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The effect of cultivation method on optimum plant population in winter wheat

by

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Contents

Abstract

This project aimed to understand the impact of reduced tillage on crop establishment and optimum plant population, by understanding how cultivation practice may limit the crop's ability to compensate for low plant populations. An additional aim was to produce quantitative data on factors affecting plant establishment.

In experiments, at three sites with differing soil types, over three years, we examined the interactions between five seed rates (40, 80, 160, 320 and 640 seeds/m^2) and three cultivation treatments using farm-scale equipment. The three cultivation treatments were: ploughing, reduced tillage and reduced tillage plus an application of nitrogen (30-40 kg/ha) between drilling and emergence to remove any effect of differences between treatments in residual nitrogen.

Conclusions

- Cultivation practice had a significant effect on seedbed quality and resultant plant establishment.
- On unstable silt-dominated soils, plough-based cultivation practice resulted in better seedbed structure, greater plant establishment (54% more plants) and greater crop growth (45-48% higher spring green area index and dry matter yield).
- On stable soils, reduced tillage cultivation practice resulted in significantly better seedbed quality, greater plant establishment (21-24% more plants) and greater crop growth (22-24% higher spring dry matter yield and 16% more green area index).
- Cultivation practice did not limit tillering compensation for low plant densities.
- Cultivation practice had a significant effect on grain yield through effects on seedbed structure or quality, resulting in improved levels of plant establishment.

Summary

Previous seed rate work

In a previous HGCA-funded project (Project Report No. 234, Spink *et al*., 2000) the effect of reducing plant population on the economic performance of winter wheat crops was tested at ADAS Rosemaund in Herefordshire, and Sutton Bonnington in Leicestershire. Seed rates ranged from 20 to 640 seeds/m^2, and sowing dates were from September to November.

Linear-plus-exponential curves were fitted to the yield data to estimate the economic optimum seed rate. The economic optimum was defined as the point on the curve at which the rate of yield increase was no longer sufficient to cover the increased seed cost. The potential for significant reductions in target plant population were identified with optimum plant populations as low as 70 plants/m^2 from a September sowing. The primary mechanism of compensation for low plant density crops was increased tiller production.

A second HGCA-funded project (Project Report No. 361, Spink *et al*., 2005) investigated a number of unanswered questions left by the previous project, such as the impact of agronomic factors on this plant compensation mechanism. The interactions of a number of agronomic factors with optimum plant population were tested at six sites across the UK. To test whether the previously determined optimum plant populations were applicable across the UK, sites were distributed from the south coast of England to Aberdeen. In addition, in each experiment an agronomic factor was varied to test its effect on optimum plant population or to test the crop response to the factor at low plant populations. The effects of slug control, rotational position, nitrogen timing and PGR use were investigated.

The agronomic factors tested had little significant effect on optimum plant population and the plant's ability to compensate for low populations, with two notable exceptions. In rotational positions where take-all infection occurred, optimum plant populations were 30-40 plants/m^2 lower. Low soil mineral nitrogen or delayed spring nitrogen application reduced tillering at most sites, although this only affected the optimum population in one of seven experiments. Overall the optima were slightly higher than in the previous project, ranging from 70 plants/m^2 in September drillings in southern England, to 250 plants/m^2 in Scotland.

The first project (Project Report No. 234, Spink *et al*., 2000) identified the potential to reduce target spring populations from the 275 plants/m^2 target that had been traditionally used in the UK. The second project (Project Report No. 361, Spink *et al*., 2005) demonstrated that most agronomic factors had little effect on optimum population. However, for a grower to accurately calculate the seed rate necessary to achieve the economic optimum plant population, an estimate of expected establishment has to be made. An HGCA-funded research review (Blake *et al*., 2003) investigated the factors affecting establishment in experiments at 27 sites over the past 25 years. Average autumn establishment was 67%, lower than the 85% figure that is commonly used for wheat. Germination and subsequent emergence were affected by a number of soil

characteristics, including soil type, clod size, soil condition and cultivation practice. For a grower to accurately predict establishment, and therefore maximise savings in seed costs, it is important to understand how these key soil characteristics can be manipulated.

Project rationale

In UK arable farming, reduced tillage systems have become increasingly common because growers need to reduce fixed costs by reducing labour costs and increasing work rate in the autumn. The establishment review (Blake *et al.*, 2003) identified that methods of secondary cultivation had a significant effect on establishment. In both of the previous seed rate projects, optimum plant populations were derived in crops established after conventional plough-based primary cultivation. Significant differences in the physical structure of soil surface can occur between different cultivation methods. Therefore, the applicability of these optima under reduced-tillage needed investigation.

Crops grown at low plant densities rely on increased tiller production and survival as the primary mechanism for compensation. Environmental conditions that restrict tillering may have an effect on optimum plant population. Late sowing, low residual soil N levels, or delayed spring N applications, were identified by the previous work as factors that reduce the crop's ability to compensate through additional tiller production. Previous studies and observations of commercial crops established with reduced cultivations suggest that these crops may suffer transitory nitrogen limitation. This may have a similar effect to low residual or delayed spring application of N and adversely affect tiller production or survival, reducing the crop's ability to compensate for low plant densities.

A project was, therefore, set up to understand the impact of reduced tillage on plant establishment and optimum population. Three cultivation treatments were compared on main plots. These were ploughing, reduced tillage, and reduced tillage plus an application of nitrogen (30-40 kg N/ha) between drilling and emergence to remove any effect of differences between treatments in residual nitrogen. Five seed rates (40, 80, 160, 320 and 640 seeds/m^2) were compared on sub-plots. Three sites with contrasting soil types were selected. A silty clay loam soil type at Rosemaund (RM) in Herefordshire; a clay soil at Boxworth (BX) in Cambridgeshire and a medium sandy loam over clay at Morley (MOR) in Norfolk. Seedbed quality, plant establishment, rate and duration of leaf and tiller production, and yield response to plant population, were assessed.

Cultivation effects on soil characteristics

Aggregate stability was assessed by dispersion ratio analysis of the differing soil types, and this indicated that the soils from BX and MOR had a similar stability and were 4-5 times more stable than the soil at RM. On these more stable soils at BX and MOR, seedbeds created by reduced tillage had significantly more moisture, a lower bulk density and significantly less large clods than those produced after ploughing. Average bulk densities after reduced tillage were 1.15 g/ml and 0.87 g/ml from BX and MOR respectively, compared with 1.23 and 0.97 after ploughing. At BX, seedbeds produced following reduced tillage had on average 18% fewer aggregates larger than 9.5 mm (P=0.080), compared with after ploughing (Figure S1). At MOR, there were 33% fewer aggregates larger than 9.5 mm (P=0.065) following reduced tillage compared with ploughing (Figure S2).

In contrast, on the unstable silt-dominated soil at RM, cultivation practice had little effect on seedbed moisture and aggregate size distribution (Figure S3). However, visual Peerlkamp scores of soil structure of the 0-10 cm horizon were 3.9 following reduced tillage and 5.8 following ploughing. Bulk density also tended to be higher after reduced tillage (1.0 g/ml) compared with ploughing, (0.95 g/ml). This, along with photographic evidence, suggested that seedbeds produced following ploughing were well structured and more porous with better seed to soil contact than those produced after reduced tillage.

In summary, effects of cultivation on soil physical properties differed according to soil type. On the stable soils, reduced tillage produced significantly better quality seedbeds with more moisture in the topsoil and with better soil structure. Where the soil type was less stable and dominated by silt, ploughing tended to produce better quality seedbeds with better soil structure than reduced tillage.

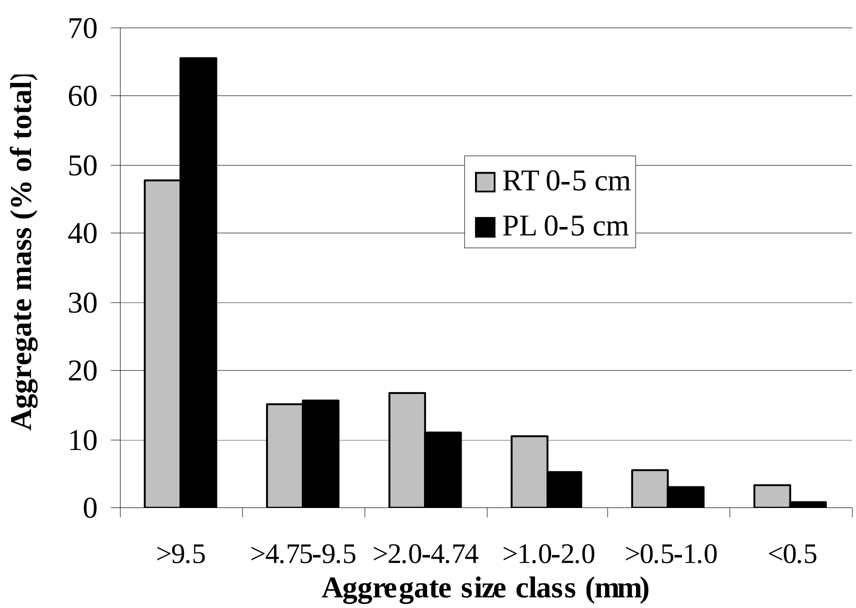


Figure S1. Cultivation effects (RT = Reduced tillage, PL = Ploughing) on aggregate size distribution at 0-5 cm soil depth, at BX. Values are % of aggregates by weight in each size class over three years.

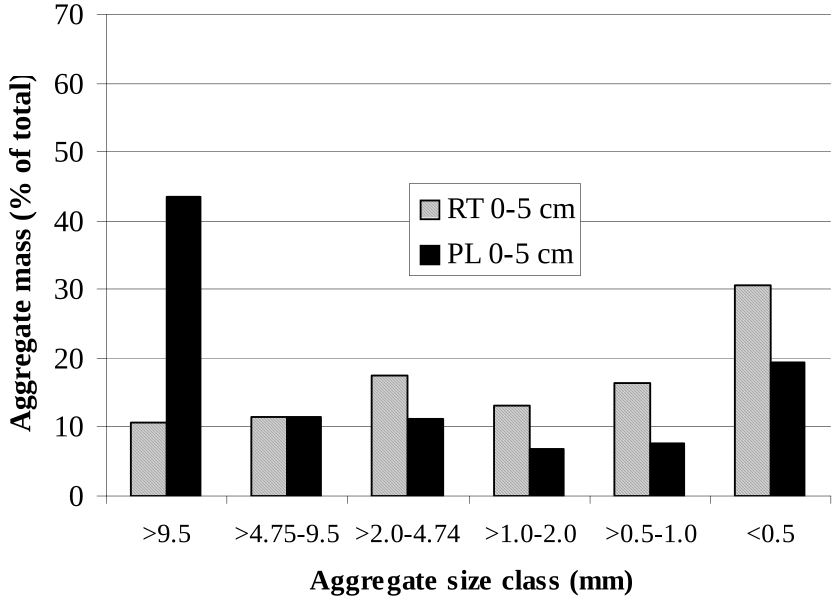


Figure S2. Cultivation effects (RT = Reduced tillage, PL = Ploughing) on aggregate size distribution (%) at 0-5 cm, at MOR. Values are % of aggregates by weight in each size class over three years

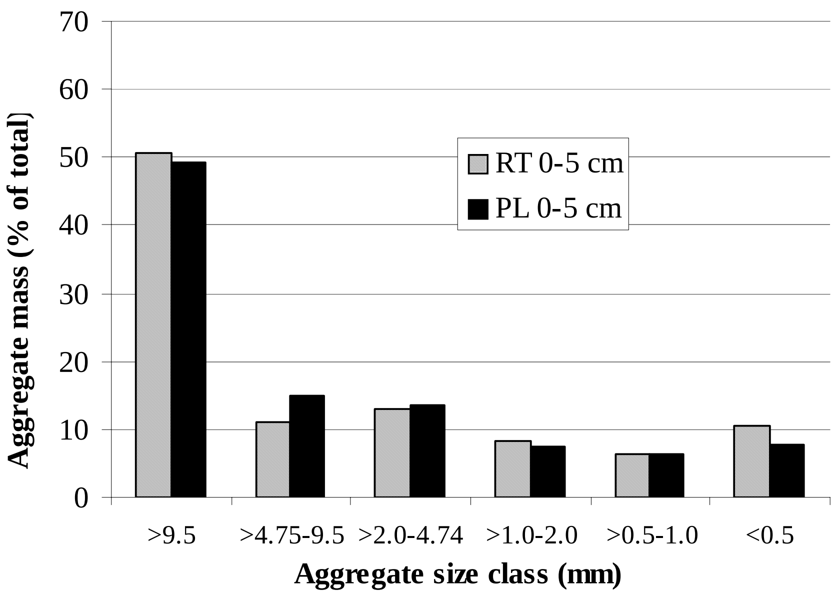


Figure S3. Cultivation effects (RT = Reduced tillage, PL = Ploughing) on aggregate size distribution (%) at 0-5 cm, at RM. Values are % of aggregates by weight in each size class over three years.

Cultivation effects on plant establishment

The effects of cultivation practice on soil physical properties and seedbed quality had a direct effect on the resultant plant establishment. A significant response to cultivation of established plant population was seen in two out of the three study years at RM. Established plant populations averaged across the seed rates and years showed 54% more plants established after ploughing compared with after reduced tillage. Average plant establishment was 78% after ploughing and 54% after reduced tillage (Figure S4). This was a direct result of the better soil structure and seed to soil contact seen after ploughing on the soil type at the RM site.

In contrast, at BX established plant populations were significantly lower after ploughing compared to reduced tillage in the second and third years, when plant populations were between 21 and 24% lower after ploughing than after reduced tillage. Average plant establishment was 64% after reduced tillage compared to 46% after ploughing (Figure S4). As at RM, these results were related to the effects of cultivation treatments on soil physical properties, except that at BX reduced tillage resulted in better quality seedbeds and lower bulk densities than ploughing. At MOR, cultivation effects on soil structure and seedbed quality did not result in significant differences in established plant populations.

Across the sites there was a consistent response in plant establishment to the addition of an autumn application of nitrogen. Additional nitrogen applied soon after drilling increased average established plant population densities by 13.3% at RM, 3.5% at BX and 3.1% at MOR. This result was probably caused by additional nutrient availability during the critical period immediately post-drilling, resulting in improved plant survival.

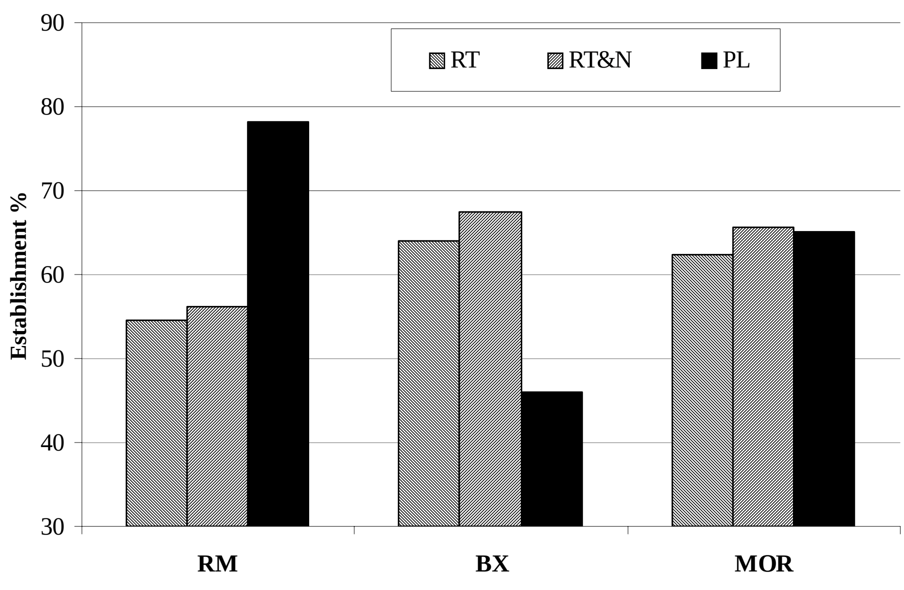


Figure S4. Cultivation and site effects (RT = Reduced tillage, RT&N = Reduced tillage plus autumn N, and PL = Ploughing) on plant establishment (%), mean of three years.

