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Management of oilseed rape to balance root and canopy growth

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Contents

ABSTRACT

Eleven commercial crops of oilseed rape were sampled in 2004 for root length density and total biomass, post flowering. Root length densities declined with depth, and were on average higher than values previously recorded in the UK for oilseed rape, but lower than those in winter wheat. Substantial variation between sites was in part attributed to cultivation and soil type differences. No relationship between crop biomass and root length density was found, suggesting that it might be possible to modify root systems maximise below ground resource capture whilst avoiding excessively large canopy sizes.

In 2005, replicated experiments at ADAS Boxworth and Rosemaund, tested single factor comparisons of sowing date, seed rate, sulphur, nitrogen, plant growth regulators, and cultivations on rooting and yield. 53% of the variation in yield at ADAS Boxworth was attributable to differences in root length density between 40 and 100cm depth in the soil. This highly significant relationship suggests that rooting is limited at depth in oilseed rape, and improving root length density at depth may improve drought tolerance and yield.

Of the treatments affecting root length density below 40cm, only spring-applied metconazole, significantly improved root length density, and only at one site. Ploughing, subsoiling, and not delaying sowing significantly increased root length density near the surface (mainly the top 20cm). There was no similar effect on rooting at depth (below 60cm). Low seed rates and delaying N strategies may improve the profile of rooting at depth; however each effect was only seen at one of the two sites, and as such would require further verification. Canopy size measurements in the second year again showed this was not linked to root length density, supporting the conclusion from the first season, that it is possible to affect root shoot balance in oilseed rape.

SUMMARY

Introduction

National average oilseed rape yields have not increased significantly in the UK for the past 20 years. Average yields in the Recommended List trials system have increased steadily at a rate of 0.5t ha^{-1} $decade^{-1}$ (Spink & Berry, 2005). It appears, therefore, that commercial yields of oilseed rape are in some way restricted, and the improved genetic potential of new varieties is not being exploited. Observation of farm crop yields from ADAS Boxworth, Cambs. UK between 1987 and 1997 indicated a positive correlation between June rainfall and yield (Figure 1). This implies that water availability may be restricting yield potential. As such improving root exploration to increase water availability during late spring and early summer may be an effective strategy to improve yield in oilseed rape.

Root systems in wheat are generally considered adequate for nutrient and water uptake (Lucas et al., 2000). Work on root length density in wheat (Barraclough, 1984) has shown that that 1cm of root length is sufficient to extract the available water from $1cm^3$ of soil. Where wheat root systems have been measured, root lengths of 2-7cm cm^{-3} have been recorded in the upper 40cm of soil, and 0.8 - 2cm cm^{-3} in the 40 - 80cm horizon (Ford *et al*. 2002, Hoad *et al*., 2004).

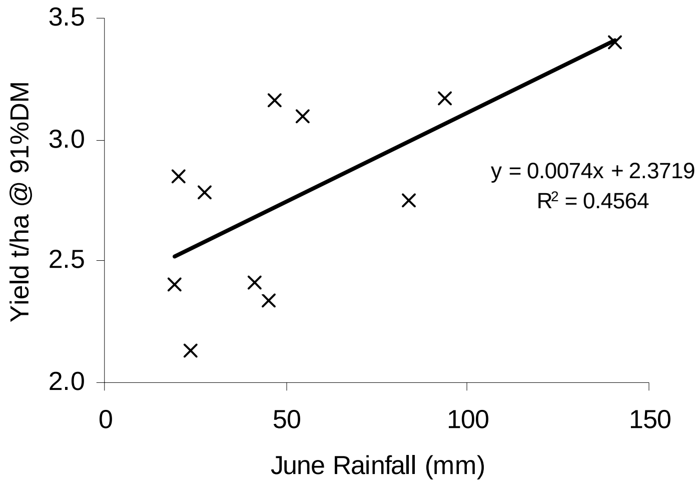

Figure 1. Effect of total June rainfall on yield of commercial crops of oilseed rape ADAS Boxworth, Cambs. 1987-1997.

There are limited data available on rooting in oilseed rape. Root length densities of 0.6cm cm^{-3} in the 40-60cm horizon, and 0.35cm cm^{-3} between 60-180cm, have been reported in oilseed rape sown in late August in Hertfordshire (Barraclough, 1989). Assuming a similar critical root length density of 1cm cm^{-3} for oilseed rape as for cereals, this suggests that oilseed rape crops may be more ‘root limited’ than winter cereals.

Assuming that the root systems of oilseed rape are restricted, in addition to potential genetic approaches to improve rooting, there is anecdotal or laboratory evidence that several agronomic practices may influence rooting.

Root growth may been enhanced by earlier sowing, however, this can cause yield loss (Carver *et al.*, 1999) as an excessive canopy is produced which utilises light inefficiently, produces too many pods, and is prone to lodging (Spink *et al.*, 2002). High plant populations may lead to increased concentration of the roots in the upper soil profile, as has been shown for cereals (Kirby and Rackham, 1971), possibly at the expense of rooting at depth (Hoad *et al.*, 2004).

The effects of spring applications of tebuconazole and metconazole applied as plant growth regulators on canopy growth have been extensively studied (e.g. Spink *et al.*, 2002). In contrast the effects of autumn applications have been the subject of little or no detailed study in the UK. In Germany, autumn metconazole applications have been promoted to improve both winter hardiness, and the root/shoot balance. However the practice is based on the results of laboratory experiments. These effects require verifying both in the UK and under field conditions, to determine if they result in useful increases in rooting i.e. at depth rather than proliferation in the surface layers of the soil.

Evidence from work on wheat suggests that early spring N applications encourage shallow rooting (Hoad *et al.,* 2004), and by delaying spring N in oilseed rape, it may be possible to encourage deeper rooting. This delay may also benefit yield by preventing excessive canopy growth as described in Lunn *et al*. (2001). Oilseed rape is considered to be sensitive to compaction. Some progressive growers have sought to establish behind subsoil cultivation equipment, to improve the rooting environment. A better understanding of subsoil cultivations and min till establishment on the extent and depth of rooting would provide an informed basis for decision making at crop establishment. Sulphur (S) deficiency is becoming increasingly widespread. Research has clearly demonstrated the yield benefits of S applied in the spring on the majority of oilseed rape crops (Blake-Kalff *et al*., 2000). The effect of S levels on root growth has not, however, been studied in the field. Sulphur deficiency has been linked to restricted root growth in glasshouse experiments (Helal & Schnug, 1995), demonstrating that adequate S levels are essential to maintain root integrity, prevent root mortality, and improve root efficiency.

