slow, energy demanding and expensive, especially where large areas are being worked. Reduced tillage that involves less intensive cultivation may provide a partial answer to the problem by having higher work rates and lower costs (Forristal and Fortune, 2002). Reduced cultivation is not a new technique: in the 1970's over 30% of cereal crops in England were established by reduced tillage but this had dropped dramatically to about 10% in the early 1990s. Reduced cultivation and direct drilling never achieved the same degree of popularity in Ireland but some cereals were sown using these techniques. The reason for the fall-off include – increasing grass weed populations, topsoil compaction, restriction on straw burning and inability to sow into trashy conditions.

Many long-term experiments conducted in the UK at that time demonstrated that well managed shallow cultivation or direct drilling for winter cereals usually gave yields as good as or better than ploughing where straw was either burnt or baled, and grass weeds controlled. Establishment of spring crops by reduced tillage tended to be less successful than winter crops except where soil conditions were particularly good. In those experiments in which reduced cultivation gave lower yields, greater populations of grass weeks and /or topsoil compaction or loss of surface structure were the causes (Davies and Finney, 2002).

What has changed since the 1970s which would make reduced cultivation more successful now. There have been some important developments in the meantime and especially in the past few years.

1) More versatile drills capable of better seed placement and an ability to deal with trash and more difficult conditions.
2) A more systematic approach to crop establishment has been developed, which uses shallow stale seedbeds, soil consolidation, rapid acting glyphosate and better timeliness.
3) Growers are more aware of the need to avoid soil compaction.
4) Better straw chopping and spreading mechanisms on combines have made it easier to cultivate and incorporate straw.

Apart from economic reasons, there is increasing pressure to adopt more sustainable cultivation systems than our traditional plough-based ones. Intensive cultivation can have a long-term damaging effect on soil structure, breaking down soil aggregates, increasing susceptibility to erosion and making seedbeds more difficult to prepare. It is also blamed for increasing soil organic matter breakdown and carbon loss to the atmosphere as carbon dioxide. At a time when there is a lot of discussion about maintaining or improving soil quality it is opportune to look at the possible contribution that reduced cultivation could make in this area.

The sowing of cereals in minimum-tillage is generally undertaken earlier in the autumn than the sowing of crops in conventional-tillage. Early sowing of cereals in autumn increases the risk of barley yellow dwarf virus (BYDV) disease since early emerging crops are more liable to infestation by viruliferous aphids than late sown crops. BYDV disease causes major yield loss in winter barley in Ireland, particularly in early sown crops (Kennedy and Connery, 2001).

Studies in Britain (Kendall, *et al.*, 1991) found less BYDV associated with barley grown in non-ploughed relative to ploughed plots. These workers also noted that partial incorporation of straw into the soil reduced the incidence of BYDV. While the reasons for these effects were not established they speculated that the greater activity of aphid predators in non-ploughed plots contributed to reduced virus incidence. Other beneficial soil animals likely to increase in crops grown in minimum-till relative to conventional-till land are earthworms, spiders and beetles (Kendall, *et al.,* 1995). A possible disadvantage of minimum-tillage is the likelihood of favouring an increase in slug populations (Jordan and Hutcheon, 1995; Jordan, 1996; Donaldson *et al.*, 1996; Hammond, 1996). However, an increase in slug numbers does not necessarily mean an increase in slug damage (Glen *et al.*, 1988; 1989; 1990; 1993).

The lack of information on the effects of minimum tillage on field and soil invertebrates instigated investigations on cereal aphids and their vectored viruses, slugs, earthworms and ground beetles in both minimum and conventionally cultivated winter barley and wheat.

The objectives of the work were:

- to assess the relative merits of plough based and reduced cultivation systems for the production of cereals.
- to assess machinery performance, work rates and costs.
- to measure the effects of reduced cultivation on soil, physical, chemical and biological conditions.

METHODS

The experiments were conducted on sites at Oakpark Research Centre and Knockbeg College Farm. The cereal crops were winter wheat, winter barley and spring barley; each crop was grown consecutively on the same site in each year, except in the rotation experiment, which also included sugar beet.

The sites were about 50 metres above sea level in an area where the mean annual rainfall is about
790 mm. Rainfall and temperature data for Oakpark Research Centre are given in Tables 1 and 2 . The Knockbeg site is about 2 km from the weather station at Oakpark.

Details of soil particle analysis for the different sites are given in Table 3. The soil on the Knockbeg site is a free draining loam down to about 700 mm overlying a heavier sandy clay loam layer to about 150 mm which merges into a light sandy loam. The soils are derived from calcareous glacial till mainly of limestone origin. They are classified as Grey Brown Podsols in the Mortarstown soil series (Alfisol, Orthic Typudalf).

The winter barley trials in the House Field and **Road Field** at Oak Park are located on a gravelly sandy loam about 1 metre deep. This overlies coarse gravelly sand. The site is well drained and easy to cultivate. The parent material is calcareous, fluvio-glacial gravel, of Weichsel age, composed mainly of limestone with a small proportion of sandstone and granite. The soil is classified as a moderately deep component of the Athy complex. (Alfisol, Orthic Glossudalph).

The spring barley site (Clonaherk) has a fine sandy loam topsoil extending to 500 mm overlying a more poorly drained loam to clay loam. (Inceptisol, Aquic Eutrochrept)

The rotation experiment site (Big Bull Park, Oak Park) is variable – the data in Table 3 is from a heavier, less free-draining part of the field. In this area the top soil to a depth of 250 mm is a fine sandy loam overlying a heavier 250 mm thick loam layer. Below 250 mm the soil is a clay loam. Parts of the site are subject to flooding at times. The parent material is calcareous, non-tenacious till of Weichsel age, composed mainly of limestone. The soil is classified as Mortarstown series (Alfisol, Orthic Typudalf).

Table 1: Monthly rainfall figures 2000-2003 and long-term averages (mm). (Oak Park Research Centre.)

Month	2000	2001	2002	2003	Longterm
January	40.5	47.1	91.9	53.9	87.9
February	57.8	63.9	102.8	42.8	62.3
March	14.2	48.8	34.5	37.7	62.1
April	62.5	63.7	80.0	61.3	49.8
May	71.3	37.4	96.7	80.7	56.8
June	31.5	46.6	52.2	68.6	49.6
July	61.9	2.5.9	38.6	64.9	49.3
August	57.1	82.9	58.9	1.9	64.2
September	93.5	44.0	22.9	36.2	66.4
October	121.4	121.0	131.0	47.0	80.5
November	117.8	30.9	134.2	56.4	74.3
December	114.3	33.8	54.7	54.7	86.2
Annual totals	843.8	646.7	917.5	606.1	789.4

Table 2: Average daily soil temperatures at 100 mm depth. (Oak Park Research Centre Meteorological Station) 2000 – 2003

Month	2000	2001	2002	2003
January	5.58	3.94	6.31	5.99
February	6.51	5.19	6.99	5.59
March	8.38	NA	7.80	7.62
April	8.83	9.62	10.29	10.00
May	13.84	13.67	12.92	11.91
June	16.01	15.97	14.96	15.37
July	17.84	17.25	16.66	17.30
August	17.74	17.32	17.62	17.98
September	15.81	15.16	14.86	15.18
October	11.46	13.43	11.81	11.20
November	7.33	10.09	9.44	8.64
December	6.88	5.65	6.87	6.99

Table 3: Soil mechanical analysis for experimental sites (% in each particle size category)

Site	Depth (mm)	Course sand (2 – 0.5mm)	Fine sand (0.5-0.05mm)	Silt (0.05-2μ)	Clay (<2μ)
	0-300	10	34	34	22
Winter Wheat	300-700	7	30	43	20
(Hockey Field,	700-1500	9	38	17	36
Knockbeg) *	1500 +	29	46	15	9
Winter Barley	0-350	34	23	28	15
(House Field,	350-700	46	20	24	10
Oakpark)	700-1000	38	15	23	24
	1000 +	gravelly coarse sand.			
Spring Barley	0-250	13	44	23	19
(Clonaherk,	205-500	8	46	30	16
Oakpark)	500-750	7	35	32	15
Rotation	0-250	13	42	28	17
(Big Bull Park,	250-500	9	36	35	20
Oakpark)	500-750	8	35	30	27

*Organic matter content measured in July 2001 (top 10cm) averaged 5.3% over the site in Knockbeg.

