April 2015

Project Report No. 530

New approaches to weed control in oilseed rape

by

Dr Sarah K Cook[1], Mark Ballingall[2], Ron Stobart[3], Thomas Doring[4], Pete Berry[5] and Denise Ginsburg[1]

[1]ADAS Boxworth, Boxworth, Cambs CB23 4NN

[2]SRUC, West Mains Road Edinburgh EH9 3JG

[3]NIAB TAG, Huntingdon Road, Cambridge CB3 0LE

[4]The Organic Research Centre, Elm Farm, Hamstead Marshall, Newbury, Berkshire RG20 0HR

[5]ADAS High Mowthorpe, Duggleby, Malton YO17 8BP

This is the joint final report of two 36 month projects (RD-2009-3652 and RD-2009-3605) which started in August 2009 and September 2009, respectively. RD-2009-3652 was funded by a contract for £155,000 from HGCA. RD-2009-3605 was funded by HGCA and Monsanto and a contract for £168,000 from HGCA.

CONTENTS

1. Abstract

Weed control in winter oilseed rape has always been challenging. Yield loss from poor broad-leaved weed control can range from 3% up to 73% depending on the vigour of the crop and this does not take into account contamination of harvested crop with weed seed which can reduce marketability of the sample. Weed control has been made more difficult because herbicides are being found in drinking water, herbicide availability has declined, legislation changes have introduced restrictions on herbicide use and herbicide resistance in grass weeds is increasing. Two research projects aimed to evaluate new approaches to weed control in winter oilseed rape. The first (3652) aimed to produce a 'specification' for an oilseed rape crop which balances the needs of crop performance with those required for weed control. The second (3605) aimed to evaluate new approaches to weed control in winter oilseed rape that use carefully-directed control methods between crop rows to minimise reliance on commonly-used selective residual herbicides. In situations where weeds are well controlled there is scope to increase row widths up to 48 cm without reducing yield potential. In situations where weed control is poor and coupled with factors which limit the plants potential for compensation (e.g. spring drought), increasing row width to 48 cm and 72 cm was shown to reduce yield potential. There was no evidence that row width affects the optimum seeds/m² sown or the optimum plants/m². However it was shown that it is not possible to establish more than 25 plants per metre of row and yields may decrease above 17 plants per metre of row. This means that it may not be possible to establish more than 50 plants/m² for 48 cm row widths or more than 35 plants/m² for 72 cm row widths.

When winter rape is established on wide rows there is an opportunity to apply targeted applications of a non-selective herbicide such as glyphosate to the inter-row gap, reducing or eliminating the need for residual herbicides. Glyphosate damage can be limited by the use of even spray nozzles coupled with simple plate type shields that can be produced in the farm workshop or all-round shields from Garfords. Timing the application of glyphosate earlier, at GS 1,3 compared to GS 1,5, limits the potential for damage as the inter-row gap becomes narrower at the later growth stage. A sequence of glyphosate applied at GS 1,5 followed by a second application may be necessary to account for a second flush of weeds.

The targeting of an inter-row non-selective herbicide application can be improved by using Vision Guidance and RTK GPS technologies. Both systems were successful but RTK GPS is simpler to set up and more commonly available. It was found that Vision Guidance coupled to an inter-row cultivator gave weed control equivalent to standard weed control (metazachlor). This result would be particularly useful in organic systems.

Variety type was not important, open pollinated varieties were shown to compensate as well as hybrids against wide row widths and low plant populations. There was no difference in crop damage between hybrid and conventional variety types with inter-row application of glyphosate. There was no evidence that plants in wide rows are attacked more by pigeons or whether the risk of lodging is altered but more work needs to be done to confirm this.

2. Introduction

Recently there have been greater pressures on weed control within a rotation, particularly in oilseed rape. Oilseed rape is not competitive at the young stage and responds well to weed control. In 2006, 50% of the rape crop was treated with metazachlor or metazachlor mixes for annual meadow grass and broadleaved weed control. Yield loss from poor broadleaved control can range from 3% up to 73% depending on the vigour of the crop (Lutman, 1999) and this does not take into account contamination of harvested crop with weed seed which can reduce marketability of the sample.

Weed control in winter oilseed rape has always been challenging but has been made more difficult because:

- herbicides are being found in water
- herbicide availability has declined,
- legislation changes have introduced restrictions on herbicide use,
- herbicide resistance is increasing (ACCase eg fops and dims).

Studies in Catchment Sensitive Farming areas in Scotland and England have shown that pesticides commonly used in winter oilseed rape, notably the herbicides propyzamide, carbetamide, metazachlor, clopyralid, are reaching water courses at levels frequently exceeding the Drinking Water Directive (DWD) limit of 0.1ug/l (Huguet *et al*. 2007, Humphrey *et al*. 2007). Water companies have a mandate to enforce the EU Directives and spend £120M annually (Pretty *et al*. 2000) removing pesticides from water just for this purpose. These herbicides are the basis of effective broad-leaved and grass weed control programmes in oilseed rape and loss of these products could seriously jeopardise weed control both within the crop and across the rotation. Herbicide resistance in grass weeds is increasing (Moss *et al*. 2005, Hull *et* al. 2008). Propyzamide (e.g. Kerb Flo, Dow AgroSciences) and Carbetamide (e.g. Crawler, MAUK) are important products for controlling black-grass in the rotation providing alternative modes of action to fop and dim resistant populations. It is estimated that the loss of carbetamide and propyzamide under the WFD would amount to a reduction in national yields of rape of 36% (HGCA Research Review 70).

Establishment systems for oilseed rape can vary substantially and the use of wide-row crop production systems are now being employed in an increasing number of winter oilseed rape and indeed other crops. Such systems combined with RTK GPS technology provide the opportunity to use novel approaches to controlling weeds between the rows, potentially enabling the dependence on selective herbicides to be reduced and/or the introduction of mechanical weeding.

Two research projects aimed to evaluate new approaches to weed control in winter oilseed rape. The first (3652) aimed to produce a ‘specification’ for an oilseed rape crop which balances the needs of crop performance with those required for weed control. The second (3605) aimed to evaluate new approaches to weed control in winter oilseed rape that use carefully-directed control methods between crop rows to minimise reliance on commonly-used selective residual herbicides.

Specifically, these research projects examined a range of approaches seeking to address the following objectives:

- Determine the optimum row spacing and plant population within the rows to achieve economic yield and prevent additional lodging.
- Evaluate the effect of the wide-spaced rows on crop performance, weed emergence and seed return, monitor the effects on pests, disease and lodging.
- Evaluate the effect of varietal type on optimum row spacing and plant population.
- assess the economic implications of conversion to wide-spaced rows and alternative methods of weed control.
- Determine the effectiveness of a technique based on a simple repositioning (and twisting) of conventional nozzles set at an angle to the spray boom and at a low boom height, to apply a non-selective (or non-crop-safe) herbicide between the crop rows.
- Evaluate nozzles with different spray angles (even spray v conventional).
- Evaluate the use of different shielding systems and shrouded inter-row CDA applicator for delivering the non-selective herbicide between crop rows.
- Assess the potential for vehicle guidance systems (RTK DGPS or vision based) to improve the accuracy and effectiveness of inter-row treatments.
- Evaluate the impact of combining directed non-selective treatments between crop rows with directed selective treatments applied over the crop rows.
- Examine the scope for non-chemical control in the inter-rows using a guided mechanical hoe.

3. Review - Weeds in oilseed rape crops

Weeds can cause direct losses due to competition for light and nutrients and are often associated with loss of quality of the crop through contamination of the harvested seed samples by weed seeds.

3.1. Weed occurrence

Winter oilseed rape is frequently grown as a break crop in a winter cereal rotation and the weeds present reflect this. There have been a limited number of formal weed surveys in oilseed rape, the previous two being in 1987 and 1989. The 1987 survey was limited to central southern England and favoured species of erect habit that had survived herbicide application (Froud-Williams & Chancellor, 1987). The 1989 survey was of autumn crops that had received no herbicide (Whitehead and Wright, 1989). Table 1 summarises the results of these surveys showing the most commonly occurring weeds.

In 2009, a survey of 26 agronomists was undertaken by BASF to determine the weeds they considered the most frequently occurring (Table 1; Reyer, 2009a). The weeds considered as becoming more of a problem were: crane's-bill (*Geranium* spp.) (48%); black-grass (*Alopecurus myosuroides*) (39%); poppy (*Papaver rhoeas*) (39%) and charlock (*Sinapis arvensis*) (35%) (Reyer, 2009b). Crane's-bill and charlock are set to become more problematical because the current suite of available herbicides does not provide adequate control.

Despite their presence, chickweed (*Stellaria media*), sow-thistle (*Sonchus* spp.) and volunteer cereals were not highlighted as problems by the agronomists. Chickweed is thought to be decreasing in the UK as control can be achieved easily within the rotation. However, there is a risk that chickweed resistance may result in an increase in this weed species in future years. Sow-thistles are noticeable in oilseed rape after flowering but have little yield effect and are killed due to application of pre-harvest treatment, usually glyphosate. Volunteer cereals can be problematical but are easily and routinely controlled with a graminicide.

Table 1. Most frequently occurring weed species in oilseed rape crops

Common name	Scientific name	1987[1]	1989[1]	*2009*[2]
Black-grass	*Alopecurus myosuroides*	4	40	*18*
Cleavers	*Galium aparine*	57	46	*15*
Poppy	*Papaver rhoeas*	21	23	*13*
Mayweeds	*Matricaria recutita.* *Tripleurospermum inodorum*	23	81	*10*
Shepherd's-purse	*Capsella bursa-pastoris*	-	-	*8*
Crane's-bill	*Geranium spp.*	13	10	*8*
Prickly sow-thistle	*Sonchus asper*	18	-	*5*[4]

Charlock	*Sinapis arvensis*	1	34	*5*
Chickweed	*Stellaria media*	5	98	*5*
Volunteer cereals	-	2	88	*3*
Annual meadow-grass	*Poa annua*	-	80	-
Wild-oat	*Avena fatua.* *Avena sterilis*	9	40	-
Common couch	*Elytrigia repens*	2	24	-
Barren brome	*Anisantha sterilis.*	6	15	-
Italian rye-grass	*Lolium multiflorum*	1	13[3]	-
Wild radish	*Raphanus raphanistrum*	-	-	-
Hedge mustard	*Sisymbrium officinale*	-	-	-

Source: Froud-Williams & Chancellor, 1987; Whitehead and Wright, 1989; Reyer, 2009a

[1] % occurrence,

[2] % agronomists who ranked a weed as one of the top 3 major weed problems (BASF survey of agronomists' views (Reyer, 2009a).