This study was funded as a pilot project with two main aims: to quantify the average and range in root length density with depth in commercial crops of oilseed rape in the UK; to identify agronomic and husbandry practices that may improve rooting.

Materials and Methods

The experimental work spanned two seasons harvest years 2004 and 2005. In the first season oilseed rape fields from across the UK were selected, to provide information on the extent of rooting in oilseed rape in commercial crops. In the second season more detailed replicated field trials were conducted at ADAS Rosemaund, Herefordshire, and ADAS Boxworth, near Cambridge.

Year 1

Eleven field sites, unaffected by the delayed autumn germination experienced in 2003, where selected. Of the 11 sites, 3 were ploughed, the other 8 established by other strategies (non-inversion or minimum tillage). Five of the fields were clays or clay loams, 4 were sandy clay or silty clay loams, 1 field was a sandy loam, and 1 a gravel loam (Table 1).

Table 1: The field sites

Site	Location	Soil type	Cultivation strategy
1	Ledgemore, Hereford	Silty clay loam	Min tilled
2	Didley, Herefordshire	Silty clay loam	Min tilled
3	Preston Wynne, Herefordshire	Silty clay loam	Ploughed
4	Heighington, Darlington	Clay loam	Non inversion tilled
5	Heighington, Darlington	Gravel loam	Non inversion tilled
6	Spilsby, Lincolnshire	Sandy Loam	Ploughed
7	Whittlesford, Cambridgeshire	Sandy clay loam	Min tilled
8	Boxworth, Cambridgeshire	Clay	Min tilled
9	Orlingbury, Northamptonshire	Clay loam	Non inversion tilled
10	Little Weighton, Yorkshire	Med clay loam (chalky)	Ploughed
11	Bridgewater, Somerset	Clay	Min tilled

At each field site 6 soil cores (2.6 cm diameter) were taken at a single, randomly selected location at least 40m away from the field edge, to a depth of 1m and sub-divided into 20 cm lengths. Samples were taken in June to coincide with the point of maximum root length. Soil cores were then frozen to reduce root degradation. The roots were extracted separately using a root washer system (Delta-T devices LTD, Burwell, Cambridge, UK.), and collected on a 550 micron wire mesh filter. Root length was then assessed using a Win-RHIZO STD LC1600+ scanner (Regent instruments Inc., Sainte Foy, Qc, Canada). An additional sample of 6 tap roots were sampled from the same area as the root cores, these were washed and photographed, to provide a record of their structure.

A $1m^2$ quadrat was also sampled from each field close to where the root cores were taken. The total fresh weight, and fresh weight of stems, pods and seeds separately, were recorded. The green area of the same components was measured using an area measurement system (Delta-t devices). Each component was then oven dried at 100^oC for 48 hours and dry weight recorded.

Year 2

In the second year, field experiments were set up at ADAS Boxworth (Cambridgeshire) and ADAS Rosemaund (Herefordshire) to test single factor comparisons of sowing date, seed rate, sulphur, nitrogen, plant growth regulators, and cultivations.

A single variety 'Winner' was used on both sites. Each treatment was managed in the standard way except for the single factor under investigation. The 'standard' crop had a seed rate of 6kg/ha, was sown in early September, received sulphur in March in the form of Kieserite at a rate of 120 kg SO_3 / ha. Total N applied was determined by RB209, following determination of Soil mineral nitrogen, and taking account of crop N at the time of sampling. Total N applied was split, 50% in late February / early March and 50% in late March / early April (Appendix 1).

Growth analysis and green area index measurements on selected plots, post flowering in mid June, were taken to measure any treatment effects on above ground resource capture. Root sampling at the point of anticipated maximum root size in June, was also conducted, as described for the first season, on all plots to identify the impact of treatments on root length density. Sampling and subsequent extraction of roots followed the same methodology as for year 1.

Weeds and pests

A robust programme to control all weeds, and pests was employed, in accordance with standard farm practice.

Disease control

A robust two spray disease control program was used across all plots to control phoma and light leaf spot. This was achieved without the use of metconazole, or tebuconazole, due to their growth regulatory effects (and inclusion as treatments). Applications for the control of sclerotinia were not applied at either site due to both sites having a low risk status.

Treatments

Cultivation treatments were set up pre-planting, such that plots were established after ploughing and a shallow surface cultivation (Min Till), each with or without prior subsoiling (treatments 1-4, Table 2). Delayed spring N treatments received no N at the first split (late Feb / early March), instead receiving their total N requirement at the second timing only. (Table 2)

Table 2: Treatment list

Treatment	Cultivations	Agronomic practices
1	Plough	Standard (early Sept sown, seed rate 6kg/ha)
2	Plough no subsoil	Standard
3	Min Till no subsoil	Standard
4	Min Till + Subsoil (SS)	Standard (control)
5	Min Till + SS	No Sulphur
6	Min Till + SS	Standard + Autumn N (40 kgN /ha late Sept)
7	Min Till + SS	Delayed Spring N
8	Min Till + SS	Standard + PGR (late March) (Tebuconazole)
9	Min Till + SS	Standard + PGR (late March) (Metconazole)
10	Min Till + SS	Standard but delayed sowing (4/5 weeks post TOS1)
11	Min Till + SS	Standard Low seed rate (3 Kg/ha)

Results

Year 1

Across the 11 sites root length density (cm of root/cm^3 of soil) varied widely (Table 3). Whilst the low number of sites precludes a formal analysis, there were general trends that could be linked to soil type and cultivation strategy. Crops on the heavier clay and clay loam soils tended to root less well than the other lighter soil types. Additionally ploughing tended to result in above average root length densities, whereas min-till or non-inversion strategies tended to be more variable in the extent of rooting achieved.

Table 3. The mean and range of root length densities recorded to a depth of 1m.

	Root length density (cm of root cm^{-3} of soil)		
Soil Depth (cm)	**Mean (all sites)**	Max	Min
0-20	**3.56**	7.43	1.37
20-40	**2.32**	4.72	1.15
40-60	**1.17**	2.52	0.61
60-80	**1.00**	1.89	0.62
80-100	**1.12**	2.09	0.72

Further measurements were taken to determine if above ground biomass could be linked to the extent of rooting recorded. Results indicated that there was no relationship between crop canpy size (Green area index) and root length density (figure 2).