Work on reduced cultivation started at Oak Park in August 2000 with preparation for a fully replicated experiment on winter wheat at Knockbeg and two split-field experiments on winter and spring barley at Oak Park. The programme was expanded in 2001 and 2002. An outline of the programme is given in Table 4. The work may be divided into three areas.

- Detailed replicated experiments comparing agronomic, soil and fauna aspects of reduced cultivation with plough based systems – winter wheat, winter barley, crop rotation.

- Observational split field areas on which some measurements, including agronomic, are made – winter barley, spring barley.
- **Work on mechanisation and labour costs – energy inputs, work rates, labour input and costs?**

Before considering the results of our experiments, it might be useful to define the term "Reduced Cultivation". In our trials it is used to describe shallow (normally **<** 100 mm deep) tine cultivation without soil inversion, with or without straw incorporation. This is more commonly called ECO tillage in Ireland. Other names used to describe reduced cultivation include "Minimum Tillage", "Min-Till", "Lo-till". "Conservation Tillage" is used to describe any non inversion tillage which leaves at least one third of the soil surface covered by residues, without reference to depth of cultivation.

In the remainder of the text and tables reduced cultivation is referred to as RC and the plough-based treatments as PL.

*Experimental layout***:** The experimental layout of the individual comparisons is outlined in Table 4. Basically there were two types of experiment – 1. Randomised small plot experiments comparing cultivation and straw disposal methods. 2. Split field non-replicated observation trials comparing cultivation techniques and in some cases, straw disposal methods in the winter wheat experiment. In Knockbeg the layout was a randomised block with four replications. The plots were 30 x 24 metres with 12 metre wide discard areas adjoining the plots to facilitate the use of farm scale cultivation and sowing equipment. Depending on the treatment the straw was either baled and removed or chopped and spread over the stubble. However in 2001 due to lack of a suitable chopper, none of the straw was chopped. In 2002 it was chopped with a tractor-mounted machine and in 2003 it was chopped and spread from the combine. Target chop length was 100 mm or less.

The winter and spring barley trials were on 4-hectare and 2-hectare fields, respectively, split in two, half of each being PL and the other prepared by RC. Straw has been baled and removed on both sites each year.

In autumn 2002 a new experiment was laid down to study the feasibility of a complete reduced cultivation system including a root crop. The rotation was winter wheat, spring barley, sugar beet. Cultivations were basically similar to those described above for the winter wheat and spring barley. The crops were grown on 30 x 12m plots (with 6 m discards beside the plots) in a randomised block layout. Each crop in the rotation was grown in each year.

Table 4: Reduced cultivation experiments in progress 2003

Crop and start-up	Layout	Factors measured
Winter wheat (continuous) August 2000	Replicated large plots 1. Plough - straw 2. Plough + straw 3. Reduced cultivation – straw 4. Reduced cultivation + straw	Establishment, weeds, disease, slugs, grain yield and quality. Soil strength, structure, nutrient stratification, organic matter, temperature and moisture, fauna – earthworms, beetles and microbiological factors.
Winter barley (I) (continuous) August 2000	Split field (4ha) Straw baled and removed Plough and reduced cultivation	Establishment, weeds, disease, grain yield and quality.
Winter barley (II) (continuous) August 2001	Replicated large plots 1. Plough 2. Reduced cultivation 3. Straw baled 4. Straw chopped and incorporated.	Effects of cultivation and straw disposal method on sphid population and BYDV incidence, earthworm and slug numbers.
Spring barley (continuous) September 2000	Split field (2ha) Straw baled and removed Plough v reduced cultivation	Establishment, weeds, disease grain yield and quality
Winter wheat (continuous) August 2002	Replicated small plots Reduced cultivation only	Herbicide rates and types of weed control Grain yield and quality
Rotation experiment under reduced cultivation October 2002	Large replicated plots Reduced cultivation 1. Sugar beet 2. Winter wheat 3. Spring barley 4. Spring barley (continuous)	Feasibility of growing sugar beet in reduced cultivation rotation. Crop performance, weed control etc. for cereal and beet. Soil effects – organic matter and soil compaction etc. Pest incidence.

Table 5: Summary of RC treatments 2000-03

Year	Cultivator	Working width (m)	Working depth (mm)	Speed (km/h)	No. of Passes
2000	Horsch FG 7.50 tine cultivator	7.5	70-100	10-12	2
2001	Horsch FG 7.50 tine cultivator	7.5	70-100	10-12	2
2002	Horsch FG 7.50 tine cultivator	7.5	70-100	10-12	1
2003	Kockerling	3.0	70-80	12	1

In the Oak Park trials, the procedure was similar for each of the cereal crops. For winter crops the ground was cultivated as soon as possible after harvest with a tine cultivator (1 or 2 passes) to 50-100 mm. This was followed immediately by a press or roller, and the area was then left until a few days before sowing when germinated weeds and volunteers were sprayed with a glyphosate herbicide. Sowing was carried out with a Vaderstad cultivator drill. Spring sown crops received the same autumn cultivation as the winter crops but the herbicide application was sometimes delayed until February before sowing in March. A second shallow cultivation was done before sowing spring crops where soil conditions appeared to warrant it.

The plough based cultivation consisted of ploughing to 200-250mm with a Kverneland 4-furrow reversible plough, followed by a singe pass with a rotary power harrow (Lely Roterra or Pottinger) to 100-120mm depth. In some instances the ground was rolled before sowing. All crops were sown with a Vaderstad cultivator drill except the plough treatments in 2000 which were sown with a Fiona. The period between ploughing and cultivation / sowing varied from about one month to one or two days.

Crop measurements: Plant establishment was measured for each of the cereal and beet crops throughout the experiment with the exception of the winter wheat in 2000. Counts were taken using a 0.5m square template; all plants within the square were counted. A number of counts were made on each plot, which varied depending on the area of the plot. These counts were done when all the plants had established. Sometimes a second count was taken later where there was a possibility of plant loss from slug damage. When the crop was ripe ear counts were taken on each treatment at random locations in each plot.

At the same time the ears from complete plants were cut from a metre length of row at different locations and taken to the laboratory where the average number of grains per ear was determined for each treatment. For yield measurement complete plots or sample strips were harvested with a combine harvester having a 2.75 metre cutting width and fitted with a weighing advice. Grain samples were taken during harvesting for various quality parameters – moisture content, hectolitre weight, 1000 grain weight, screenings and protein content. Yields at field moisture contents were converted to the equivalent at a standard 15% for comparisons between treatments.

Seed rates for the cereal crops were generally dictated by sowing date and were usually similar to those used in farm practice for the particular crops. Fertilizer, fungicide, herbicide, pesticide and growth regulator rates were based on standard recommendations. Apart from herbicides there were no differences in rates or timings between the PL and RC treatments**. Details of the management treatments over the 3 years are given in tables 4 and 5.**

Root and stem samples were taken before harvest each year from the cereal crops for Take-all (*Gaeumanomyces gramini var. tritici*), Eyespot (*Pseudocercosporella herpotrichoides*) and Sharp Eyespot (*Rhizoctonia cerealis*) assessments

Leaf disease incidence was not measured but crops were observed regularly and visual observation of disease incidence noted.

Invertebrate investigations: An experiment to assess the effect of cultivation and straw disposal method on invertebrate pests and non-pests in PL and RC winter barley was started in Autumn 2001.

The plot layout was a randomised block with four replications. Plot size was 36 x 24 metres; each plot was divided longitudinally into two sub-plots, one of which had the straw baled and removed and the other had the straw chopped and incorporated. The cultivar Regina was sown in 2001 and 2002 and pearl was sown in 2003. The crop was sown in the second week of September in each year.

In a concurrent investigation into the effect of seed and spray treatments on the incidence of Barley Yellow Dwarf Virus (BYDV) under PL and RC cultivation regimes the plots (30 x 24m) were again split in two. Half of each was sown with seed treated with imidacloprid insecticide (Raxil – secure) and the other half with non-insecticide treated seed. Within each system of cultivation, plots of treated and untreated seed received 0, 1 or 2 foliar aphicide sprays. Single sprays were applied during the first week of November. The two sprays were applied in early October and in the first week of November.

Aphid sampling was carried out using a vacuum insect net (D-vac, Dietrich 1961) fitted with a 0.0929 m^2 sampling cone.