[3] figure for *Lolium* spp

[4] figure is for 'thistles'

3.2. Weed germination

Knowledge of weed germination can help in predicting the effectiveness of weed control measures. Most problems occur with species that germinate at the time of crop emergence when the crop is small and not competitive. The germination periods of the most commonly occurring weeds in oilseed rape are detailed in Table 2.

Table 2. Germination periods of the common weeds of oilseed rape

Common name	Latin name	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Black-grass	*Alopecurus myosuroides*	0	0	2	2	1	0	0	0	0	1	0	0
Cleavers	*Galium aparine*	0	0	0	2	1	1	0	0	1	1	1	0
Poppy	*Papaver rhoeas*	0	0	0	2	1	1	0	0	1	1	1	0
Mayweeds	*Tripleurospermum inodorum*	0	0	0	2	1	1	0	0	1	1	1	0
Shepherd's purse	*Capsella bursa-pastoris*	1	1	1	1	0	0	0	0	0	1	1	1
Crane's-bill	*Geranium spp.*	1	1	1	1	0	0	0	0	0	1	1	1
Sow-thistle	*Sonchus asper*	1	1	1	1	0	0	0	0	0	1	1	1
Chickweed	*Stellaria media*	1	1	1	1	0	0	0	0	0	1	1	1
Charlock	*Sinapis arvensis*	1	1	1	0	0	0	0	0	1	2	2	1
Volunteer cereals	-	1	2	2	2	2	1	0	0	0	0	0	0

% germination 0 under 5% 1 5-20% 2 over 20%

Germination patterns of the most common weeds that infest oilseed rape indicate that they are predominantly late summer and autumn germinating, with a further germination period in the spring. In an autumn-drilled rotation these weeds have been selected for by August-October cultivations, use of selective herbicides and the weeds' own inbuilt germination patterns. There may also be some weed seed brought into the crop through sown seed (e.g. charlock) which has very similar seed to oilseed rape. The current trend of warmer autumns may also lead to an increase in weed germination, assuming moisture is not limited.

3.3. Weed seed production

To avoid an increase in population that can then cause problems in future years, weeds must not be allowed to flower and shed viable seeds. Table 3 details the seed production and longevity of the most commonly occurring weeds in oilseed rape. Most seeds are formed by plants that germinate early, usually just after establishment of the crop. Later germinating weeds can be suppressed by the crop if it is vigorous and has an adequate population. The oilseed rape crop can be very open over winter, especially where pigeon damage is present, and these open areas can allow weeds to flower. Seeds return to the soil seedbank and can be brought to the surface by cultivations. Most seeds germinate in the top 5 cm of soil.

Table 3. Seed production and longevity of common weeds of oilseed rape

Common name	Scientific name	Max. seed production per plant	*Seed longevity (years)*
Italian rye-grass	*Lolium multiflorum*	800	*1–5*
Black-grass	*Alopecurus myosuroides*	800	*1–5*
Poppy	*Papaver rhoeas*	20,000	*100*
Cleavers	*Galium aparine*	300–400	*1–5*
Crane's-bill	*Geranium spp.*	1–9,500	*1–5*
Wild radish	*Raphanus raphanistrum*	160	*>5*
Scentless mayweed	*Tripleurospermum inodorum*	10,000–20,000	*>5*
Prickly sow-thistle	*Sonchus asper*	5,000	*>5*
Shepherd's-purse	*Capsella bursa-pastoris*	2,000–40,000	*>5*
Charlock	*Sinapis arvensis*	16–25,000	*>5*
Hedge mustard	Sisymbrium officinale	*2,700*	-

3.4. Preventing oilseed rape becoming a weed

Seed losses in oilseed rape at harvest have been reported as averaging 3,575 seeds/m², with a range of 2,000 to 10,000 seeds/m². There is a rapid decline in seed numbers in the first few months after harvest (60%) and seed numbers in the seedbank can decline at 20% per year with 95% loss of seeds after nine years (Lutman, 1999).

In a typical wheat-rape rotation, volunteer oilseed rape should not be a problem as good control can be achieved in cereal crops. There could be contamination of following rape crops with volunteers, particularly when changing variety e.g. conventional to hybrids. If other broad-leaved crops are included in the rotation, such as beans and sugar beet, there may be issues with the control of volunteer oilseed rape.

Fresh seeds falling from plants are not dormant and will germinate immediately as long as moisture is available. Dormancy can be induced by placing seeds into darkness by cultivating stubbles immediately after harvest. Dry soil conditions, certain varieties and constant temperatures also induce dormancy.

To minimise oilseed rape becoming a volunteer avoid immediate cultivation after harvest giving seeds time to germinate or be predated. Cultivations should be delayed for 4 weeks where soil conditions are dry and 2 weeks when soils are moist. This will allow seed to be exposed to light and alternating temperatures and to predation. Banhardt *et al*. (2011) showed that 67% of oilseed rape seed was predated where fields were left uncultivated compared to 15% after ploughing and 11% after a chisel plough.

3.5. Competitiveness of weeds and timing of weed control

The vigour of the oilseed rape crop is important when considering its ability to withstand weed competition (Lutman & Dixon, 1991), with more vigorous crops needing less weed control. Lutman *et al*. (1995) studied 11 weed species and ranked them in order of competitiveness (Table 4).

Table 4. Competitive ability of a range of weed species with winter-sown oilseed rape (from Lutman *et al*., 1995)

Competitive ability	Weed species
Very high	Cleavers
High	Poppy, chickweed (charlock*)
Moderate	Red-dead nettle, scentless mayweed, speedwell, annual meadow-grass (charlock*)
Poor	Shepherd’s-purse, fumitory
Very poor	Pansy

*** Competitiveness of charlock depends on how well it survives the winter**

As in cereals, cleavers were the most competitive weed in oilseed rape. Cleavers populations between 1–10 plants/m² can reduce seed yields and cause problems at harvest via contamination of the harvested seed (Lutman *et al*., 1995). Freeman & Lutman (2004) reported that although cleavers emerged during the autumn and the spring, most cleavers growth occurred late in the growing season and delaying their removal until early spring did not affect final yield.

Scentless mayweed is much less competitive than cleavers, and populations of up to 100 plants/m² can be tolerated by an oilseed rape crop (Lutman *et al*., 1995). The mayweed was unable to break through the rape leaf canopy in spring or early summer and did not compete with crop growth. On this basis, specific treatment to control the weed alone cannot be justified at low populations. Where oilseed rape plant populations are low and the canopy is not complete, the weed can become well established.

Chickweed is a competitive weed and autumn populations of between 1 and 328 plants/m² can cause a 5% yield loss in oilseed rape (Lutman *et al*., 2000). The variation in the number of weeds able to cause this yield loss have been attributed to crop competitiveness during the autumn/winter period. Chickweed has the potential to be a very competitive weed as it can grow at lower temperatures than oilseed rape (Section 3.7.4). It fails to capitalise on its low-temperature advantage in the autumn due to the small size of the plant compared to that of oilseed rape. This means it only becomes competitive later in the winter when it has compensated for its small initial size (Lutman *et al*., 2000).

Geranium species such as dove's foot crane's-bill and cut-leaved crane's-bill have become a problem in oilseed rape in recent years through increased herbicide selectivity. Populations are often very high and the weeds can compete with less vigorous crops.

Control of grass weeds such as volunteer cereals and black-grass in oilseed rape has been shown to be important (Ogilvy, 1989). Volunteer cereals are a problem in many crops but more so when oilseed rape establishment is delayed; their large seed size means they can quickly establish in late drilling situations or drier autumns (Lutman, 1991). There is a clear linear relationship of increasing yield loss with increasing volunteer numbers. This relationship is exacerbated by a delay in sowing and by thin or less vigorous crops. For a crop sown on 26 August, 100 volunteers/m² can give a 5% yield loss but for crops sown on 9 September this is reduced to only 10 volunteers/m² (Lutman, 1991).

There has been a wide range of research done on the timing of weed control but there is no clear evidence as to the benefits of early broad-leaved weed control (Freeman & Lutman, 2004). The most important factor is the size and competitive ability of the oilseed rape crop itself. Delaying weed control allows the grower to assess weed levels and species present. In reality, the current spectrum of herbicides available has limited the ability of the grower to delay weed control. It is more important to know what weeds are likely to be present so the most effective pre-emergence herbicide can be selected.

Growers establishing crops by broadcasting seed after combining the previous wheat crop, which is a no-till form of establishment, experienced few broad-leaved weeds and savings in the cost of herbicide application. Volunteer cereals and other grass weeds can be prolific following this type of establishment (Freer, 2002), but are shallowly germinating. Establishment methods where seed is not covered by soil limits the type of seed dressing and herbicide that can be used and may jeopardise crop establishment.

3.6. Chemical control of weeds

Weed control in oilseed rape is predominantly based on autumn application with many applications being made pre-emergence (Table 5). This places an onus on knowing what weeds can be expected, especially with regard to poppies.

Table 5. Active substances and their approximate timing available for weed control in winter oilseed rape

	Application window													**Weeds controlled**	
Active Ingredient	**Pre-em**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Grass**	**BLW**
napropamide														✓	✓
clomazone															✓
clomazone + metazachlor														✓	✓
tri-allate														✓	✓
dimethenamid-p + metazachlor															✓
dimethenamid-p + metazachlor + quinmerac														✓	✓
metazachlor														✓	✓
metazachlor + quinmerac														✓	✓
Imazamox + metazachlor[2]				GS 1,8										✓	✓
bifenox (EAMU)															✓
clopyralid															✓
propaquizafop														✓	
clethodim														✓	
fluazifop-P-butyl														✓	
pyridate (EAMU)															✓
cycloxydim														✓	

quizalofop-P-ethyl														✓	
quizalofop-P-tefuryl														✓	
tepraloxydim														✓	
clopyralid + picloram															✓
propyzamide														✓	✓
Propyzamide + Aminopyralid														✓	✓
carbetamide														✓	✓
In the pipeline															
Ethametsulfuron-methyl				GS 1,8											✓

[2]Clearfield® varieties only

Cleavers are best controlled by the use of a pre-emergence herbicide but there are also post-emergence options, pyridate (Lentagran, EAMU) and clopyralid + picloram (Galera), which can be used before stem extension. Cleavers can often germinate in the spring making control more difficult (Table 6).