Interaction of cultivation and seed rate effects on plant establishment

Effects of seed rate on plant establishment were similar to those seen in previous HGCA-funded seed rate studies, and the establishment review. In all of these studies, percentage crop establishment decreased with increasing seed rate. On average, for every 100 seeds/m^2 increase in seed rate there was a 5.2 % reduction in establishment (Figure S5). For example, in a field where 60 % establishment could be expected at a seed rate of 400 seeds/m^2, one could expect 75.6 % establishment at 100 seeds/m^2. But it is also worth noting that there was greater variation in establishment at low seed rates. This relationship was similar for the different cultivation treatments, with reductions in % establishment per 100 seeds/m^2 of 4.6 % for ploughing, 5.1% for reduced tillage plus N and 5.6% for reduced tillage. This indicates that, on average, under reduced tillage, slightly poorer percentage establishment can be expected as seed rate is increased.

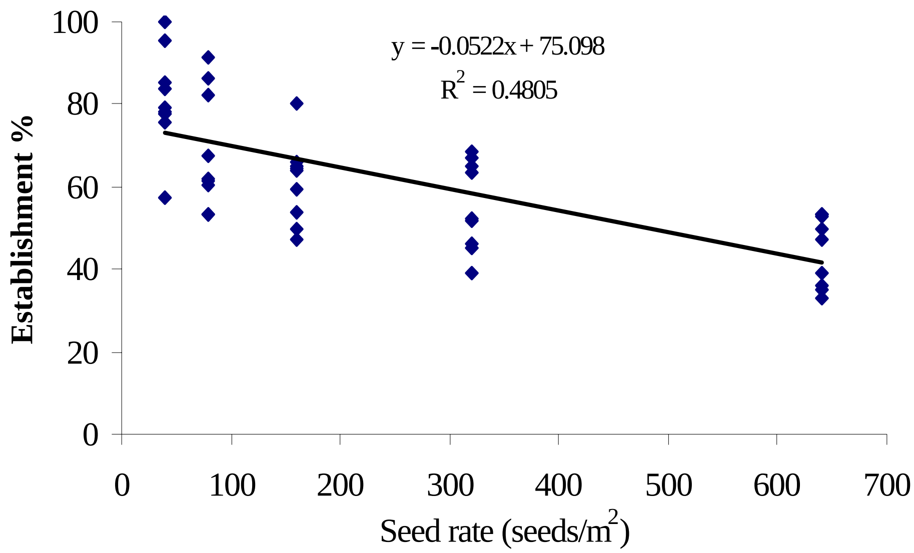


Figure S5. Relationship between seed rate (seeds/m^2) and plant establishment (%): average of 9 site seasons.

Compensation for low plant population

In previous HGCA-funded seed rate studies, the primary plant compensatory mechanism was increased tiller production. This project investigated whether cultivation practice would limit the crop's ability to compensate for low plant densities. Shoot number data from tagged plants, from 40, 80 and 320 seeds/m^2 treatments, showed average final shoot numbers per plant of 12.7, 10.2 and 4.4 respectively. An exponential relationship was found between plant number and shoot number per plant (Figure S6).

This increased shoot number per plant appeared to be due to an increase in the duration of tillering at low plant densities. Tillering in the two lowest seed rates was extended by 30 to 60 days compared to the 320 seeds/m^2 treatment, in which no more tillers were produced after about mid-April. Both findings confirmed those of earlier seed rate work, in that tiller production is controlled by competition for resources between shoots.

Effects of cultivation practice on tiller production were only seen where cultivation affected plant establishment. At RM, where fewer plants were established after reduced tillage, there was a tendency for more shoots per plant at low plant densities. Following reduced tillage, there were12.3 and 9.6 shoots/plant compared to 10 and 7.9 shoots/plant after ploughing, from seed rates of 40 and 80 seeds/m^2 respectively. However, at BX the converse was true, as poorer establishment was seen after ploughing but again, there was tillering compensation at low plant densities. After ploughing, there were 15.3 shoots/plant from a seed rate of 40 seeds/m^2 and 11.9 shoots/plant from 80 seeds/m^2 compared with 14.6 and 10.2 shoots/plant respectively after reduced tillage. This again indicates that resource competition between shoots controls tiller production and death.

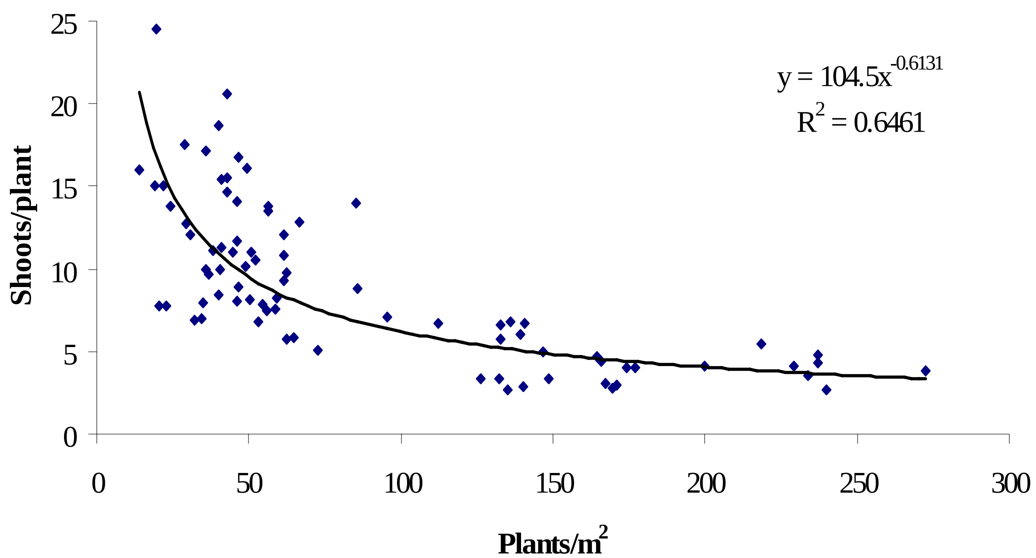


Figure S6. Relationship between plant density and shoots/plant: average of 9 site seasons.

Crop growth compensation

As expected, seed rate had a significant effect ($P < 0.001$) on crop growth in terms of total dry matter and green area index assessed in March. When target seed rate was increased from 40 to 80 seeds/m^2, crop biomass increased 1.4 fold, with a further 2 fold increase from 80 to 320 seeds/m^2. Green area indices showed a similar response with a 1.7 fold increase as target seed rate was increased from 40 to 80 seeds/m^2, and an additional 3.3 fold increase, as seed rate was increase to 320 seeds/m^2. This was further evidence of the crop's ability to compensate for low plant densities, as the 8 fold difference in the 40 and 320 target seed rates resulted in differences of 3 and 5 fold for biomass and green area respectively.

On average, at RM, significantly lower crop biomass (48 %) and green area index (45 %) were recorded after reduced tillage compared with ploughing. The additional application of autumn nitrogen after reduced tillage reduced this difference to 24 % and 29 % for biomass and green area index respectively. In contrast, but again related to plant establishment at BX and MOR, reduced tillage tended to produce a crop of greater biomass than ploughing, although the effect was only significant in one year at BX, and two at MOR. On average, crops at BX following ploughing had 24 % and 16 % lower biomass and green area index respectively compare to reduced tillage. At MOR, 22 % less biomass was produced after ploughing than after reduced tillage. Autumn nitrogen application increased biomass by 10 % at BX and 9 % at MOR compared to reduced tillage alone.

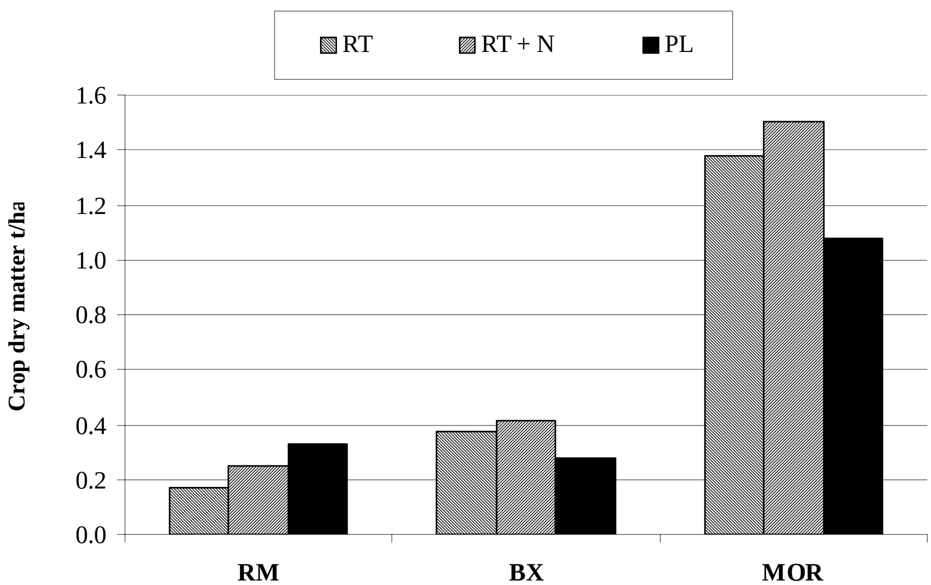


Figure S7. Cultivation effects on crop biomass (t/ha) measured in early March at three sites, mean of three years.

Effects on grain yield

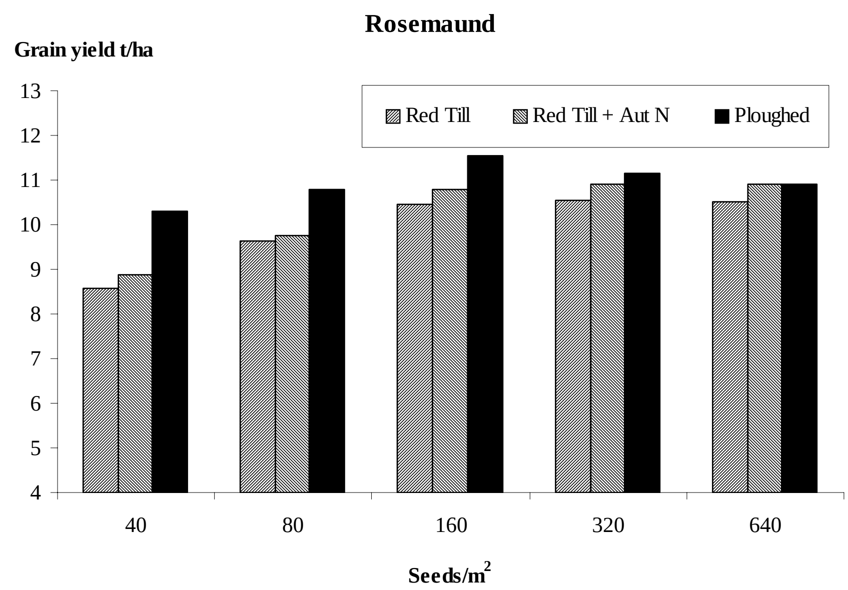
Greatest mean grain yield across the nine site seasons and cultivation treatments was from a seed rate of 320 seeds/m^2 (Table S1). There was, however, no significant difference when seed rate was halved to 160 seeds/m^2. At two sites (RM and MOR) the greatest mean yield was from 160 seeds/m^2. The calculated optimum seed rate across these two sites, however, varied across the years between 90 and 250 seeds/m^2 depending on the curve fitting approach used, and the percentage plant establishment achieved. Reducing seed rate to 40 seeds/m^2 caused a mean yield loss of 1.47 t/ha. This indicated that the plant compensation described earlier had reduced the seed rate differences further still by the time of harvest, such that one eighth of the seed rate achieved 86 % of maximum yield and one quarter seed rate achieved 95% of the maximum. As in previous studies, this indicates the crop's ability to compensate for low plant density and the potential for reduced seed rates.

Effects of cultivation on grain yield were directly related to effects on seedbed quality, plant establishment and crop growth on the different soil types at the three sites. At RM, where ploughing produced seedbeds with better soil structure resulting in 23 % higher plant establishment, there was a yield benefit of 0.98 t/ha (Figure S8 a) compared with reduced tillage. At BX, there was again a cultivation effect with reduced tillage giving a yield benefit of 0.35 t/ha (Figure S8 b). At MOR, where cultivation did not result in effects on plant establishment, there were no significant differences, but there was a tendency for reduced tillage to show a yield benefit of 0.29 t/ha (Figure S8 c).

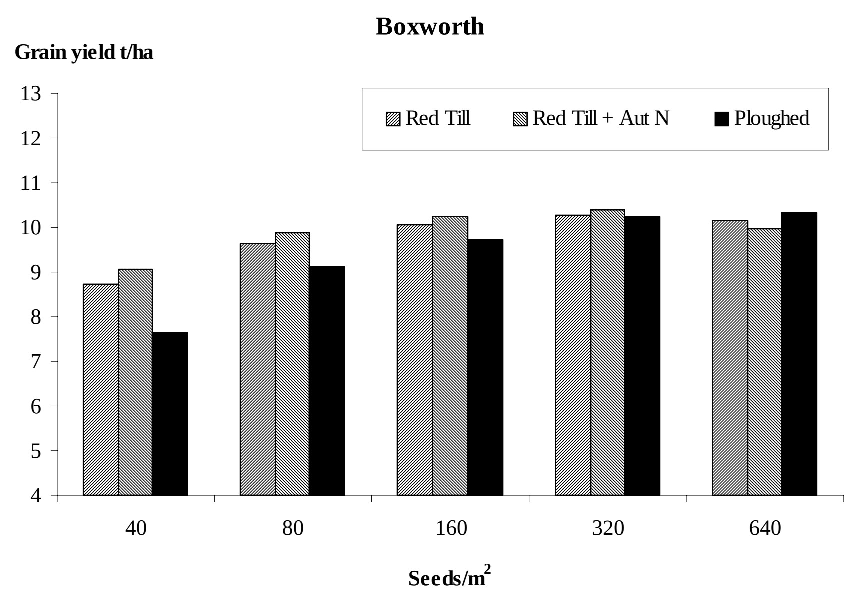
An autumn application of nitrogen after reduced tillage tended to give a yield benefit of 0.13 t/ha although this was only significant on one occasion.
The results indicate that the main seed rate responses are not adversely affected by cultivation practice.

Table S1. Seed rate effects on grain yield (t/ha @ 85% dm).