Earthworm numbers and species were assessed by taking 25 x 25 x 25 cm soil samples from each plot during the period November to January using a steel quadrat. Worms from deeper in the profile were recovered by pouring approximately 2 litres of formalin (0.25% solution) into the excavated sample holes and examining for 1½ hours. The worms were extracted from the soil samples by hand sorting in the laboratory. The worms were counted, weighed and stored in formalin (4%) for later identification. The publication 'Earthworms – Notes for identification of British species' by R.W. Sims and B.M. Gerard (Linnaian Society, London) was used for this purpose.

Slug occurrence was measured using i) Refuge-traps and ii) Slug mats (Bayer). Refuge-traps, 30 x 30 x 1 cm having four legs permitting a soil clearance of 1.5 cm, were operated for a six-week period from early-November to mid-December. Twelve grams of methiocarb molluscicide pellets were placed beneath each trap. Slug mats, 44 x 44 cm, were operated in parallel with refuge traps. Slug damage to cereal plants was measured by excavating two 25 cm drill length at plant growth stage 23. In the laboratory, plants were examined for damage to leaves, stems and 'mother' seed.

Ground beetles were captured by pitfall traps (7.5 cm diam.), directional traps (1m long) and emergence-arenas (1/m^2). The role of ground beetles in reducing virus incidence by preying on aphid vectors is under investigation.

Plant measurements and sampling were carried out at locations along the longitudinal axis of plots and equidistances apart.

For virus testing leaf samples (10 to 15) were collected at 5 separate locations approximately 3 m apart in each plot at growth stage 41 to 43. Sap was extracted from 1g of leaf sample and tested by TAS-ELISA for MAV and a 50:50 mixture of PAV and RPV type virus. Reagents were supplied by Adgen SAC, Scotland. Samples were considered positive when their spectrophotometer reading (405 nm) was three times greater than the mean value of negative controls.

The percent BYDV was determined by counting tillers with and without symptoms in each of four quadrats per plot. Symptoms were recorded at growth stage 43 to 49 using quadrats of 0.25 m^2.

Grain yields were recorded by harvesting a 2.3 metre width along the full plot length using a specially modified combine harvester. Grain analyses (specific weights, percent screenings <2.2mm, 1000 grain weights and moisture content) were carried out on a grain sample from each plot.

Similar investigations on pest and non-pest invertebrates were undertaken on winter wheat at Knockbeg, Carlow.

Soil measurements: Soil strength was measured with a Bush recording cone penetrometer having a cone angle of 30° and base area 1.29 cm^2. Readings were taken at depth increments of 20 or 35mm from a base plate resting on the soil surface, with a maximum of 15 readings per penetration. The spacing between the readings was determined by the spacing of a series of holes in an interchangeable metal bar combined with an optical system of infra-red source and detector which enabled the force to be recorded as the source passed each hole. In the winter wheat experiment at Knockbeg 10 penetrations per plot, giving a total of 40 penetrations per treatment, were used to get an average value at each depth for each treatment. Soil shear strength was determined using a Pilcon shear vane fitted with 29 x 19 mm blades. Readings were taken at two depths, 40 and 120 mm; 10 readings per plot were recorded at each depth at Knockbeg (40 per treatment). Some of the sites were too stony or sandy to get meaningful penetrometer or shear vane readings.

Weed counts: From autumn 2001 onwards weeds were counted on each treatment. The counts were done using 0.5m x 0.5m square wooden templates individual counts were done at random on each plot. The total number of counts per treatment varied with the plot size and number of replications. Counts were taken in autumn on the winter wheat and barley and in April-May on the spring sown crops. They were always taken before the weeds were controlled by herbicides, which were applied according to standard practice.

RESULTS

Winter Wheat

Plant establishment: The weather was very wet and soil conditions were poor in autumn and winter 2000. The winter wheat experiment was sown on 19-21 October. Establishment was very poor on the PL and RC treatments. Because of the poor soil conditions and risk of damage from trampling on the plots no plant counts were taken in 2000, but it was obvious that plant populations were very low, particularly on the RC areas.

The experimental design and lay-out in the field made provision for straw chopping and incorporation on half the PL and RC treatments, but in 2000 none of the plots had straw incorporated due to the unavailability of a straw chopper. Straw was baled and removed from all treatments. In 2001 a tractor-mounted straw chopper was acquired and straw was chopped into 100-120mm lengths and incorporated by ploughing or cultivating on the relevant plots.

Two sets of plant counts were taken in autumn 2001 (25/10 and 11/12). In the first count, the plant numbers on the PL plots were significantly higher than those on the RC. The poorer establishment was due to poorer seedbed conditions on the RC treatment, which, in the wet conditions after sowing, reduced oxygen supply to the young plants. The difference between treatments was maintained at the second count, although all the counts were down by about 25%. Much of the plant loss was attributed to slug damage. Straw disposal method did not have any effect on establishment (Table 6).

Soil conditions were good in autumn 2002 and establishment was much better than in previous years on all treatments. There was no significant difference between the treatments. The straw was chopped and spread from the combine on the relevant plots in 2002 and subsequent years. Establishment was good in 2003 but plant counts were significantly better after ploughing (Table 6).

Table 6: Plant establishment – Winter wheat, Knockbeg, 2001-2003

	Plant establishment (plants/m²)			
Treatment	2001		2002	2003
	Count 1	Count 2		
PL – straw	202	166	239	256
PL + straw	219	171	254	256
RC – straw	158	123	240	239
RC + straw	169	124	237	234
s.e.d.	11.5	8.3	9.9	3.6
Significance	***	***	NS	***

Grain yield: Despite the substantial differences in plant establishment between the PL and RC treatments in 2000 there was little difference in yield; it was slightly higher on the PL treatment but the difference was not significant.. There were more ears on the PL plots but the RC compensated by having more grains per ear. 1000-grain weights were slightly higher on the RC but the differences was not significant (Table 7).

In 2002 yields were higher on the RC treatments but again the differences were not significant (Table 8) There were fewer plants but more ear-bearing tillers on the RC treatments and there were fewer ears where the straw was incorporated than where it was baled and removed. The ears were larger (more grains/ear) and the grains heavier on the RC area.

Grain yields were good in 2003 with the PL treatments averaging 10.4 t/ha and the RC 10.0 t/ha (Table 9). The RC treatment with straw removed had a lower yield than the others due to severe infestation of annual meadow grass (*Poa annua*) on one plot which severely reduced the yield on this plot (See Table 12)

Grain quality assessments for the harvest years 2002 and 2003 are shown in Table 10. Generally there was little difference in quality between treatments. In 2002 when screenings levels were low the RC – straw treatment had a slightly but significantly lower screening percentage. There was no significant difference in grain density (hectolitre weight) in either year.

Table 7: Effects of cultivation system on winter wheat yield, Knockbeg, 2000-01

Cultivation system	Grain yield (t/ha @15% m.c.)	Ears/m²	Grains/ear	1000-grain weight (g)
PL	10.280	455	37.4	45.7
RC	10.185	391	43.7	47.6
s.e.d.	0.3595	37.6	1.93	0.94
Significance	NS	NS	**	NS

Table 8: Effect of cultivation treatment on winter wheat yield, Knockbeg, 2001-02

Cultivation system	Grain yield (t/ha @15% m.c.)	Ears/m²	Grains/ear	1000-grain weight (g)
PL – straw	9.72	592	48	46.9
PL + straw	9.79	550	50	47.0
RC – straw	10.56	548	53	51.7
RC + straw	10.23	480	55	50.3
s.e.d.	0.605	16.5	2.0	1.6
Significance	NS	***	*	*

Table 9: Effect of cultivation method on winter wheat yield, Knockbeg, 2002 –03

Cultivation system	Grain yield (t/ha @15% m.c.)	Ears/m²	Grains/ear	1000-grain weight (g)
PL – straw	10.222			48.4
PL + straw	10.592			49.1
RC – straw	9.780			48.9
RC + straw	10.312			48.8
s.e.d.	0.6361			0.8q
Significance	NS			NS

Table 10: Grain quality assessment, winter wheat, Knockbeg, 2002 and 2003

	2002		2003	
Cultivation treatment	Hectolitre wt (kg/hl)	Screenings < 2mm (%)	Hectolitre wt (kg/hl)	Screenings <2mm (%)
PL – straw	77.6	1.1	74.7	2.29
PL + straw	77.9	1.0	73.7	2.64
RC – straw	76.8	0.8	72.6	2.20
RC + straw	77.2	1.1	75.5	2.75
s.e.d.	0.71	**	NS	NS

Weeds: In autumn 2001 weeds were counted on the PL – straw and RC – straw treatments. The population of broad-leaved weeds was low totalling about 10 plants/m² on the PL plots, and only 2 plants/m² on the RC (Table 11). The most numerous weeds were – chickweed (*Stellaria media*), charlock (*Sinapis avensis*), nipplewort (*Lapsana communis*), groundsel (*Senecio vulgaris*) plus small amounts of cleavers (*Gallium aparine*) and fat hen (*Chenopodium album*). Annual meadow grass (*Poa annua*) was the main grass weed and was more numerous on the RC treatments.