The options for poppy control are limited to pre- and very early post-emergence applications of metazachlor with or without quinmerac. Better control is achieved with a split application targeted at an extended emergence period of the weed. A more reliable post-emergence option comes from aminopyralid, available in mixture with propyzamide.

Mayweed control can be achieved with both pre- and post-emergence herbicide application. Control of shepherd's-purse can be achieved with herbicide applications applied pre-emergence (Table 6).

Crane's-bill control is difficult and relies on the use of pre-emergence applications or a post-emergence application of bifenox (EAMU) (Table 6). Recent developments in herbicides have targeted this weed in particular including ethametsulfuron-methyl (an ALS herbicide).

Black-grass control in oilseed rape is difficult; most populations have a moderate to high level of resistance to graminicides (Table 7). Some control can come through the use of metazachlor applied pre-emergence. No resistance to the post-emergence herbicides propyzamide and carbetamide has been recorded, applications of these herbicides begin when the crop has 3–4 leaves and soil temperature falls below 8–10°C (early November). These herbicides work best when oilseed rape has been established by shallow cultivations. Propyzamide forms a layer in the top 5 cm of soil (Dow, 2008) and any weeds germinating in this layer can be controlled by the herbicide. These herbicides are best used in combination with shallow cultivations rather than ploughing to keep weed seeds in this layer.

Volunteer cereals are always present in oilseed rape unless ploughing has occurred. A general rule of thumb is when 20 volunteers/m² are present they should be removed by graminicides (Table 7) but most growers act at lower levels than this.

Table 6. Broad-leaved weeds controlled in winter oilseed rape by currently available active substances (information taken from product labels) s =susceptible, ms=moderately susceptible, mr = moderately resistant r = resistant, - = not on label

	Active ingredient																				
	Pre-emergence				Pre- or post-emergence								Post-emergence								
					pre-em	post-em	pre-em	post-em	pre-em	post em*	pre-em	post-em							
Weed	napropamide	clomazone	clomazone + metazachlor	tri-allate (EAMU)	dimethenamid-p + metazachlor		dimethenamid-p + metazachlor + quinmerac		metazachlor		metazachlor + quinmerac		Bifenox (EAMU)	Pyridate (EAMU)	clopyralid	clopyralid + picloram	propyzamide	carbetamide	Propyzamide + aminopyralid
Charlock	-	-	-	ms	-	-	-	-	mr	mr	-	-	-	-	-	-	r	ms	-
Chickweed, common	s	s	s	ms	s	s	s	s	s	s	s	s	-	-	-	-	s	s	s
Cleavers	-	s	s	ms	s	r	s	s	mr	mr	s	s	mr	s	-	ms	ms	s	mr
Crane's-bill	-	-	mr	-	s	s	s	s	mr	mr	mr	-	s	-	-	-	-	-	-
Dead-nettle, red	-	s	s	ms	-	-	s	ms	s	s	s	ms	s	-	-	-	-	r	-
Forget–me-not, field	-	-	s	ms	ms	r	ms	r	s	s	s	r	ms	-	-	-	ms	r	ms
Fumitory, common	-	-	-	ms	-	-	-	-	r	r	ms	-	-	-	-	-	-	s	-
Groundsel	-	-	s	-	-	-	-	-	s	s	s	r	-	-	s	-	-	-	-
Hemp-nettle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marigold, corn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	s	-	-	-	-
Mayweeds	s	-	s	ms	s	r	s	r	s	s	s	s	-	-	s	s	-	r	s
Mustard spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nettle, small	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	s	s	s
Pansy, field	ms	-	mr	ms	mr	r	mr	r	r	r	ms	-	s	-	-	-	-	-	-
Parsley-piert	-	-	s	-	-	-	-	-	s	s	s	r	-	-	-	-	-	-	-
Poppy	-	ms	s	ms	s	r	s	r	ms	ms	s	s	ms	-	-	-	-	-	s
Radish, wild	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shepherd's-purse	-	s	s	-	s	ms	s	ms	s	s	s	r	mr	-	-	-	-	-	-
Speedwells	-	-	s/ms	ms	s	s	s	s	s	s	s	s	s	-	-	-	s	s	s
Sow-thistles	-	-	-	-	-	-	-	-	-	-	s	s	-	-	s	s	s	-	-
Thistle, creeping	-	-	-	-	-	-	-	-	-	-	-	-	-	-	s	-	-	-	-

*** Metazachlor can be applied when the crop is post-emergence but is only effective before the weeds emerge**

s =susceptible, ms=moderately susceptible, mr = moderately resistant r = resistant, - = not on label

Table 7. Grass weeds controlled in winter oilseed rape by currently available active substances (information taken from product labels)

	Active ingredient															
	Pre-emergence			**Pre- or post-emergence**				**Post-emergence**								
Weed	napropamide	clomazone + metazachlor	tri-allate (EAMU)	dimethenamid-p + metazachlor	dimethenamid-p + metazachlor + quinmerac	metazachlor	metazachlor + quinmerac	propyzamide	carbetamide	propaquizafop	fluazifop-P-butyl	cycloxydim	quizalofop-P-ethyl	quizalofop-P-tefuryl	tepraloxydim	clethodim
barley	-	-	-	-	-	-	-	s	s	s	s	s	s	s	s	s
oat	-	-	s	-	-	-	-	s	s	s	s	s	s	s	s	s
wheat	-	mr	-	-	-	-	-	s	s	s	s	s	s	s	s	s
annual meadow grass	-	s	s	-	-	s	s	s	s	mr	r	r	-	-	s	s
rough meadow grass	-	-	s	-	-	-	-	-	s	-	-	mr	-	-	-	-
barren brome	-	-	s	-	-	ms		s	s	s	s	s	s	-	s	-
black-grass	ms	s	s	mr	ms	s	s	s	s	increasing resistance						
wild-oat	-	-	s	-	-	-	-	s	s	s	s	s	s	s	s	-
couch	-	-	-	-	-	-	-	-	m	s	s	s	s	s	s	-
Italian ryegrass	-	-	-	-	-	-	-	s	s	ms	s	s	s	s	-	-
perennial ryegrass	-	-	-	-	-	-	-	s	s	s	s	s	s	s	s	-
black bent	-	-	-	-	-	-	-	-	s	-	s	s	-	-	-	-
creeping bent	-	-	-	-	-	-	-	-	s	-	s	s	-	-	-	-
canary grass	-	-	-	-	-	-	-	-	s	-	s	-	-	-	-	-
loose silky bent	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
onion couch	-	-	-	-	-	-	-	-	-	-	-	mr	-	-	-	-
Yorkshire fog	-	-	-	-	-	-	-	s	-	-	-	-	-	-	-	-

s =susceptible, ms=moderately susceptible, mr = moderately resistant r = resistant, - = not on label

3.6.1. New developments

Clearfield®

The Clearfield oilseed rape production system brings together specific herbicides from BASF and specific herbicide tolerant hybrid varieties. The varieties are bred using a traditional technique used for many years in plant breeding (Tan *et al*., 2005). In 2011, the first hybrids (PT100CL and PX200CL) were successfully registered by Pioneer, but were not progressed to the HGCA Recommended List. Further Clearfield hybrids are expected to achieve National Listing next season.

There are two herbicides currently available for use only on Clearfield winter oilseed rape (January, 2015); Cleranda (metazachlor + imazamox) and Clesima (imazamox + metazachlor + quinmerac). It is critical that these herbicides are only used on hybrids carrying the Clearfield brand, or total crop loss will occur.

In addition to the broad spectrum weed control, key benefits for the grower include control of problem cruciferous weeds including charlock, runch and hedge mustard.

SALSA™

SALSA™ (ethametsulfuron-methyl) from DuPont is a post-emergence ALS herbicide currently in trials for the control of charlock, dove's foot crane's-bill, cut-leaved crane's-bill, chickweed and shepherd's purse plus a range of other broad-leaved weeds (Brachaczeck & Salas, 2011).

3.7. Competitiveness of oilseed rape

Compared to other arable crops, winter oilseed rape has a high potential to produce a large canopy which, in theory, should suppress weeds. Canopy closure in the autumn is often not achieved due to low seed rates, poor establishment or pigeon damage. In some years (e.g. autumn 2009) many crops had full canopy closure which then hindered the application of herbicides such as propyzamide, carbetamide, fops and dims. After pod set, leaf fall occurs and canopies can open up again allowing weeds to grow that may obstruct harvest at maturity and/or affect seed purity. It can also allow increased multiplication and seed production of surviving weeds.

More vigorous oilseed rape crops need less weed control irrespective of the weed species present and the level of infestation (Lutman e*t al.*, 1995). In a series of experiments manipulating crop canopy, Sim *et al*. (2007) concluded that seed return in grass weeds can be substantially reduced by planting early and sowing 120 seeds/m² with the aim to achieve a green area index (GAI) of 4.5 in March.

3.7.1. Variety

In a pot trial, hybrid oilseed rape varieties were twice as competitive as open-pollinated cultivars when weed (wild-oat) populations were large and vigorous. This effect was less apparent when weed populations were smaller (Zand & Beckie, 2002).

In Canada, spring rape weed levels were lower in the hybrid variety compared to the less competitive open-pollinated variety (O'Donovan *et al*., 2007). The Canadian work indicated that crops could be more competitive when high quality seed was shallowly planted at high seed rates; this allowed crops to emerge ahead of the weeds.

A 2007-08 trial for BASF and Pioneer showed that when comparing low biomass and semi-dwarf varieties at a range of populations effective weed control could be achieved with the herbicides available, but the key to weed control success was good crop establishment (Cook, *unpublished data*)

3.7.2. Green area index

For optimum yield an oilseed rape canopy must achieve an optimum green area index (GAI) of 3.5 at flowering. Larger canopies set fewer seeds and are prone to lodging (Lunn *et al*., 2001). Seed rate, sowing date, nitrogen rate and defoliation could be used to manipulate crop canopies to produce this target GAI. Reducing seed rates was more consistent than delaying sowing which could lead to poorer crops.

