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THE RELATIONSHIP BETWEEN ESTABLISHMENT AND YIELD OF AUTUMN-SOWN OILSEED RAPE

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THE RELATIONSHIP BETWEEN ESTABLISHMENT AND YIELD OF AUTUMN-SOWN OILSEED RAPE

by

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1. Introduction

Oilseed rape is currently a major arable crop in its own right and the main break crop in the UK. In the 1993/94 season, just under half a million hectares of rape was grown, 404,000 ha on the main scheme (winter and spring sown crops for human consumption) and 91,000 ha of industrial rape on set-aside. The current position of oilseed rape within UK agriculture has been largely encouraged by EU support mechanisms; first by yield support and since 1992, the area payment scheme. The introduction of this scheme effectively halved the value of the seed yield and shifted the focus toward minimising production costs whilst maintaining consistent yields. Optimising establishment and understanding the yield potential of a given plant population will help growers to achieve this.

Previous studies have endeavoured to show direct and causal mechanisms between cultivation choice and final yield without examining the factors that contributed to final plant populations or how the crops responded as a result of this in terms of canopy size, light interception and yield formation. The work reported here aims to redress this situation.

In two separate studies we have examined the effect of specific and combined seedbed characteristics on oilseed rape establishment and investigated the likely effect of low population by studying the physiological link between establishment and final harvest.

2. Establishment of oilseed rape

2.1 Background

The main entry for winter rape is after winter wheat or barley. Consequently, there is little time for seedbed preparation between cereal harvest (early to mid August) and the optimum drilling period between late August and early September. Since the introduction of the straw burning ban in 1992, this situation has been further complicated by the need to deal with cereal residues. Limited outlets for straw mean that in many cases baling is not a viable option, so straw is chopped and spread behind the combine. This problem has been partly alleviated by the introduction of set-aside, which has provided an entry facilitating earlier cultivations and better control over drilling date. Bowerman (*pers comm*) suggested that almost 40% of oilseed rape drilled in the autumn of 1994 followed set-aside.

2.1.1 Where oilseed rape is grown

The first step in understanding influences on establishment is to identify how the soil on which oilseed rape is grown is likely to respond to cultivation and weather.

Winter oilseed rape is grown throughout the UK with the highest density of cropping in Eastern England, the East Midlands and Eastern Scotland. Within these regions, over half the crop is grown on clay soils; in the rest of the UK, clays and medium loams predominate (Table 1). Hence, the majority of oilseed rape is grown on clay soils and it is towards these heavy, difficult soils that the emphasis of our analysis is directed.

Table 1 : Soil types on which autumn-sown oilseed rape is grown

	Proportion of rape area	
Topsoil texture	High density cropping (6-17%)	Low density cropping (4-6%)
Sands and light loams	16	28
Medium loams	30	37
Clays	54	35

were that the increased need for cultivation to incorporate straw would result in loss of soil moisture critical to germination, physical and chemical effects of straw would reduce the potential for emergence and that straw may physically impede drilling.

2.2 Objectives

In view of this situation, our overall objective was to improve establishment of oilseed rape in the presence of cereal residues. We sought to achieve this objective by developing a set of principles that would guide cultivation choice according to soil and weather characteristics, identifying which is likely to be the best approach and indicating which is likely to be the worst. The first step in this process is to define exactly what we mean by `establishment' and the time period during which it can be influenced.

2.3 Principles of establishment

2.3.1 Defining establishment

A crop can be said to have established when a `stable' crop stand has been produced, i.e. one in which all the plants will contribute to yield. For winter rape, establishment covers the seven month period from September to March.

Establishment should not be considered as a single event in the life cycle of the crop, but rather the culmination of three sequentially linked phases:

- Sowing to Germination
- Germination to Emergence
- Emergence to Establishment

Factors controlling establishment can operate in one or all of the three phases, eg water is likely to have overriding influences in the first phase, whilst pigeon grazing is likely to exert its influence in the third phase.

Having defined establishment we next seek to characterise the ideal seedbed which is likely to maximise seedling and plant survival in all three stages.

Uncultivated

With the surface tilth intact, this seedbed (Figure 2) has many features in common with the 'ideal' seedbed. In the absence of straw, the surface tilth should be maintained and utilised by direct drilling. This was common practice before the burning ban was implemented. If wet conditions lead to the breakdown of the surface tilth then this leaves an unstructured surface zone which, if wet, will be prone to smearing during direct drilling or, if dry, may prevent penetration of the drill.

Shallow cultivation to 5cm

In terms of the seedbed produced this is a variation on direct drilling. Where present, it maintains the natural tilth and was a common practice before the burning ban. Where surface tilth has been lost it does little to improve the seedbed because poorly structured soil remains near the surface.

Discing to 10cm

With the surface tilth intact discing effectively mixes the fine surface tilth with larger aggregates (Figure 3) brought from depth which, if dry, require energetic cultivation to break them down. Discing to this depth also leads to moisture loss. However, rolling after cultivation can minimise the loss which is important when soil moisture is marginal. If the surface tilth has been lost then discing 'dilutes' the poorly structured surface soil with more easily worked aggregates from depth.

Ploughing to 15-20cm

Ploughing tends to bury the majority of the surface tilth (Figure 4), replacing it with larger aggregates from depth which can quickly dry, leading to increased soil strength and a requirement for very energetic secondary cultivations. Ploughing can result in very rapid drying because it produces a looser, less dense medium encouraging wind to penetrate and remove water. This is exacerbated by the break in capillarity at plough depth which prevents the upwards movement of water. Where surface tilth has been lost under predominantly wet conditions ploughing usually leads to the complete burial of the poorly structured surface soil bringing comparatively better structured aggregates to the surface.

Having considered the effects of cultivation in the absence of straw, we need next to consider where these cultivations place the straw and the potential problems it may cause.

Where surface straw remains after direct drilling or shallow cultivation, the depth of sowing is effectively increased, since the depth of straw is not usually taken into account at drilling. Shoot growth is fuelled from seed reserves and therefore small seeds with few reserves will be prone to exhaustion if the effective sowing depth is increased by straw. This is most likely to be a problem after poor spreading where the straw lies in thick patches.

If the soil is waterlogged, anaerobic conditions are likely because gaseous exchange between the soil and atmosphere is limited. This is more probable where straw is decomposing and this condition can be particularly harmful to seedlings.

Effect of straw : emergence to establishment

Analyses of slug populations in winter wheat have shown that where straw is incorporated into clay soils, slugs are more likely to be a problem (Glen *et al.*, 1984). This results from the less firm seedbed produced, which is more conducive to slug movement. Furthermore, slug activity is dependent on adequate soil moisture and surface straw may increase slug damage by acting as a mulch, keeping the soil surface moist. However, potential damage may be mitigated through cereal residues providing an alternative food source, either directly, or through fungal growth on the decomposing straw.

Surface straw may encourage pigeon grazing by providing a relatively clean surface upon which to land and walk. There is anecdotal evidence that pigeons avoid, where possible, grazing in muddy conditions.