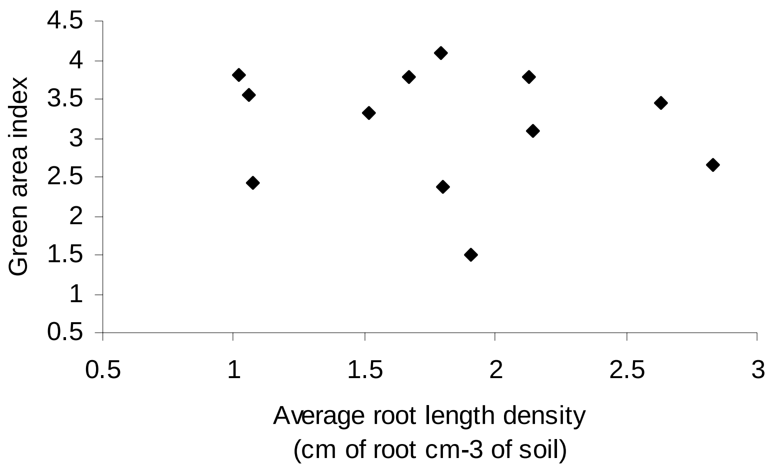

Figure 2. Green area index of commercial field crops of oilseed rape in 2004 compared to average root length density.

Tap root samples also indicated a potentially adverse effect of minimal cultivations at some sites. There tended to be more forking of the root where crops were either direct drilled or min-tilled compared to where soils were ploughed, which is indicative of greater mechanical impedance to root penetration in min tilled soils.

Year 2

Meteorological data

At ADAS Boxworth, favourable autumn conditions, led to good establishment in both the standard and delayed sowing treatments. In addition, consistently warmer than average overwinter conditions meant that overwinter plant loss was low, despite the crop being generally quite small during the autumn as a result of the 16 Sept sowing date for the main trial. At Rosemaund good growing conditons in September allowed crops to emerge successfully. Despite an earlier sowing date at this site (7 Sept) A wet October (101.2mm) and cooler than average November, limited autumn plant growth. At both Rosemaund and Boxworth, rainfall in May was lower than average, however at Boxworth this was also followed by a dry (43.0mm) and hot (3.0°C above average) June. June rainfall at Rosemaund was higher than that at Boxworth (54.8mm), and temperatures only 1.4°C above average (Table 4).

Table 4 Meteorological data for ADAS Rosemaund and Boxworth

	Average monthly temp (^oC)		Monthly rainfall (mm)	
Boxworth				
	2004/05	*1961-1990*	*2004/05*	*1961-1990*
Sep	16.5	14.1	21.4	46
Oct	12.0	10.9	34.4	48
Nov	8.3	6.3	48.6	51
Dec	5.1	4.3	23.8	50
Jan	6.5	3.3	35.4	45
Feb	4.8	3.4	24.1	35
Mar	7.9	5.5	22.2	44
Apr	10.3	7.7	54.6	45
May	12.5	11.0	37.4	50
Jun	17.2	14.2	43.0	53
Rosemaund				
	2004/05	*1961-1990*	*2004/05*	*1961-1990*
Sep	14.8	13.3	47.0	58
Oct	10.6	9.9	101.2	67
Nov	5.2	6.6	37.4	58
Dec	7.8	4.5	36.6	70
Jan	6.3	4.0	23.8	65
Feb	4.4	4.1	29.8	52
Mar	7.2	6.2	62.0	47
Apr	8.8	7.9	42.4	48
May	11.3	11.1	32.6	48
Jun	15.3	13.9	54.8	51

Root length density

Across both sites the root length density ranged from 2.2 to 5.0 cm cm^{-3} in the top 0-20cm depth reducing to 0.3 – 0.7cm cm^{-3} at the lowest depth. Overall, rooting appeared to be more extensive in the top soil at Boxworth (Figure 3). Whereas root density declined steady with depth at Rosemaund, at Boxworth root length density in the 20-40 cm depth was lower than might be expected, and was in most cases the same or higher in the 40-60cm depth, suggesting some form of rooting restriction, such as a compacted layer between 20 and 40cm. Sulphur treatments had no significant effects on rooting, whereas differences in rooting as a result of cultivations, N timing, plant growth regulators (PGR’s), seed rape and sowing date were observed as described below.

Effects of cultivations on rooting

At Rosemaund, ploughing with subsoiling resulted in a greater root length density(RLD) in the 0-20cm horizon compared with min till cultivations with no subsoiling (Figure 3). With increasing depth rooting densities converged, and although differences between these treatments did appear to be still present down to 80cm, these were not statistically significant. Min tilled with subsoiling, and ploughed without subsoiling treatments were intermediary.

Ploughing at Boxworth appeared to increase root length density at the 20-40cm depth, compared with min tillage without subsoiling, though this was not significant at the 5% level.