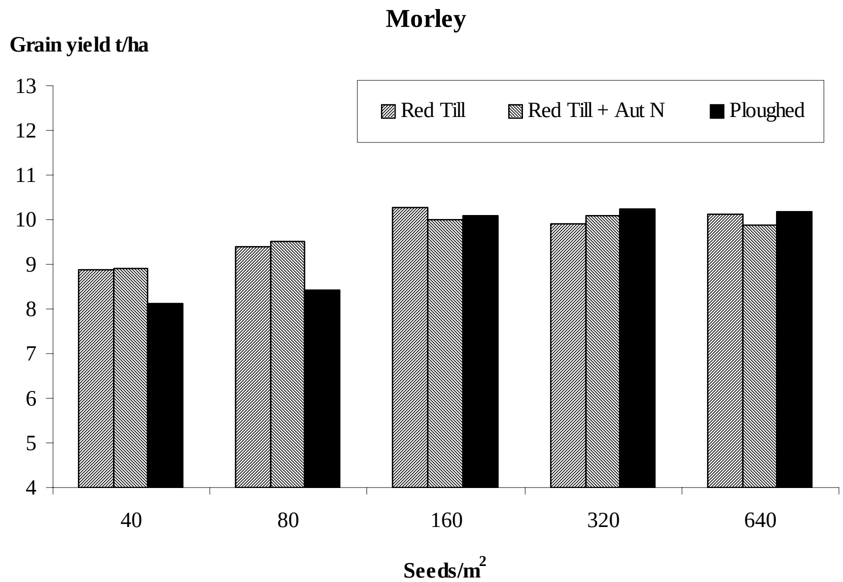
	2002/3			2003/4			2004/5			
Seed rate	RM	BX	MOR	RM	BX	MOR	RM	BX	MOR	**Mean**
40	9.57	7.10	8.74	10.53	8.56	6.84	7.65	8.47	10.32	8.92
80	10.31	7.04	8.96	11.20	10.15	7.66	8.65	9.54	10.72	9.84
160	11.16	7.06	9.58	12.07	10.85	9.45	9.55	10.02	11.32	10.34
320	11.48	7.59	9.57	11.61	11.31	9.37	9.52	10.30	11.29	10.39
640	11.29	8.17	9.69	11.65	10.39	9.50	9.41	10.16	10.96	10.21
Mean	10.76	7.41	9.32	11.41	10.25	8.56	8.95	11.45	10.92	9.94
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
SED	0.168	0.147	0.117	0.179	0.221	0.563	0.201	0.223	0.190	
df	24	24	24	24	24	24	24	24	24	


Rosemaund
Grain yield t/ha
13
12
11
10
9
8
7
6
5
4
Red Till
Red Till + Aut N
Ploughed
40
80
160
320
640
Seeds/m2

S8 a)


Boxworth
Grain yield t/ha
13
12
11
10
9
8
7
6
5
4
Red Till
Red Till + Aut N
Ploughed
40
80
160
320
640
Seeds/m2

S8 b)



S8 c)

Figure S8. Effect of seed rate on grain yield, mean of three years. a) RM, b) BX and c) MOR.

Conclusions

- Cultivation practice can have a significant effect on seedbed quality and resultant plant establishment.
- On unstable silt-dominated soils, plough-based cultivation practice resulted in better seedbed structure, greater plant establishment (54% more plants) and greater crop growth (45-48% higher spring green area index and dry matter yield).
- On stable soils, reduced tillage cultivation practice on average resulted in significantly better seedbed quality, greater plant establishment (21-24% more plants) and greater crop growth (22-24% higher spring dry matter yield and 16% more green area index).
- The main plant compensatory mechanism for low plant densities was confirmed as increased tiller production and extension of the tillering phase.
- Cultivation practice did not limit tillering compensation for low plant densities.
- Cultivation practice had a significant effect on grain yield through effects on seedbed structure or quality, resulting in improved levels of plant establishment.

Introduction

Research in previous HGCA-funded projects on winter wheat has demonstrated the economic benefits of optimising plant population (Spink *et al*., 2000). That project identified that there was the potential to reduce target spring plant populations significantly without compromising the economic output of the crop. It compared a range of seed rates (20 to 640 seeds/m^2) at sowing dates from September to November at ADAS Rosemaund in Herefordshire, and Sutton Bonnington in Leicestershire. Economic optimum plant populations as low as 70 plants/m^2 from a September sowing were identified. These economic optima were derived by fitting linear-plus-exponential curves to the yield data. The point on the curve at which the rate of yield increase was no longer sufficient to cover the increased seed cost was determined as the economic optimum. As a result of this and other work, including work demonstrating the reduction in lodging risk from a reduced plant population (Berry *et al.*, 1998), there has been a trend for seed rates in winter wheat in the UK to be reduced.

In order for the grower to decide how much seed to plant to achieve the target spring plant population, an estimate of the likely establishment is made. This has usually been estimated at around 85% or lower depending on seedbed conditions. An HGCA research review (Blake *et al*., 2003) investigated the factors affecting establishment from experiments at 27 sites over the last 25 years. It found that the average autumn establishment was 67%, lower than the 85% figure that is commonly used for wheat by growers. There was also significant variation, ranging from 2 to 100%. The review identified important soil characteristics that affected seed germination and subsequent emergence. Those important in germination were seed-to-soil contact and soil water status. Emergence was affected by those factors causing impedance such as clod size distribution. All of these soil characteristics can be affected by a number of factors at drilling, such as soil type, soil condition and cultivation practice. But the review also identified a knowledge gap with few quantitative records of seedbed quality or soil moisture, the abiotic factors influencing establishment.

In recent years in UK arable farming there has been a move to reduced-tillage systems because growers need to reduce fixed costs by reducing labour costs and increasing work rate in the autumn. Therefore in certain areas and on certain soil types, minimum, reduced or non-inversion tillage has become prevalent. The review of establishment indicated that the type of machinery used to create the seedbed affected establishment. Out of three forms of cultivation, power harrow, disc, or tined cultivation, the last was the most successful with 80% establishment compared to 62-66% for the other two methods. In addition, questions were raised about the relevance of the first phase of the plant population work (Spink *et al*., 2000) to crops grown under a reduced-tillage system, because it was carried out under conventional tillage systems. Cultivation method has significant effects on the way residues from previous crops are incorporated, on the amount of residue left on the soil surface, and therefore on the physical structure of the soil surface. As well as impeding germinating seeds it may also affect biotic factors such as slug survival and activity, and therefore differences in establishment between cultivation practices may occur. This could result in significantly different seed rates needed to establish the optimum plant populations for different cultivation practices.

The ability of reduced-population crops to compensate through additional tiller production and tiller survival can be severely affected by environmental restrictions. Early indications from the second phase of plant population work (Spink *et al*., 2005) suggested that low residual nitrogen levels or delayed spring nitrogen applications could restrict crop compensation. Commercial experience and observation suggested that crops established using reduced cultivation techniques suffer periods of nitrogen limitation. These periods are often transitory and manifest themselves in a paler appearance of the crops. This is possibly due to reduced mineralisation of nitrogen from seedbeds produced with reduced soil movement. There may also be some ‘lockup’ of nutrients due to higher levels of crop residue in the top 0 – 10 cm of soil than if this residue was buried in a plough-based system. Although both of these phenomena may be of short duration and affect a specific part of the soil profile, they may adversely affect either tiller production or survival, reducing the crops’ ability to compensate for low plant population.

To investigate the questions raised in previous HGCA-funded plant population work a project was set up with three plant population response experiments each year. A comparison of three cultivation treatments (ploughing, reduced-tillage and reduced-tillage plus nitrogen application) was randomised within each experiment. Three sites with contrasting soil types were selected, one for each experiment. Each of the experiments was monitored to provide information on seedbed quality, establishment, rate and duration of leaf and tiller production and yield response to plant population, to test the hypothesis that cultivation method would only adversely affect optimum population if it effected establishment or tillering.

Materials and Methods

Field experiments were carried out on winter wheat cv. Napier at three sites (ADAS Rosemaund (RM), ADAS Boxworth (BX), Morley Research Centre (MOR)) with three contrasting soil types over three years (2003 – 2005, Table M1). Two generic cultivation methods (conventional ploughing and reduced tillage) were imposed. The cultivation and drilling operations used commercial scale farm machinery and were modified each year according to prevailing weather conditions and local site practice (Tables M2 and M3). An additional treatment of an autumn nitrogen application following the reduced tillage cultivation resulted in a total of three cultivation treatments. Superimposed on these were seed rate treatments of 40, 80, 160, 320, 640 seeds/m^2, which were consistent at all sites in all years.

Table M1. Sites, soil types and soil series.

	Year		
Site	2002/3	2003/4	2004/5
RM	Silty clay loam	Silty clay loam	Silty clay loam
	Bromyard series	Bromyard series	Bromyard series
BX	Hanslope Clay	Hanslope Clay	Hanslope Clay
MOR	Loamy sand.	Loam over clay	Loam over clay
	Burlingham series	Beccles series	Ashley series

Table M2. Cultivation and drilling methods for the ploughing cultivation treatment in each experiment.

Site	Harvest Year	Primary Cultivation	Secondary Cultivation	Drill Type
RM	2003	Plough	Power harrow	Disc drill
	2004	Plough	Power harrow	Kraus Disc drill
	2005	Plough	Power harrow	Kraus Disc drill
BX	2003	Plough + press	Power harrow	Disc drill
	2004	Plough	Power harrow	Disc drill
	2005	Plough	Power harrow	Disc drill
MOR	2003	Plough + press	Cultivator drill	Vaderstad
	2004	Plough + press	Cultivator drill	Vaderstad Rapid
	2005	Plough + press	Cultivator drill	Vaderstad Rapid

Table M3. Cultivation and drilling methods for the reduced tillage cultivation treatments in each experiment.

Site	Harvest Year	Primary Cultivation	Secondary Cultivation	Drill Type
RM	2003	Pegasus Disc cultivator	Cultivator drill	Disc drill
	2004	Pegasus Disc cultivator	Cultivator drill	Kraus Disc drill
	2005	None	Cultivator drill	Kraus Disc drill
BX	2003	Q-Von	Power harrow	Disc drill
	2004	Q-Von	Power harrow	Disc drill
	2005	Q-Von	Power harrow	Disc drill
MOR	2003	Tera-disc + press	Cultivator drill	Vaderstad
	2004	Vaderstad Carrier Disc and press	Cultivator drill	Vaderstad Rapid
	2005	Vaderstad Carrier Disc and press	Cultivator drill	Vaderstad Rapid

A split-plot design was used with cultivation treatments on main plots and seed rate on sub-plots, replicated three times. Plot dimensions were 3-4 m wide depending on drill width, by 24 m long. Seed was supplied from a single batch each year with a common thousand-grain weight. A standard single purpose seed dressing (Sibutol) was used. Sowing dates were aimed to be typical for the site (Table M4.).

Table M4. Sowing dates.

	Year		
	2002/3	2003/4	2004/5
RM	19 Sept 2002	8 Oct 2003	11 Oct 2004
BX	1 Oct 2002	22 Sept 2003	17 Oct 2004
MOR	19 Sept 2002	17 Sept 2003	21 Sept 2004

At or immediately post-drilling, six soil samples per main plot were taken from the 0-5 cm and 5-10 cm horizons, from the two main cultivation treatments, and analysed for soil moisture and bulk density. Additional samples of soil and organic matter were taken from three 0.04m^2 quadrats from the same horizons in each cultivation main plot per replicate. The bulked replicate main plot samples were then air-dried. Aggregate size distribution was determined by sieving the air-dried samples with a 'Endecott' shaker for 3 minutes using sieve sizes of 9.5, 4.75, 2.0, 1.0 and 0.5 mm. The aggregates collected from each sieve were collected, oven dried and dry weight recorded. Thus determining the distribution by mass for air-dry stable aggregates in each sample. Dispersion ratio was determined using a 200g sub-sample from the < 2 mm sieved soil. The weight of aggregates that settle out of a suspension of distilled water in a set time was measured and a dispersion ratio calculated.

Also immediately post-drilling, digital photographs of seedbed structure, and a visual Peerlkamp (Techniques for measuring Soil Physical Properties pp 41-43, MAFF Reference Book 441, 1982) score were taken from the 0-5 cm and 5-10 cm horizons from the ploughed and reduced-tillage treatments. In autumn, soil samples were taken from the ploughed and reduced-tillage main plots,from 0-15 cm, 15-30 cm and 30-60 cm depths, for determination of soil mineral nitrogen (SMN). Crop establishment was assessed pre-tillering by counting the number of plants in five 1 m lengths of row per plot. Plant population was calculated using the following equation:

Plants/m^2 = (Total number of plants in 5 m of row) / (5 x mean row width in m)

Leaf number and tiller production were assessed by counts on ten tagged plants per plot on three seed rates (40, 80, and 320 seeds/m^2). The numbers of main-stem leaves were counted from the onset of tillering (GS21) until flag leaf emergence (GS39), at approximately 100^{o}C day intervals; the numbers of potentially fertile shoots per plant were assessed until harvest.

In spring (February/March), measurements of canopy green area index, total biomass and plant nitrogen were taken. Crop samples from four representative areas of 0.25 m^2 were taken from seed rates 40, 80 and 320 seeds/m^2 of each main plot. Green area index was measured using a digital image analysis system (Delta-T devices). Dried plant samples were analysed for nitrogen concentration using the Dumas method. At the same timing soil samples were taken from all main plots at 0-15 cm, 15-30 cm and 30-60 cm horizons for determination of soil mineral nitrogen.

A plot combine harvester was used to measure the grain yield on each plot. A representative grain sample of 1 kg of grain was taken and after cleaning, part of this sample was used for determination of the moisture content and specific weight using a Dickey John grain analysis computer. Grains were counted using a Numigral grain counter and the thousand-grain weight determined.

The data for each site were analysed by analysis of variance for a split-plot design using Genstat software to identify main factor effects of cultivation and seed rate and interactions.

1. Factors affecting establishment

1.1 Results

1.1.1 Cultivation effects on soil physical properties

Different cultivation techniques affect the physical properties of the soil and thus may affect crop establishment. A number of key soil properties were assessed to quantify these effects in the establishment phase of the crop.

1.1.1.1 Seedbed moisture

Soil samples taken immediately post drilling showed that reduced tillage resulted in significantly (P = 0.002) more moisture (12.2%) in the 0-5 cm topsoil horizon than following ploughing (10.9%). However, there was a significant interaction (P <0.05) between site and cultivation (Figure 1.1). At BX and MOR ploughing always resulted in less moisture in the top 5 cm of soil. At RM, on average there was no difference between cultivations in moisture content in the upper horizon.

Soil in the 5-10 cm horizon generally had more moisture than in the 0-5 cm horizon, and there were significant differences (P <0.001) between the sites with means of 15.74, 14.61 and 13.57 for BX, RM and MOR respectively. However, there was no significant cultivation effect or interaction between site and cultivation, as was seen in the shallower horizon.

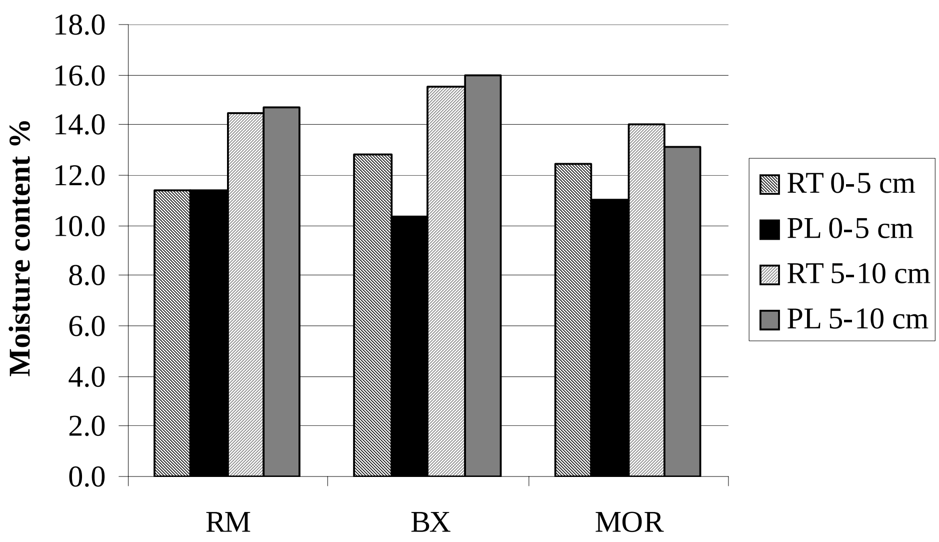


Figure 1.1. Cultivation (RT = Reduced tillage, PL = Ploughing) and site effects on seedbed moisture content (%) at two depths (0-5 cm and 5-10 cm).

A significant seasonal effect (P <0.001) was seen in both horizons, with 2005 having the wettest seedbeds and 2004 the driest (Figure 1.2). The upper horizon always had less moisture than the lower horizon and this was more pronounced in drier years.