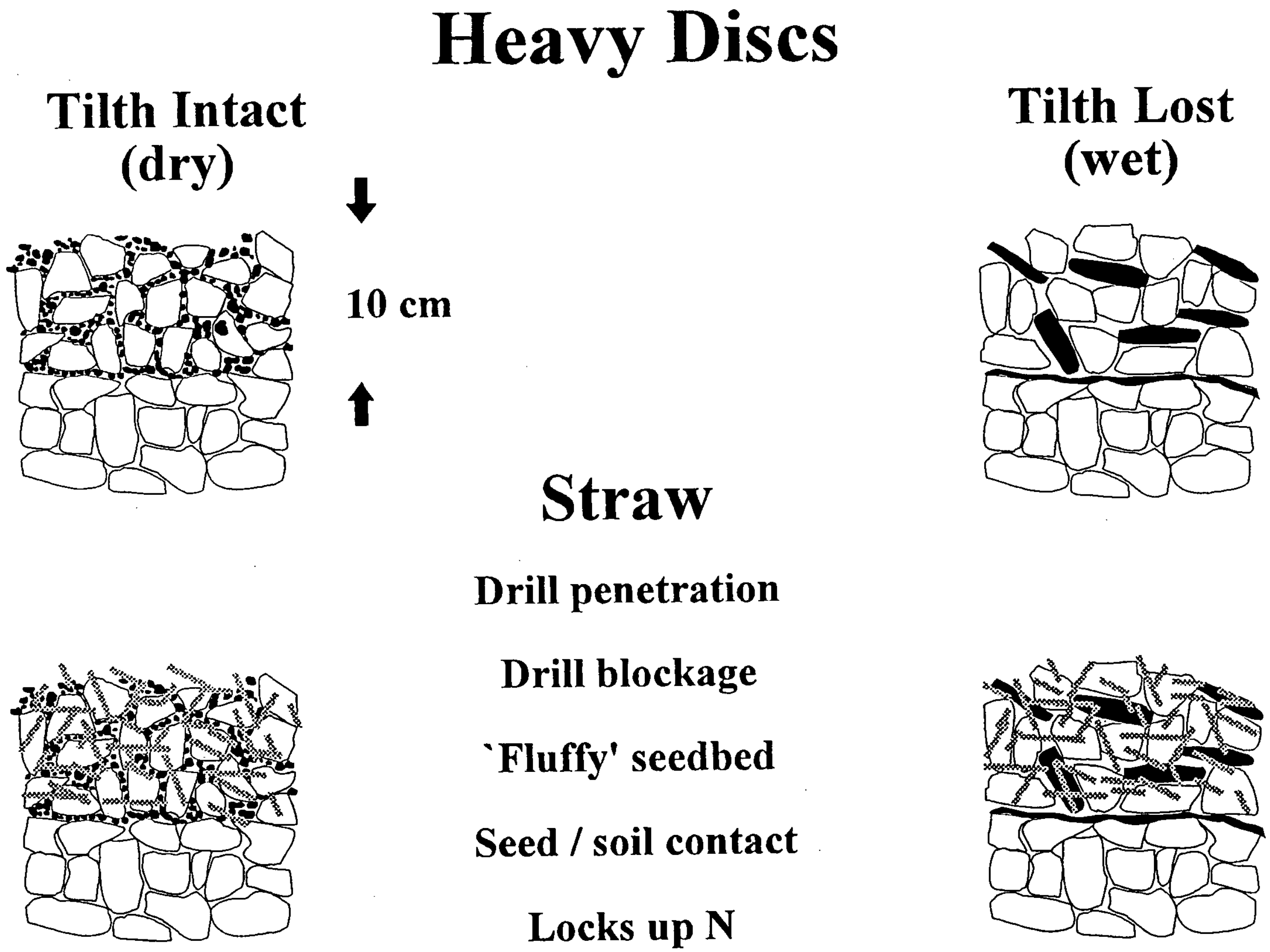

Figure 3 : Diagrammatic representation of the effect of discing on aggregate distribution and straw placement and potential effects, under predominantly dry and wet conditions where the surface tilth remains intact and lost.

2.3.5 Options for dealing with straw

Having examined how different cultivation methods affect the nature of the seedbed through their influences on aggregate size and the position and dilution of straw, the next logical step is to see how these concepts transfer to the field environment and interact with other factors to influence plant populations.

Three approaches to cultivation have been tested in autumn sowings in 1991 and 1992 at three sites with clay soils of differing stability.

- Straw left on or near the surface (direct drilling) (broadcasting)
- Straw mixed throughout top 10cm layer (heavy discing)
- Straw buried at depth (ploughing)

In each case, following secondary cultivation, the characteristics of the seedbed were recorded and related to emergence and the subsequent plant populations achieved. To complement this work, controlled environment experiments were conducted to test specific characteristics of seedbeds away from confounding influences in the field. In addition, the influence of the physical environment has been examined by monitoring plant emergence and survival in sowings made monthly from October 1993 to October 1994, at Sutton Bonington. In these sequential sowings, the influence of pigeons and slugs was minimised through extensive control measures.

2.4 Experiments in 1991

Cultivation experiments were conducted at Drayton (Evesham -- stable), Lidlington (Denchworth -- unstable) and Kneesall (Worcester -- unstable).

2.4.1 Weather patterns

The autumn was characterised by extremely low rainfall during August and the first weeks of September. The monthly rainfall for Drayton typifies this pattern which was experienced at all three sites (Table 3). Soil moisture at drilling in the first week of September and the subsequent two to three week period afterwards were very low. Heavy rain late in September raised the soil moisture which was sustained by continued rainfall events throughout October.

2.4.3 Sowing to maximum emergence

At Drayton and Kneesall, low soil moisture retarded the onset of emergence, even after direct drilling, and ploughing and discing resulted in further drying. At Drayton and Kneesall following rainfall, emergence occurred 30 and 21 days after sowing respectively. In both cases, the rainfall was sufficient to make good the soil moisture deficits caused by cultivation and there was no difference in either the onset or maximum emergence observed.

At Lidlington on the Denchworth soil, ploughing severely reduced soil moisture from 16% to 6%, partly because the plots were not rolled for 2 days after ploughing. Rainfall events totalling 7mm on September 15 triggered emergence in the direct drilled and disced treatments but not in the ploughed. Here, emergence was initiated following 40mm of rain 26 September (Figure 6).

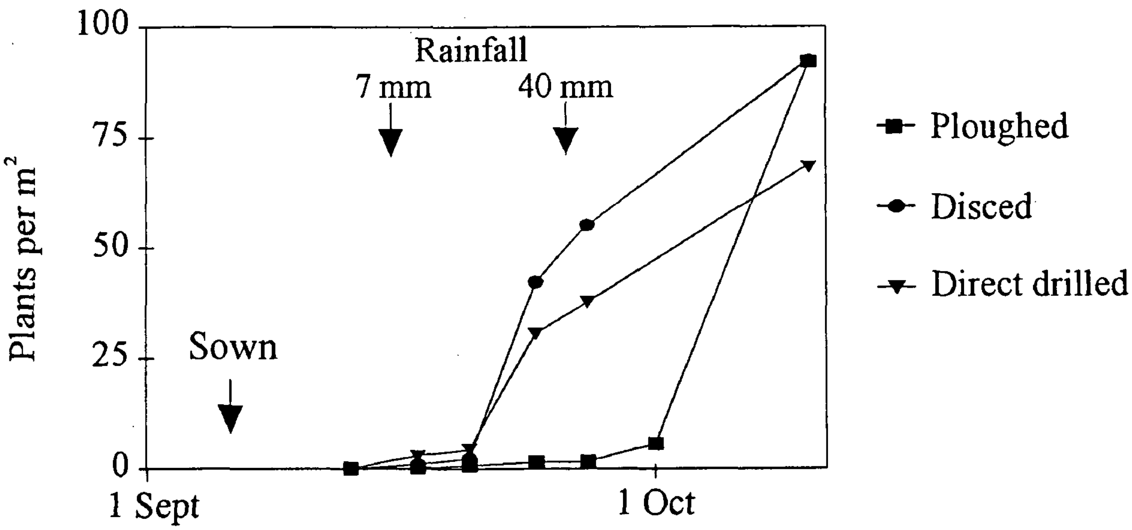

Figure 6 : Plant emergence from 150 seeds, at Lidlington 1991 (Denchworth soil).

Although soil moisture appeared to be inhibiting emergence after ploughing at Lidlington, other factors could have played a role. Deeper drilling, associated with looser seedbeds, is common after ploughing and this would tend to both delay the onset and reduce maximum emergence. Measurements in sequential sowings at Sutton Bonington indicated drilling depths of 4cm after ploughing compared to 2.7cm after discing and our controlled environment experiments have shown that we could expect a 10 to 15% drop in maximum emergence for every 1cm increase in sowing depth below 1cm (Figure 7). If deep sowing, and not soil moisture was responsible for the delay in the ploughed treatment at Lidlington, firstly, we would not expect irrigation to alter the onset of emergence and secondly, we would expect maximum emergence to be lower. This was not the case, irrigation resulted in the rapid onset of emergence (Figure 8) and the maximum emergence was not reduced compared to that following discing or direct drilling (Figure 6).