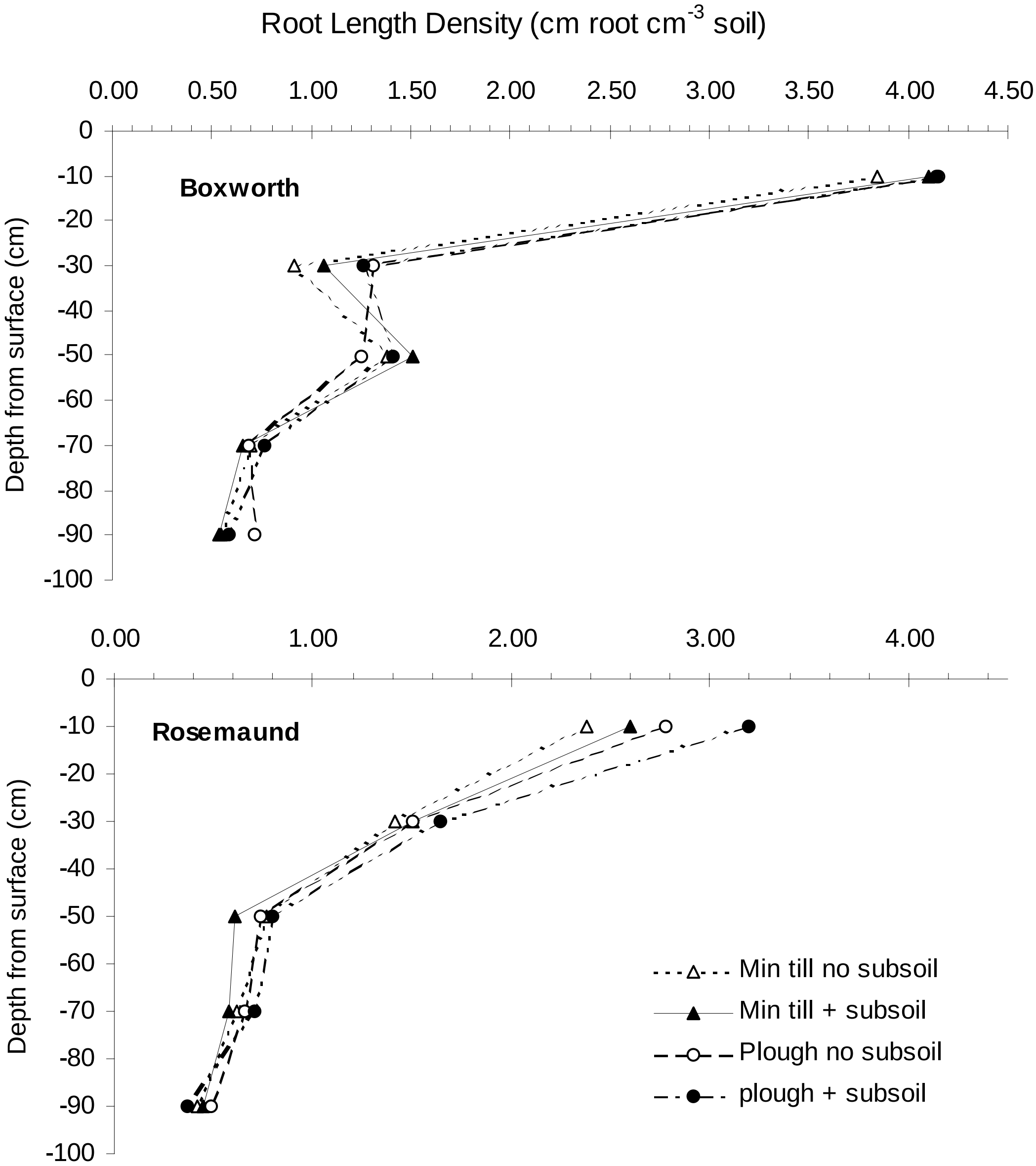

Figure 3. Effect of ploughing and min tilling cultivations with and without subsoiling on rooting at ADAS Rosemaund and Boxworth. Data points for depth are at the mid point between the upper and lower depths of each 20cm horizon.

Spring N timing and additional autumn N

Delaying the spring N application, appeared to increase root length density in the top 0-20cm depth at Boxworth decrease it at Rosemaund, although neither of these differences were significant. However at Boxworth delaying spring N did significantly increase the root length density in the 20-40cm horizon, compared to the standard treatment, from 1.06 cm cm^{-3} to 1.53 cm cm^{-3} (P= 0.04, SED = 0.206).

Autumn N treatments appeared to result in more rooting in the top 0-20cm, and possibly also at depth, however at Boxworth this may have related to crop size. Here the crop was small and possibly N limited overwinter, and the additional N may have assisted in overall growth. However, these apparent differences were not significant at any depth at either site (Figure 4).

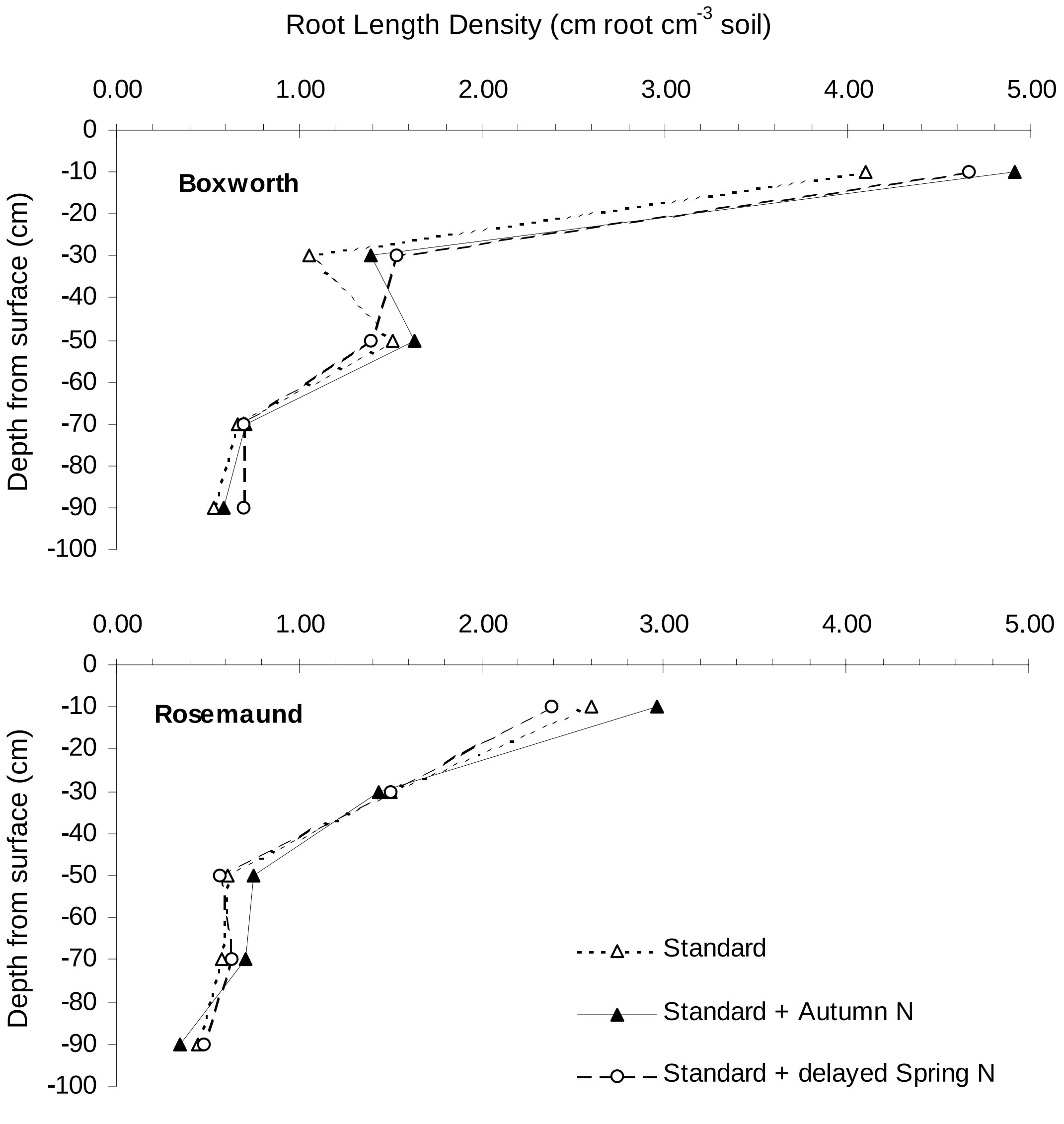

Figure 4. Autumn N and delayed spring N effects on root length density. Data points for depth are at the mid point between the upper and lower depths of each 20cm horizon.