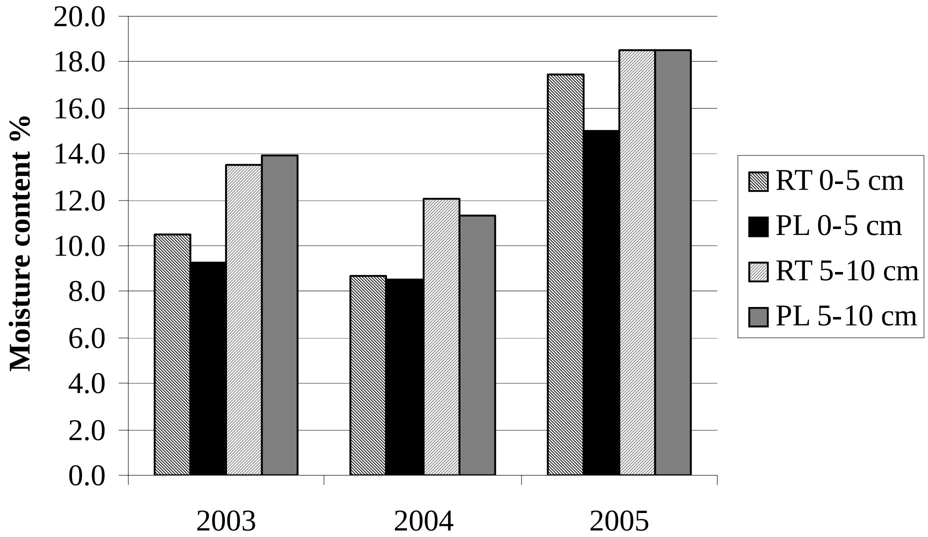


Figure 1.2. Cultivation (RT = Reduced tillage, PL = Ploughing) and season effects on seedbed moisture content (%) at two depths (0-5 cm and 5-10 cm).

1.1.1.2 Bulk density and stability

There were distinct differences between sites in the effects of cultivation on dry bulk density. This can be related to the stability of the different soil types at each of the sites and therefore suitability for reduced cultivation practices. The stability of the soil types was assessed by a dispersion ratio analysis. This measures the weight of aggregates that settle out of a suspension in a set time and gives an indication of aggregate stability (Table 1.1). Results over the three years of 19.1, 4.7 and 3.8 % for RM, BX and MOR respectively demonstrate that the silty clay loam at RM is 4 to5 times more unstable than the soils at BX and MOR.

On the more stable soils at BX and MOR, the seedbeds created by reduced tillage tended to have significantly lower (P =0.007) bulk densities compared to ploughing (Figure 1.3). On average, over the three study years at BX, bulk density after reduced tillage was 1.15 compared with 1.23 g/ml after ploughing. At MOR bulk density after reduced tillage was 0.87 compared with 0.97 g/ml after ploughing. This indicates that these soil types were well suited to reduced tillage, which can improve their soil structure. However, on the silt-dominated soil at RM, reduced tillage tended to result in higher bulk densities (P=0.13) than ploughing, indicating that reduced tillage could result in structural problems on this soil type.

Table 1.1. Dispersion ratio analysis %.

	Year		
	2002/3	2003/4	2004/5
RM	12.4	22.2	22.6
BX	3.3	3.2	7.5
MOR	3.9	3.8	n/a

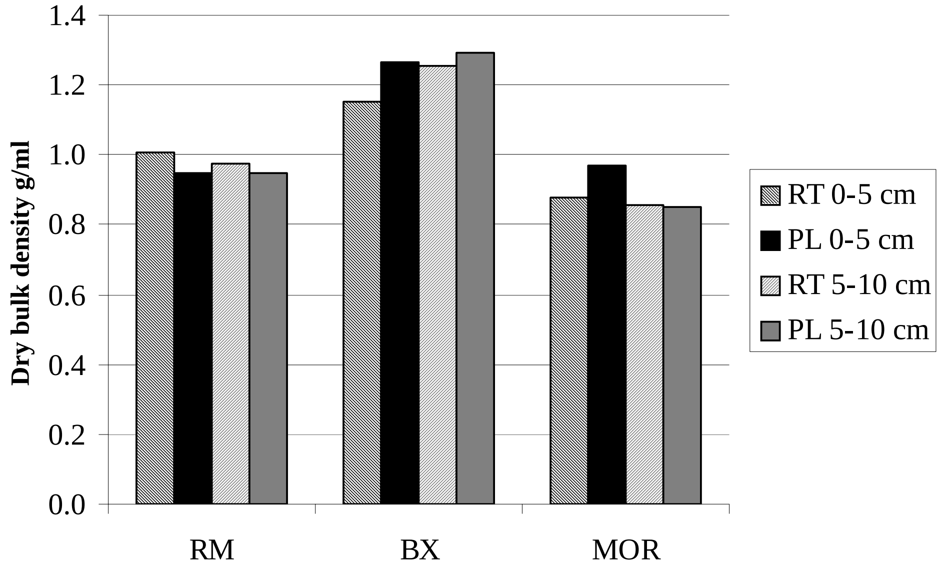


Figure 1.3. Cultivation (RT = Reduced tillage, PL = Ploughing) and site effects on dry bulk density (g/ml) at two depths (0-5 cm and 5-10 cm).

1.1.1.3 Seedbed quality – aggregate size distribution

Results from the aggregate size distribution assessments supported the bulk density results. At the two sites with more stable soils (BX and MOR), ploughing tended to produce cloddier seedbeds (Figure 1.4). On average, across the three years of this study, at BX 65.5% of aggregates in the 0-5 cm horizon were larger than 9.5 mm after ploughing compared with 47.9% after reduced tillage (P=0.08). At MOR, from the two years of available data, cultivation effects were greater with 43.3% aggregates larger than 9.5 mm after ploughing, and 10.6% after reduced tillage (P=0.065). In contrast, at RM, little difference was seen in aggregate size distribution between the two cultivation techniques, with 49.3% of aggregates larger than 9.5 mm after ploughing and 50.6% after reduced tillage. However, visual observations and photographic evidence (Figure 1.5 c and d) were that seedbeds after ploughing were better structured. It may be that differences in aggregate size distribution were not detected on this soil type because sampling this unstructured topsoil horizon may have disturbed the aggregates before analyses were undertaken.

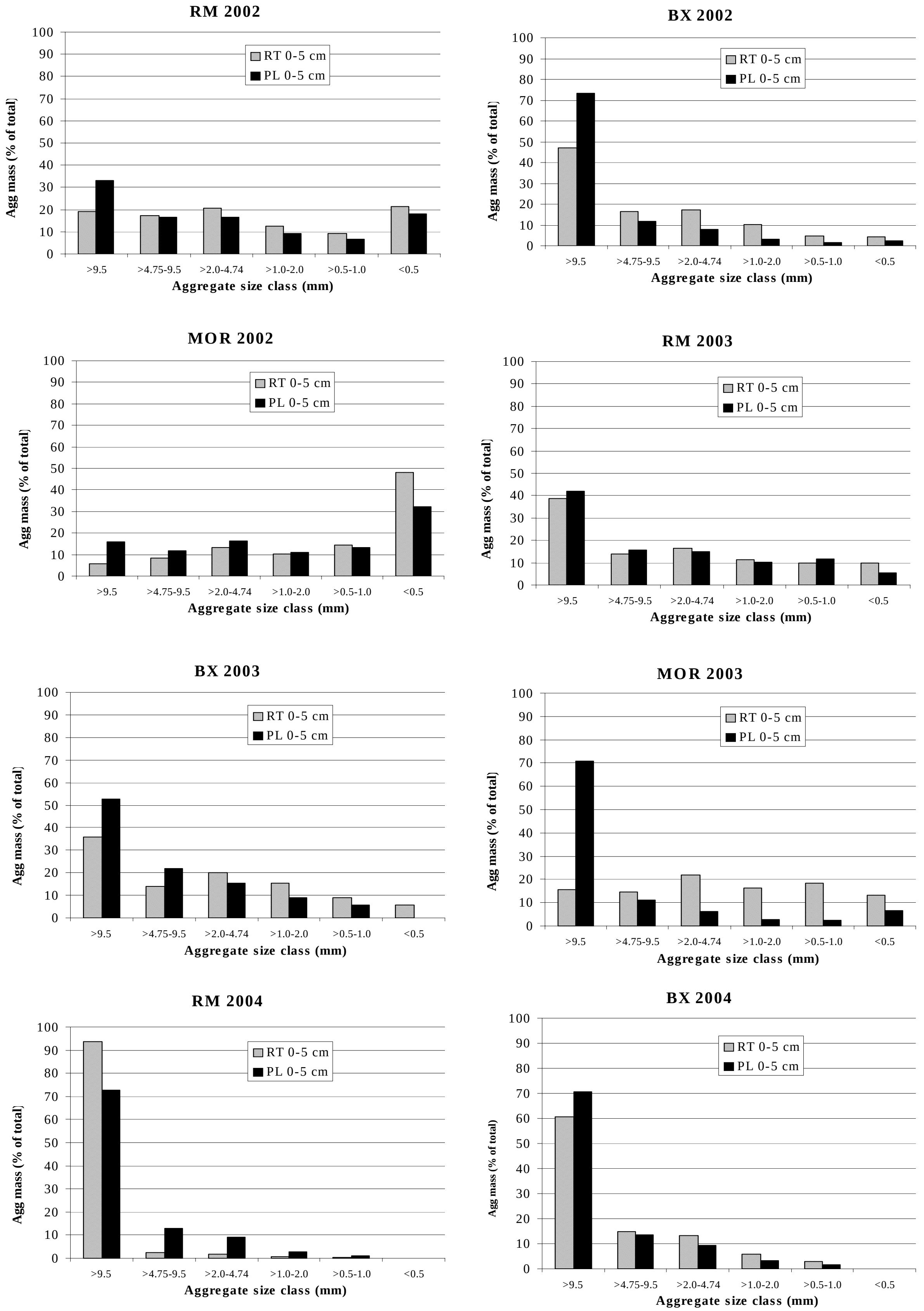


Figure 1.4. Cultivation (RT = Reduced tillage, PL = Ploughing) and site effects on aggregate size distribution (%) at 0-5 cm depth. Values are % of aggregates by weight in each size class.

The measurement of aggregate size distribution is a recognised method for quantifying seedbed quality. However it is time consuming and costly, therefore a simple method of qualitatively measuring seedbeds would aid growers in predicting establishment rates. At the two ADAS sites, at the same time as the samples were taken for aggregate size distribution, an assessment of soil structure was made using a modified version of the Peerlkamp score, and photographs of the top soil horizons were taken (Figure 1.5). The Peerlkamp score divides soil structure into categories: these range from: category 1, dense closely fitting clods, to category 9, few porous aggregates. The results of this assessment generally concurred with the quantitative assessments. At RM, mean scores for the 0-10 cm depth were 3.9 following reduced tillage and 5.8 following ploughing, indicating that ploughing produced a more porous well-structured seedbed on this soil type. At BX, mean scores were similar for both cultivation techniques at 7.2 for reduced tillage and 7.9 for ploughing.

a) BX 2002/3, Plough treatment b) BX 2002/3, Min Till treatment

c) RM 2003/4, Plough treatment, d) RM 2003/4, Min Till treatment

Figure 1.5 Photographs of topsoil profile taken in autumn at BX in 2002, and at RM in 2003.

1.1.2 Effects on crop establishment

The main cultivation effects (averaged across the seed rates) on plant population were directly related to the effects on soil structure and seedbed quality. At RM, the effects were significant in two out of three years (Table 1.2). In 2002 and 2004, significantly fewer plants established from reduced tillage, and the same trend was seen in 2003. The greatest differences were seen in 2004 when the reduced tillage treatment was direct drilled and resulted in plant populations 43% lower than that from the plough based treatment. Over the three study years, ploughing resulted in 54% more plants than for the reduced tillage treatment.

The increased bulk density, and poorer quality seedbed produced from ploughing at BX resulted in poorer establishment (Table 1.3). In 2003 and 2004, percentage establishment after ploughing tended to be lower (21.2 % in 2003 and 24.2% in 2004) than from reduced tillage. A similar trend was seen in 2002. At MOR, the detrimental effects of the plough based cultivation system on seedbed quality did not result in a significantly lower plant establishment (Table 1.4).

Table 1.2. Cultivation effects on autumn established plant population (plants/m^2) at RM.

	Year			
Cultivation treatment	2002	2003	2004	Mean
Reduced tillage	88.4	139.2	92.9	106.8
Reduced tillage + autumn N	121.7	143.2	98.2	121.0
Plough	174.1	156.1	162.7	164.3
P	0.017	ns	<0.001	
SED	16.68	15.50	6.71	
df	4	4	4	

Table 1.3. Cultivation effects on autumn established plant population (plants/m^2) at BX.

	Year			
Cultivation treatment	2002	2003	2004	Mean
Reduced tillage	154.7	113.6	94.9	121.1
Reduced tillage + autumn N	153.1	125.1	97.7	125.3
Plough	116.9	94.1	73.0	94.7
P	ns	0.051	0.084	
SED	15.15	8.44	8.63	
df	4	4	4	

Table 1.4. Cultivation effects on autumn established plant population (plants/m^2) at MOR.

	Year			
Cultivation treatment	2002	2003	2004	Mean
Reduced tillage	155.9	99.7	156.6	137.4
Reduced tillage + autumn N	166.7	95.9	162.1	141.6
Plough	176.1	92.9	177.7	148.9
P	ns	ns	ns	
LSD	21.2	25.2	28.8	
df	4	4	4	

The general trend at all sites was for percentage establishment to decrease with increasing seed rate, and for higher establishment after ploughing at RM, the converse at BX and no difference at MOR. On average across the cultivation treatments and the nine site years, establishment was reduced by 5.2 % for every 100 seeds/m^2 increase in seed rate (Figure 1.6). The same relationships for the cultivation treatments were 4.6% for ploughing, 5.1% for reduced tillage plus autumn N and 5.6%, for reduced tillage. These relationships suggest that under reduced tillage, slightly poorer percentage establishment can be expected as seed rate is increased. It also indicated that an application of autumn nitrogen after reduced tillage had a beneficial effect on percentage establishment. The individual site data suggested that this effect was seen most commonly at the extreme high and low seed rates. At RM, a significant (P = 0.001) interaction was seen in two out of the three years and resulted in the overall trend seen in figure 1.7. Despite the beneficial effect of nitrogen at seed rates of 40 and 640 seeds/m^2, establishment was still poorer than after ploughing.

Similar trends were seen at BX and MOR (Figures 1.8 and 1.9) although they were not statistically significant at either site. At BX beneficial effects of nitrogen were seen at 40 seeds/m^2 and to a lesser extent at 80 and 640 seeds/m^2. At MOR small beneficial effects of nitrogen were seen at all seed rates apart from 320 seeds/m^2.

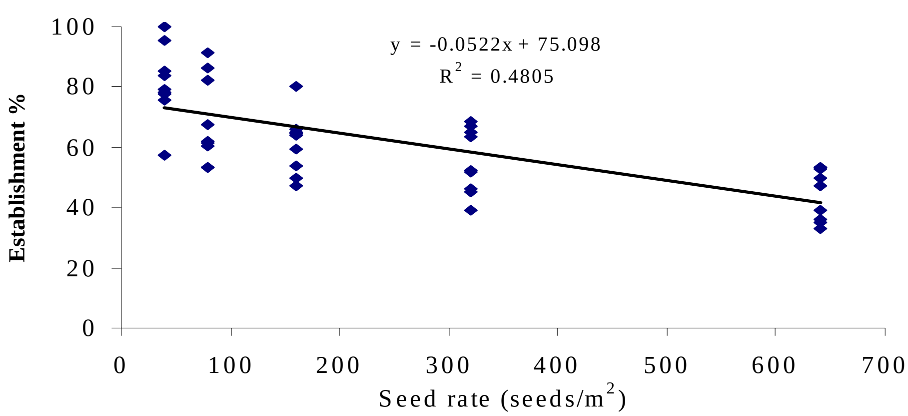


Figure 1.6. Seed rate effects on plant establishment (%), average of nine site seasons.