Table 11:, Annual broad leaved and grass weeds in winter wheat, Knockbeg, 2001

	Weeds/ m²	
Weed type	PL- straw	RC – straw
Broad leaved	10	2
Grass	50	72

Weeds were counted twice during the 2002-03 growing season – 6/12/02 (pre herbicide) and 11/1/03 (Post herbicide). There were very few broad-leaved weeds present at these times but there was a significant population of annual meadow grass, particularly on the RC plots with straw baled, at both counts (Table 12). This was not controlled by the herbicide applied (Cougar-diflufenican/isoproturon combination @ 1.5 l.ha) Early herbicide application is essential to control meadow grass.

The meadow grass problem manifested itself later in the season, forming a dense mat and contributing to the lower yield obtained on the RC plots with straw removed.

Table 12: Weed assessments, winter wheat, Knockbeg 2002-03

	Weed species – plants/m²					
Treatment	Charlock	Cleavers	Groundsel	Annual meadow grass	Nipple-wort	Sow-thistle
Pre-herbicide count 6/12/02						
PL – straw	1.8	1.3	-	7.3	0.6	-
PL + straw	0.5	-	-	14.5	0.1	-
RC – straw	0.4	-	0.3	36.5	-	0.9
RC + straw	0.1	0.4	-	12.3	-	-
Post herbicide count 11/1/03*						
PL –straw	-	-	-	8.0	-	-
PL + straw	-	0.3	-	12.6	-	-
RC – straw	-	-	-	46.1	-	-
RC + straw	-	-	-	15.8	-	-

*Herbicide- Cougar @ 1.5 l/ha – applied 11/12/02

Disease: Before these experiments commenced there were some concerns that non-inversion or reduced cultivation techniques would increase the incidence of some some stem and root diseases such as eyespot (*Pseudocercosporella herpotrichoides*) and take-all (*Gaeumanomyces gramini var tritici*). This has not occurred. The experiment started at a high risk point in the then rotation (2^{nd} cereal after a break crop) so it was decided to use seed treated with Latitude (Siltiofam) to reduce take-all incidence.

In 2001 the disease assessments showed that there were slightly lower levels of take-all and eyespot on the RC areas (Table 13)

Table 13: Effect of cultivation treatment on root and stem disease levels in winter wheat, Knockbeg, 2000-01

Treatment	Take-all (%)	Eyespot (%)	Sharp Eyespot (%)
PL	43.4	46.2	8.7
RC	39.6	42.4	8.4

Disease measurements in 2002 showed a greater incidence of take-all and sharp eyespot on the PL treatments but the differences were significant only with the latter (Table 14). There was some indication that straw incorporation reduced eyespot symptoms, but cultivation method did not appear to have any effect on this disease.

Table 14: Effect of cultivation method on root and stem disease levels in winter wheat, Knockbeg 2001-02

	Take-all %	Eyespot %	Sharp eyespot %
PL – straw	73.0	55.8	19.3
PL + straw	70.1	39.7	26.7
RC – straw	52.9	51.4	2.5
RC + straw	52.3	42.1	7.2
Significance	NS	NS	**

There were no significant differences in disease levels between treatments in 2003 (Table 15). Eyespot and take-all incidence was high in all three years and there was a lot of variation between individual plots of the same treatment making it difficult to confirm differences between cultivation or straw incorporation treatments. However there was no evidence that reduced cultivation increased the degree of infection of any of the diseases.

Levels of foliar diseases such as *Septoria tritici* were not measured but were monitored regularly and there did not appear to be any difference between treatments.

Table 15: Effect of cultivation method on root and stem disease levels in winter wheat, Knockbeg, 2002-03

	Take-all %	Eyespot %	Sharp eyespot %
PL – straw	68.5	75.8	9.7
PL + straw	79.08	57.85	16.83
RC – straw	79.28	67.78	10.28
RC + straw	77.83	69.03	8.17
s.e.d.	8.118	7.736	8.601
Significance	NS	NS	NS

Soil Measurements: Soil strength measurements were made on various occasions during the project using (1) a Bush recording cone penetrometer which recorded the force on the cone at 15 x 35 mm intervals as it was being pushed into the soil; (2) a Pilcon shear vane was used at two depths – 40 and 120 mm.

One of the concerns regarding reduced cultivation is the possibility of soil compaction by wheel traffic which is not removed by the shallow cultivation. Measurements with the cone penetrometer at Knockbeg in December 2003 showed little variation between cultivation treatments down to about 6-7 cm. The cone resistance on the RC plots increased very rapidly from 8 to 18 cm and then less rapidly down to 44 cm. On the PL plots the soil strength increased at a much lower rate down to about 23-24 cm (ploughing depth) below which it increased rapidly again reaching the same strength as the RC at about 36 cm (Fig. 6). The presence or absence of straw had no significant effect on the soil cone resistance.

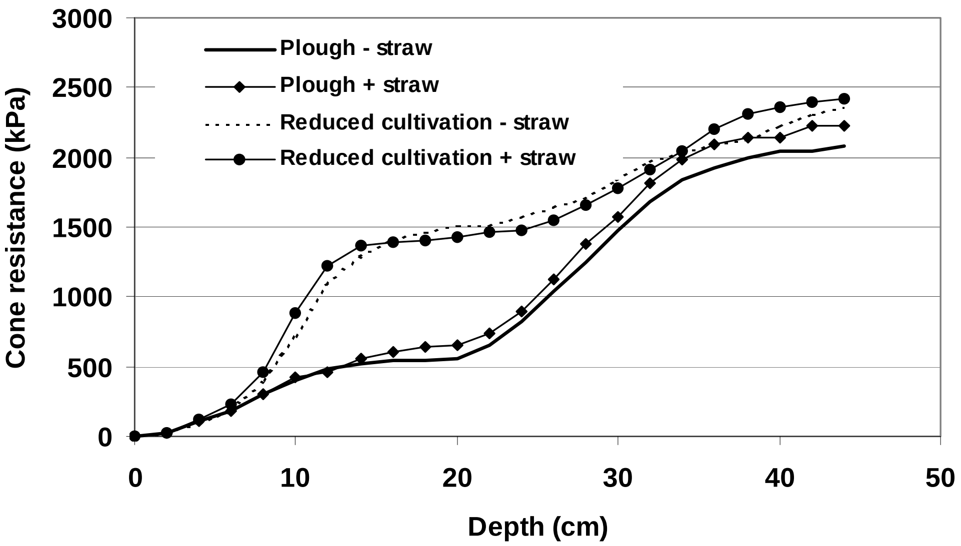

Fig. 6: Cone penetrometer resistance – winter wheat, Knockbeg – December 2003

Results from shear vane tests (another measure of soil strength) show a similar pattern (Fig. 7). Readings were taken at two depths 4 and 12 cm below the surface. At the shallower depth differences between the treatments were small but the RC figures were slightly higher. At 12 cm the readings from the PL plots were similar to those at 4 cm but those on the RC area were significantly higher.