Low seed rates and delayed sowing

Delaying sowing by 5 weeks (16 Sept to 22 Oct) at Boxworth, and 4.5 weeks (7 Sept to 8 Oct) at Rosemaund appeared to reduce root length density in the top 20cm, though this was only statistically significant at Rosemaund (P=0.008, 55df, SED = 0.79). At Boxworth and Rosemaund, root length densities in the 0-20cm horizon, when sowing was delayed, were 3.02, and 1.76 cm root cm^{-3} of soil respectively, compared to 4.10 and 2.60 cm root cm^{-3} of soil, at the earlier sowing dates (Figure 5). Differences were not signifiant at lower depths. Low seed rates did not significantly affect root length density at any depth, though the low seed rate treatment at Rosemaund did have a consistently higher root length density at the 40-60, 60-80 and 80-100cm depths compared with the standard. At Boxworth, low seed rate treatments appeared to root less well in the top 60cm than the standard, but differences were not evident at lower depths.

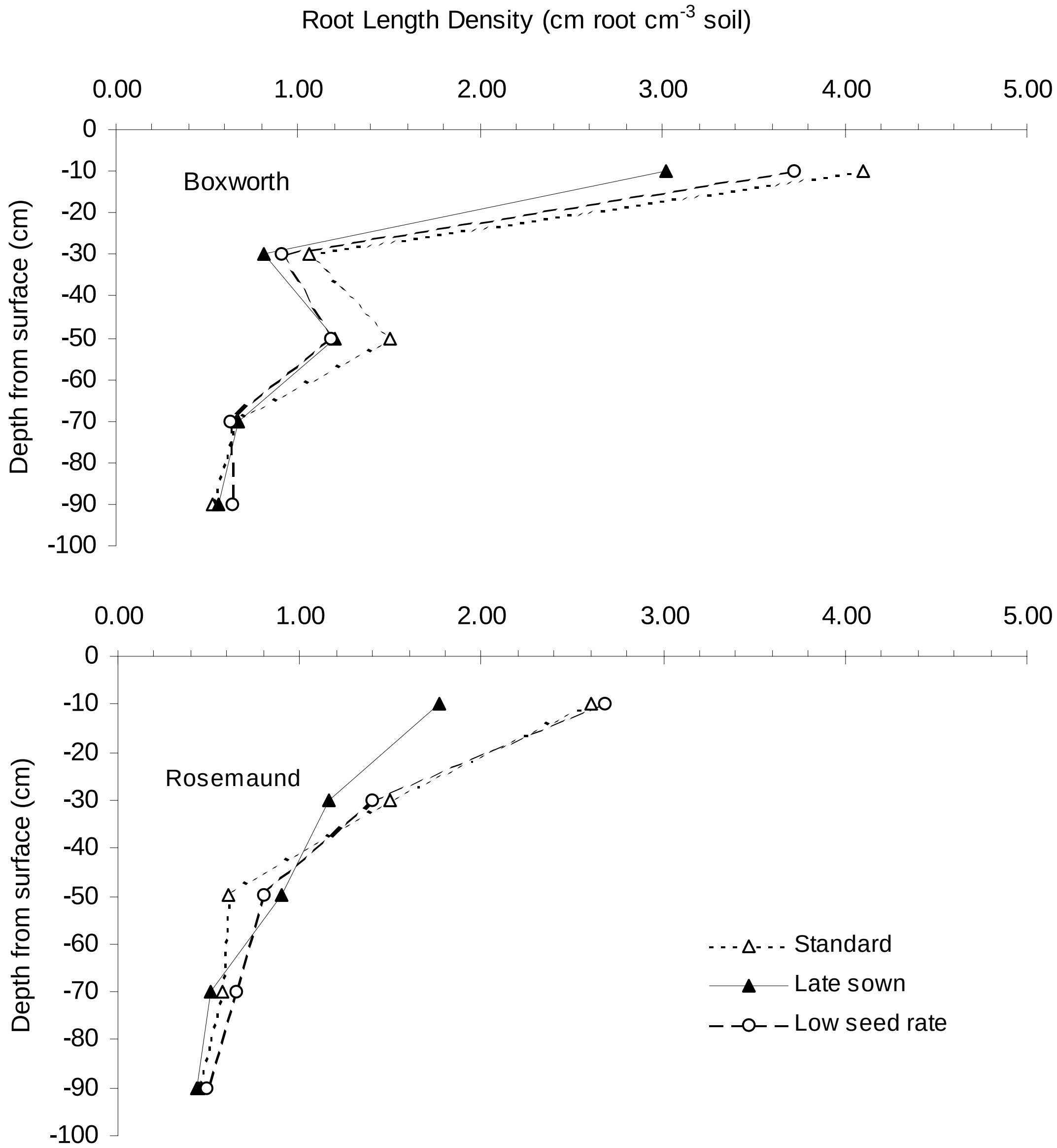

Figure 5. Effect of sowing date and seed rate on root length density. Data points for depth are at the mid point between the upper and lower depths of each 20cm horizon.

Spring growth regulators

Plant growth regulator metconazole 0.6 l/ha had a significant positive effect on root length density at ADAS Rosemaund in both the 0-20cm (P=0.008, 55 d.f., SED = 0.790) and 40-60cm horizons (P=0.008, 55 d.f., SED = 0.297). Treatment with tebuconazole 0.5 l/ha, resulted in numerically higher root length densities in the 20-40cm horizon, however this was not statistically significant. At Boxworth, no clear differences in rooting as a result of spring growth regulators were observed. Both treatments resulted in numerically higher root length densities in the 20-40cm horizon, compared to the standard treatment, however this pattern was reversed at the 40-60cm depth. At neither depth were these differences statistically significant (Figure 6) .