To achieve good weed control, the establishment of a dense vigorous stand is critical. Ninety percent of oilseed rape crops are sown in late-August or early-September when the soil tends to be dry. Any cultivation at this time exposes the soil to drying and seedlings can easily desiccate. As rape is sown into mainly clay soils (70%) the seedbeds tend to be cloddy and unsuitable for small seeds (Stokes *et al*., 2000). Use of minimum tillage retains moisture and ensures crops establish quickly.

3.7.3. Crop density

Herbicide efficacy can be improved by increasing crop seed rate (Sansome, 1989, 1991). Lutman *et al*. (1995) showed that there was little effect of crop density on yield losses caused by weeds. Only when crop density was less than 22 plants/m^2 was there a detectable increase in weed competitiveness. A similar response was observed by Sim *et al*. (2007) where the size of black-grass heads was reduced by 9% when the oilseed rape population increased from 29 to 51 plants/m^2. Typical seed rates for winter crops range from 3 kg/ha (60 seeds/m^2) to 6 kg/ha (120 seeds/m^2). Low plant populations are usually the result of poor establishment rather than low seed rates. The target should be 20–50 plants/m^2.

3.7.4. Sowing date

Delaying sowing decreases crop size and vigour but also decreases the vigour of the weeds present (Lutman *et al*., 1995). The base temperature for dry matter accumulation in oilseed rape is 5°C compared to 0°C and -2°C for volunteer cereals and chickweed, respectively (Lutman *et al*., 2000), hence oilseed rape is at a disadvantage when sown late and soil temperature is lower or in cool autumns.

3.7.5. Nitrogen

Application of autumn nitrogen increased the growth of both rape and weeds maintaining the competitive balance between the two (Lutman *et al*. 1995). There was no evidence that increasing spring nitrogen application rates encouraged the competitive ability of nitrophilic weeds such as chickweed, but there was some evidence that reducing nitrogen rates increased chickweed competition (Lutman *et al*., 1995). In Canadian spring-sown oilseed rape, applying nitrogen to the crop row rather than broadcasting enhanced the ability of crops to compete with weeds (O'Donovan *et al*., 2007)

3.8. Mechanical weeding

Mechanical weeding is the most common non-chemical method for weed control in a range of crops. It can deal with all weeds, including those that are herbicide resistant, and can preserve the effectiveness of herbicides by limiting their use. When used appropriately it can cut herbicide costs, but there are still costs associated with it.

The following does not go into great detail on all mechanical methods available as this area has been comprehensively reviewed and work is still ongoing. Reviews of non-chemical weed management, particularly with reference to the organic sector, can be found in Welsh *et al*. (2002), Bond *et al*. (2003), Melander *et al*. (2005), Melander (2006) and Chicouene (2007). Illustrations of the majority of implements mentioned can be seen in Bowman (1997). A review of robotic weed control systems can be seen in Slaughter *et al*. (2008). Two valuable handbooks are available; 'Weed management for organic farmers, growers and smallholders' (Davies *et al*., 2008) and 'Practical weed control in arable farming and outdoor vegetable cultivation without chemicals' (Van der Schans *et al*., 2006).

3.8.1. Strategies for mechanical weed control

Weeds growing between the crop rows (inter-row) are relatively easily controlled by mechanical weeding but the effects can be sub-optimal (Van der Weide *et al*., 2008). Mechanical weeding is non-selective and cannot distinguish between crop and weed plants. The effectiveness of mechanical weeding depends on factors such as plant height and rooting depth. If there is a large difference between crop and weed size then good control can be achieved. The intensity of the cultivation is important as the more intense the cultivation is, the greater the level of weed control but also, the greater the risk of damaging the crop. Weeds within the crop row cannot be controlled if significant yield losses are to be avoided.

If mechanical weed control is planned the following should be considered:

- Ensure weed populations are reduced prior to sowing, to reduce the in-crop weed burden to be controlled.
- Increase the distance between rows so that inter-row hoeing can take place and crop damage is minimised.

- Increase seed rate to cover any crop losses
- Ensure crops are well rooted so they can withstand mechanical damage.
- Smaller the weeds the better the control.
- If possible, ensure a size difference between the crop plant and weeds (large crop, small weeds).
- Aim to cultivate as close to the row as possible to control the maximum number of weeds, accurate guidance will be needed to minimise damage.

3.8.2. Soil issues

French work on oilseed rape (Lieven *et al*., 2008) used the rotary hoe, tine weeder or inter-row hoe. The work showed that the tine weeder was more successful on lighter soils and less suited to heavy land, whilst the rotary hoe worked best on calcareous clay soils or soils with crushed stones that was damp (Table 8). Inter-row hoeing worked on a range of soil types but was better when weather conditions allowed desiccation of the weeds on the soil surface.

Table 8. Suitability of different soil types to mechanical weeding (CETIOM, 2008)

Soil type	Inter-row hoe	Finger weeder	Rotary hoe	Tine weeder
Silt	+	+	++	--
Clay	+	+	-/+	-
Clay loam	++	++	+	++
Stony	-	-/+	-	-/+

Key

++	Very suitable	+	Suitable	-	Unsuitable	--	Not advised

Winter oilseed rape is sown during August and September when residual soil moisture is low but tending to increase as rainfall increases in the autumn. Field capacity is usually reached during October and this limits the opportunities for mechanical weeding as the number of hoeing opportunities and level of weed desiccation declines (Figure 1). Soils are not usually fit for travel again until March. The opportunities for autumn mechanical weeding will be more limited on the heavier soil types.

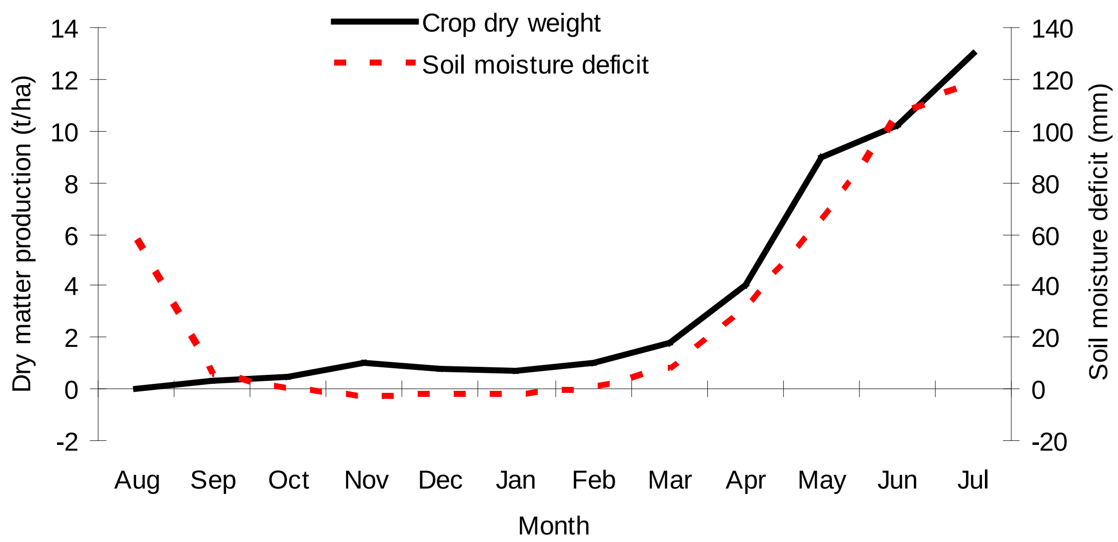


Figure 1. Changes in soil moisture deficit and dry matter production of oilseed rape throughout the year.

3.8.3. Rooting issues

Oilseed rape plants are anchored by a rigid tap root; laterals are few in number and emerge from the tap root approximately 30 cm below the soil surface (Goodman *et al*., 2001). Blake *et al*. (2006) attributed 53% of yield variation to differences in root length density between 40 and 100 cm depth in the soil. Ploughing, subsoiling and not delaying sowing increased root density in the top 20 cm of soil (Blake *et al*., 2006). As rooting is often insufficient below 40 cm, cutting root axes higher up i.e. by hoeing could have important consequences on plant productivity (Berry, *pers. comm*.).

3.8.4. Mechanical weeding of oilseed rape

In Denmark, inter-row hoeing of winter oilseed rape crops sown in 50 cm rows is common in organic crops and was used in conventional crops until a new herbicide became available. There is a move now to consider mechanical weeding again with the advent of integrated pest management (IPM) (Melander, *pers. comm*.). Winter oilseed rape is sown in August and the first pass made with a hoe occurs just as the rape crop emerges (1–2 leaves). Getting the hoe close to the plants is important to minimise the untreated area but requires good steering from the operator. The second pass is done in early October and the aim is to achieve a slight ridging effect to control weeds growing between the crop plants, the size of the ridge is dependent on crop size. A third pass is done in early spring (early April) which controls other weeds and also breaks the soil crust and improves general crop growth.

In Germany unspecified weeding trials conducted in autumn 2007, showed oilseed rape losses from 10 to 30% (Anonymus, 2008) due to damage caused by the mechanical implement.

Mechanical weed control in oilseed rape is mainly carried out in the autumn but can also be supplemented by spring weeding (Arnold, 2011). The exact timing of weeding depends on the machinery; suitable soil conditions and the growth stage of the weeds and crop.

Mechanical weeding methods have been assessed in France in oilseed rape (Lieven *et al*., 2008; Lieven & Lucas, 2009); the work was done from 2003 to 2006 in 15 farmers' fields. Mechanical weeding using a tine weeder (Figure 2), rotary hoe (Figure 3) or inter-row hoe (Figure 4) was evaluated either alone or in conjunction with herbicide use. Herbicide use was targeted (band sprayed) or as an over-all spray.

Figure 2. Tine weeder

Figure 3. Rotary hoe

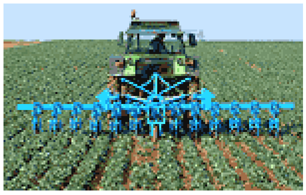


Figure 4. Inter-row hoe

Tine weeder

Tine weeders work at a depth of 2–3 cm by uprooting the seedling weeds and covering them with a thin layer of soil. They require a level medium to fine seedbed with no large clods or clumps of grass. They work independently of the row spacing. The aggressiveness of the cultivation is determined by the angle of the tines and the tractor speed (van der Schans, 2006).