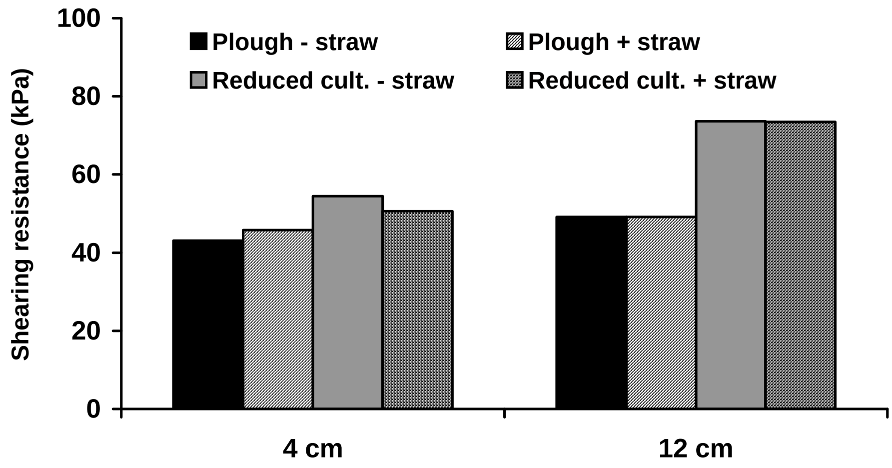

Fig. 7: Soil shear strength – winter wheat, Knockbeg

BYDV: The incidence of BYDV in winter wheat at Knockbeg was extremely low in 2001 and 2003. In 2002, 2.6% of tillers in PL plots without straw incorporation had BYDV while those with incorporated straw had 1.2% infection. BYDV was considerably lower in RC plots when compared with PL plots. There was 0.6% virus infection in RC plots without straw while those treated with straw had 0.06%. The pattern of virus occurrence in wheat in 2002 was similar to that recorded for winter barley (correlation coefficient r = 0.89). There was less virus in RC plots relative to PL and in straw treated plots relative to non-straw plots.

Aphids: There was a low infestation of aphids (< 5) on the ears of wheat plants in 2001 and 2004. Aphids were fewer, though not significantly, on wheat in RC plots relative to wheat in PL plots. Aphids were scarce in 2002 and were not recorded in 2003.

Slugs: The number of slugs, captured by refuge trap, did not differ between PL and RC plots with or without straw incorporation during autumn 2001. During autumn 2002, there was an increase of 76% in the number of slugs trapped relative to 2001. The number of slugs trapped in PL plots without straw was 131/trap, which was significantly greater than PL plots with straw and greater than RC plots with or without straw (Table 16). In autumn 2003, slug numbers were similar to those of 2001 and did not differ significantly between treatments. The number of slugs trapped by ‘slug mats’ was similar to those for refuge traps.

Slug damage: There was no difference in slug damage to wheat plants, as evidenced by shredding and severing of leaves, between PL and RC plots for the three seasons 2001/2002 to 2003/2004. Neither was there a significant difference in damage between straw and non-straw plots either within or between the two methods of cultivation. In general slug damage was proportional to slug abundance and had a correlation coefficient value r = 0.67. While in excess of 60% of plants in the various treatments had leaf damage due to slugs in 2003/2004 (Fig. 4) there was no evidence of slugs feeding on seed or of severing plants below the soil surface. The number of plants per metre row did not differ for the various treatments in the four seasons for which data is available.

Table 16: Numbers of slugs captured in refuge traps, Winter Wheat, Knockbeg, 2001 – 2004

	Slugs captured in refuge traps		
Treatment	2001 – 2002	2002 – 2003	2003 - 2004
PL – straw	66.8	130.8	55.0
PL + straw	52.3	103.0	47.5
RC – straw	58.0	95.8	64.5
RC + straw	63.5	93.8	67.8
LSD (5%)	NS	24.09	NS

Earthworms: The number and mass of earthworms increased in the RC and PL plots over the period 2002 to 2004. The number of worms in the PL - straw treatment increased by 1.8 fold from 72/m2 in 2002 to 130/m2 in 2004. There was more than a 2-fold increase in worm numbers in RC – straw plots over this period, reaching 180/m^2 in January 2004. In straw treated plots of each cultivation method the increase in earthworm numbers was greater than that for non-straw treated plots. In January 2004 the number of worms in the PL + straw was 214 / m^2 while in RC + straw plots the number was 256/m^2. The numbers on these plots increased by factors of 2.6 and 2.3 respectively. Comparing worm numbers in RC - straw and PL - straw plots showed there were 38% more worms in the RC plots for 2004. A similar comparison of straw treated plots showed a 20% greater abundance in worms in RC plots. These differences, however, were not statistically significant. The increase in worm biomass in all treatments in the period 2002 to 2004 was greater than the numerical increase indicating an increase in worm size. Worm biomass increased by 2.9 and 1.6 fold, respectively, in PL plots with and without straw between 2002 and 2004. The corresponding increase in RC plots was 3.8 and 3.5 fold. In January 2004 there was a worm biomass of 20.6 g/m^2 in PL – straw plots while in the RC + straw plots there was a significantly greater mass of 62.7 g/m^2 (Figure 4).

The species breakdown of earthworms in 2004 was Allolobophora chlorotica 24%, *Aporrectodea caliginosa* 3%, *A. rosea* 3%, *Lumbricus terrestris* 1%, *Lumbricus rubellus* 1%, immature tanylobics 3%, immature epilobics 54% and unidentified (damaged) 11%.

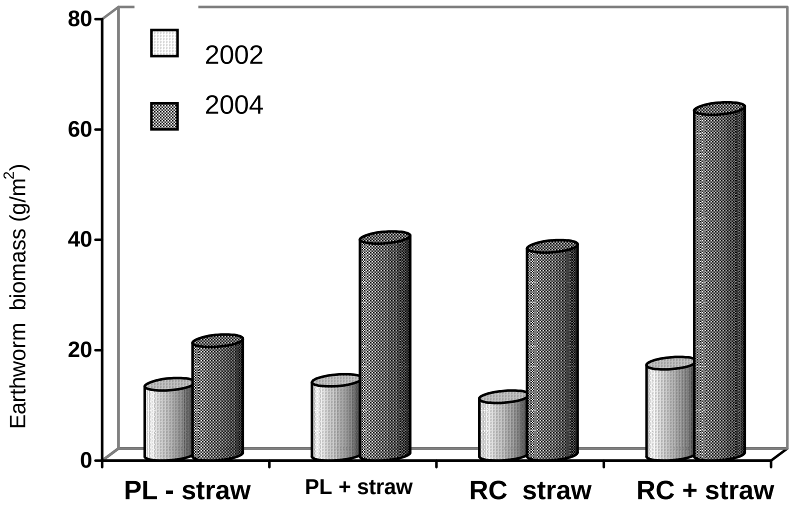

Figure . The earthworm biomass in PL and RC wheat plots, with and without straw in Carlow, 2002 and 2004

Table 17: Earthworm numbers, winter wheat, Knockbeg, 2002 - 04

Treatment	Earthworm Numbers*		
	2002	2003	2004
PL – straw	72	130	130
PL + straw	84	220	214
RC – straw	84	142	180
RC + straw	114	162	256
LSD (5%)	NS	NS	NS

Winter Barley

There were two experiments with winter barley in this series. (i) The first, which was started in autumn 2000, was a split field, non-replicated comparison of PL + RC. Straw was baled & removed from the whole site. The site was a 4-hectare field divided into 2 - hectare blocks. The trial was initiated to compare the effects of PL & RC on establishment, growth and yield of the crop. plus weed populations, disease incidence and general husbandry. (ii) The second was a fully replicated randomised block experiment designed to evaluate the effects of RC & PL, with or without straw incorporation, on aphid infestation and barley yellow dwarf virus incidence on winter barley. It was also designed to assess the effects of cultivation and straw disposal method on slug numbers, slug damage and earthworm populations. This experiment commenced in autumn 2001.

Winter barley (i)

Plant establishment and grain yield: There was no difference in yield between the PL & RC treatments in 2000-01. The PL area had more ears per square metre but fewer grains per ear and a lower 1100-grain weight (Table 18).

Table 18: Effect of cultivation system on winter barley yield, Oak Park (House

Cultivation system	Grain yield (t/ha @ 15% m.c.)	Ears/m²	Grains/ear	1000-grain weight (g)
PL – straw	8.723	707	22.72	58.80
RC – straw	8.740	566	25.32	62.67

In 2001-02 plant establishment was slightly higher on the PL area (Table 19). At harvest there were more ears/m² and grains/ear on the RC treatment resulting in a grain yield difference of about / tonne/ hectare.

Table 19: Establishment and yield, winter barley, Oak Park (House Field), 2001-02

	PL – straw	RC – straw
Plant establishment (plants/m²)	256	238
Ears/m²	879	922
Grains/ear	20.3	21.1
1000-grain weight (g)	47.8	46.9
Hectolitre weight (kg/hl)	59.1	62.0
Screenings < 2mm (%)	5.7	6.0
Grain yield (t/ha @ 15% m.c.)	6.2	7.2

In autumn 2001, significant net blotch was measured on the winter barley. There was a lot more net blotch on the reduced cultivation treatment and the degree of infection on individual plants was also much greater (Table 20). While the main area of the trial was sprayed against net blotch, a small replicated experiment was laid down on the PL and RC areas comparing no-fungicide with one or two sprays. There was no significant difference in yield between any of the spray treatments on either cultivation. There was also an attack of ramularia on both treatments; in the autumn this was more severe on the RC, but in spring the PL treatment was more severely affected.