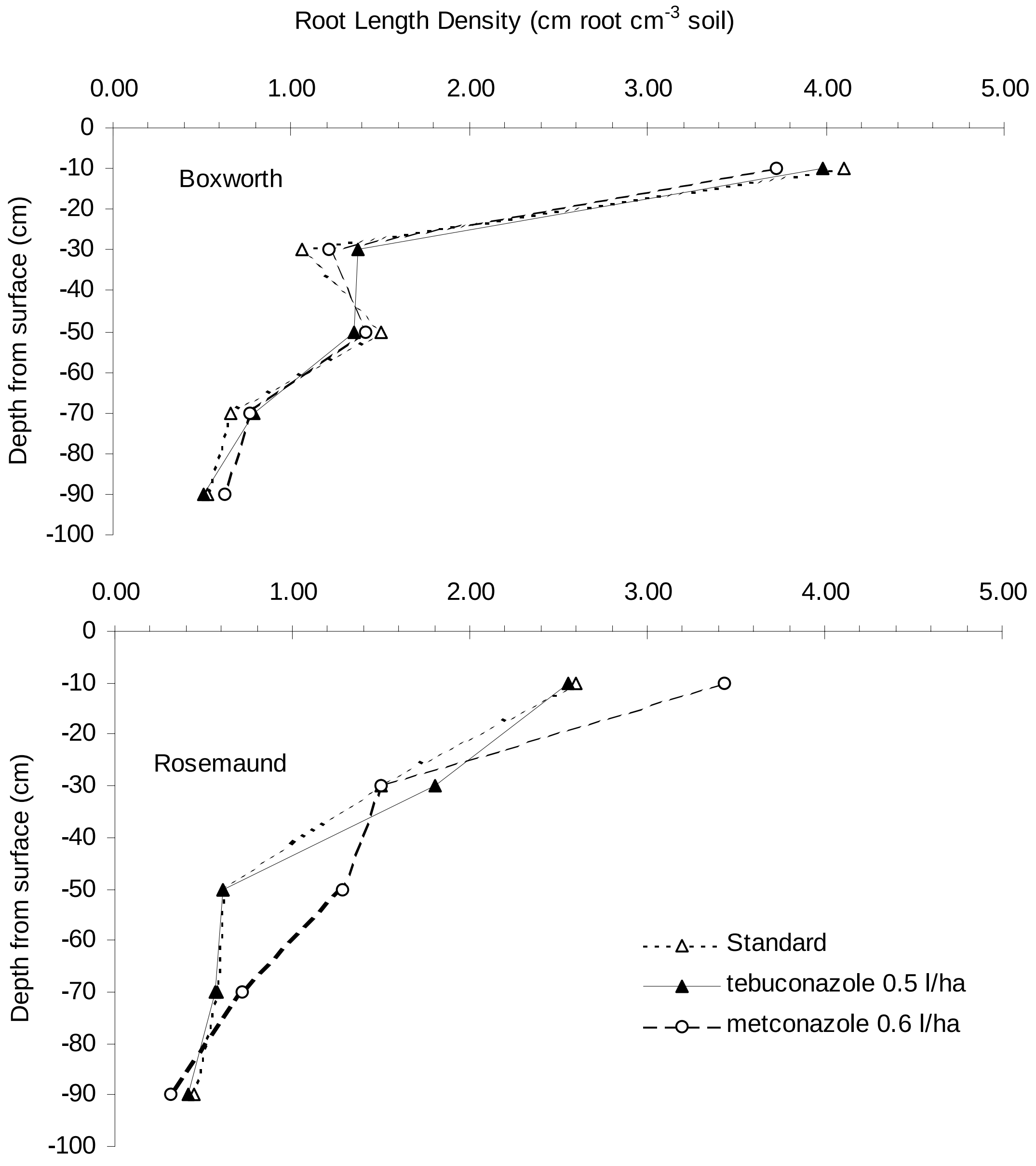

Figure 6. Effect of spring plant growth regulators, metconazole and tebuconazole on root length density. Data points for depth are at the mid point between the upper and lower depths of each 20cm horizon.

Yields

Table 5. Combine yields at ADAS Boxworth and Rosemaund 2005.

Treatment	Primary cultivations	Agronomic practices	Yield t ha^{-1} @ 91%DM	
			Rosemaund	Boxworth
1	Plough	-	5.03	3.70
2	Plough no subsoil (SS)	-	4.79	3.84
3	Min Till no subsoil	-	5.19	3.59
4	Min Till + SS	-	5.16	3.70
5	Min Till + SS	No Sulphur	5.17	3.55
6	Min Till + SS	Autumn N	4.96	3.88
7	Min Till + SS	Delayed spring N	5.31	3.68
8	Min Till + SS	Tebuconazole 0.5 spring	5.11	3.98
9	Min Till + SS	Metconazole 0.6 spring	4.92	4.16
10	Min Till + SS	Delayed sowing	3.42	3.42
11	Min Till + SS	Low seed rate	5.44	3.63
		FPr	<0.001	0.002
		SED	0.193	0.161

Yields averaged 3.74t/ha at Boxworth, and 4.96t/ha at Rosemaund. Some differences were evident at each site. At Rosemaund delayed sowing had a negative effect on yield (P<0.001, 55 df). This was also the lowest yielding treatment at Boxworth (Table 5).

Delaying spring N, and the use of low seed rates at Rosemaund resulted in yields of 5.31 t ha^{-1} and 5.44 t ha^{-1} respectively, the latter representing a significant yield improvement (p<0.001 55 d.f.) compared to the standard treatment (5.16 t ha^{-1}). There were no significant yield differences between cultivation treatments, or the with and without sulphur treatments.

At Boxworth the use of both tebuconazole and metconazole in the spring appeared to have a positive effect on yield, though this was only significantly higher than the standard treatment where metconazole was applied (p=0.002, 55 d.f.).

There was no significant relationship between crop yield and canopy size. Despite some lodging at both sites near at harvest, this was not linked to yield. A range of other measures of crop and root length density were also examined for their relationship with yield at both sites (Table 6)

Table 6. Results of linear regression analysis of yield (at 100% dry matter) against a range of explanatory variables.