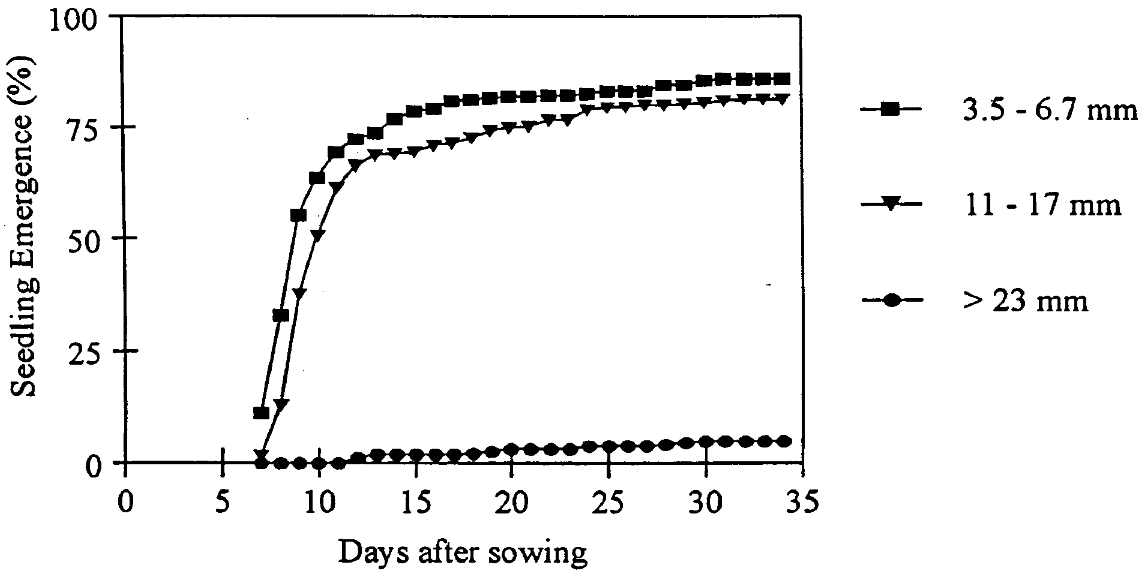

Figure 9 : Effect of aggregate size on plant emergence at 12% soil moisture.

2.4.4 Maximum emergence to establishment

In spring 1992, plant number varied markedly between treatments. Maximum emergence was similar in all treatments, so establishment was critically affected by losses over winter. Plant losses were associated with the amount of surface straw (Figure 10) which encouraged pigeon grazing.

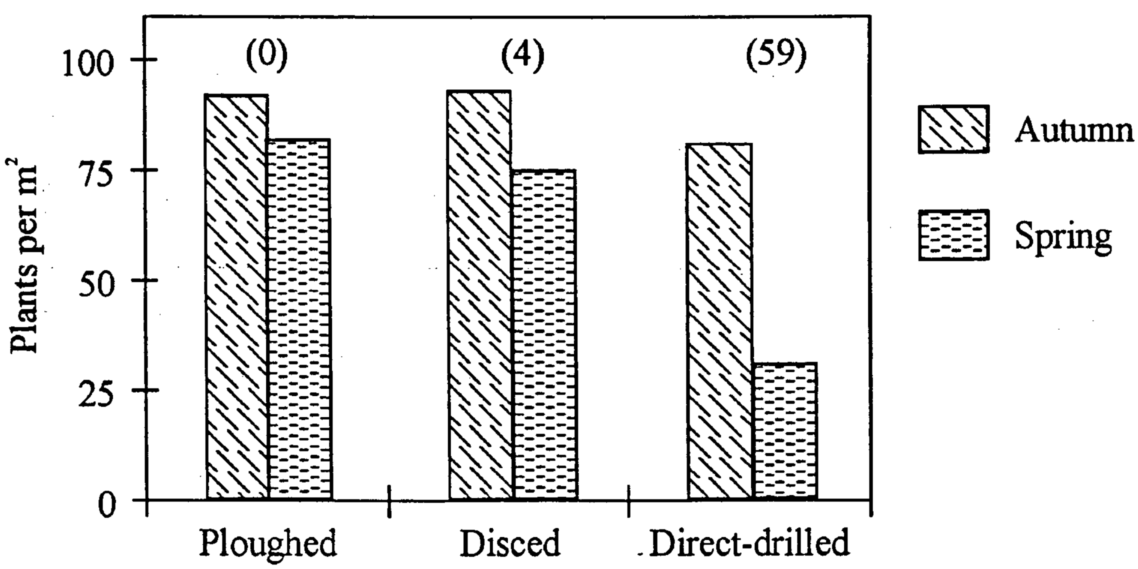

Figure 10 : Effect of cultivation on plant number in autumn and spring (Kneesall 1991); figures in parentheses indicate the percentage surface straw.

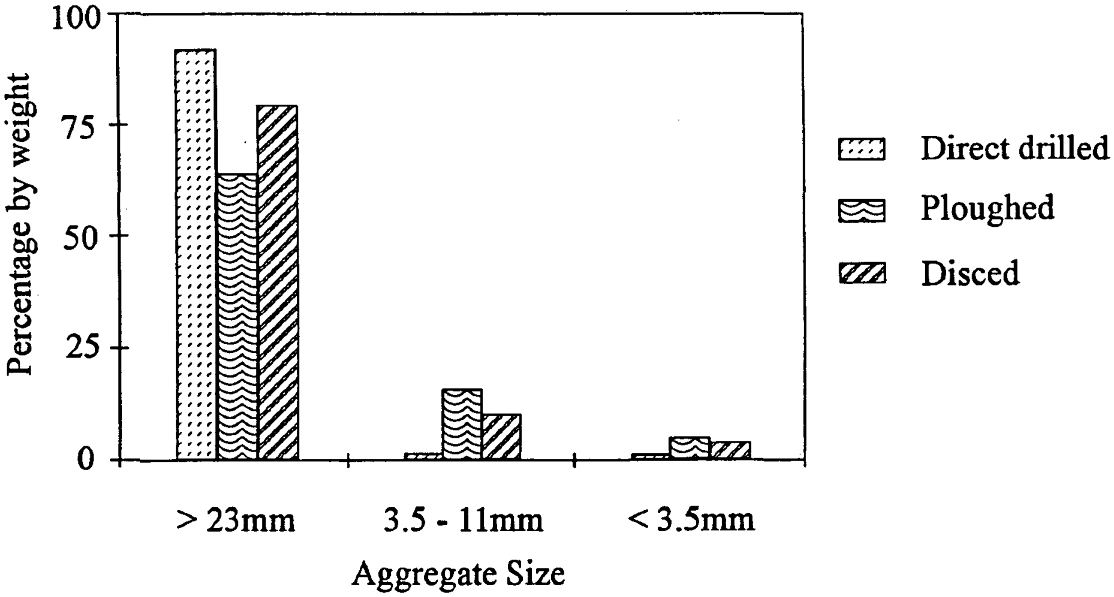

Figure 11 : Effect of cultivation on the proportion of `large' and `fine' aggregates at Drayton in 1992 (Evesham soil).

2.5.3 Sowing to maximum emergence

Following cultivation in 1992, all soils had a greater proportion of large aggregates than in 1991. This did not, however, greatly affect the onset of emergence because soil moisture was always in excess of 20% and sufficient water was available to the seed to initiate germination.

At Drayton on the Evesham soil, maximum emergence was very similar in all three treatments (Figure 12). This result indicated that at this site, using the conventional Moore drill, the proximity of the seed to the straw in the drill slit was not detrimental.