Table 20: Disease assessments (% plants affected) winter barley, Oak Park (House Field), 2001-02

	Net blotch[1]	Rhynchosporium	Slug damage
PL – straw	29.8	0.0	1.10
RC – straw	72.9	3.0	2.3

[1]Degree of infection on plants (on scale 0-10): reduced cultivation =7; plough = 1-2

In 2002-03 plant establishment was slightly better on the RC area but at harvest the PL treatment had a higher ear count (Table 21). It also had more grains per ear and a higher 1000-grain weight which combined to give a substantial yield increase of almost 2 tonnes per hectare over the RC area. The data in Table 22 help to explain the yield difference. While there were significantly more broad-leaved weeds, such as red deadnettle and speedwell on the RC area, the really big difference was in the annual meadowgrass populations, which, as in the winter wheat, were not controlled by the Cougar application. These persisted to cause significant competition and yield reduction for the barley crop in the RC treatment. The weed situation in the winter barley in 2002-03 was a reversal of the previous two years when there was a greater infestation of annual weeds on the P treatment. Disease was not a problem on either treatment in 2002-03.

Table 21: Establishment and yield, winter barley, Oak Park (House Field), 02-03

	PL – straw	RC - straw
Plant establishment (plants/m²)	253	277
Ears/m²	684	632
Grains/ear	23.4	21.5
1000-grain weight (g)	64.1	62.3
Hectolitre weight (kg/hl)	64.19	62.49
Screenings <2mm (%)	0.88	1.33
Grain yield (t/ha @15% m.c.)	8.31	6.27

Table 22: Weed counts (weeds/m²), winter barley, Oak Park (House Field), 2002-03

	Counted 13/11/02 – Pre-herbicide		Counted 27/1/03 – Post herbicide*	
Weed	PL – straw	RC – straw	PL – straw	RC – straw
Charlock	-	0.53	-	-
Chickweed	0.80	0.93	-	-
Cleavers	0.53	-	-	-
Forget-me-not	0.53	-	-	-
Fumitory	3.33	0.53	0.27	-
Groundsel	0.53	1.07	-	0.53
Knotgrass	-	2.27	-	-
Annual meadow grass	3.20	194.27	1.07	113.07
Pansy	42.67	40.13	0.93	3.73
Parsley piert	-	0.67	0.67	0.40
Poppy	2.93	1.20	-	0.93
Red deadnettle	7.60	15.73	0.70	0.80
Speedwell	14.00	79.60	0.40	2.67

*Herbicide applied: Cougar @ 1.5 l/ha – 22/11/02

Aphids Winter Barley(ii): In 2001, aphid numbers and virus incidence in RC plots were approximately 50% and 30%, respectively, of those recorded for PL plots (Table 23). The addition of straw to RC plots significantly reduced aphid numbers by 68% and virus by 56%. The addition of straw to PL plots gave a small reduction in aphid numbers and virus incidence. The reduction was significant for aphids ($P \leq 0.05$) but not for virus.

Grain yield from RC plots was significantly greater than from conventional plots. The incorporation of straw on PL plots gave a non-significant increase in grain yield of 0.5 t/ha when compared with conventional-till plots to which no straw was added. RC + straw plots out-yielded RC - straw by 0.3 t/ha. The yield increase on the straw incorporation areas resulted from having fewer aphids and consequently less BYDV on these plots.

Table 23: Aphid numbers and BYDV incidence, Winter barley, Oak Park (Road Field), 2001 – 2003.

Treatment	**2001 – 2002**		**2002 – 2003**		**2003 - 2004**	
	Aphids (/m^2) 12 Oct	BYDV (%) 30 Apr.	Aphids (/m^2) 12 Oct	BYDV (%) 30 Apr.	Aphids (/m^2) 12 Oct	BYDV (%) 30 Apr.
PL – straw	278.8	46.2	9.7	13.2	75.9	18.3
PL + straw	222.8	42.3	3.0	14.2	82.6	9.8
RC – straw	144.8	13.4	5.9	7.4	74.0	14.2
RC + straw	46.3	6.0	3.8	8.0	95.8	10.7
LSD (5%)	34.4	8.6	NS	5.31	NS	NS

NS = Not significant

Aphid numbers on plants did not differ significantly between the two methods of cultivation in 2002/2003. However, consistent with results from the previous season, the incidence of BYDV was significantly lower in RC plots when compared with PL plots (Table 23). The addition of straw to plots of each of the two methods of cultivation resulted in non-significantly fewer aphids but had no effect of virus incidence. Overall, grain yields were low in 2003 and did not differ significantly between method of cultivation or between straw and non-straw treatments within each system of cultivation. The low yields in the PL plots were due mainly to BYDV infection and to a lesser extent to grass weeds while the low yields in the RC plots was due to high infestation of sterile brome grass (*Bromus sterilis L.*) and other grass weeds.

In 2003/2004, there was no significant difference in aphid numbers or virus incidence between RC and PL plots (Table 23). The addition of straw to plots of either RC or PL did not significantly affect aphid numbers or virus incidence when compared with plots of the same cultivation to which no straw was added. Barley was much slower emerging and becoming established in the PL plots in autumn 2003. This slow establishment, possibly due to deep sowing, would have contributed to fewer aphids and low virus occurrence.

Grain yields were non-significantly greater for PL plots relative to RC plots. RC plots treated with straw yielded 2.7 t/ha while those without straw had 2.9 t/ha. The low yield in RC plots was due in large measure to a high infestation of sterile brome. Despite the application of graminicides, the brome infestation in some RC plots was almost 70 ear-bearing tillers per square metre.

Overall, the combined data for the three seasons shows there were 11% fewer aphids and 27% less virus in winter barley grown in min-till plots when compared with barley grown in plots tilled in a conventional manner. The overall effect of adding straw to each method of cultivation, for the seasons 2001, 2002 and 2003, was a reduction in aphid infestation and viral infection but no difference in grain yield. RC plots had 36% fewer aphids and 31% less virus, over the three seasons, for plots treated with straw relative to those not receiving straw. The comparable data for PL plots was 15% fewer aphids and 15% less virus in straw treated plots.

Seed treatment: Barley grown from seed treated with the insecticide imidacloprid had significantly fewer aphids, in early winter, than barley grown from untreated seed. Aphid populations on crops grown from imidacloprid treated seed and RC cultivation, in 2001, 2002 and 2003, were 38%, 84% and 27%, respectively, of the population on crops from untreated seed and RC cultivation. Overall, the seed treatment/RC cultivation had only 38% the aphid density on untreated seed/RC combination. In PL plots, the early-winter aphid infestation on seed treated plots was 67%, 57% and 24% of the density recorded for untreated seed/PL combination. Overall, the seed treatment had 56% the aphid population infesting untreated plots.

In the seasons 2001, 2002 and 2003 the seed treatment reduced autumn aphid infestations in RC plots by 62%, 16% and 73%, respectively, when compared with untreated plots. The corresponding reductions in aphid numbers in PL barley were 33%, 43% and 76%.

The incidence of BYDV in barley grown from seed treated with the insecticide imidacloprid was lower than in barley grown from untreated seed. The seed treatment had significantly lower virus infection in five of the six trials in which comparisons were made. In RC plots, the mean BYDV infection in seed treated barley for 2001, 2002 and 2003 was 4% (tillers with virus symptoms) while barley from untreated seed had 13% infection. In PL plots barley grown from treated seed had a mean of 7% infection over the three seasons relative to 25% for barley from untreated seed.

A comparison of the efficacy of imidacloprid seed treatment in controlling BYDV symptoms in 2001, 2002 and 2003 showed the treatment was less effective than a single insecticide spray application at the 2-leaf stage of growth (Figure 5). The seed treatment gave 71% control of virus symptoms. A single autumn applied insecticide spray gave 94% control of symptoms while two autumn applied sprays gave 95% control. The seed treatment was more effective in controlling virus in RC than in PL plots. However, as reported earlier, BYDV was less prevalent in RC than in PL plots.