Description of explanatory variable	P	R^2
ADAS Boxworth		
Crop Biomass – mid June	0.034	0.300
Canopy Size	0.247	0.030
Lodging % at harvest	0.810	0.005
Average RLD 0-20cm	0.191	0.127
Average RLD 0-40cm	0.083	0.214
Average RLD 0-60cm	0.052	0.261
Average RLD 0-80cm	0.034	0.300
Average RLD 0-100cm	0.037	0.297
Average RLD 20-100cm	0.003	0.515
Average RLD 40-100cm	0.002	0.539
Average RLD 60-100cm	0.08	0.216
Average RLD 80-100cm	0.506	0.035
ADAS Rosemaund		
Crop Biomass – mid June	0.134	0.160
Canopy Size	0.680	0.013
Lodging index at harvest	0.606	0.021
Average RLD 0-100cm	0.223	0.120
Average RLD 0-20cm	0.210	0.128
Average RLD 0-40cm	0.423	0.059
Average RLD 0-60cm	0.414	0.061
Average RLD 0-80cm	0.164	0.092
Average RLD 20-100cm	0.297	0.090
Average RLD 40-100cm	0.637	0.020
Average RLD 60-100cm	0.526	0.037
Average RLD 80-100cm	0.583	0.026

There was a clear relationship between yield and rooting at Boxworth. Although significant relationships between yield and average root length density were present across the whole profile (0-100cm) (P=0.037. R^2 = 0.297) and the 20-100cm depth (P=0.003. R2 = 0.515), average root length density between 40-100cm accounted for the greatest proportion of the variablility in yield (P=0.002, R^2=0.539) Figure 6. No such relationship was observed at Rosemaund, where yield were generallly higher.

A significant relationship existed between crop biomass and yield at ADAS Boxworth (P=0.034, R^2 = 0.30. Such a relationship might be expected under some circumstances where crops are not excessively large, though it is worth noting this relationship was heavily influenced by a single point, which was the late sown treatment.

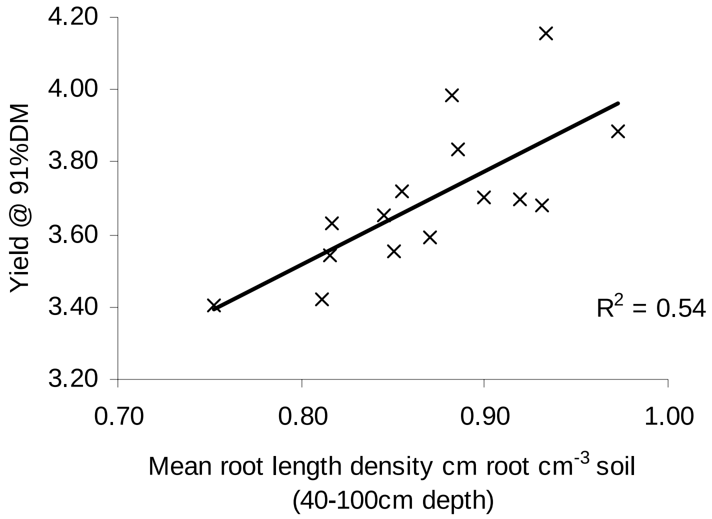

Figure 7. Correlation of yield with root length density between 40cm and 100cm depths at ADAS Boxworth.

Discussion

In the first season, across the 11 sites, the absolute values attained for root length density were above those reported previously by Barraclough (1989), but these are on average lower than the root length densities that might be expected in a winter wheat crop. It is assumed the value of 1cm root cm^{-3} of soil is sufficient for wheat to capture the available soil water. If the same is true for oilseed rape, as mean root length density reached this critical level between 40 and 60cm, it can be assumed that half of the crops sampled were below this threshold and were not able to fully exploit the soil resources below this depth. Whilst this may not affect yield where adequate moisture is available during May and June, these crops are likely to be more drought prone, and suffer yield losses under dry conditions. Encouragingly the lack of relationship between crop canopy size (Green area index) and root length density, suggests RLD is not intrinsically linked to crop size, and implies that it might be possible to achieve moderate canopy sizes whilst maximising below ground resource capture.

Results from the replicated field trials in year 2 support the findings of Carver et al. 1998, that sowing date may affect the extent of rooting. In this experiment delayed sowings had lower root length densities than crops sown at a more conventional timing (Early September). However differences were only observed in the top 0-20cm, and here even the delayed sowings had root length densities of over 2.2 cm cm^{-3} soil. Unless the critical root length density is markedly different from that observed for wheat, this reduction in near surface rooting would not be expected to have a significant effect on water and N capture and thus yield. Low seed rates appeared to increase rooting at depth at Rosemaund and decrease rooting near the surface at Boxworth. Although not statistically significant at any individual depth, this did suggest altering seed rate may beneficially adjust the profile of rooting in oilseed rape, and provides some support of previous findings in wheat that the high plant populations cause excessive rooting near the surface at the expense of rooting at depth (Hoad *et al*. 2004).

Ploughing and subsoiling did significantly affect the extent of rooting in the top 20cm, at one site (Rosemaund), and ploughing there also appeared to be an increase in root length density at the 20-40 cm depth. However, root length density differences at depth (below 40cm) between cultivation strategies were small and non significant, as such this study has insufficient evidence to support the notion that cultivation strategies may affect yield through improvements in rooting.

The lack of either rooting or yield penalties as a result of not applying sulphur, suggest that despite the widespread occurrence of S deficiency across the UK, neither of these sites was limited by S availability.

Delaying N applications had a significant effect on root length density at just one site and one depth (Boxworth 20-40cm), and appeared to have no positive effect on root length density deeper in the soil.

Autumn N treatments despite appearing to improve rooting in the top 20cm at Boxworth, did not significantly affect rooting at any depth, at either site. It is not possible to conclude from this dataset that applying autumn N, or adjusting spring N strategies can provide useful improvements in rooting at depth. However there were indications of effects worthy of further investigation.