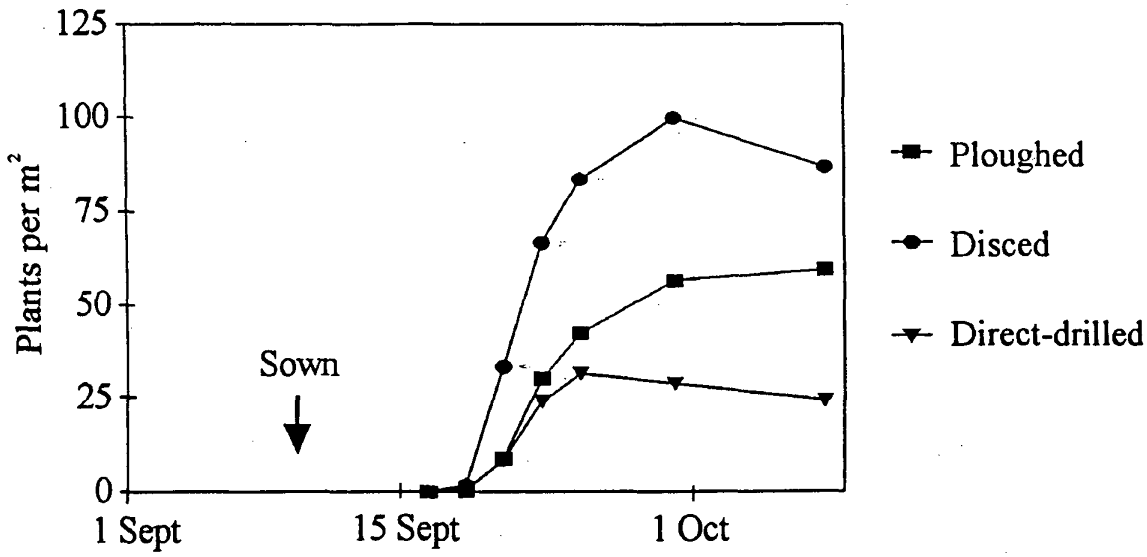

Figure 13 : Plant emergence from 150 seeds at Swineshead 1992 (Denchworth soil).

At Kneesall (low stability Worcester soil), overall emergence was much lower than at Drayton (better structured Evesham soil). Ploughing and direct drilling resulted in poor maximum emergence (Figure 14) and this was linked with extensive slug grazing following poor slug control. An application of molluscicide on 28 September led to a slight recovery in these treatments, indicating that slugs were the overriding problem.

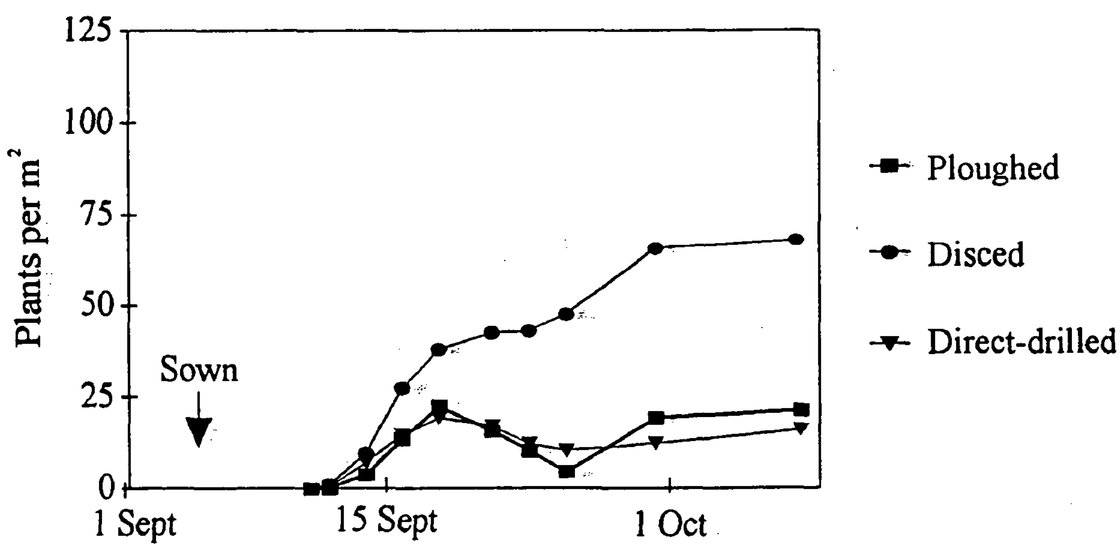

Figure 14 : Plant emergence from 150 seeds at Kneesall 1992 (Worcester soil).

2.6 Uniformity of establishment

So far our analyses have concentrated on the average number of plants that have emerged or established. A vital objective of establishing oilseed rape however, is to achieve a uniform distribution of plants, i.e. to avoid patchiness. Areas with few or no established plants are prone to weed infestation and provide `landing strips' for pigeons which then graze on the adjacent plants and may kill them, thereby enlarging the unpopulated area. To identify which seedbeds produced the most uniform establishment in 1992/93, the 36 sample areas of 1m² for each cultivation treatment were analysed and the number of quadrats containing between 0 - 10 plants and 10 - 20 plants calculated. The occurrence of these areas with very few plants is shown in Figure 15. This clearly shows that discing produced fewest patches with very low plant populations.

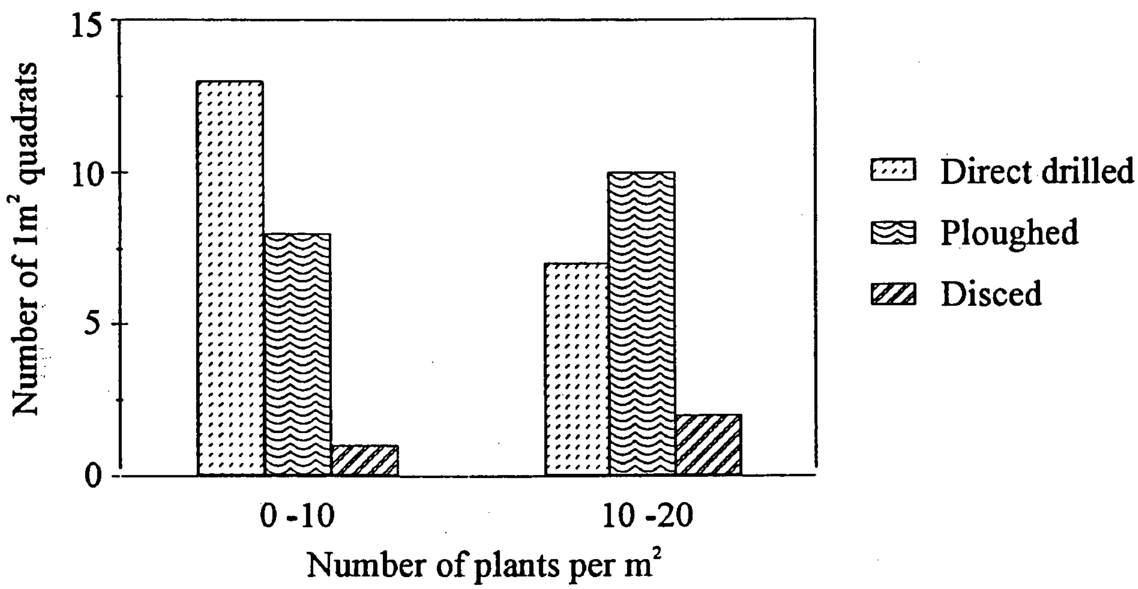

Figure 15 : The number of 1m² sample areas (out of 36) with either 0 - 10 or 10 - 20 plants.

2.7 Establishment conclusions

Maximising the potential for good establishment starts with a long-term approach to soil management, specifically minimising compaction, panning and maintaining high organic matter contents. In the run up to and during harvest of the preceding crop consideration must be given to conserving the natural tilth, if present. Choice of tillage and drilling method will be dependent on whether the straw has been baled or chopped, the amount of straw and evenness of spread and most importantly, the presence or absence of a fine surface tilth.

Intermediate Year : Surface tilth intact

Aim: *Retain natural tilth / dilute straw / conserve soil water*

Direct drilling: Conserves soil moisture and natural tilth, but is risky, particularly where straw is thick.

Ploughing: Buries natural tilth and results in loss of soil moisture.

Discing: Best compromise, since it retains a proportion of the surface tilth, dilutes straw and loses less water than ploughing.