Slugs: The number of slugs captured by refuge trap, for a six week period from mid-October, increased considerably in all treatments over the seasons 2001 to 2004. The mean number of slugs per refuge trap was 1.5 in November 2001 increasing to 117 per trap in November 2004. In November 2004, slugs were significantly more numerous in RC plots [t-test ($P \leq 0.005$)] when compared with PL plots. However, most of the increase in slug numbers was due to factors other than cultivation since in PL plots slug numbers increased from 1 per trap in 2001 to 102 per trap in 2004. Additionally, the possibility of slugs migrating between plots was considerably lessened by the installation of plastic barriers between plots.

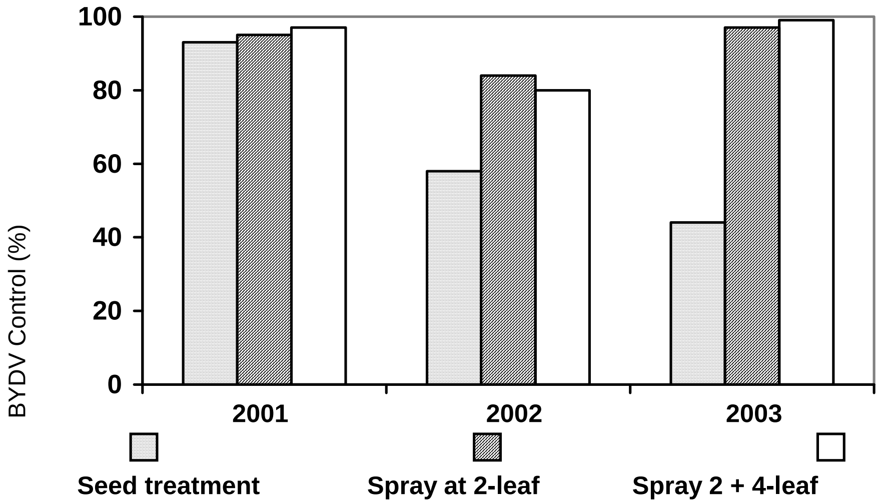

Figure 5: The percent BYDV control provided by insecticide seed treatment a two aphicide sprays to autumn sown barley, Oak Park, 2001 to 2003.

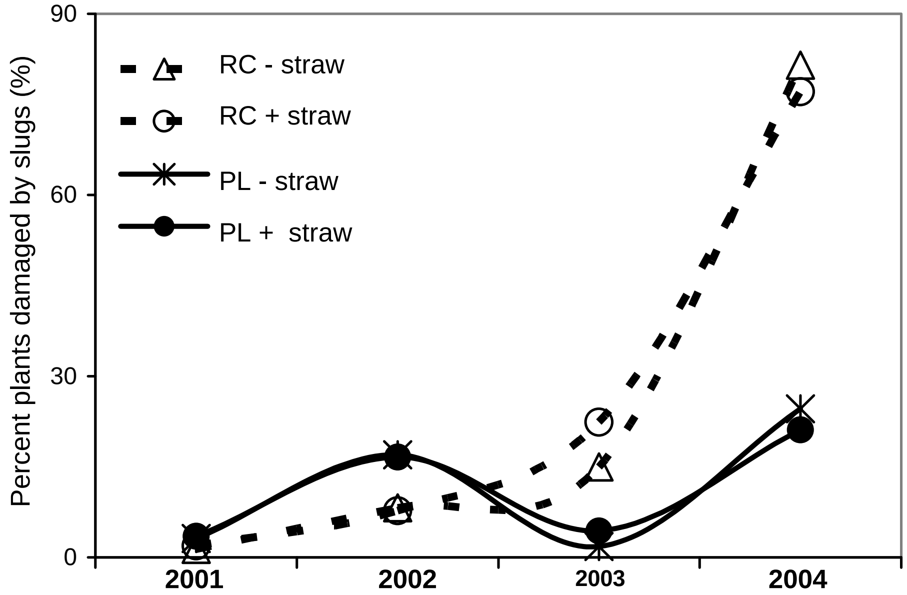

Figure 6.   Plant damage by slugs in RC and PL plots, Oak Park (road field), 2001 - 2004

The breakdown of slug species in 2001 was – grey field slug (*Deroceras reticulatum*) 90%, garden slug (*Arion hortensis*) 3%, keeled slugs (*Milax* species) 0, and unknown 7%.   In 2004, the species breakdown was 98%, 1.4%, 0.3% and 0.3%, respectively.

Damage to plants by slugs either as severed or shredded leaves was proportional to slug abundance (Fig. 7). The correlation coefficient r for slug numbers under refuge traps with percent plant damage in the four seasons 2001 to 2004 for RC - straw, RC + straw, PL - straw, and PL + straw was 0.93, 0.92, 0.99 and 0.99, respectively. Slugs did not damage barley seed nor reduce plant numbers.

The incorporation of straw in either RC or PL plots did not result in an increase in either slug numbers or slug damage.

Earthworms: Earthworm numbers and biomass did not differ significantly between RC and PL plots at the commencement of the investigation in autumn 2001. In the period 2001 to 2004 both numbers and biomass of worms increased in all treatments and in particular in RC plots. In general, numbers and biomass of worms increased by a factor of 2.5 in PL plots between 2001 and 2004. The corresponding increase in RC + straw plots was 13 fold (Table 24 and Figure 7). From 2002, worms were significantly more abundant in RC plots relative to PL plots.

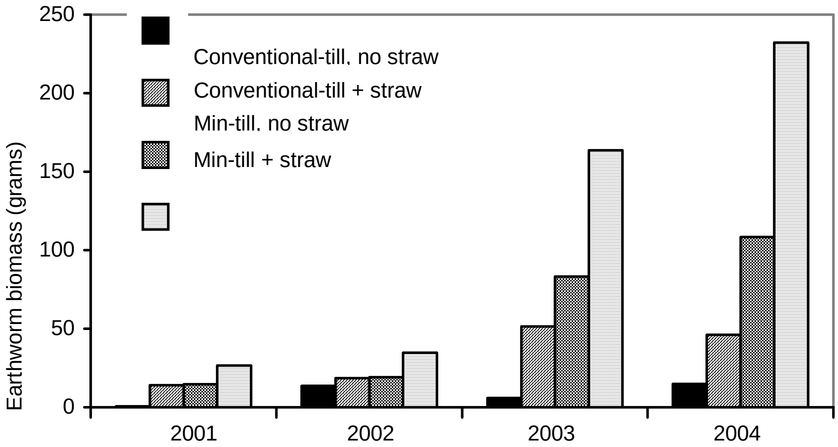

Figure 7: Earthworm biomass, winter barley, Oak Park (Road Field), 2001 - 2004

The positive influence of straw incorporation on worms was also recorded in autumn 2004 when straw treated plots within each system of cultivation had significantly more worms than non-straw treated plots.

The breakdown of earthworm species in 2003/2004 was: *Allolobophora chlorotica* 21%, *Aporrectodea caliginosa* 9%, *A. ro*sea 3%, *Lumbricus terrestris* 4%, *L. festivus* 7%, immature tanylobics 15%, immature epilobics 34% and unidentified (damaged) 7%. The population density of the large deep-burrowing *L. terrestris* in RC ± straw in autumn 2003 was $24/m^2$ for each treatment. This density increased to $72/m^2$ for each of these treatments by autumn 2004. Only a single *L. terrestris* was found in the straw treated PL plots in 2003 and none was found in any of the PL plots in autumn 2004.

Table 24: Earthworm numbers, winter barley, Oak Park (Road field) 2000 – 2004

	Earthworm counts/m^2			
Treatment	2001	2002	2003	2004
PL – straw	2	24	40	58
PL + straw	38	48	28	94
RC – straw	18	114	114	286
RC + straw	36	94	184	456
LSD (5%)	NS	44.7	112.3	11.1

NS = Not significant

Ground beetles: The ground beetle fauna (Family Carabidae) was investigated in RC and PL plots in 2003 and 2004 to determine if method of cultivation and straw incorporation affected the abundance and community structure of these predatory beetles. The results show there was no significant difference in beetle numbers due to treatment in the two seasons. However, in 2004 there was a 45% reduction in the number of beetles captured as well as a shift in community structure. In 2004, there was a significant decline in the abundance of the seven more dominant species trapped in 2003. In contrast, four species were significantly more numerous in 2004 than in 2003 (Table 25). In general, the effect of method of cultivation on beetle abundance was greater than the effect of straw incorporation. Large species such as Pterostichus melanarius were favoured by RC while smaller species like Bembidion were generally captured in greater numbers in PL plots. In addition to the direct impact of method of cultivation on beetle life-cycles and reproduction the distribution patterns of most of the species indicate an influence of other factors such as food supply and competition.