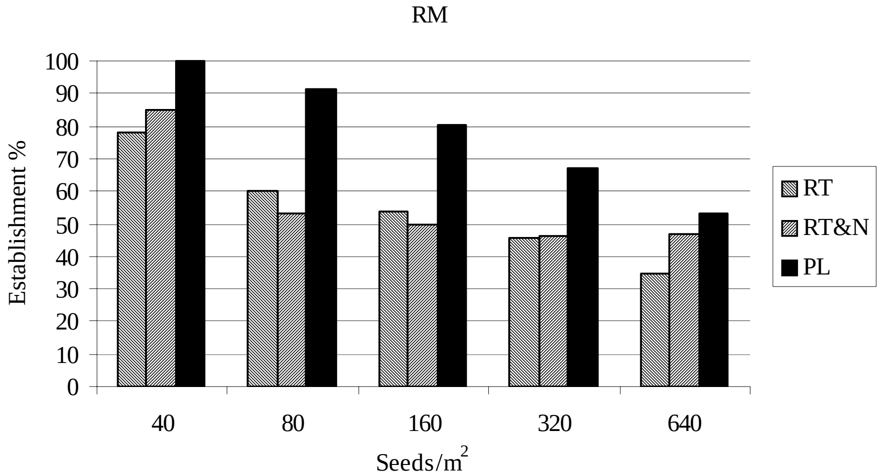


Figure 1.7. Cultivation (RT = Reduced tillage, RT&N = Reduced tillage plus autumn N, and PL = Ploughing) and seed rate (Seeds/m^2) effects on plant establishment (%),at RM mean of three years.

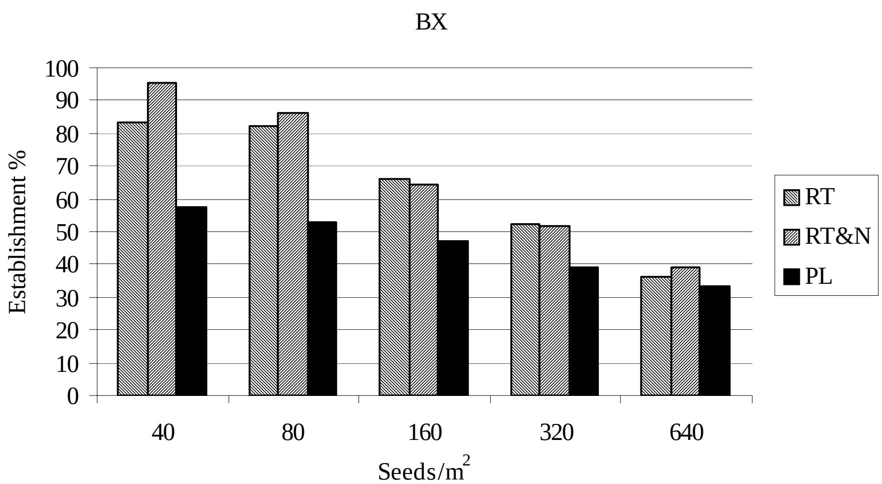


Figure 1.8. Cultivation (RT = Reduced tillage, RT&N = Reduced tillage plus autumn N, and PL = Ploughing) and seed rate (Seeds/m^2) effects on plant establishment (%),at BX mean of three years.

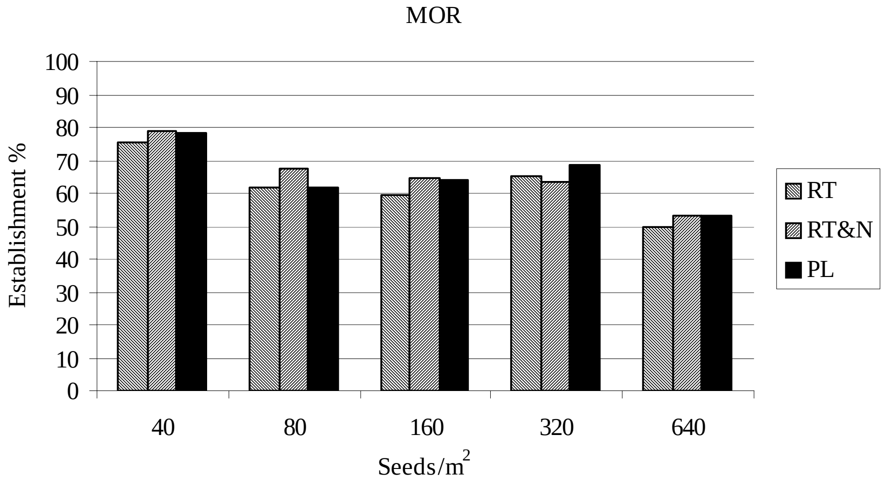


Figure 1.9. Cultivation (RT = Reduced tillage, RT&N = Reduced tillage plus autumn N, and PL = Ploughing) and seed rate (Seeds/m^2) effects on plant establishment (%),at MOR mean of three years.

1.2 Discussion

Seedbed moisture can be a critical factor in crop establishment. Normal UK autumn conditions do not usually result in soil moisture being limiting, except for the earliest drillings. However, changes in agricultural practice and climate may result in soil moisture becoming more limiting in the future under UK conditions. In the UK, there has been a trend for earlier drillings of winter wheat driven by the need to spread fixed costs in order to reduce costs of production. This has resulted in larger areas of wheat being drilled into drier seedbeds. In addition, there are predictions of lower summer rainfall and warm temperatures due to long term climate change. An average increase in temperature by as much as 1.5 degC coupled with a 4% reduction in summer rainfall by 2020 has been predicted (Hulme and Jenkins, 1998). Both of these factors suggest that conserving soil moisture could become an increasingly important factor in ensuring satisfactory crop establishment.

This study has shown that reduced tillage produces seedbeds on certain soil types that have significantly more moisture in the upper 0-5 cm horizon than those created using a plough based system. This difference was more pronounced in drier seasons when soil moisture was more limiting.

The effects of cultivation techniques on the physical properties of soil have been well documented. There is evidence that frequent ploughing can increase porosity and aeration and cause decreases in bulk density in the plough layer (Ekeberg, 1992; Stokes *et al*., 1992). However, there is also evidence that repeated tillage can cause a deterioration of soil structure (Low, 1972; Greenland, 1977). Although contrasting evidence exists for the effects of cultivation techniques on soil physical properties, it can be certain that the effects differ depending on soil type. UK soils can be categorised into their suitability for direct drilling (Cannell, 1978). This work provides evidence for the site differences in cultivation effects seen in this study. Both the Hanslope and Beccles series of soils, predominant at BX and MOR respectively, were category 2 soils. These are defined as soils where, with good management, the yield of winter cereals is likely to be similar after direct or reduced tillage and conventional (plough based) tillage. Results from this study suggested that on these soil types reduced tillage was most appropriate and produced better quality seedbeds. The Bromyard series typical of the RM site is a category 3 soil. This category is defined as having substantial risk of loss of yield after direct or reduced tillage. On this soil type a plough based system of cultivation will more reliably produce better quality soil structure and seedbed.

Previous work by Bouaziz and Bruckler (1989) had shown that the ease with which water moves from soil into the seed is determined by seed to soil contact. Aggregate size distribution has a large influence on seed soil contact and therefore is a key determinant of the quality of the seedbed. Cultivation techniques determine the seedbed quality but how effective a cultivation technique is in producing a seedbed with an ideal distribution of particle sizes is influenced by a number of factors, such as soil type and soil moisture.

Therefore, the most appropriate cultivation technique will differ with soil type and the soil conditions at the time of cultivation.

Results from this study have shown that seedbed quality strongly influences crop establishment and therefore final plant population. Regardless of what cultivation technique has been used to produce the seedbed, if it has had a detrimental effect on soil structure and seedbed quality it will have a detrimental effect on final crop establishment.

The poorer percentage establishment at higher seed rates seen in this study was consistent with previous work (Whaley *et al.*, 2000; Spink *et al*, 2005). This effects is due to allelopathy and is well documented in the literature (Molisch, 1937; Putman, 1985; Wu *et al.*, 2000). Allelopathy occurs when a plant releases phytotoxic chemical substances (allelochemicals) that inhibit or delay germination and growth of neighbouring plants when growing in close proximity and competing for resources. At high seed rates these allelopathic effects are commonly seen. The reduction in percentage establishment seen in this study was higher than that reported by Blake *et al.* (2003). In that review there was, on average, a 2.6 % reduction in establishment for every 100 seeds/m^2 increase in seed rate. In this study, a 5.2% reduction per 100 seeds/m^2 was observed. However, the review also found that there was variation from 0-15% therefore findings from this study were well within the expected range that have been previously reported and associated with allelopathy.

Straw residues have also been shown to release allelopathic chemicals, which can affect seedling growth. Under a reduced tillage system, where more surface trash is common, the effect of straw residues could be hypothesised as being an important factor in increasing allelopathic effects. However in previous, published studies (Kimber, 1967; Alam, 1990) the crops were following wheat. In this study the wheat was drilled in a first wheat rotational position following either oilseed rape or oats. Therefore, the slightly poorer percentage establishment from higher seed rates after reduced tillage compared to ploughing is unlikely to be due to additional allelopathic effects associated with straw residues. It is more likely that this effect is due to higher levels of surface trash after reduced tillage causing physical impedance of germination and associated plant loss due to slug damage.

The addition of an autumn nitrogen application between drilling and emergence after reduced tillage was intended to negate the effect of lower levels of mineralisation found under reduced tillage. A review by Silgram and Shepherd (1999), detailed published work that showed that between 10 and 65 kg N/ha more soil mineral nitrogen can be found due to a flush of mineralisation following conventional ploughing compared to reduced tillage. However, the establishment data suggest that nitrogen had a beneficial effect on crop establishment, particularly at each end of the range of the seed rates used. The most likely explanation is that the addition of nitrogen is making additional nutrients available to weaker plants that have managed to germinate, therefore increasing plant survival in the early post emergence period. At high seed rates, competition for resources even at this early stage would be greater than at lower seed rates. Where no autumn nitrogen is applied these plants would produce weaker growth and fail to survive to the three to four leaf stage when first plant counts were made.

2. Plant compensation

2.1 Results

Previous work (Spink *et al*., 2000) has shown that the primary plant compensatory mechanism (at low plant densities) is increased tiller production. An objective of this project was to understand how cultivation practice might limit a crop's ability to compensate through tillering.

2.1.1 Tillering compensation

Data from assessments on tagged plants confirmed that increased tiller production and duration was the main plant mechanism for compensating for low plant densities. Average final shoot numbers per plant were 12.7, 10.2 and 4.4 from 40, 80 and 320 seeds/m^2 respectively (Table 2.1). At low plant densities an extension of the duration of tillering was seen in all sites and seasons. The 320 seeds/m^2 treatment tended to cease tillering between the end of March and mid-April, whereas both the 40 and 80 seeds/m^2 treatments continued tillering until at the earliest, early May, and at the latest, early June (Figure 2.1). This confirmed the findings of Spink *et al.* (2000), that the timing of the tiller production and death phases in wheat growth is primarily controlled by competition for resources between shoots.

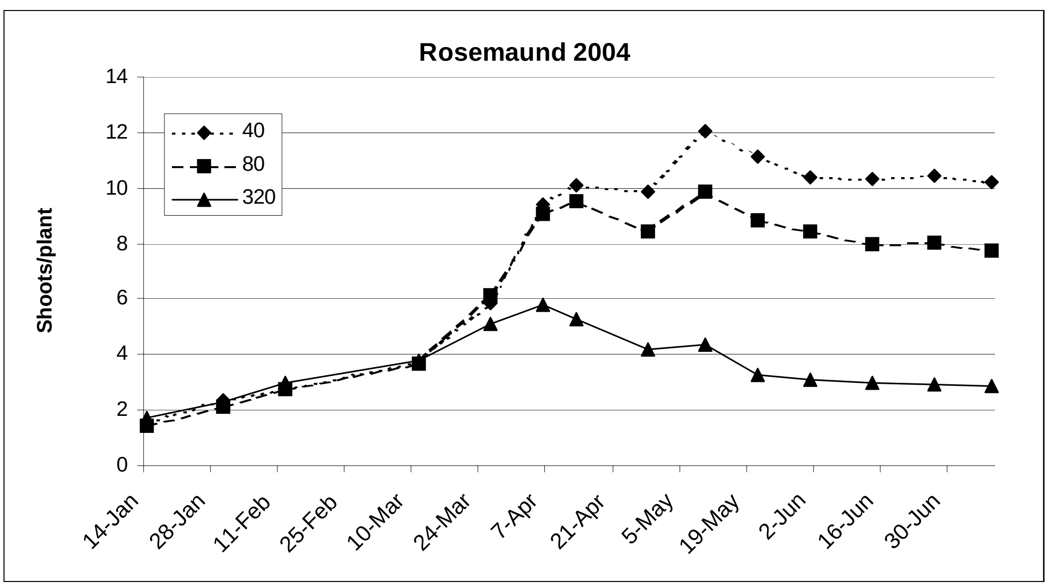


Figure 2.1. Number of shoots per plant produced through the season at 40, 80 and 320 seeds/m^2 at RM in 2004.

Cultivation practice seemed to have an effect on tiller production. On average, from 40 seeds/m^2 there were 12.3 shoots per plant following ploughing compared with 13.4 following reduced tillage and at 80 seeds/m^2 there were 9.9 shoots following ploughing and 10.2 followed reduced tillage. However, these differences can be explained by the differences in plant establishment at different sites discussed above. Where lower establishment occurred irrespective of cultivation practice increased numbers of shoots per plant were produced. At RM in 2002/3, 31 plants established from 40 seeds/m^2 following reduced tillage and 40 plants established following ploughing. These produced 12 shoots/plant following reduced tillage and 9 shoots/plant following ploughing. At the other sites, where the establishment differences were higher from reduced tillage compared with ploughing, tiller production was also related to established plant population. For example, at BX in 2003/4, 40 and 80 seeds/m^2 established 40 and 67 plants/m^2 following reduced tillage, compared with 19 and 47 plants/m^2 following ploughing. The number of shoots/plant from 40 and 80 seeds/m^2 were 21 and 13 following reduced tillage, and 25 and 17 following ploughing. This indicates that cultivation practice only affects tiller production when it affects plant establishment. It also confirms that tiller production is totally controlled by the density of the population established and the intra-shoot competition for resources.

Table 2.1. Final numbers of shoots per plant from tagged plant assessments from nine site seasons.

		Shoots per plant for given seasons, sites and assessment dates									
		2002/3			2003/4			2004/5			
		RM	BX	MOR	RM	BX	MOR	RM	BX	MOR	
Cultivation treatment	**Seed rate**	6/6	23/5	21/5	27/6	28/5	20/5	19/5	22/2	17/5	**Mean**
Reduced tillage	40	12.0	15.5	7.4	11.1	20.6	15.0	13.8	7.8	17.5	**13.4**
	80	7.0	9.8	5.7	7.9	12.8	11.0	13.8	8.1	15.4	**10.2**
	320	3.3	4.1	3.3	3.0	4.4	4.0	5.7	6.6	5.5	**4.4**
Reduced tillage + autumn N	40	9.7	14.6	6.8	10.0	18.7	15.0	12.7	7.9	17.1	**12.5**
	80	8.4	10.8	5.1	8.1	14.0	11.0	11.3	8.9	16.1	**10.4**
	320	2.7	4.1	3.4	3.0	4.7	4.0	6.7	6.8	4.3	**4.4**
Plough	40	9.3	13.5	7.5	10.2	24.6	16.0	10.6	7.7	11.7	**12.3**
	80	6.7	12.1	5.8	8.2	16.8	10.0	8.8	6.9	14.1	**9.9**
	320	2.7	4.8	2.8	2.7	6.0	5.0	3.6	7.1	3.8	**4.3**
Reduced tillage mean		**7.4**	**9.8**	**5.5**	**7.3**	**12.6**	**10.0**	**11.1**	**7.5**	**12.8**	**9.3**
Reduced tillage +N mean		**7.5**	**10.8**	**5.7**	**7.8**	**15.5**	**11.5**	**10.3**	**7.8**	**12.3**	**9.9**
Plough mean		**6.2**	**10.1**	**5.4**	**7.0**	**15.8**	**10.3**	**7.7**	**7.2**	**9.9**	**8.9**

2.1.2 Soil nitrogen reserves

There was no significant difference in autumn soil mineral nitrogen (SMN) reserves after reduced tillage or ploughing (Figure 2.2). Average SMN levels were 77.4 kg/ha following reduced tillage compared with 72.6 kg/ha after ploughing. Significant differences (P <0.001) in SMN reserves were found between the years. The significantly drier autumn of 2003 resulted in SMN reserves being 74% higher compared to either 2002 or 2004 (Figure 2.3). There was also a site effect (P = 0.067) with the more fertile silty-clay loam soil at RM on average having SMN reserves of 82.6 kg/ha compared with 70.1 and 72.3 at BX and MOR respectively (Figure 2.3).