Examples of yield data from the establishment experiments, which formed the basis of the previous section, also indicates that poor yields do not always result from low plant populations and more interestingly the yield potential for each site (the maximum yield attained) isn't necessarily associated with the highest population (Table 8). At Kneesall, the highest yield (3.2 t/ha) was achieved from only 37 plants per m², while the highest population at this site 81 plants per m² produced 0.6 t/ha less. At Drayton in 92/93 where one treatment produced an average population of 6 plants per m², this resulted in a yield of only 0.8 t/ha; however this was only 0.6 t/ha less than the yield potential for the site produced from populations of 23 and 45 plants per m².

Table 8 : Spring plant counts and final yields from four of the establishment sites.

	Kneesall 91/92		**Drayton 91/92**		**Drayton 92/93**		**Swineshead 92/93**	
	Plants / m²	**Yield t/ha**	**Plants / m²**	**Yield t/ha**	**Plants / m²**	**Yield t/ha**	**Plants / m²**	**Yield t/ha**
Ploughed	81	2.6	64	2.6	65	1.4	25	0.7
Disced	74	2.9	81	2.7	50	1.2	45	0.9
Tined	50	2.9	53	2.8	23	1.4	20	0.6
Broadcast	44	2.7	24	2.1	16	1.1	26	0.5
Chop Direct Drilled	24	2.7	37	2.6	6	0.8	12	0.5
Bale Direct Drilled	37	3.2	45	2.5	48	1.3	13	0.6

In most arable crops a higher population results in more rapid ground cover, hence increased interception of radiation, greater biomass accumulation and ultimately more yield. This is not the case with oilseed rape, in which there is no simple link between plant density and yield.

3.2 Objectives

To move toward a more incisive framework, based on a knowledge of canopy size, light capture and assimilate partitioning to seed, so as to produce more reliable estimates of the effects of poor establishment on the yield potential of autumn-sown oilseed rape.

In the previous section on establishment we identified that poor establishment can manifest itself as:

- Low average plant populations
- Uneven plant populations ⇨ Patchiness (particularly in very low populations)
- Backward crops resulting from poor overwinter growth and or pigeon grazing.

The spray regime for the 91/92 season is shown in Table 10, all populations received identical applications.

Table 10 : Spray details for Late 92 sowing.

Date	Spray	Rate	Active compound	Target
15 Nov 91	Fusilade	0.75 l/ha	Fluazifop-P-butyl 125g/l	Volunteer cereals
2 July 92	Fastac & Agral (adj)	0.1 l/ha	alpha-cypermethrin 100g/l	Pod midge

3.3.2 1992/93 Season

In this second season two sowings, 8 September (Early 93) and 9 October (Late 93), were established following winter wheat on a heavy clay loam, pH 6.5. The straw from the wheat crop was baled and removed prior to subsequent cultivations and lime applied at rate of 4 t/ha. Seedbed preparation for the early-sown crop consisted of two passes with a Hankmo turbo tiller; for the late-sown crop an additional two passes with spring tines were required. For both sowings five plots 5m by 36m, arranged in each of four blocks, were drilled with a Nordsten drill unit, row width 11.9cm; Table 11 shows the target populations, seed rates and thinning regimes.

Sub-plots within the Late 93 sowing were defoliated on 30 March using a reciprocating blade mower (Mayfield motor-scythe) with the aim of removing 50% of the leaf area without removing the growing tip.

A total of 182 kg/ha of nitrogen was applied, split into two doses the first on 20 February (50 kg/ha) and the second on 19 March (132 kg/ha).

The spray regime for the 92/93 season is shown in Table 12; all populations received identical applications.

3.5 Canopy structure results

For each sowing and population, the plant densities achieved and yields arising from each treatment are presented. These data are then related to the growth and development of the crop with emphasis on the 7,15 and 120 target populations in which detailed measurements were made. The treatments are referred to by their actual populations rather than their target populations.

3.5.1 Late 92

Thinning to the required populations was relatively successful in Late 92, although the range of populations was quite wide at higher populations, Table 13.

Table 13 : Late 92 plant populations.

Target plant population (plants per m²)	Mean	Standard error	Range	
			Max	Min
7	7.4	0.43	12	4
15	14.9	0.47	22	10
30	27.2	0.49	39	17
60	53.2	0.90	72	28
120	105.4	3.75	146	68

Seed yield

Table 14 shows the yields and components of yield for the five population densities. Although not significantly different, the highest population (105 plants per m²) produced a smaller yield than the other populations.

Seed numbers per pod decreased with increasing population whilst 1000 seed weight increased. Pod numbers at harvest were highest in the 7 and 15 plants per m² treatments. Oil contents were not significantly different.

Table 14 : Late 92 yields and components of yield for the five populations.

Target population plants / m²	Actual population. plants / m²	Yield (t/ha) 91% DM SED 0.16 12 DF	Pods per m²	Seeds per pod	1000 seed wt (g)	Harvest index (%)	Oil content (%)
7	7	2.86	4179	18	3.44	0.32	43
15	15	2.91	3890	18	3.81	0.30	44
30	27	2.80	3514	18	4.09	0.29	45
60	53	2.92	3579	16	4.51	0.29	45
120	105	2.66	3735	14	4.56	0.26	44

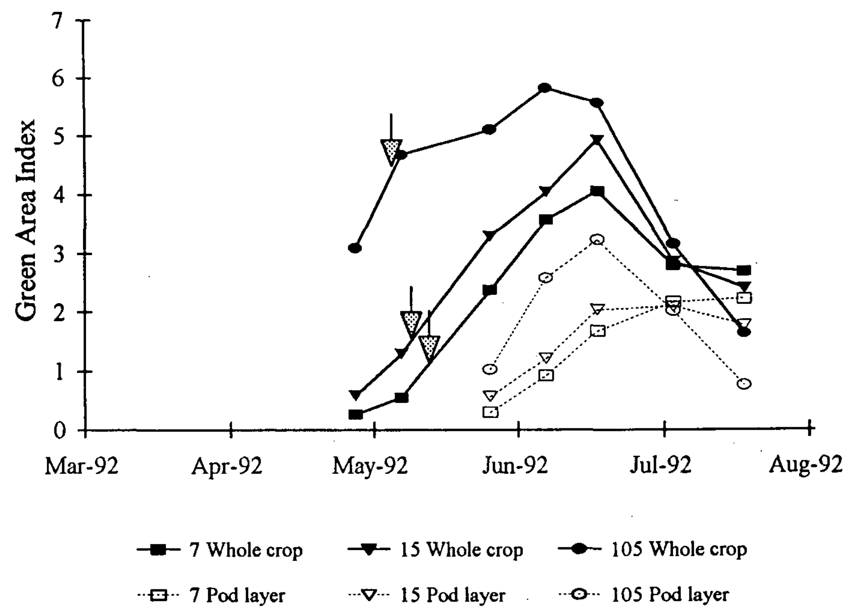

Figure 17 : Late 92 green area index (GAI) for total crop and pod layers in the 7, 15 and 105 populations (arrows indicate start of flowering).

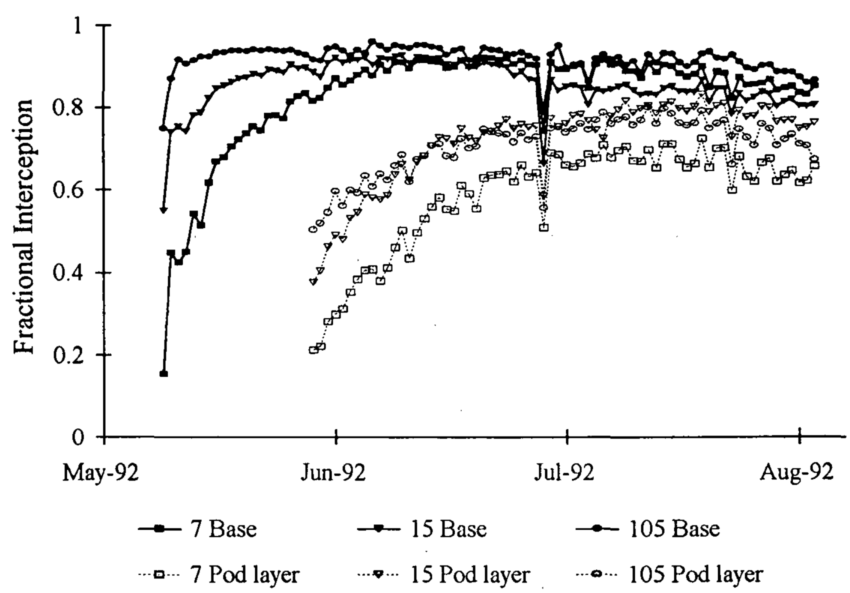

Figure 18 : Late 92 fractional interception, measured at the base of the crop and below the pod layer in each of the 7, 15 and 105 populations.