In the work of Lieven *et al*. (2008) and Lieven & Lucas (2009) use of the tine weeder between cotyledon and GS 1,2 led to yield losses by removing and damaging plants. If used pre-emergence it displaced seeds from the row and sometimes delayed crop emergence. Plants were robust enough to cope with tine harrowing from the 3 leaf stage and up to stem extension. Lucas (2006) indicated that tine weeding was suitable for use in oilseed rape at germination and between 4 and 6 leaves. A current leaflet from Agrotransfert (France) advises that tine weeding was best between 3 and 5 leaves (Table 9). Whilst CETIOM (2008) include treatment up to 6 leaves (Table 10).

Table 9. Tine weeder efficiency and selectivity according to crop growth stage of oilseed rape

Number of crop leaves							
Emergence / cotyledon	**1**	**2**	**3**	**4**	**5**	**8**	**10**
--	--	--	+/-	++	+/-	--	--

Key: ++ appropriate; +/- limited; -- inappropriate

Source: Agrotransfert (France) *http://www.eau-seine-normandie.fr*. Accessed 10 January 2012.

Seed rates needed to be increased by 10–15% to compensate for any losses, especially if multiple passes were made or in dry conditions when the crop was poorly established (Lieven *et al*., 2008).

Weed control levels of over 70% can be achieved when used at the 3-4 leaf stage and crop loss can be up to 10% (CETIOM, 2008, Lieven &Lucas, 2009) (Table 10 and Table 11).

Table 10. Crop growth stage guidelines for the use of the tine weeder

Crop growth stage	After drilling	3–4 leaves	5–6 leaves	>7 leaves
Efficiency		>70%	<50%	
Crop loss	5%	5–10%	5–10%	

Key:

	Good		Acceptable		Avoid

Source: CETOM (2008)

Table 11. Estimated losses of plants at a range of growth stages of oilseed rape (%)

Pre-emergence	Cotyledon	Number of leaves			stem elongation
		2	4	6	
8 (±8)	29 (±9)	17 (±3)	8 (±3)	8 (±3)	8 (±3)

Source: Lieven & Lucas, 2009

The tine weeder is most effective when the weeds are between cotyledon to 2 leaves and has very little effect on clumps of grass or on perennial weeds (van der Schans, 2006) and this is supported by the literature from Agrotransfert (Table 12). Weeds over 3 leaves were poorly controlled (Lieven & Lucas, 2009).

Table 12. Tine weeder efficiency according to the weeds stage

Number of crop leaves						
	Germination	Emergence / cotyledon	1	2	3	4 +
Annual dicots	++	++	++	+	-	--
Grasses	++	++	+	-	--	--
Perennials	--	--	--	--	--	--

Key: ++ Very satisfactory; + satisfactory; - poor; -- very poor

Source: Agrotransfert (France) *http://www.eau-seine-normandie.fr*. **Accessed 10 January 2012.**

Mckinlay *et al*. (1994) noted that the effectiveness of the tined weeder harrows fell by 20% in clay soils.

The rotary hoe and tine weeder had better selectivity on rape drilled in wider rows at the same seed rate as narrow rows. The increased plant population within the row increased the plant tolerance to hoeing (Lieven *et al*., 2008).

The advantages and disadvantages of the tine weeder are as follows:

Advantages

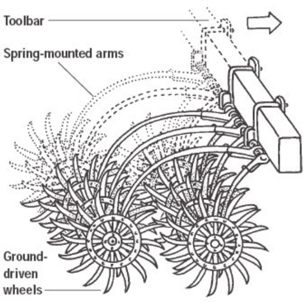
- Useful on many different crops
- Broad spectrum efficiency on weed seedlings
- Work rapidity (5 to 8 ha/h)
- Reasonable utilisation cost, low maintenance
- Effective over the entire soil surface
- Does not need much power (7 to 10 hp/m)

Disadvantages

- Poor on larger (older) weeds and perennial weeds
- Requires an even soil surface/structure
- Operation can be difficult to plan when the forecast is unsettled
- Blockages occur when there is too much straw or stubble remaining on the soil surface
- Machine adjustments can be difficult on heterogeneous soil conditions
- Excessively deep harrowing can head to crop damage

Source: Agrotransfert (France) http://www.eau-seine-normandie.fr. Accessed 10 January 2012 and Van der Schans (2006).

Rotary hoe



The rotary hoe (Figure 3) referred to in the following section is ground driven, it has one or more sets of vertical star shaped wheels mounted on a horizontal axis. The wheels are 21 inches in diameter with 16 teeth. Speed of work is 15–18 km/hr. They work at 2–3 cm depth. The machine works over the whole field area like the tine weeder.

The rotary hoe was found to be less damaging to the crop than the tine weeder and was selective at high speed 10–12 km/hr from pre-emergence to GS 1,4. Selectivity was decreased by very crumbly soil and deeply-drilled rape (Lieven *et al*., 2008). A current leaflet from Agrotransfert (France) advises that rotary hoeing is best between emergence and 3 leaves in oilseed rape (Table 13), this agrees with the work from Lucas (2006) and Lieven & Lucas (2009).

Table 13. Rotary hoe efficiency and selectivity according to crop growth stage for oilseed rape and other crops

Number of crop leaves								
Emergence / cotyledon	**1**	**2**	**3**	**4**	**6**	**8**	**10**	**12**
+/-	++	++	+/-	--	--	--	--	--

Key: ++ appropriate; +/- limited; -- inappropriate

Source: Agrotransfert (France) http://www.eau-seine-normandie.fr. Accessed 10 January 2012.

The information from CETIOM (2008) indicates that plant losses were less than 10% with a weed control efficiency of 50% if weeding was done between drilling and 4 leaves, crop loss was low (Table 14). Lucas & Lieven (2009) noted similar levels of damage.

Table 14. Guidelines for the use of the rotary hoe (CETIOM, 2008)

Crop growth stage	**After drilling**	**2–4 leaves**	**5–6 leaves**	**>7 leaves**
Efficiency		50%		
Crop loss	<5%	<2%		

Key:

Good	Acceptable	Avoid

Source: CETOM (2008)

A current leaflet from Agrotransfert (France) makes more specific recommendations for different species of weeds (Table 15). Control of grasses and volunteer cereals is more difficult than broad-leaved weeds.

Table 15. Rotary-row hoe efficiency according to the weeds stage

	Number of leaves					
Weed species	**Emergence**	**Cotyledons**	**1**	**2**	**3**	**4 +**
Grasses	++	++	+	-	--	--
Cleaver spp. Brassica spp. Speedwell spp.	++	+	-	--	--	--
Mayweed spp. Chickweed spp. Poppy spp.	++	++	++	+	-	--
Sow-thistle spp. Annual mercury spp. Black nightshade Fat hen spp.	++	++	+	-	--	--

Key: ++ Very satisfactory; + satisfactory; - poor; -- very poor

Source: Agrotransfert (France) http://www.eau-seine-normandie.fr. Accessed 10 January 2012.

The advantages and disadvantages of the rotary hoe are as follows:

Advantages

- Useful in many different crops
- Broad spectrum efficiency on seedlings
- Work rapidity (4 to 8 ha/h)

Disadvantages

- Low efficiency on mature and perennial weeds
- Requires an even soil surface
- Operation can be difficult to plan when the forecast is unsettled

- Effective over the entire soil surface
- Inexpensive, low maintenance
- Able to break soil caps
- Easy and fast adjustments

- Low efficiency when there are many stones or a lot of straw/stubble remaining
- Power requirement (20 to 25 hp/m)

Source: Agrotransfert (France) *http://www.eau-seine-normandie.fr*. Accessed 10 January 2012.

Inter-row hoe

Inter-row hoes work between the rows of crops and cut of weeds 1 to 2cm below the surface, when used in combination with ridging plates, loose soil can be moved onto the crop row to cover small weeds. As with other weeders they require level, loose, moderately fine soil and can be fitted with guards to protect small crop plants. Rows need to be a minimum of 15 cm wide (Van der Schade, 2006)

The inter-row hoe is less damaging than the tine weeder as it works between the crop rows but is only suitable to be used from 3 leaves until canopy closure (CETIOM, 2008; Lieven & Lucas, 2009). A current leaflet from Agrotransfert (France) advises that inter-row hoeing was best between 3 and 10 leaves in oilseed rape (Table 16).

Table 16. Inter-row hoe efficiency and selectivity according to crop growth stage for oilseed rape and other crops

Emergence / cotyledon	1	2–3	4	6	8–10	Canopy closure
--	--	+/-	++	++	+/-	--

Key: ++ appropriate; +/- limited; -- inappropriate

Source: Agrotransfert (France) *http://www.eau-seine-normandie.fr*. Accessed 10 January 2012.

The information from CETIOM (2008) indicates that the efficiency of weed control is high after the crop reaches the 2 leaf stage (>70%) and crop loss is low <5% (Table 17). Lieven & Lucas (2009) recorded losses of less than 1% at these growth stages. Losses were negligible at the later growth stages if guards were fitted to protect the crop rows.

Van der Schans (2006) noted that the inter-row hoe is most effective when the weeds are between cotyledon to 4 leaves.

Table 17. Guidelines for the use of the inter-row hoe

Crop growth stage	After drilling	2–4 leaves	5–6 leaves	>7 leaves
Efficiency		>70%	>70%	>70%
Crop loss		<5%	<5%	

Key

Good	Acceptable	Avoid

Source: CETOM (2008)

Lieven *et al*. (2008) noted that in oilseed rape the inter-row hoe has a working speed between 5km/hr (small plants) and 10 km/hr (later passes). Speeds of up to 14 km/hr can be achieved with self-guided systems. The hoe was very good on clay loams, acceptable on silt and clays and poor on stony soil.

The advantages and disadvantages of the inter-row hoe are as follows:

Advantages

- Useful in many different row crops
- Broad spectrum efficiency
- Cheap maintenance
- Soil tilling, reduces the surface run off, improves the water balance
- Usable for a long cropping period
- Able to cover up weeds on the row by throwing some soil on the row base
- Work can be fast with 12 rows equipped with vision guidance (4 ha/h)

Disadvantages

- Requires an even soil surface
- Usable only on row crops
- Weeding only in the inter-row
- Slow work without guidance (2 ha/h)
- Low efficiency when there are many stones

Source: Agrotransfert (France) *http://www.eau-seine-normandie.fr*. **Accessed 10 January 2012.**

3.8.5. Level of weed control

French work (Lieven *et al*., 2008) indicated that the rotary hoe and tine weeder were suited to controlling weeds that appeared soon after drilling, the tine weeder being the most efficient as it was more aggressive than the rotary hoe. *Veronica* spp. were better controlled at the cotyledon stage (78%) than at the 2 leaf (31%) and 4 leaf (23%) stages. Broad-leaved weeds were better controlled than grass weeds, and tap rooted weeds were best controlled early before the tap root had time to develop. Control of fast-growing weeds such as fat hen and charlock was difficult with machines if their 'woody' stems were allowed to develop (McKinlay *et al*., 1994).