Table 25: The species of carabid beetles having significant differences in abundance in the seasons 2003 and 2004, Oak Park, Carlow.

Carabid species	2003	2004	p-value
Species for which a population decline was recorded			
Amara plebeja	225	57	<0.001
Nebria brevicollis	87.4	55	<0.001
Bembidion tetracolum	80.9	17.8	<0.001
Loricera pilicornis	62.5	15.5	<0.001
Notiophilus substriatus	54.2	11	<0.001
Bembidion lampros	48.9	15	<0.001
Bembidion aeneum	24.4	1.3	<0.001
Species for which a population increase was recorded			
Pterostichus melanarius	73	103.2	0.023
Harpalus rufipes	6.5	21.2	<0.001
Pterostichus strenuous	2.7	10.8	<0.001
Trechus quadristriatus	7.0	16.3	<0.001
Amara similata	0.6	5.5	0.002

Molecular studies on virus diseases, vectors and vector-predators: Sources of viruses and vectors as well as the probable role of vector-predators in reducing virus incidence are under investigation. Primers for the coat protein genes of the three strains of BYDV were selected and tested. Primers, targeting the mitochondrial gene cytochrome oxidase, were successfully designed for aphid detection. Initial investigations of aphid predation by field captured beetles using aphid primers is given in Table 26. The table gives the results for the seven most common species encountered. Investigations on beetles and beetle larvae are continuing.

Table 26: The number of field captured beetles examined and the percent testing positive for the aphid *Sitobion avenae* using 103 bp product size

Species (*Carabidae*)	Number of beetles examined	Percent positive (103 bp size)
Nebria brevicollis	181	5.5
Bembidion tetracolum	62	12.9
Bembidion lampros	28	14.3
Pterostichus melanarius	17	11.8
Amara species	83	15.6
Notiophillus biguttatus	179	13.4
Trechus quadristriatus	50	16.0

Spring Barley

The spring barley experiment was not replicated. It consisted of a 2-hectare field divided in two large plots which were PL and RC. In 2000-01 the RC area was further divided into: (a) shallow cultivation (100 mm) in autumn only, (b) shallow cultivation in autumn plus a shallow cultivation again before sowing in spring. Straw was baled and removed from all plots in autumn 2000 when the first cultivations for the 2001 crop were done.

The results are given in Table 27. There seemed to be a trend towards a lower grain yield on the reduced cultivation area whether cultivated in autumn or spring, but only small differences between components of yield between both treatments.

Table 27: Effect of cultivation system on spring barley yields, Oak Park (Clonaherk), 2001

Cultivation system	Grain yield (t/ha @ 15% m.c.)	Ears/m²	Grains/ear	1000-grain weight (g)
PL	8,320	925	15.31	46.1
RC[1]	7,937	997	14.57	45.34
RC[2]	7,860	966	15.00	45.29

[1] Cultivated in autumn 2000 only.
[2] Cultivated in autumn and spring only.

In 2002 the comparisons at the Clonaherk site were altered. The basic split field comparison between PL & RC were maintained but two drills were used on the RC plot. A Vaderstad cultivator drill was used to sow the PL and half the RC plot, and a John Deere the other half of the RC treatment. All the RC area was cultivated in autumn 2001 only.

There was little difference in yield between PL and RC when sown with the same drill (Vaderstad) but the yield was lower when sown with a John Deere drill (Table 28). The Clonaherk site was quite wet and in 2002 the crops suffered from excess water and lack of oxygen on PL and RC areas. The headlands on the RC area appeared to suffer more in the adverse conditions and this was accompanied by an increase in annual meadow grass infestation.

Table 28: Grain yield and components of yield, spring barley, Oak Park (Clonaherk), 2002

	PL	RC	
	Vaderstad	Vaderstad	John Deere
Plant establishment (plants m²)	208	167	145
Ear numbers (ears m²)	1137	1177	1278
Grains/ear	17.1	16.2	15.1
10000-grain weight (g)	40.5	39.2	40.4
Grain yield (t/ha @ 15% m.c.)	7.7	7.9	7.0

In 2002-03 the experiment reverted to a single shallow (10cm) cultivation on the RC area in autumn and sowing with one drill – the Vaderstad Rapid cultivator drill. All straw was baled and removed.
Plant establishment was better on the PL area (Table 29) and the grain yield was slightly better after ploughing also. Hectolitre and 1000-grain tended to be higher weights and screenings lower on the PL treatment.

Table 29: Plant establishment, grain yield and quality spring barley, Oak park (Clonaherk), 2003

Treatment	Plant establishment (/m²)	Grain m.c. (%)	Grain yield @ 15% m.c. (t/ha)	1000-grain weight (g)	Hectolitre weight (kg/hl)	Screening < 2mm (%)
PL – straw	325	12395	8.40	43.5	68.76	1.38
RC – straw	281	11.99	8.25	42.7	67.07	1.87

Rotation experiment on RC only site

A new element was added to the programme in autumn 2002, when a rotation experiment on a reduced cultivation system was laid down. The cropping sequence in this experiment is:

1. Sugar beet
2. Winter wheat
3. Spring barley
4. Spring barley (continuous) is also included.

Shallow cultivations (one pass at 7-10cm) were done soon after harvest of the previous crop. In the case of winter wheat, this is sown as soon as possible after the beet harvest; for the spring-sown crops the cultivation is followed by a total herbicide (Sting CT) application when the volunteers and weeds have become established (3-6 weeks). Herbicide may be applied again in spring if required and a further shallow cultivation for the sugar beet and , depending on soil condition, for the spring barley.

In the first year, winter wheat yields were excellent, spring barley fair and sugar beet good (Tables 30 and 31)

Table 30: Plant establishment and grain yield (cereals), - rotation experiment, Oak Park (Big Bull Park) 2002-03

Crop	Plant establishment (plants/m²)	Grain yield @ 15% m.c. (t/ha)	Hectolitre weight (kg/hl)	1000-grain weight (g)	Screenings <2mm (%)
Winter wheat	222	10.92	72.63	44.7	7.28
Spring barley (rotational)	284	6.05	64.05	40.1	7.01
spring barley (continuous)	291	5.71	62.1	40.6	6.84

Table 31: Plant establishment and root and sugar yields, rotation experiment Oak Park (Bill Bull Park) 2002-03

Plant establishment (/ha)	88,083
Root count (/ha)	84,834
Root yield (t/ha)	56,898
Sugar content (%)	20.16
Sugar yield (t/ha)	11.467
Badly forked roots (%)	18.26

Conclusions

- Plant establishment tends to be lower on RC than on PL especially in the first couple of years of the transition from a plough-based system. However, RC provides the opportunity to cultivate and sow large areas in a short time allowing crops to be sown in good conditions.

- Straw disposal method had no effect on plant establishment in these experiments, probably because the straw was well chopped and spread where it was being incorporated. Good chopping and spreading of straw is essential to maximise plant establishment under reduced cultivation systems.

- Reduced cultivation is capable of giving yields equal to or better than those after ploughing particularly with winter wheat, but problems arise which do not occur to the same extent with the conventional system. Diseases, such as take-all, may be less of a problem with shallow cultivation.

- Annual broadleaved weed populations tend to be lower under the reduced cultivation system but grass weeds may be more of a problem. Sterile brome in winter barley has proved to be a serious problem in these experiments.

- Crops grown in reduced cultivation systems, particularly where straw is incorporated, may have fewer aphids and less BYDV problems than those in plough-based systems.

- While slug numbers and leaf damage may increase after changing over to reduced cultivation, there does not appear to be any increase in damage to the seed or increase in plant loss. This may be due to slightly deeper sowing and the better consolidation which cultivator drills provide.

- Earthworms increase over time under shallow non-inversion tillage compared with ploughing. Straw incorporation also boosts earthworm populations.

- Soil strength increases in the topsoil under shallow cultivation making it less susceptible to compaction from wheel traffic. However, because the shallow cultivation will not remove any compaction that is caused, great care must be taken to avoid unnecessary traffic when the soil is moist and to use low ground pressure tyres on tractors, trailers and combines.

- Sugar beet yields have been lower and root shape poorer under reduced cultivation. Deeper cultivation may be needed for beet than we have used to date. Where weed beet is a serious problem reduced cultivation may provide a solution by reducing the seed bank in the top layer.

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