May 7 marked the onset of flowering in the 105, in the 15 and 7 populations flowering was delayed by three and five days respectively. At the start of flowering the biomass of 105 was 1.2 and 0.7 t/ha greater than the 7 and 15 respectively. The total number of flowers produced by each

The earlier development and initial greater number of pods in the 105 was reflected in the GAI measurements of the pod layers (Figure 17), and the fractional interception in this layer (Figure 18).

Maximum pod number was achieved between early and mid June, pod abortion was greater in the higher populations so that by early July all populations had the same pod number. GAI declined in the 105 as pod numbers decreased, part of this loss also came from a decline in leaf area (Figure 20). GAI did not decline in the pod layer of the 7 or 15 despite loss of pods, this was due in part to small increases in leaf area but may also have been attributable to pod expansion.

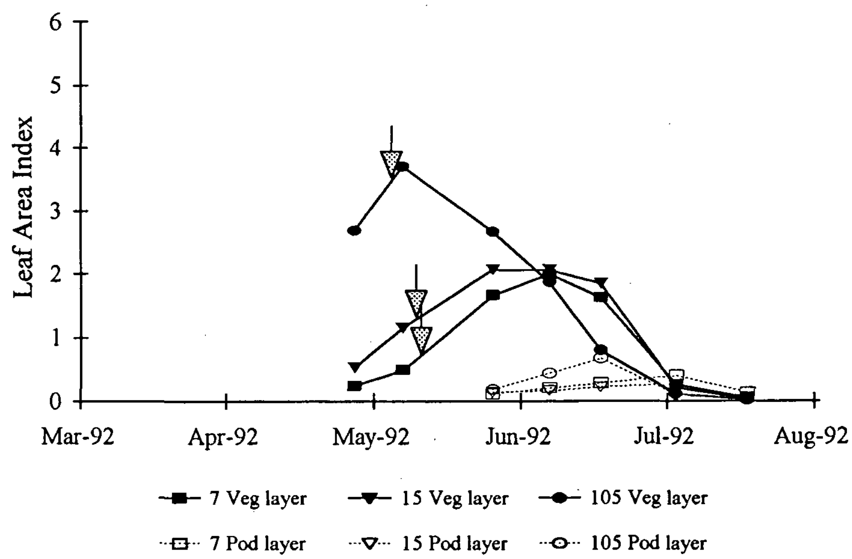

Figure 20 : Late 92 leaf area index (LAI) in the vegetative and pod layers (arrows indicate start of flowering).

Loss of green area in total crop and the pod layer occurred earlier and was more rapid in the 105 compared to either the 15 or 7.

The period between flowering and final harvest seems crucial for yield formation in oilseed rape; during this period the biomass differential between the 7, 15 and 105 was reduced, a result of greater pod retention in the low population. We have shown that the 7 and 15 were slower to cover the ground and consequently intercepted a smaller proportion of total radiation compared to the 105. If the 7 and 15 accumulated more biomass but intercepted less radiation then their improved performance must result from better utilisation of the light intercepted; the amount of biomass produced per Mega Joule (MJ) of radiation is termed light use efficiency (LUE). Table 16 shows the biomass accumulation between flowering and harvest for the three populations and the amount of radiation intercepted over this same time frame; the LUE calculated from these indicates that the 7 and 15 were more efficient at converting radiation to biomass.

Seed yield

Table 18 shows the yield and components of yield from the early sowings (1993 harvest). The regenerated plants contributed 0.53 t/ha to yield in the 7 and 0.28 t/ha in the 15. Including this with the yield from the main plants in these populations, then the 7, 15 and 26 all produced statistically higher yields than the 68 and 113. Consistent with Late 92, seeds per pod declined with increasing population, as did harvest index. As in 1992 there was no significant difference between oil contents.

Table 18 : Early 93 yields and components of yield for the five populations.

Target population plants / m²	Actual population. plants / m²	Yield (t/ha) 91% DM SED 0.21 12 DF	Pods per m²	Seeds per pod	1000 seed wt (g)	Harvest index (%)	Oil content (%)
7	7	3.06	3516	17	4.78		
7 Regenerated	9	0.53	741	14	4.78		
7 TOTAL	16	3.58	4257	15	4.78	0.32	49
15	17	3.16	4322	15	4.49		
15 Regenerated	6	0.28	379	14	4.69		
15 TOTAL	23	3.43	4701	14	4.59	0.30	49
30	26	3.75	5884	13	4.40	0.30	48
60	68	2.94	5189	11	4.84	0.24	48
120	113	2.95	5696	10	4.56	0.23	48

Biomass production

The pattern of biomass production followed a similar trend to Late 92; at the end of March, the 113 had over four times the biomass of the 17 and over nine times that of the 7 (Figure 21). However, as the season progressed the difference declined; by flowering the 113 was just over twice that of the 17 and just under four times the 7 and by final harvest there was only 0.1 t/ha difference between the 113 and 7.

The 113 population always had a larger GAI than either the 7 or 17 populations (Figure 22). At the beginning of April the difference between the 113 and 7 was almost 4 units; this differential gradually declined through the season so that by the beginning of July it was less than one unit. Leaf formed most of the green area early in the season (Figure 23); higher LAI's in the 113 compared to either the 17 or 7 populations that lead to more rapid canopy closure, indicated by fractional interception of 0.9; the 7 never actually achieved full canopy closure, fractional interception never rising above 0.8 (Figure 24).

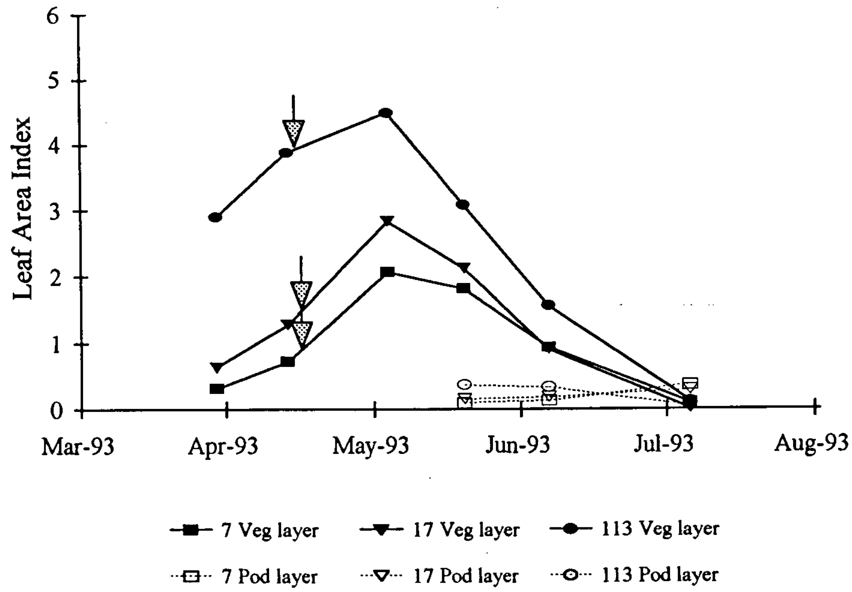

Figure 23 : Early 93 leaf area index in the vegetative and pod layers (arrows indicate the start of flowering).