Mechanical weeding was effective at low weed populations especially on difficult-to-control weeds (black-grass 7/m², crane's-bill 2/m² and sow-thistle 11/m². (Lieven *et al*., 2008) (Figure 5).

Figure 5. Level of control of weeds in oilseed rape at GS 1,6 (% of untreated, herbicide = trifluralin/metazachlor+ quinmerac; Lieven *et al*., 2008).

The inter-row hoe was used in combination with herbicide applied to the row only. Without the herbicide application weed numbers increased after hoeing (Lieven *et al*., 2008) (Figure 6).

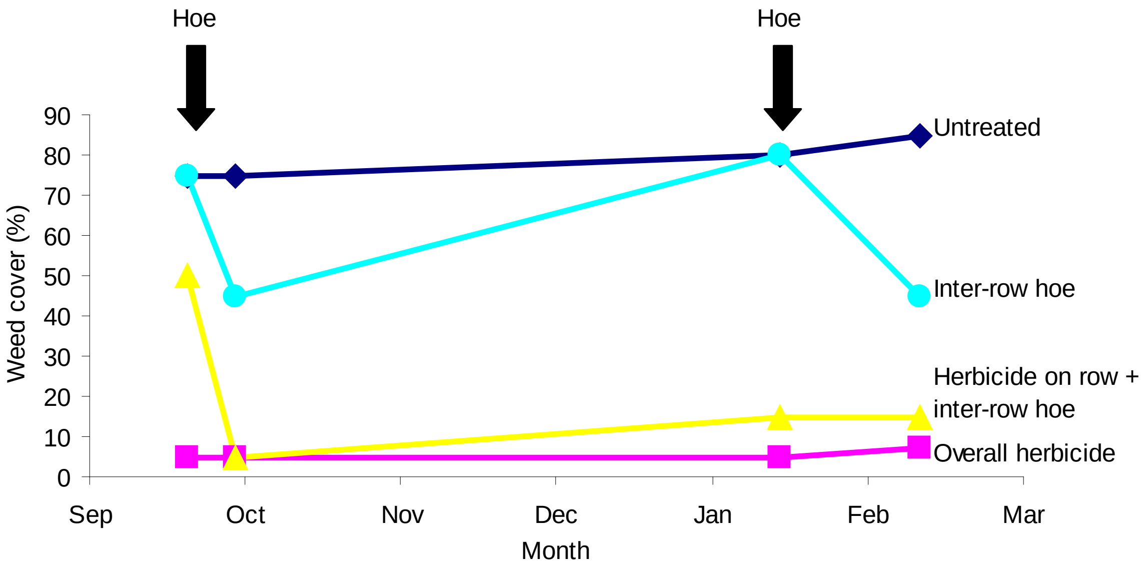


Figure 6. Efficacy of herbicide inter-row hoeing combinations. Weeds present: crane's-bill, wild radish, scarlet pimpernel, poppy and ryegrass (Lieven *et al*., 2008).

There was good control of groundsel (*Senecio vulgaris*) and pansy (*Viola arvensis*). Sow-thistles (*Sonchus spp.*), mayweeds (*Matricaria spp.*) and shepherd's purse (*Capsella spp.*) were seen in the work of Lieven & Lucas (2009) (Figure 7). Volunteer cereals and black-grass (*Alopecurus myosuroides*) were more difficult to control. Multi-rooted weeds such as chickweed (*Stellaria spp.*) and speedwells (*Veronica spp.*) were also less well controlled. No yields were reported in this work.

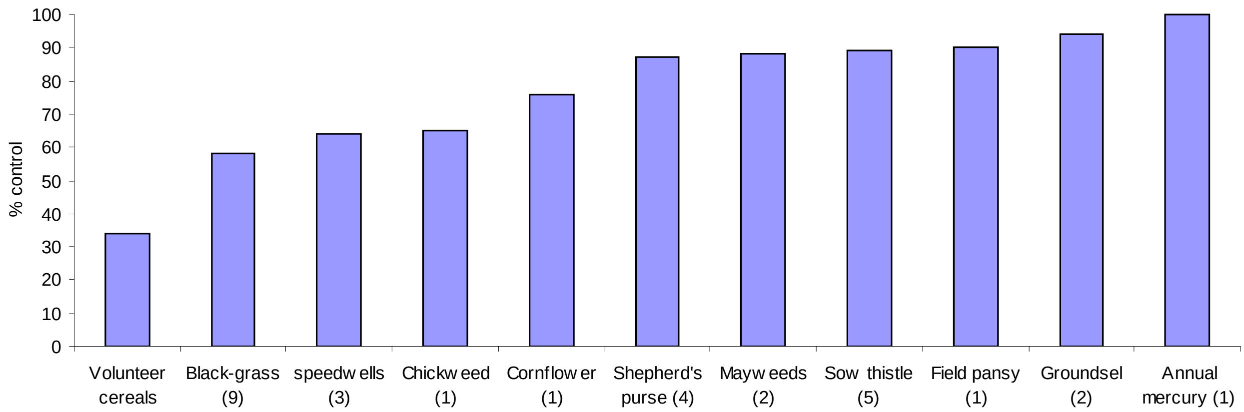


Figure 7. Summary of the efficiency (and control) of the tined weeder on weeds of oilseed rape (figures in brackets refer to the number of references). Source: Lieven & Lucas, 2009.

Hoeing in spring was studied in an organic winter oilseed rape in a one-year pseudo-randomised trial in Germany (Leisen 1999). In April, weed cover was reduced in the hoed treatment (25 cm row width) compared to the un-weeded plots (12.5 cm row width), but this effect did not last into the summer and had disappeared by June, when both treatments showed 50% weed cover. However, no yield data were reported.

In a series of field trials in Germany on organic oilseed rape, four cultivation methods were tested with and without fertilisation in spring for effects on weeds, nitrogen losses during winter and grain yield (Stumm 2007, 2009, Stumm *et al.,* 2009). The trials were conducted in five different environments (in the West of Germany) over three years. The oilseed rape was sown mid to late August and weeding was carried out once in mid-September.

In four out of the five trials, hoeing did not reduce weed biomass (Treatments A & B) (Table 18). In spring, weed biomass was highest in the double row treatments (C and D) (Stumm *et al*., 2009). The most cost-efficient was treatment A, narrow rows and no weeding, this controlled weeds effectively.

Table 18. Effect of hoeing on weed biomass in organic oilseed rape (DM t/ha) (Stumm, 2009)

			Treatment			
			A	**B**	**C**	**D**
Trial No.	**Site**	**Rows**	**Narrow rows (12cm)**	**Wide rows (24cm)**	**Double rows[1]**	**Double rows[2]**
		Hoeing	**No**	**Yes**	**No**	**Yes**
		Intercropped	**No**	**No**	**Buckwheat**	**No**
		Assessment date				
1	WG	Autumn 2008	0.9 ab	0.4 b	1.4 ab	1.8 a
2	HH[3]	Autumn 2008	3.1 a	0.9 b	0.7 b	1.1 b
3	WG	Spring 2009	3.1 a	3.7 a	3.9 a	4.8 a
4	HH[3]	Spring 2009	2.6 b	1.8 b	5.9 a	4.1 ab
5	MH	Spring 2009	0.5 a	0.5 a	1.1 a	0.9 a

[1] Oilseed rape intercropped with buckwheat (*Fagopyrum esculentum* Moench) both sown in double rows, row distance 12 cm

[2] Oilseed rape sown in double rows with the remaining double rows left free

[3] Plots received an additional second weeding in the autumn.

Sites: WG Wiesengut; HH Höfferhof; MH Mühlenhof. Within rows numbers with the same letter are not significantly different.

Grain yield was not significantly lower in the narrow row non-weeded treatment (A) compared to the more cost-intensive treatments (B & D) where hoeing was performed (Table 2).

In three out of four sites, grain yield in oilseed rape was significantly lower in the intercropped treatment compared to the other treatments (Table 19). In contrast to expectations, treatment C, oilseed rape intercropped with buckwheat, neither controlled weeds efficiently nor enhanced nitrogen uptake before winter (Stumm *et al*., 2009).

Table 19. Performance of oilseed rape in mechanical weeding trials (Stumm 2007, 2009, Stumm *et al*., 2009). Table shows plant density (number/m^2) and grain yield (t/ha) under four different treatment regimes.

				Treatment			
	Site	Year*	Trial	A	B	C	D
Rows				Narrow rows	Wide rows	Double rows	Double rows
Hoeing				No	Yes	No	Yes
Intercropped				No	No	Yes	No
Plants/m²	SW	2007	1	42.0 a	46.0 a	52.0 a	54.0 a
	WG	2008	2	50.5 ab	49.5 ab	58.0 a	43.0 b
	WG	2009	3	64.0 a	68.5 a	57.5 a	57.0 a

	HH	2009	4	40.0 a	42.5 a	26.5 b	41.0 a
Yield (t/ha @ 91% DM)	SW	2007	1	1.11 a	1.36 a	1.13 a	1.65 a
	WG	2008	2	2.95 a	3.01 a	2.54 b	2.99 a
	WG	2009	3	**ab	a	b	a
	HH	2009	4	a	a	b	a

***harvest year. SW Schloss Wendlingshausen; WG Wiesengut; HH Höfferhof; ** in original publication, data not shown in table but in a graph**

In a separate trial series oilseed rape was tested over three years for its suitability in organic wide row cropping systems (Becker and Leithold, 2007a, b). These authors compared wide rows (50 cm), where duck-feet hoeing was used to tine-weeded narrow rows. Seed densities were equal in both wide and narrow rows and ranged from 73 to 85 seeds/m^2 (Becker & Leithold, 2007a). Under-sowing was included as a further trial factor (with and without), but the under-sown crop could not be established in the oilseed rape because of the high competitiveness of the rape plants. Even in the wide rows, oilseed rape plants reached 100% cover by mid-May. The study also found substantial and significant yield increases in the wide row system compared to the narrow rows in the two trials where comparison was possible. However, no details were reported on the effect or extent of tine-weeding in the narrow rows and the potential damage to the oilseed rape plants that this technique may have caused.