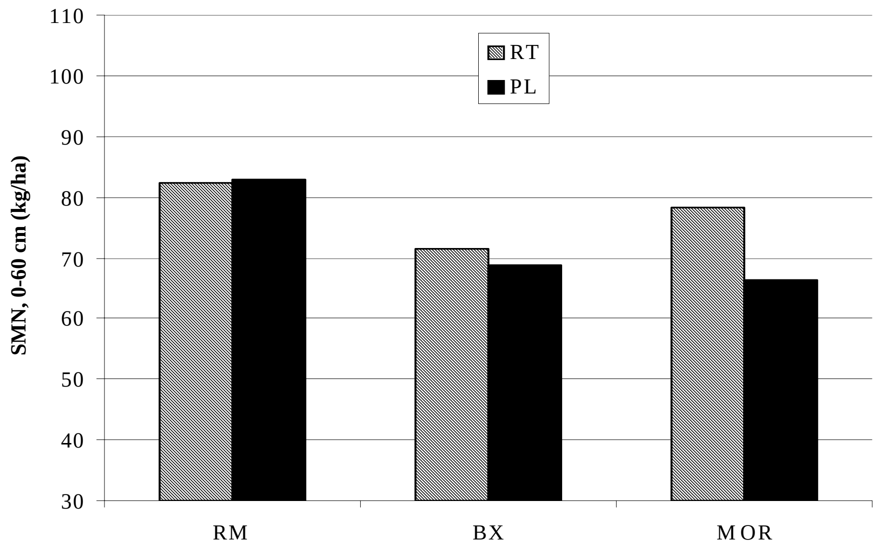


Figure 2.2. Site and cultivation effects on SMN (kg/ha), 0-60 cm, measured in the autumn, mean of all years.

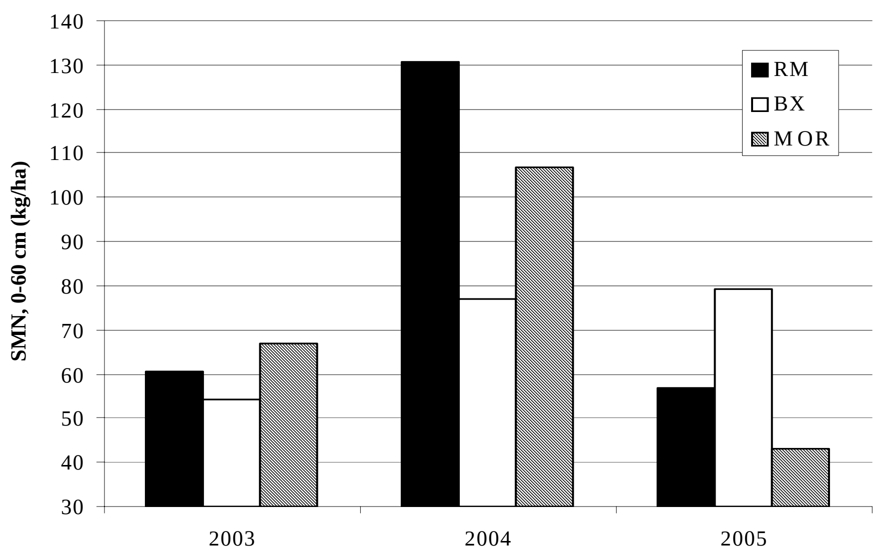


Figure 2.3. Site and season effects on SMN (kg/ha), 0-60 cm, measured in the preceding autumn, mean of all cultivation treatments

Results of the spring SMN sampling, taken in March, were similar to results from the autumn sampling. No significant effect of cultivation was detected (Figure 2.4). There were, however, significant ($P < 0.001$) main effects of season and site on SMN reserves. The higher levels of SMN measured in autumn 2003 were still evident in the following spring with 46% more compared to 2002/3 and 2004/5. RM soils again had significantly more nitrogen available, although the difference between the sites had increased with RM having 89.6 kg/ha compared to 57.3 and 49.1 at BX and MOR respectively.

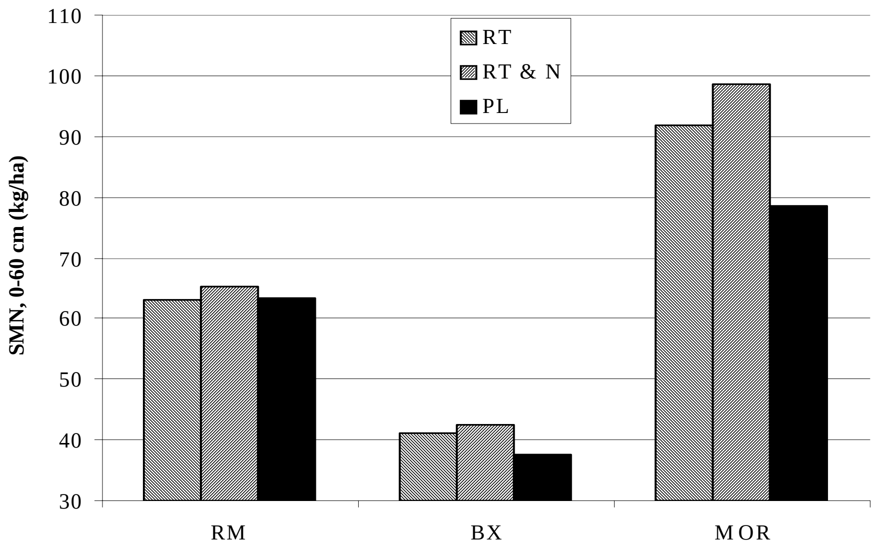


Figure 2.4. Site and cultivation effects on SMN (kg/ha), 0-60 cm, measured in March, mean of all years.

2.1.3 Crop growth compensation.

Predictably, seed rate had a significant effect on crop biomass and green area index ($P < 0.001$) at all sites and in all seasons (Table 2.2). On average, there was a 1.4 fold increase in biomass as seed rate was increased from 40 to 80 seeds/m^2, and a 3.4 fold increase between 40 and 320 seeds/m^2. A slightly larger, but very similar response, was seen in green area index with a 1.7 fold increase as seed rate was increased from 40 to 80 seeds/m^2, and a 5 fold increase between 40 and 320 seeds/m^2 (Table 2.3). These results were further quantifiable evidence of plant compensation, in terms of biomass and green area index, for low plant densities. The 8 fold difference in seed rate between the 40 and 320 seeds/m^2 had been reduced to a 3 fold difference for biomass and a 5 fold difference for green area index.

Table 2.2. Seed rate effect on crop dry matter (t/ha) assessed in spring from eight site seasons.

	2002/3			2003/4			2004/5		
	RM	BX	MOR	RM	BX	MOR	RM	BX	**Mean**
Date	11/3	12/3	19/3	24/2	8/3	3/3	16/3	15/3	
Seeds/m^2									
40	0.24	0.05	1.30	0.05	0.06	0.37	0.05	0.26	**0.28**
80	0.35	0.09	1.39	0.09	0.10	0.66	0.11	0.48	**0.40**
320	0.73	0.31	2.28	0.30	0.31	1.92	0.34	1.52	**0.96**
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
SED	0.059	0.011	0.144	0.014	0.016	0.097	0.024	0.065	
df	12	12	12	12	12	12	12	12	

Table 2.3 Seed rate effect on green area index assessed in spring from six site seasons.

	2002/3		2003/4		2004/5		
	RM	BX	RM	BX	RM	BX	**Mean**
Date	11/3	12/3	24/2	8/3	16/3	15/3	
Seeds/m^2							
40	0.22	0.09	0.04	0.11	0.05	0.33	**0.14**
80	0.36	0.16	0.09	0.13	0.10	0.60	**0.24**
320	0.60	0.67	0.31	0.38	0.31	1.95	**0.70**
P	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	
SED	0.049	0.032	0.012	0.059	0.028	0.198	
df	12	12	12	12	12	12	

The effects of cultivation on crop biomass and green area index followed the same patterns at the different sites, as for crop establishment (Figure 2.5). At RM, the plough based cultivation treatment produced significantly higher biomass (Table 2.4) and green area index (Table 2.5) than reduced tillage in all site seasons. Averaged across the three years at RM, crop biomass in spring after reduced tillage was 48% lower than after ploughing. The application of autumn nitrogen halved this difference to 24%. The effects on green area index were very similar to effects on crop biomass with reduced tillage having 45% less green area than after ploughing. Autumn nitrogen after reduced tillage reduced this difference to 29%.

Whereas at BX and MOR reduced tillage tended to produce a larger crop, this was only significant in 2003/4 at BX, and 2002/3 and 2003/4 at MOR (Table 2.4). At BX on average, crops after ploughing produced 24% lower biomass than those following reduced tillage. The autumn application of nitrogen after reduced tillage resulted in a positive response in crop biomass with a 10% increase in biomass compared to reduced tillage alone. Crop biomass data from two years at MOR showed similar responses to those at BX. Crops after ploughing had 22% less biomass compared with reduced tillage and the addition of autumn nitrogen gave a 9% increase. Green area data available from BX only showed a similar pattern to the biomass data. Green area index following ploughing was 16% lower than for reduced tillage and the addition of autumn nitrogen gave an average increase of 12%.

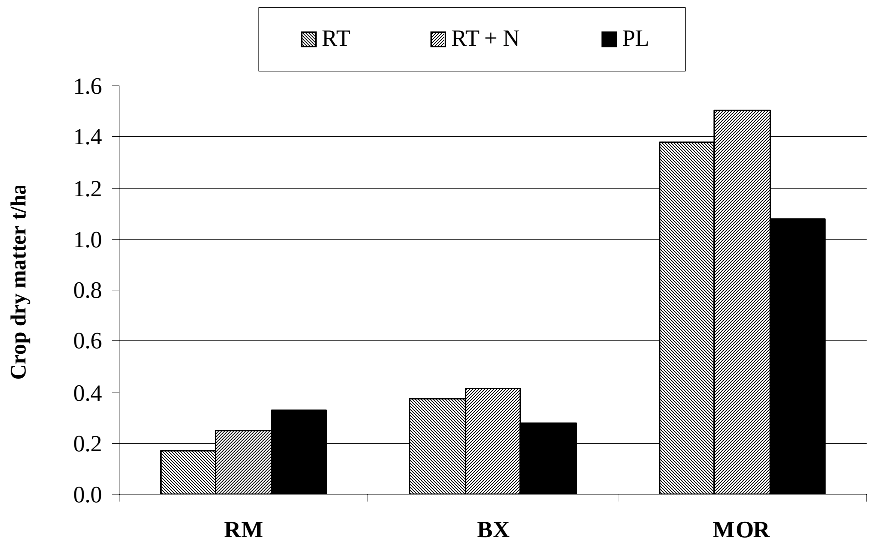


Figure 2.5. Cultivation effects on crop biomass (t/ha) measured in spring at three sites, mean of three years.

Table 2.4. Cultivation effect on crop dry matter (t/ha) assessed in spring from eight site seasons.

	2002/3			2003/4			2004/5		
	RM	BX	MOR	RM	BX	MOR	RM	BX	**Mean**
Date	11/3	12/3	19/3	24/2	8/3	3/3	16/3	15/3	
Cultivation									
Red. till	0.27	0.18	1.60	0.10	0.17	1.15	0.14	0.76	**0.55**
Red. till + N	0.51	0.16	1.80	0.13	0.23	1.21	0.10	0.85	**0.62**
Plough	0.53	0.11	1.57	0.21	0.07	0.59	0.25	0.65	**0.50**
P	0.046	ns	0.011	0.028	0.004	0.001	0.004	ns	
SED	0.076	0.034	0.044	0.024	0.020	0.163	0.0198	0.095	
df	4	4	4	4	4	4	4	4	

Table 2.5. Cultivation effects on green area index assessed in spring from six site seasons.

	2002/3		2003/4		2004/5		
	RM	BX	RM	BX	RM	BX	**Mean**
Date	11/3	12/3	24/2	8/3	16/3	15/3	
Cultivation							
Red. till	0.27	0.35	0.10	0.22	0.13	0.92	**0.33**
Red. till + N	0.45	0.36	0.12	0.26	0.09	1.05	**0.39**
Plough	0.46	0.21	0.22	0.13	0.23	0.91	**0.36**
P	0.052	0.052	0.028	ns	0.004	ns	
SED	0.059	0.044	0.028	0.048	0.019	0.258	
df	4	4	4	4	4	4	

The main effects on crop nitrogen offtakes measured in the spring (Figure 2.6) were directly related to the effects seen in crop biomass. Nitrogen offtake increased significantly with increase in seed rate in all site seasons. Ploughing at RM gave larger offtakes whereas at BX it was higher following reduced tillage.

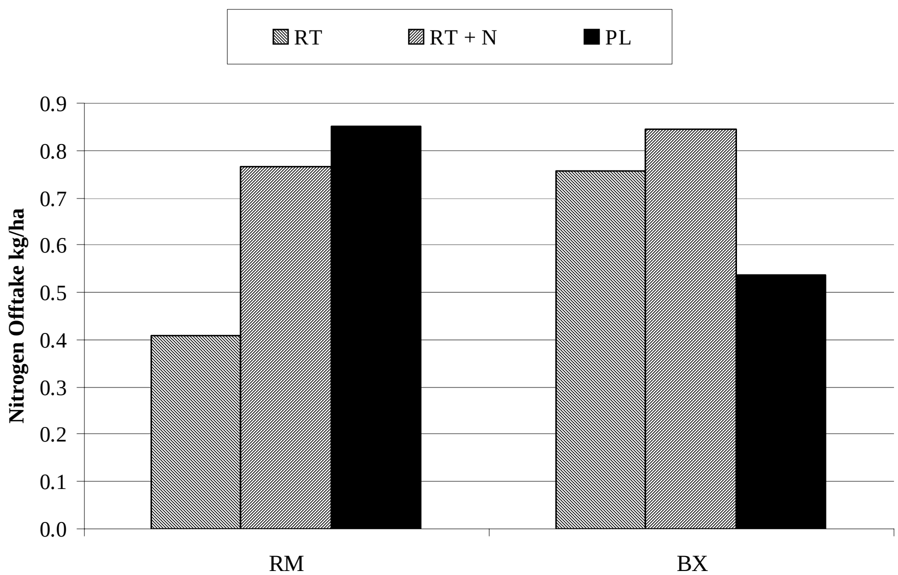


Figure 2.6. Cultivation effects on crop nitrogen offtake (kg/ha) measured in spring at two sites, mean of three years.

2.1.4 Effect on grain yield.

Mean grain yield was above national average at 9.94 t/ha, but there were significant seasonal and site differences. Year 1 (2003) mean yield was the lowest at 9.16 t/ha with a site ranking of RM>MOR>BX. Mean yield in year 2 (2004) was 10.07 t/ha, again with RM having the highest yield followed by BX and MOR. Year 3 (2005) had the highest mean yield at 10.44 t/ha, and the site ranking was BX>MOR>RM.