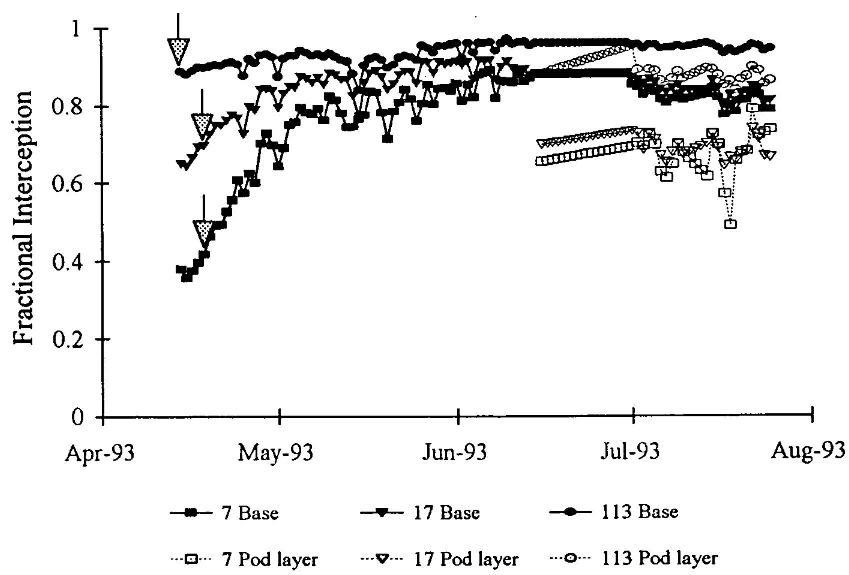

Figure 24 : Early 93 fractional interception at the base of the crop and below the pod layer (arrows indicate the start of flowering).

The start of flowering occurred on 16 April in the 113 population and 19 April in the 7 and 17 populations. In line with Late 92 flower number was related to crop biomass (Table 19); however, the amount of biomass per flower produced differed between the two sowings.

The GAI of the pod layer increased from mid May to early June after which it declined in the 113 but continued to rise in the 7 and 17. The loss in the 113 was associated with a decline in LAI and loss of pods, compared to increased LAI in the 7 and 17 with fewer pod losses.

Between flowering and final harvest the lower populations accumulated more biomass despite intercepting less radiation, indicating they utilised the radiation more efficiently (Table 20).

Table 20 : Early 93 Light use efficiency.

Population plants / m^2	Biomass accumulation flowering - final harvest (g / m^2)	Radiation intercepted (MJ)	Light use efficiency (g / MJ)
7	881	1272	0.7
17	806	1351	0.6
113	613	1503	0.4

3.5.3 Late 1993

Table 21 shows the plant populations for Late 93; poor initial establishment resulted in the 60 and 120 being much lower than target.

Table 21 : Population statistics for Late 93.

Target plant population (plants per m^2)	Mean	Standard error	Range	
			Max	Min
7	6.8	0.17	11	5
15	15.4	0.46	21	10
30	24.8	1.00	32	15
60	40.9	3.79	66	25
120	78.0	4.49	113	55

Seed yield

Table 22 shows the yield components for the Late 93 harvest. The yields of the highest and lowest population were not significantly different from the other populations. Pod numbers at harvest were much lower than in Early 93. Consistent with previous sowings seeds per pod showed a general decline with increasing density, although was less marked due to the reduced range of plant populations. 1000 seed weight was generally similar across the range of populations as were harvest index and percentage oil contents.

Canopy closure (fractional interception > 0.9) occurred quicker in the 78 and 15 compared to the 7. The rapid increase in LAI in this sowing, compared to Early 93 meant that by the beginning of May there was little difference in fractional interception between comparable plant populations in the two sowings.

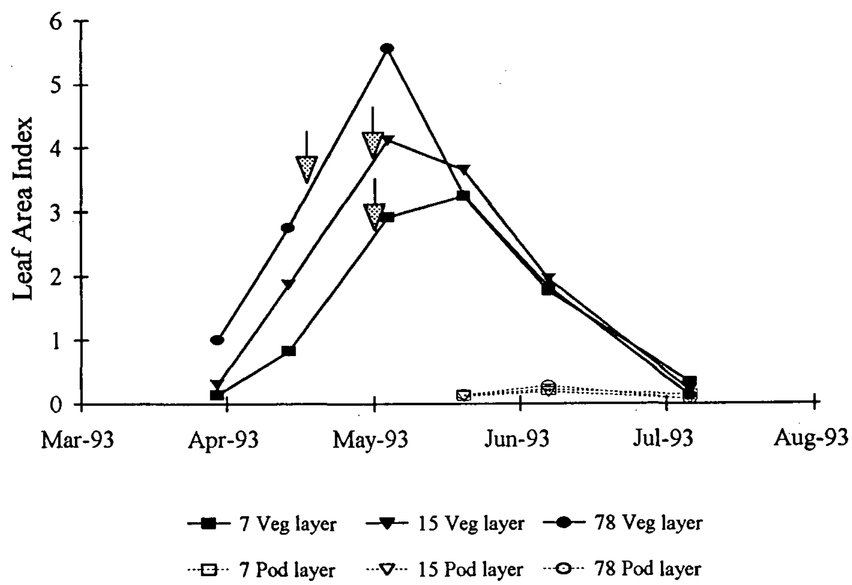

Figure 27 : Late 93 leaf area index of total crop and pod layers in the 7, 15 and 78 populations (arrows indicate the start of flowering).

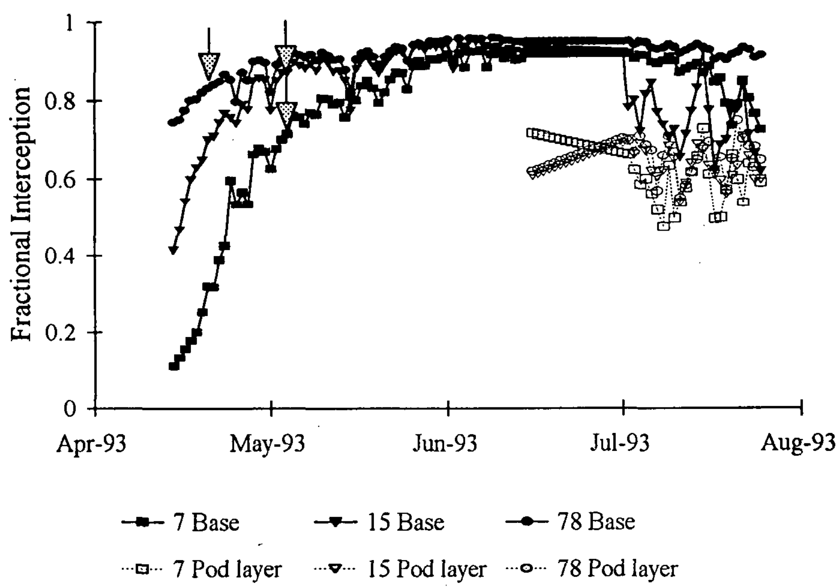

Figure 28 : Late 93 fractional interception at the base of the crop and below the pod layers (arrows indicate the start of flowering).

Table 24 : Late 93 light use efficiency.

Population plants / m^2	Biomass accumulation flowering - final harvest (g / m^2)	Radiation intercepted (MJ)	Light use efficiency (g / MJ)
7	965	1217	0.8
15	890	1212	0.7
78	760	1455	0.5

3.5.4 Late Defoliated 1993

Table 25 shows the plant populations Late Defoliated 93; the highest population achieved in this sowing was lower than in the Late 93 (non-defoliated) and thus direct comparisons must be treated cautiously.

Table 25 : Late Defoliated 93 plant populations.

Target plant population (plants per m^2)	Mean	Standard error	Range	
			Max	Min
7	7.4	0.67	10	5
15	15.3	0.81	23	11
30	23.1	0.63	28	15
60	37.3	3.79	58	20
120	48.8	4.12	78	19

Seed yield

Table 26 shows the components of yield from Late Defoliated 93. In the 7, 15, 23 and 37 plants per m^2 treatments yield increased with population density, although there was no significant difference between them; the 49 plants per m^2 produced a yield of only 3 t/ha inconsistent with the general trend and significantly different from the 23 and 37 populations. There was no significant difference between yields in Late Defoliated 93 and Late 93 (non-defoliated).

Pod number increased with population except in the 49; correspondingly seed number per pod decreased from 17 to 9 as plant population increased from 7 to 49 plants per m^2. Harvest index and oil content did not vary significantly across populations nor did they differ from the non-defoliated populations.