In oilseed rape trials in France, Huguet *et al*. (2007) found better or similar weed control with mechanical weeding than was achieved by herbicide treatments. Also, the costs for weed control were reported to be lower with the mechanical than the chemical treatment.

3.8.6. Economics of inter-row hoeing

Machinery and operating costs can be offset by the savings made on herbicides but this depends upon the cost and sophistication of the machinery, manpower availability and the area to be worked. Combining herbicide and mechanical control can be more expensive and involve more labour (Figure 8).

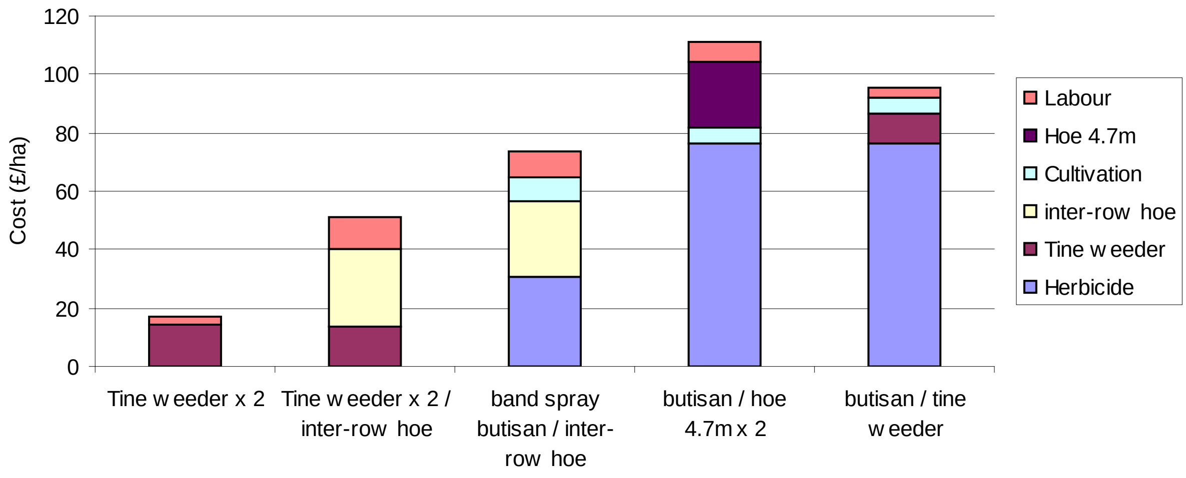


Figure 8. A comparison of different methods of weed control in oilseed rape (*taken from CETIOM, 2008*).

3.9. Mechanical weeding in other brassica crops

Whilst the effects on weeds of machinery may be comparable between crops, the only experience in the UK of mechanical weeding in brassicas can be found in the horticultural sector.

Transplanted cabbages in 56 cm rows, with 30 cm between plants were weeded in August (3–4 leaves) and September (< 15 cm). Three types of machines were used; a rolling cultivator (Opico), spring tines and a brush weeder. The brush weeder was less effective than the other two implements. Control of weeds from two passes between rows reached 99% but within the row levels of control only reached 11% (McKinlay *et al*., 1994). The level of weed control was greater from September treatment.

Where crops were mechanically weeded between the rows and a herbicide applied to the row, there were problems experienced due to weed plants being covered in dust which lessened the effect of the contact herbicides.

Cabbage (Elisa) transplanted out in early September and weeding treatments were done at 16, 23 and 33 days after transplanting. Weeding was done at 1.8 km/hr using a tool frame mounted with inter-row and intra-row cultivators. Weed control was best at 16 or 23 days after transplanting by 77% and 87%, respectively. By 33 days weeds had grown too large and were too robust for control. After treatment, weed populations did not recover and there was no further germination (Grundy, 2007). Few weeds were found within 80 mm of the cabbage indicating the competitive nature of the crop. Crop damage was low but the hooked stems indicated that plants should be given a larger uncultivated zone (50–60 mm radius) to avoid root damage (Grundy, 2007).

3.10. Summary and conclusions

Control of weeds in oilseed rape has always been problematical but they need to be controlled within a balanced crop rotation rather than in the crop alone. Cleavers and mayweeds have become less of a problem due to good control being achieved in cereal crops. Broad-leaved weeds that are considered as becoming more of a problem are crane's-bill, common poppy and charlock because current herbicides do not provide adequate control. Increasing levels of black-grass are being seen in the crop due to herbicide resistance. Good control of weeds in oilseed rape is a combination of many factors but the main aim should be to establish a good crop with a target population of 20–50 plants/m^2. Next, select herbicide programmes that target potential weed problems and apply them at the optimum timing for the weeds identified. Selecting more competitive varieties and maintaining an optimum GAI of 3.5 will optimise the competition afforded by the crop. Mechanical weeding can give good control of weeds but row width needs to be increased in order to minimise crop damage, drying weather conditions and small weed size are critical for success.

There will be options for non-chemical weed control in oilseed rape if herbicides are withdrawn, but these methods will have to be robust and effective on large areas of crop. Band spraying of herbicides will reduce the overall amount of herbicide being applied to a field and mechanical weeding could reduce this to zero. Mechanical weeding comes with its own set of problems particularly related to soil type and condition. The HGCA-funded projects 3652 and 3605 aim to provide growers with information in this area.

4. RD-2009-3652 Improving oilseed rape for effective weed control

4.1. Introduction

Previous experience suggests that simply reducing the rates of herbicides in oilseed rape (OSR) is not a feasible option to maintain yields and maintain the value of rape as a cleaning crop for reducing weeds for following crops in the rotation.

In oilseed rape crops one option for adapting to the loss of key herbicides or for reducing herbicide use, is to increase row spacing to allow for band spraying herbicides or mechanical weeding. This project builds on previous knowledge about the physiological principles that determine yield which is based on normal row spacing of 12 to15 cm. For wide spaced rows there are several important issues which must be addressed to understand how they can be employed by commercial practice:

- If wide-spaced rows can lead to reduced herbicide use per unit area, what is the optimum row spacing and plant population within the rows?
- What is the effect of the wide-spaced rows on crop performance, weed emergence and competition and are there increased pest (including pigeons), disease and lodging implications?

Over the past 15 years a series of research projects based on normal row widths of 12 to 15cm has developed principles of canopy management for maximising OSR yields (Stokes *et al*., 1998; Lunn *et al*., 2001; 2003; Berry and Spink, 2006; 2009; Berry, 2009). The canopy management principles explain that OSR should achieve a green area index (GAI) of between 3 and 4 units at flowering in order to maximise the number of seeds/m^2 that are set. This GAI should be maintained for as long as possible during seed filling in order to maximise seed size. At the beginning of this project relatively little research had been carried out on the effect of plants/m^2 on yield determination. Lunn *et al.* (2001) showed that similar or greater yields could be achieved by planting 60 seeds/m^2 compared with 120 seeds/m^2 at normal row widths, however, no published work existed to describe the effects of a wider range of seed rates. During the lifetime of this project there have been two projects (Ellis and Berry, 2012; Ellis *et al*., 2013) which investigated a wide range of seed rates (20 to 160 seeds/m^2) at normal row widths for conventional and hybrid OSR varieties that allowed optimum seed rates to be calculated. The results of these projects will be summarised in the discussion section of this project.

Increasing row spacing may have implications on several aspects of OSR growth. It is possible that closer spacing of plants within the row may reduce plant establishment and lead to smaller weaker plants that are more prone to lodging. Light interception may be reduced from that achieved at the optimum Green Area Index (GAI) of 3 to 4 units at flowering due to the failure of the crop canopy to meet between the rows. Weeds will exploit areas where competition from the crop is reduced and wider plant spacing between rows can lead to greater weed emergence (as was seen in SAFFIE Skylark plots in wheat (Clarke *et al*., 2007)). The area between the rows could also provide a landing strip for pigeons.

The presence of a competitive crop is the strongest option for good weed control, maintaining this competitive crop whilst allowing alternative methods of weed control was the target of this project. Increasing row spacing would allow the use of band spraying and possibly tractor hoeing hence reducing the total amount of herbicide applied to the crop.

Although much is already known about the implications of changing timing of herbicide applications, little information is available on the competitive ability of OSR and yield implications of changing row spacing. Understanding these is critical for any novel weed control strategy, whether band spraying or inclusion of inter-row cultivations. This project aims to produce this understanding which can then be deployed whatever the future available herbicide or cultivation options.

4.1.1. Overall aim

To produce a 'specification' for an oilseed rape crop which balances the needs of crop performance with those required for weed control.

4.1.2. Specific objectives

1. To determine the optimum row spacing and plant population within the rows to achieve economic yield and prevent additional lodging.
2. To evaluate the effect of the wide-spaced rows on crop performance, weed emergence and seed return, monitor the effects on pests (including pigeons), disease and lodging.
3. To evaluate the effect of varietal type on optimum row spacing and plant population.
4. To assess the economic implications of conversion to wide-spaced rows and alternative methods of weed control.

4.2. Materials and methods

4.2.1. Site details

The trials were located at two sites in the east of the UK with heavy soil types (Table 20). Each year the trials were sown to oilseed rape; a conventional open pollinated variety at Boxworth and a hybrid variety at Terrington (Table 20). The previous crop was winter wheat with the straw chopped and spread. The trials were drilled using a Sulky combination air drill following non-inversion cultivations. The cultivations used and all chemical and fertiliser inputs are detailed in Appendix 1.

Table 20. Site location

Site name	Harvest years	Location	County	Soil type	Variety	Drilled
	2010				Castille	7/9/2009
Boxworth	2011	TL 34112 61807	Cambs	Clay	Catana	5/9/2010
	2012				Catana	1/9/2011
	2010	TF 49397 22235			Excalibur	9/9/2009
Terrington	2011	TF 51062 20433	Norfolk	Silty clay loam	Excalibur	17/9/2010
	2012	TF 49397 22235			Excalibur	9/9/2011

The site at Boxworth in 2010 established poorly due to dry conditions at drilling and the data has been excluded from this report.