At 10.39 t/ha, the 320 seeds/m^2 seed rate gave the highest yield across all the sites and seasons (Table 2.6). There was an average yield loss of 1.47 t/ha between this and the lowest-yielding seed rate (40 seeds/m^2). Reducing seed rate from 320 to 160 seeds/m^2 resulted in a slight yield loss of 0.05 t/ha on average across the sites. This was made up of yield losses in four site seasons, two of which we significant (BX 2002/3 and 2003/4), and five site season yield increases where one was significant (RM 2003/4). A mean yield decrease of 0.18 t/ha across the site seasons resulted from increasing seed rate from 320 to 640 seeds/m^2. This was made up of increases at four site seasons, and decreases at five. Of the yield increases, only one was significant (BX in 2002/3) and of the yield decreases, two were significant (BX in 2003/4 and MOR in 2004/5).

Averaged across the three seasons, the highest yielding seed rate at both RM and MOR was 160 seeds/m^2, whereas at BX 320 seeds/m^2 gave the greatest yield.

Table 2.6. Seed rate effects on grain yield (t/ha @ 85% dm).

	2002/3			2003/4			2004/5			
Seeds/m^2	RM	BX	MOR	RM	BX	MOR	RM	BX	MOR	**Mean**
40	9.57	7.10	8.74	10.53	8.56	6.84	7.65	8.47	10.32	**8.92**
80	10.31	7.04	8.96	11.20	10.15	7.66	8.65	9.54	10.72	**9.84**
160	11.16	7.06	9.58	12.07	10.85	9.45	9.55	10.02	11.32	**10.34**
320	11.48	7.59	9.57	11.61	11.31	9.37	9.52	10.30	11.29	**10.39**
640	11.29	8.17	9.69	11.65	10.39	9.50	9.41	10.16	10.96	**10.21**
Mean	**10.76**	**7.41**	**9.32**	**11.41**	**10.25**	**8.56**	**8.95**	**11.45**	**10.92**	**9.94**
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
SED	0.168	0.147	0.117	0.179	0.221	0.563	0.201	0.223	0.190	
df	24	24	24	24	24	24	24	24	24	

Significant effects of cultivation on grain yield were recorded in five out of the nine site seasons (Table 2.7). The yield effects were a result of the effects of cultivation techniques on seedbed quality, plant establishment and crop growth on the different soil types at the different sites. At RM, where seedbed quality and resultant crop establishment and growth were better after ploughing, significant yield benefits resulted in all three years. Across the three years, the yield benefit from ploughing was 0.98 t/ha compared with reduced tillage. At BX, where reduced tillage produced better quality seedbeds, crop establishment and growth, significant yield benefits were seen in two out of the three years. An average yield benefit of 0.35 t/ha from reduced tillage compared with ploughing was the result.

At MOR, where the differences in seedbed quality between reduced tillage and ploughing did not result in significant crop establishment differences, the resultant effects on grain yield were not significant in any of the years. There was, however an overall tendency for yield a benefit of 0.29 t/ha from reduced tillage compared to ploughing.

The application of autumn nitrogen after reduced tillage tended to have a yield benefit over reduced tillage in eight out of nine site seasons although it was only a significant effect on one occasion at RM in 2003/4. Across the site seasons, a 0.13 t/ha yield improvement resulted with positive site responses of 0.3 and 0.13 t/ha from RM and BX respectively and no difference at MOR. These benefits were a result of the increased biomass and green area index discussed above.

Table 2.7. Cultivation effects on grain yield (t/ha @ 85% dm).

	2002/3			2003/4			2004/5			
Cultivation	RM	BX	MOR	RM	BX	MOR	RM	BX	MOR	**Mean**
Red. till	10.44	7.28	9.37	10.96	10.47	8.84	8.44	11.58	10.93	**9.85**
Red. till + N	10.48	7.57	9.40	11.52	10.57	8.65	8.75	11.59	10.97	**9.97**
Plough	11.37	7.38	9.18	11.75	9.71	8.20	9.67	11.19	10.86	**10.00**
P	0.014	ns	ns	0.071	0.015	ns	0.011	0.042	ns	
SED	0.192	0.162	0.386	0.243	0.176	0.656	0.218	0.173	0.14	
df	4	4	4	4	4	4	4	4	4	

2.2 Discussion

A previous study on plant population in wheat (Spink *et al.* 2000) reported increased tiller numbers per plant at reduced populations. In that study there was a 3 to 4 fold increase in total shoot number per plant from 40 seeds/m^2 compared with 320 seeds/m^2. Results from the current study confirmed these results with a 2 to 4 fold increase from the same seed rates. These increases were a result of an increased duration of tillering at low plant densities. At low seed rates (40 and 80 seeds/m^2) the tillering phase was extended by between 18 and 71 days. This extension of the duration of tillering concurred with the previous findings of Darwinkel (1978) and Spink *et al.* (2000).

Cultivation practice affected tillering only where plant establishment had been significantly affected. Where establishment was relatively unaffected by cultivation practice, there was no significant difference in final shoot numbers per plant. This indicates that that the plants' compensatory response of tiller production is dependent on the competition for resources between shoots. A similar conclusion on the control of the tiller production phase at low plant densities was made by Spink *et al.* (2000). Therefore, as long as cultivation practice does not limit resource capture, then it should not limit plant compensation for low plant densities.

The hypothesis was that crops established after reduced tillage may suffer transitory nitrogen limitation, which may limit the crop's ability to compensate for low plant densities. This hypothesis was based on observations of crops established after reduced tillage, and also published findings of reduced amounts of nitrogen mineralisation due to accumulations of carbonaceous material in the upper topsoil horizons. It was thought that this might have an effect similar to the findings of Spink *et al.* (2000) where low-density crops grown after low residual nitrogen, or where spring nitrogen applications were delayed, resulted in reduced tillering. However, no differences in soil nitrogen reserves were detected between the reduced tillage and plough-based systems. This lack of any residual nitrogen differences could be explained by the levels of cultivation associated with each of the cultivation treatments. The primary cultivation of the reduced tillage treatment, although non-inversion, involved working and mixing of soil organic matter to a depth of 150 - 200 mm in most cases. This may have stimulated as much, or in some site seasons, more nitrogen mineralisation than the ploughed treatment. Much of the published data referenced in a review by Silgram and Shepherd (1999) states that the largest differences compared with conventional cultivation are from zero tillage or direct drilling. However, at RM in 2005, where the reduced tillage treatment was direct drilled, there was also no significant difference in soil nitrogen detected.

Despite the lack of any significant differences in residual SMN, measurements of crop growth taken in the spring found significant differences associated with cultivation practice. However these differences were correlated with cultivation effects on crop establishment rather than any nitrogen limitation associated with cultivation practice. At RM, significantly more biomass and green area was produced from crops after ploughing which had also had better crop establishment. At BX and MOR the converse was true with reduced tillage producing larger crops and more green area than ploughing although no significant differences were detected in SMN in either the autumn or spring sampling. There was a tendency for higher levels of SMN in spring from the reduced tillage plus autumn nitrogen treatment compared with reduced tillage alone. Consequently an overall benefit of 12% in crop biomass and 18% in green area was seen from this treatment compared with standard reduced tillage.

The seed rate effects, as expected, were significant in all site seasons with crop dry matter and green area index increasing with increasing seed rate. These crop measurements taken in early March indicated that through a combination of improved establishment and increased tillering, compensation for low plant densities had occurred. By this relatively early stage in the season, low plant densities had compensated and reduced the 8 fold difference between 40 and 320 seeds/m^2 seed rates to a 3.4 fold difference in plant biomass. Further compensation by increased tillering continued for a further 4-6 weeks.

The responses in grain yield to seed rate concurred with previous seed rate work in wheat. Across the nine site seasons the highest yield was achieved from 320 seed/m^2, which equated to 177 established plants/m^2 but there was no significant yield loss in reducing seed rate to 160 seeds/m^2, or 98 plants/m^2. Increasing seed rate from 320 to 640 resulted in a slight yield depression of 0.18 t/ha. On average, 1.47 t/ha yield was lost when seed rate was reduced to 40 seeds/m^2 (33 plants/m^2). The highest yielding seed rate differed, when meaned across the three years, at the individual sites. At RM and MOR 160 seeds/m^2 (95 and 100 plants/m^2 respectively) produced the highest yield whereas at BX it was 320 seeds/m^2 (153 plants/m^2).

Grain yield responses to cultivation treatment related directly to the effectiveness of the different cultivation treatments in producing a good quality seedbed and therefore establishing the crop as discussed earlier. At RM where the plough-based system was most effective in producing a superior quality seedbed and consequently having better plant establishment, significant yield responses were seen compared to reduced tillage in all site seasons. At BX, where the converse was true, reduced tillage resulted in significant yield benefits compared to ploughing in two out of three years. At MOR similar overall responses were seen although they were not significant. At all sites the application of autumn nitrogen showed a yield benefit over reduced tillage alone. Although no differences between cultivation treatments in soil nitrogen supply were detected, the crop growth and grain yield responses indicate autumn nitrogen maybe beneficial where a reduced tillage practice is being adopted and perhaps more so with direct drilling. However with current NVZ rules and the requirement to comply with Good Agricultural and Environmental Condition (GAEC) for the single payment scheme this practice may be difficult to justify for a grower.

A central hypothesis of this study was that the seed rate optima previously calculated following a plough based cultivation practice may not be applicable under the now prevalent minimum or reduced tillage systems. Results from this study have disproved this hypothesis, as there is no evidence for differences in the response of yield to established population. This suggests that reductions in wheat seed rates are as applicable under any tillage system as long as the cultivation does not adversely affect seedbed quality and subsequent establishment.

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Appendix A. – Yield Results (t/ha @ 85% dm)

RM Year 1 (2003 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	9.17	8.91	10.64
80	9.88	9.85	11.19
160	10.79	10.88	11.83
320	11.05	11.49	11.89
640	11.32	11.27	11.29
Mean	10.44	10.48	11.37
CV%		3.3	
Cultivation SED		0.1921	
P value		0.014	
df		4	
Seed rate SED		0.1677	
P value		<0.001	
df		4	
Cult x Seed rate SED		0.3231	
P value		0.008	
df		23	

BX Year 1 (2003 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	7.30	7.38	6.62
80	6.84	6.91	7.38
160	6.66	7.26	7.25
320	7.47	7.96	7.34
640	8.12	8.32	8.07
Mean	7.28	7.57	7.38
CV%		4.3	
Cultivation SED		0.1656	
P value		0.162	
df		4	
Seed rate SED		0.1471	
P value		<0.001	
df		4	
Cult x Seed rate SED		0.2817	
P value		0.048	
df		23	

MOR Year 1 (2003 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	8.93	8.71	8.57
80	9.02	9.21	8.65
160	9.74	9.55	9.44
320	9.52	9.92	9.27
640	9.66	9.63	9.79
Mean	9.37	9.40	9.18
CV%		2.7	
Cultivation SED		0.3859	
P value		0.827	
df		4	
Seed rate SED		0.1173	
P value		<0.001	
df		4	
Cult x Seed rate SED		0.4266	
P value		0.104	
df		23	

RM Year 2 (2004 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	9.71	10.43	11.44
80	10.82	11.11	11.68
160	11.63	12.23	12.34
320	11.19	11.78	11.86
640	11.47	12.05	11.42
Mean	10.96	11.52	11.75
CV%		3.3	
Cultivation SED		0.2429	
P value		0.071	
df		4	
Seed rate SED		0.1795	
P value		<0.001	
Cult x Seed rate SED		0.3693	
P value		0.026	
df		23	

BX Year 2 (2004 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	9.40	9.62	6.65
80	10.51	10.92	9.02
160	11.16	11.44	9.94
320	11.13	11.08	11.71
640	10.12	9.81	11.24
Mean	10.47	10.57	9.71
CV%		4.6	
Cultivation SED		0.1759	
P value		0.015	
df		4	
Seed rate SED		0.2211	
P value		<0.001	
df		4	
Cult x Seed rate SED		0.3851	
P value		<0.001	
df		23	

MOR Year 2 (2004 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	7.45	7.54	5.52
80	8.43	8.71	5.83
160	9.75	9.17	9.43
320	9.01	8.93	10.18
640	9.58	8.88	10.04
Mean	8.844	8.646	8.2
CV%		14.0	
Cultivation SED		0.656	
P value		0.633	
df		4	
Seed rate SED		0.563	
P value		<0.001	
df		4	
Cult x Seed rate SED		1.092	
P value		0.064	
df		23	

RM Year 3 (2005 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	6.82	7.33	8.79
80	8.17	8.30	9.47
160	8.99	9.23	10.43
320	9.41	9.44	9.70
640	8.79	9.44	9.98
Mean	8.44	8.75	9.67
CV%		4.8	
Cultivation SED		0.218	
P value		0.011	
df		4	
Seed rate SED		0.201	
P value		<0.001	
df		4	
Cult x Seed rate SED		0.380	
P value		0.108	
df		24	

BX Year 3 (2005 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	9.514	10.138	9.613
80	11.603	11.768	10.948
160	12.397	12.053	12.001
320	12.176	12.173	11.655
640	12.222	11.816	11.717
Mean	11.582	11.589	11.187
CV%		4.6	
Cultivation SED		0.1729	
P value		0.042	
df		4	
Seed rate SED		0.2232	
P value		<0.001	
df		4	
Cult x Seed rate SED		0.3867	
P value		0.598	
df		23	

MOR Year 3 (2005 harvest)

	Cultivation Method		
Seed rate (seeds/m^2)	Min Till	Min Till + Aut N	Ploughed
40	10.26	10.46	10.24
80	10.76	10.65	10.75
160	11.32	11.28	11.37
320	11.22	11.39	11.25
640	11.11	11.09	10.69
Mean	10.93	10.97	10.86
CV%			
Cultivation LSD		0.14	
P value		0.260	
df		4	
Seed rate LSD		0.19	
P value		0.0001	
Cult x Seed rate LSD		0.32	
P value		0.242	
df		28	

Appendix B. – Site Details

Year 1 – 2003 harvest year

Site:	**RM**		
Year:	2003		
Trial Location:	Flat field, ADAS RM, Preston Wynne		
Drainage:	Good		
Soil type:	Silty Clay Loam	Bromyard series	
Soil analysis:			Date sampled
	pH	6.7	04/11/03
	P (index)	2	04/11/03
	K (index)	2+	04/11/03
	Mg (index)	2	04/11/03
	Year		
Previous cropping:	2002	Winter Oats	
	2001	Winter Wheat	
	2000	Forage Maize	
	Date		
Sowing date:	19/09/2002		
		Equipment used	Date
Cultivations:		Sub soil	13/9/02
	Plough treatment	Plough	19/9/02
		Power Harrow	19/9/02
	Min till treatment	Pegasus Discs	19/9/02
Drill type:		Disc Drill	19/9/02
	Products	Rates	Date
Herbicides:	Topik	0.2 l/ha	10/10/02
	Panther	1.0 l/ha	26/2/03
	Arelon	3.0 l/ha	26/2/03
	Cheetah S	0.7 l/ha	24/3/03
	Eagle	40 g/ha	15/4/03
Insecticides:	Cyperkill	0.25 l/ha	10/10/02
	Cyperkill	0.25 l/ha	27/02/03
Molluscicides:	Hardy Slug pellets	4.9 kg/ha	8/10/02
	Draza	2.3 kg/ha	8/10/02
	Hardy Slug pellets	7.5 kg/ha	31/10/02
	Draza	2.2 kg/ha	31/10/02
	Hardy Slug pellets	7.5 kg/ha	25/11/02
	Draza	2.8 kg/ha	25/11/02
Fertiliser:	Ammonium Sulphate	S 39.9 kg/ha	13/3/03
	Ammonium Sulphate	N 13.6 kg/ha	13/3/03
	Nitram	N 30.0 kg/ha	31/3/03
	Nitram	N 63.6 kg/ha	11/4/03
	Nitram	N 39.9 kg/ha	14/5/03
Fungicides:	Landmark	0.5 l/ha	9/5/03
	Amistar	0.5 l/ha	28/5/03
	Opus	0.7 l/ha	28/5/03
Growth Regulators	Chlormequat	1.25 l/ha	15/4/03
	Moddus	0.2 l/ha	15/4/03
Harvest Date:			14/8/03