The positive effect of spring applied plant growth regulator metconazole 0.6 l/ha on root length density at ADAS Rosemaund in both the 0-20cm and 40-60cm horizons, despite not being repeated at Boxworth, provides some evidence to support the use spring plant growth regulators as a means of imporving rooting at depth. However this requires further verification over different sites and seasons, to indentify circumstances where a positive effect might be found

At Boxworth, root length density between 40-100cm accounted for 54% of the variation in yield. During May and June, Boxworth had lower than average rainfall. Despite some effects of treatments on rooting at Rosemaund the same association with yield was not observed. Several factors may be responsible for the lack of an association at Rosemaund. Rainfall in June was higher at Rosemaund, temperatures closer to the seasonal average, and the silty clay loam (Bromyard series) at Rosemaund has a higher available water capacity (AWC) compared to Boxworth clay soils (Hanslope series). This supports previous correlations between June rainfall and yield, and emphasizes the importance of developing strategies to improve rooting in oilseed rape, to improve drought tolerance in oilseed rape

Recommendations for further research

The replicated results from this study are for only one season. A fuller investigation of the crop establishment factors shown here to affect rooting (cultivations, and seed rate) would allow growers to evaluate the potential benefits of adjusting their crop establishment strategies. In addition, more information on how PGR's might be targeted to responsive crops, and a fuller understanding of how N strategies can affect root length density, would allow growers to determine the most cost effect strategy to achieve a sufficient root length density at depth.

Genetic differences in rooting may also exist between semi-dwarf, conventional and hybrid varieties and would be worthy of further investigation, as this potentially represents the simplest and lowest cost strategy for improving drought tolerance.

To truly determine the extent of root limitation in oilseed rape, further work is needed to identify the critical root length density required for oilseed rape to fully exploit the available soil resources. This information would permit a more quantitative evaluation of the yield penalties suffered from insufficently rooted crops.

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APPENDIX

Table 7. Site Details for replicated field experiments in 2004/05 at ADAS Boxworth

SITE DETAILS:2005 ADAS Boxworth

Site Manager: Peter Gladders

Site:	Boxworth
Field name:	Grange Piece
Soil texture:	Clay loam
Soil analysis	
N	Index 1
Phosphorus	Index 1
Potassium	Index 3
Magnesium	Index 2
pH	8.2
Sowing date	16.09.04
Delayed sowing date	22.10.04
Standard seed rate	6 kg/ha
Low seed rate	3 kg/ha
Harvest date:	28.08.05

Previous cropping

Harvest year	Crop
2004	Winter Wheat
2003	Winter Wheat
2002	Winter Oilseed Rape

Nutrition PK and S

Product	Rate applied (product)		Date applied
Kieserite	120kg/ha		10.03.06
N treatments (standard)	105kgN/ha		10.03.05
	105 kgN/ha		29.03.05
N treatments (delayed)	210 kgN/ha		29.03.05
34.5%N Product		307	29.03.05

Crop Protection

Product	Rate applied	Date applied
Herbicides		
Butisan	1	27.09.04
Trifluralin	2	27.09.04
Falcon	0.405	26.10.04
Roundup	4	11.07.05
Insect/molluscides		
Draza	7.5	16.09.04
Draza	5	21.10.04
Cypermethrin	0.243	26.10.04
Fungicides		
Punch C	0.405	26.10.04
Punch C	0.405	13.12.04
PGRS applied to specific treatments		
Caramba (spring)	0.6	31.03.05
Folicur (spring	0.5	31.03.05

Table 8. Site Details for replicated field experiments in 2004/05 at ADAS Rosemaund

SITE DETAILS: 2005 ADAS Rosemaund

Site Manager:	Jonathan Blake
Site:	Rosemaund
Field name:	Holbach
Soil texture:	Slity clay loam
Soil analysis	
N	64.88 KgN/ha (from SMN)
P	Index …….3
K	Index …….3
pH	7.1
Sowing date	07/09/2004
Delayed sowing date	08/10/2004
Standard seed rate	6 kg/ha
Low seed rate	3 kg/ha
Harvest date:	05/08/2005

Previous cropping

Harvest year	Crop
2004	Winter Barley
2003	Winter Wheat
2002	Maize

Nutrition PK and S

Product	Rate applied	Date applied
Kieserite	120kg	18/02/2005
N treatments (standard)	First app = 42	16/03/2005
	Second app = 42	04/04/2006
N treatments (delayed)	84kgN/ha	04/04/2005

Crop Protection

Product	Rate applied	Date applied
Herbicides		
Katamarran	2.0 l/ha	27/09/2004
Fusilade Max	0.5 l/ha	
Laser	1.0 l/ha	08/03/2005
Dow Shield	0.35 l/ha	08/03/2005
Insect/molluscides		
Mini slugs	7.13 kg/ha	15/09/2004
Cyperkill	0.25 l/ha	
Mini slugs (TOS 2)	7.13 kg/ha	22/12/2004
Fungicides		
Punch C	0.4 l/ha	11/11/2004
Plover	0.5 l/ha	08/03/2005
PGRS applied to specific treatments		
Caramba (spring)	0.6 l/ha	23/03/2005
Folicur (spring	0.5 l/ha	23/03/2005

Table 9. Locations, Soil types, root length densities, and canopy sizes for the 11 farm crops measured in 2004

Location	**Soil type**	**Cultivation strategy**	**Root Length Density cm root cm^{-3} soil**					**Canopy size - June**
			0-20	20-40	40-60	60-80	80-100	GAI
Ledgemore, Hereford	Silty clay	Min tilled	7.43	3.62	0.67	0.63	0.81	2.55
Didley, Herefordshire	Silty clay	Min tilled	5.68	1.92	1.21	1.89	*	2.33
Preston Wynne, Herefordshire	Silty clay	Ploughed	3.44	1.96	1.60	0.90	1.11	2.28
Heighington, Darlington	Clay loam	Non inversion tilled	3.74	1.61	0.61	0.86	0.80	1.90
Heighington, Darlington	Gravel loam	Non inversion tilled	3.47	4.72	2.52	1.36	2.09	1.86
Spilsby, Lincolnshire	Sandy Loam	Ploughed	1.37	1.30	0.91	0.62	0.89	2.05
Whittlesford, Cambridgeshire	Sandy clay loam	Min tilled	3.55	2.58	0.90	0.66	1.28	2.66
Boxworth, Cambridgeshire	Clay	Min tilled	1.65	1.35	0.63	0.78	0.88	2.52
Orlingbury, Northamptonshire	Clay loam	Non inversion tilled	2.13	1.15	0.68	0.69	0.72	2.12
Little Weighton, Yorkshire	Chalky med loam	Ploughed	3.45	2.52	1.31	1.05	*	2.50
Bridgewater, Somerset	Clay	Min tilled	3.47	2.25	1.54	1.18	1.11	2.31