There was relatively little difference in LAI and GAI between populations (Figures 31and 32).

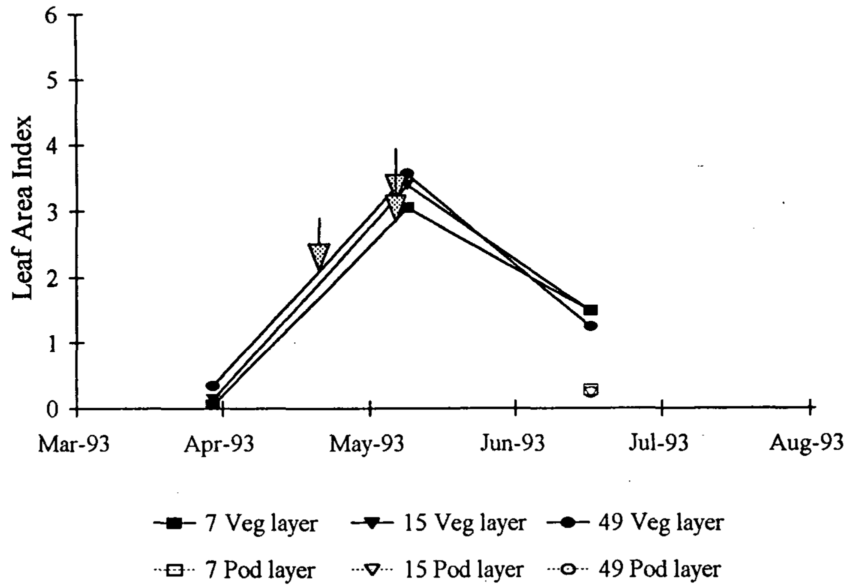

Figure 31 : Late Defoliated 93 leaf area index (LAI) in the vegetative and pod layers (arrows indicate start of flowering).

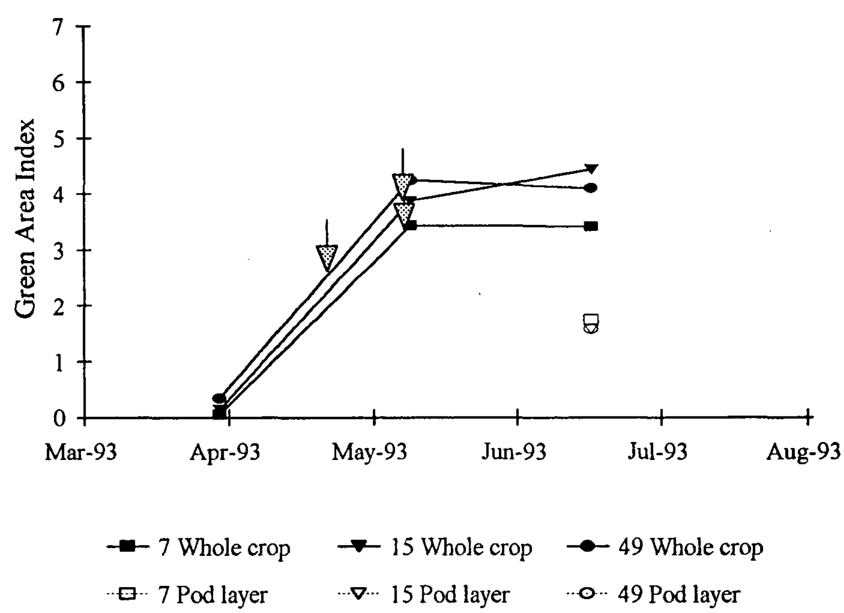

Figure 32 : Late Defoliated 93 green area index (GAI) for total crop and pod layers in the 7, 15 and 49 populations (arrows indicate start of flowering).

Light use efficiency followed the same trend as in previous sowings with better utilisation of light energy in lower populations (Table 28); the values in the 7 and 15 were the same as in Late 93 non-defoliated.

Table 28 : Late Defoliated 93 light use efficiency

Population plants / m^2	**Biomass accumulation flowering - final harvest (g / m^2)**	**Radiation intercepted (MJ)**	**Light use efficiency (g / MJ)**
7	870	1150	0.8
15	830	1175	0.7
49	810	1410	0.6

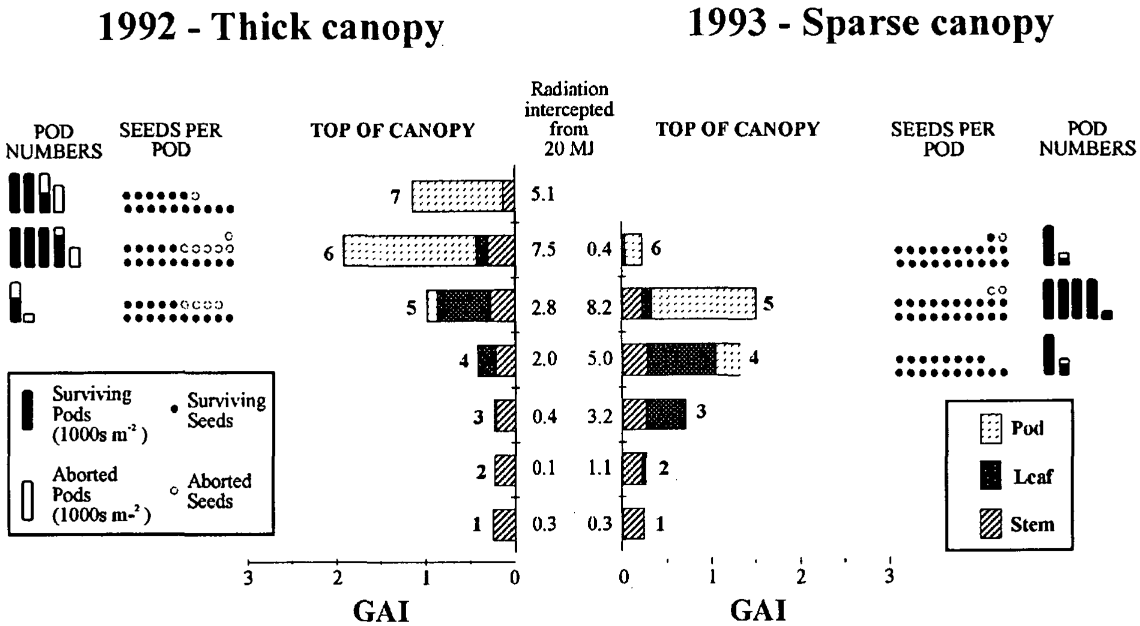

Figure 34 : Diagrammatic representation of the thick (1992) and sparse (1993) canopies in 20cm layers (numbered 1 - 7 from the ground upward) showing the distribution and nature of the foliage, radiation interception and abortion of pods and seeds. The key on the left refers to pod numbers and seeds per pod and the key on the right to canopy structure and radiation penetration - see the centre two columns.

The thick crop resulted from 50% more pods setting. The top layer was well illuminated and few seeds per pod were lost. The pods lost in this layer were initiated late and almost certainly doomed not to survive, irrespective of the radiation environment. In layer 6 of the thick crop, which was also dense, the shading from the top layer resulted in losses of pods and seeds per pod. Importantly, only one quarter of the radiation penetrated through to the lower layers (5 and 4) where the majority of the leaves were situated. In contrast, the sparse crop allowed almost half the radiation to penetrate to the base of the pod layer and it seems that this better illumination and hence greater contribution to photosynthesis from the lower leaves and pods is the likely causal mechanism leading to the maintenance of a high seed number per pod and the route through which sparse crops yield better than expected.

From our studies on plant population and the detailed measurements on canopy structure it appears that the key step towards producing an efficient canopy is to produce just sufficient pods so that the number of seeds (sink) is in balance with assimilate supply (source). The lower pod number and hence more open canopy have the added advantage that leaf material toward the base of the pod layer is better illuminated. This is important because leaves are more efficient at photosynthesis than pods (or stems) and assimilate supply from leaves plays a key role in maximising pod and seed retention especially during early pod development.

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