Site:		**BX**	
Year:		2002/03	
Trial Location:		Long Field	
OS grid ref.		SO 339638	
Drainage:		Wetness class II – slowly permeable	
Soil type:		Hanslope clay	
Soil analysis:			
	pH	7.0	
	P (index)	2	
	K (index)	2	
	Mg (index)	2	
	Year	Crop	
Previous cropping:	01/02	Winter beans	
	00/01	W. wheat	
	99/00	W. wheat	
			Date
Sowing date:			1/10/02
		Equipment used	Date
Cultivations:		Plough and press	17/09/02
		Disc	18/09/02
		Power harrow	30/09/02
		Roll	2/10/02
Drill type:		3 m Sulky	1/10/02
		Products and rates	Date
Herbicides:			
		Crystal 4.00 l/ha	07/10/02
		Duplosan 1.00 l/ha	25/02/03
		Ipu 3.00 l/ha	25/02/03
		Panther 0.512 l/ha	25/02/03
		Monitor 25.00 g/ha	27/05/03
		Starane 0.293 l/ha	27/05/03
Insecticides:		Cypermethrin 0.244 l/ha	25/02/03
Fertiliser:	P @		
	K @		
	N @		
		Nitram 115.923 kg/ha	11/10/02
		7:21:0:0 400.00 l/ha	14/03/03
		Nuram 37 3000.00 l/ha	29/03/03
		Nuram 37 2000.00 l/ha	26/04/03
Fungicides:		Bravo 0.756 l/ha	16/04/03
		Amistar 0.488 l/ha	06/05/03
		Opus 0.488 l/ha	06/05/03
		Opera 0.756 l/ha	30/05/03
Harvest Date:		09.08.03	

Site:	**MOR**		
Year:	2003		
Trial Location:	Chapel Field, Hall Farm		
OS grid ref.	TG 048 013		
Drainage:	Good		
Soil type:	Loamy sand. Burlingham series		
Soil analysis:			Date sampled
	pH	7.4	August 03
	P (index)	1+	August 03
	K (index)	1	August 03
	Mg (index)	1-	August 03
	Year	Crop	
Previous cropping:	2002	Winter beans	
	2001	Winter barley	
			Date
Sowing date:			19/09/02
		Equipment used	Date
Cultivations:	Min till	Tera-disc + press	16/09/02
	Plough	Plough + press	08/09/05
Drill type:	Vaderstad	Cultivator drill	19/09/05
		Products and rates	Date
Herbicides:		IPU 2.0 l/ha	15/11/02
		Treflan 1.5 l/ha	15/11/02
		Duplosan 0.75 l/ha	15/11/02
		Topik 0.08 l/ha	31/03/03
		Starane XL 1.0 l/ha	30/04/03
		Ally 0.02 g/ha	30/04/05
Insecticides:		Toppel 10 0.25 l/ha	15/11/02
Growth Regulator:		Chlormequat 2.2 l/ha	31/03/03
		Terpal 0.75 l/ha	21/05/05
Fertiliser:		Nitrogen 100 kg/ha	25/03/03
		Sulphur 7 kg/ha	25/03/03
		Nitrogen 102 kg/ha	02/05/03
		Sulphur 8 kg/ha	02/05/03
Fungicides:		Opus 0.2 l/ha	30/04/05
		Bravo 1.0 l/ha	30/04/05
		Fortress 0.1 l/ha	30/04/05
		Opus 0.4 l/ha	29/05/03
		Twist 1.0 l/ha	29/05/03
		Bravo 0.5 l/ha	29/05/03
		Amistar 0.3l/ha	09/06/03
		Folicur 0.2l/ha	09/06/03
Harvest Date:			12/08/03

Year 2 – 2004 harvest year

Site:	**RM**		
Year:	2004		
Trial Location:	Bigyard field, ADAS RM, Preston Wynne		
Drainage:	Good		
Soil type:	Silty Clay Loam	Bromyard series	
Soil analysis:			Date sampled
	pH	6.9	4/11/03
	P (index)	5	4/11/03
	K (index)	4	4/11/03
	Mg (index)	3	4/11/03
	Year		
Previous cropping:	2003	Winter Oilseed rape	
	2002	Winter Wheat	
	2001	Winter Oats	
	Date		
Sowing date:	8/10/2003		
		Equipment used	Date
Cultivations:		Pegasus Discs	5/9/03
		Sub soil	12/9/03
	Plough treatment	Plough	22/9/03
		Power Harrow	8/10/03
	Min till treatment	Pegasus Discs	22/9/03
		Cambridge Roll	8/10/03
Drill type:		Kraus Disc Drill	8/10/03
	Products	Rate	Dates
Herbicides:	Crystal	2.5 l/ha	12/11/03
	Starane XL	1.0 l/ha	11/5/04
	Topik	0.125 l/ha	11/5/04
	Contact (Adj)	1.0 l/ha	11/5/04
Insecticides:	Cyperkill	0.25 l/ha	12/11/03
	Dursban 4	0.75 l/ha	8/6/04
Fertiliser:	Potassium Sulphate	S 40.9 kg/ha	23/3/04
		K 45.54 kg/ha	23/3/04
	Nitram	N 60.05 kg/ha	1/5/04
	Nitram	N 89.03 kg/ha	16/5/04
Fungicides:	Bravo 500	1.0 l/ha	30/3/04
	Bravo 500	1.0 l/ha	22/4/04
	Opus	0.2 l/ha	22/4/04
	Mantra	0.5 l/ha	22/4/04
	Bravo 500	0.8 l/ha	24/5/04
	Opus	0.8 l/ha	24/5/04
	Twist	0.8 l/ha	24/5/04
Growth Regulators:	Chlormequat	1.25 l/ha	30/3/04
	Chlormequat	1.0 l/ha	15/4/04
	Moddus	0.2 l/ha	15/4/04
Harvest Date:	1/9/04		

Site:		**BX**	
Year:		20003/04	
Trial Location:		Pamplins North	
OS grid ref.		SO 345636	
Drainage:		Wetness class II slowly permeable	
Soil type:		Hanslope clay	

Soil analysis:			Date sampled
	pH	7.3	9/10/03
	P (index)	2	
	K (index)	3	
	Mg (index)	2	
	Year	Crop	
Previous cropping:	02/03	Winter beans	
	01/02	Winter wheat	
	00/01	Winter wheat	
			Date
Sowing date:			22/09/03
Emergence date:		Min Till	13/10/03
		Ploughed	24/11/03
		Equipment used	Date
Cultivations:		Mole plough	28/08/03
		Flat lift & roll	2/09/03
		Power Harrow	2/09/03
		Machio trial area	22/09/03
		Drilled plots	22/09/03
Drill type:		Sulky	22/09/03

	Products and rates units		Date
Herbicides:	Glyphos	4.00 l/ha	22/08/03
	Crystal	4.00 l/ha	25/09/03
	Duplosan	1.00 l/ha	07/12/03
	Lexus 50df	20.00 g/ha	07/12/03
	Stomp	3.30 l/ha	07/12/03
	Attribute	0.105 l/ha	14/04/04
Insecticides:	Cypermethrin 100	0.250 l/ha	07/12/03
	Cypermethrin 100	0.250 l/ha	04/06/04
	Pontoon	0.697 l/ha	14/06/04
Moluscicides:	Draza	3.500 kg/ha	24/10/03
Fertiliser:	7:21:0:0	400.00 l/ha	03/03/04
	Nuram 37	260.00 l/ha	30/03/04
	Nuram 37	260.00 l/ha	14/05/04
Fungicides:	Bravo 500	1.00 l/ha	16/04/04
	Landmark	0.50 l/ha	12/05/04
	Opus	0.197 l/ha	12/05/04
	Landmark	0.697 l/ha	04/06/04
Harvest Date:	7/09/04		

Site:	**MOR**		
Year:	2004		
Trial Location:	Hastings, Wood Farm		
OS grid ref.	TM 047 977		
Drainage:	Good		
Soil type:	Beccles series		
Soil analysis:			Date sampled
	pH	8.2	August 02
	P (index)	3-	August 02
	K (index)	2-	August 02
	Mg (index)	2-	August 02
	Year	Crop	
Previous cropping:	2003	Spring beans	
	2002	Winter wheat	
	2001	Sugar beet	
			Date
Sowing date:			17/09/05
		Equipment used	Date
Cultivations:	Disc and press	Vaderstad Carrier	10/09/03
	Plough and press	Plough	10/09/03
Drill type:	Cultivator drill	Vaderstad Rapid	17/09/03
	Products	Rates	Date
Herbicides:	Panther	0.5 l/ha	06/11/03
	IPU	2.5 l/ha	06/11/03
	Duplosan	0.75 l/ha	06/11/03
	Platform S	0.75 kg/ha	09/04/04
	Topik	0.1 l/ha	20/04/04
	Starane 2	0.5 l/ha	17/05/04
Insecticides:	Hallmark Zeon	0.05 l/ha	07/06/04
Fertiliser:	Nitrogen	40 kg/ha	20/02/04
	Sulphur	7 kg/ha	20/02/04
	Nitrogen	123.8 kg/ha	13/04/04
	Sulphur	22 kg/ha	13/04/04
	Nitrogen	70 kg/ha	26/04/04
	Sulphur	12 kg/ha	26/04/04
Fungicides:	Opus	0.25 l/ha	20/04/04
	Fortress	0.1 l/ha	20/04/04
	Bravo	1.0 l/ha	20/04/04
	Opera	0.4 l/ha	17/05/04
	Bravo	1.0 l/ha	17/05/04
	Opus	0.5 l/ha	17/05/04
	Swing Gold	0.5 l/ha	07/06/04
Growth Regulators	Chlormequat	2.25 l/ha	09/04/04
	Chlormequat (5C)	0.75 l/ha	20/04/04
	Terpal	1.0 l/ha	17/05/04
Harvest Date:			18/08/04

Year 3 – 2005 harvest year

Site:	**RM**		
Year:	2005		
Trial Location:	Stoney field, ADAS RM, Preston Wynne		
Drainage:	Good		
Soil type:	Silty Clay Loam	Bromyard series	
Soil analysis:			Date sampled
	pH	6.6	17/11/04
	P (index)	2	17/11/04
	K (index)	2+	17/11/04
	Mg (index)	3	17/11/04
	Year		
Previous cropping:	2004	Winter Oats	
	2003	Winter Wheat	
	2002	Winter Oilseed rape	
	Date		
Sowing date:	11/10/2004		
		Equipment used	Date
Cultivations:		Sub soil	23/8/04
	Plough treatment	Plough	5/10/04
		Power Harrow	6/10/04
Drill type:	Min till treatment	Kraus Disc Drill	11/10/04
	Products	Rates	Date
Herbicides:	Glyphosphate	3.0 l/ha	15/9/04
	Topik	0.125 l/ha	12/11/04
	Cropoil (Adj)	1.0 l/ha	12/11/04
	Isoproturon 500	2.5 l/ha	14/3/05
	Tigress	2.0 l/ha	12/4/05
	Eagle	25 g/ha	22/4/05
	Ally	20 g/ha	22/4/05
Insecticides:	Cyperkill	0.25 l/ha	12/11/04
Molluscicides:	Hardy slug pellets	4.0 kg/ha	13/4/05
Fertiliser:	Ammonium Sulphate	S 34.0 kg/ha	12/3/05
		N 11.9 kg/ha	12/3/05
	Nitram	N 32.0 kg/ha	15/3/05
	Nitram	N 99.0 kg/ha	21/4/05
	Nitram	N 29.0 kg/ha	12/5/05
Fungicides:	Proline	0.6 l/ha	26/4/05
	Bravo 500	1.0 l/ha	26/4/05
	Opera	1.0 l/ha	23/5/05
	Opus	0.4 l/ha	23/5/05
	Bravo 500	1.0 l/ha	23/5/05
	Folicur	0.5 l/ha	14/6/05
Growth Regulators	Chlormequat (5C)	0.75 l/ha	12/04/05
	Terpal	1.0 l/ha	17/05/05
Harvest Date:	15/8/05		

Site:		**BX**	
Year:		2004/05	
Trial Location:		Big Field	
OS grid ref.		SO 338637	
Drainage:		Wetness class II	
Soil type:		Hanslope Clay	
Soil analysis:			Date sampled
	pH	8.1 8.2	18/11/04
	P	14 13	
	K	296 283	
	Mg	118 99	
	Year	Crop	
Previous cropping:	03/04	Spring beans	
	02/03	Winter wheat	
	01/02	Winter wheat	
			Date
Sowing date:			17/10/04
Emergence date:		50% emergence date	1/11/04
		Equipment used	Date
Cultivations:		Plough or disk + power harrow all	7/10/04
		Min-till with Q-Von	
Drill type:		3m Sulky	
		Products and rates and units	Date
Herbicides:		Glyphos 2.00 l/ha	25/9/04
		Cmpp-P 0.750 l/ha	10/12/04
		Atlantis 0.395 kg/ha	
		Starane 0.50 l/ha	20/04/05
		Topik 240Ec 0.132 l/ha	17/05/05
Insecticides:		Cypermethrin 100 0.250 l/ha	10/12/04
		Cypermethrin 0 .250 l/ha	18/03/05
		Pontoon 0.803 l/ha	07/06/05
Moluscicides:		Draza 5.00 kg/ha	6/11/04
Fertiliser:	P @		
	K @		
	N @		
		12:18:0:0 400.00 l/ha	14/03/05
		Liquid N 37 200.00 l/ha	02/04/05
		Nitram 252.00 kg/ha	26/04/05
		Liquid N 37 235.00 l/ha	28/04/05
Fungicides:		Bravo 500 1.00 l/ha	01/04/05
		Tracker 0.75 l/ha	20/04/05
		Opera 0.50 l/ha	26/05/05
		Opus 0.60 l/ha	26/05/05
Harvest Date:		16/08/05	

Site:	**MOR**		
Year:	2005		
Trial Location:	Home Close, Manor Farm		
OS grid ref.	TM 054 996		
Drainage:	Good		
Soil type:	Ashley series		

Soil analysis:			Date sampled
	pH	7.3	August 02
	P (index)	3-	August 02
	K (index)	1+	August 02
	Mg (index)	1+	August 02

	Year		
Previous cropping:	2004	Winter beans	
	2003	Winter barley	
	2002	Spring barley	

			Date
Sowing date:			21/09/04

		Equipment used	Date
Cultivations:	Disc and press	Vaderstad Carrier	15/09/04
	Plough and press	Plough	15/09/04
Drill type:	Cultivator drill	Vaderstad Rapid	21/09/04

	Products	rates	Date
Herbicides:	Avadex excel	15 kg/ha	20/10/04
	Panther	0.25 l/ha	28/10/04
	IPU WDG	1.0 kg/ha	28/10/04
	Stomp	2.0 l/ha	28/10/04
	Eagle	15 g/ha	25/03/05
	Topik	0.1 l/ha	12/04/05
	Duplosan	1.5 l/ha	21/04/05
Insecticides:	Cypermethrin	0.25 l/ha	28/10/04
	Hallmark zeon	0.05 l/ha	08/06/05
Fertiliser:	Nitrogen	70 kg/ha	21/03/05
	Sulphur	12 kg/ha	21/03/05
	Nitrogen	105 kg/ha	20/04/05
	Sulphur	19 kg/ha	20/04/05
	Nitrogen	36 kg/ha	04/05/05
	Sulphur	6 kg/ha	04/05/05
Fungicides:	Fortress	0.1 l/ha	21/04/05
	Bravo	1.0 l/ha	21/04/05
	Opus	0.25 l/ha	21/04/05
	Opus	0.5 l/ha	12/05/05
	Amistar opti	0.75 l/ha	12/05/05
	Swing Gold	0.6 l/ha	08/06/05
Growth Regulators	Chlormequat	2.25 l/ha	12/04/05
	Terpal	1.0 l/ha	12/05/05

Harvest Date:			28/08/05