4.2.2. Treatments

Herbicides

There were two herbicide treatments: no-herbicide and with-herbicide. The 'with-herbicide' treatment received a full herbicide programme including pre- and post-emergence treatments. Metazachlor was used pre-emergence followed by an autumn graminicide and propyzamide applied in November/December. Products used, application date and rate are detailed in Appendix 1. The no-herbicide treatment received a graminicide in the autumn to control volunteer cereals and sterile brome (*Bromus sterilis*) which would have compromised the experiment. Black-grass (*Alopecurus myosuroides*) present at Boxworth was known to be resistant to the graminicides used and populations in the no-herbicide treatment were unaffected by the graminicides used.

Row spacing and seed rate

There were four row spacings, 12, 24, 48 and 72 cm, with three seed rates in 2010 and four seed rates in 2011 and 2012 (Table 21). The trial was drilled using a Sulky 3m combination air drill and the different row widths were achieved by blocking off appropriate coulters. Seed rates were achieved by calibrating the drill to vary the drilling rate.

In the no-herbicide treatment the seed rates were restricted to 20 and 80 seeds/m² in 2010 and 30 and 120 seeds/m² in 2011 and 2012.

Table 21. Seed rate of oilseed rape (seeds sown/m²)

Treatment number	2010	2011–2012
1	20	15
2	40	30
3	80	60
4		120

Treatment summary

A summary of the treatments is detailed in Table 22 below.

Table 22. Summary of treatments

		With herbicide Seed rate (seeds sown/m²)							No herbicide Seed rate (seeds sown/m²)						
Year	Row width (cm)	15	20	30	40	60	80	120	15	20	30	40	60	80	120
2010	12		✓		✓		✓			✓				✓	
	24		✓		✓		✓			✓				✓	
	48		✓		✓		✓			✓				✓	
	72		✓		✓		✓			✓				✓	
2011 & 2012	12	✓		✓		✓		✓			✓				✓
	24	✓		✓		✓		✓			✓				✓
	48	✓		✓		✓		✓			✓				✓
	72	✓		✓		✓		✓			✓				✓

4.2.3. Experimental design

The experiment was done as a split plot design with the herbicide treatments as main plots and the row width and seed rate as sub plots in a two way factorial. The design was unbalanced due to uneven numbers of seed rate treatments in the herbicide main plots. There were three replicates each year. Plot size was a minimum of 3 m wide and 12 m long.

4.2.4. Assessments

Assessment dates are detailed in Appendix 2. Data is shown in Appendix 4.
Each year a plant count was done in the winter and again in the spring. In 2012 at Boxworth, the spring plant count was replaced by a stubble count. Plant and stubble counts were done on 10 replicates of 1 m lengths of row.

Weed counts were done in December/January and March; additionally, in 2012 a count of oilseed rape volunteers was done in February. At both assessment dates, weed counts were done in circular quadrats (Figure 9). The quadrat was placed over an oilseed rape plant and the weeds of each species counted in both the inner and outer circles. The growth stage of the weeds and growth stage, height and width of the oilseed rape plant was also recorded.

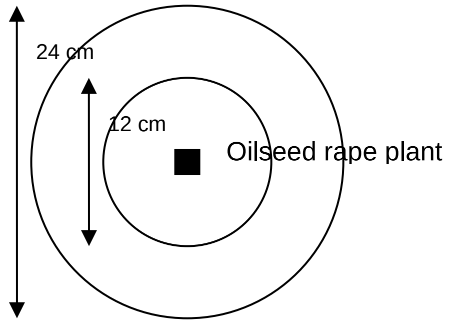


Figure 9. Design of the circular quadrat.

Green area index (GAI) assessments were done in late February/early March on the first replicate of each treatment. The entire crop from 1 m² was cut off at ground level, the total fresh weight was recorded and the green leaf area of a 25% subsample was measured. Photographs of three 1 m² areas of the plot were taken of the plot on the same date. The GAI was assessed using the BASF GAI tool (www.totaloilseedcare.co.uk) and a mean figure calculated.
The fraction of incident radiation that was intercepted by the crop or reflected by the crop was measured using a Sunscan at mid-flowering. Measurements were taken on a uniformly sunny or cloudy day between 10am and 4pm. Measurements at ten points per plot were made of:
1) incident light above the crop,
2) the light level at ground level,
3) the light reflected from the canopy by turning the Sunscan upside down and recording the light intensity.

The percentage area of each plot that was lodged at an angle of 10° to 45° and 45° to 90° from the vertical was measured at the end of flowering and at harvest.

Plots were harvested using a plot combine harvester and samples taken for determination of moisture content. Subsamples of harvested grain were assessed for weed seed content.

4.2.5. Data analysis

All data were analysed by ANOVA or regression analysis using Genstat 12.

The relationship between plant population and the seed rate was poor due to different plant establishment rates between experiments and between the seed rate and row width treatments (Figure 2). Furthermore, altering the row width alters the number of seeds drilled per metre of row without affecting seeds/m^2. For example, with a 12 cm row width only four seeds are sown per metre of row when the seed rate is 30 seeds/m² (Table 23). If the row width is increased to 72 cm then the number of seeds sown increases to 22 per meter length of row. Therefore, to investigate the effects of plants/m^2 and plants/m on response variates such as yield the spring plant population data was used to develop two new factors: plant density and linear plants. Each factor consisted of 5 categories using the maximum and minimum as the outer boundaries. The categories for these factors are detailed in Table 24. Each plot was allocated to one of five categories for each factor using the spring plant count data.

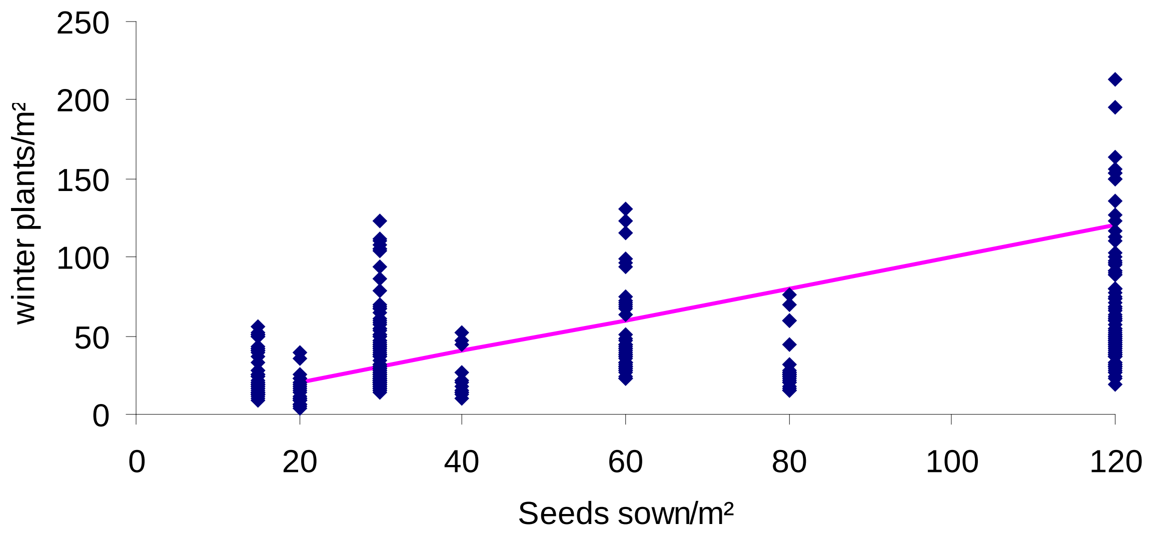


Figure 10. The relationship between seeds sown/m² and winter plant establishment.

Table 23. The number of plants per m length of row at a range of seed rates and row widths

Seed rate	**Row width (cm)**			
(seeds/m²)	**12**	**24**	**48**	**72**
15	2	4	7	11
30	4	7	14	22
60	7	14	29	43
120	14	29	58	86

Table 24. The new factors developed from spring plant populations

New factor	**Plant density**	**Linear plants**
1	1–24	1–8
2	24–48	8–16
3	48–72	16–24
4	72–96	24–32
5	96–120	32–48

4.2.6. Curve fitting

Exponential seed rate response curves were fitted to the seed yield for, seeds/m^2, plants/m² and plants per meter length of row of the form:

$Y = A + B*R^X$: Equation 1

where *Y* is the seed yield (t/ha), *A, B* and *R* are constants and *X* is the selected seed rate or plant number factor. An exponential function was chosen because this curve was found to describe the yield response best which was frequently typified by a steep initial yield increase followed by a plateau. For the oilseed rape experiments, each exponential function was fitted using a stepwise process within GenStat 12 involving the following steps: i) fitting a common curve, ii) fitting separate parallel curves for each row width, iii) fitting separate curves by allowing parameters *A* and *B* to vary, and iv) fitting separate curves for each treatment by allowing all parameters to vary. The sums of squares explained at each stage was calculated, and a test was made of the improvement in fit over the previous model. If there was no significant improvement between two stages, then the previous model was taken as the best description of the data. In general, fitting at stage (i) or (ii) was most satisfactory.

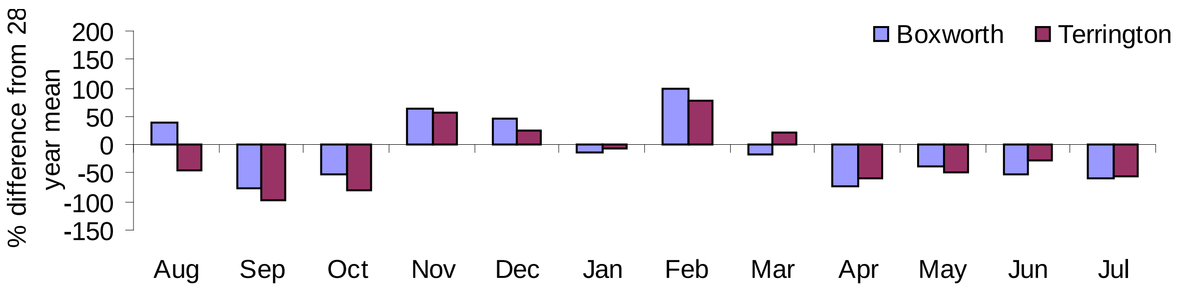
The equation for the best-fit curve was then used to calculate the economically optimum population for each trial by assuming oilseed rape seed costs of £10/kg for a conventional variety and £20/kg for a hybrid variety. The cost of each seed rate treatment (seeds/m^2) was calculated by using the seed costs described above and the thousand seed weight of the seed (which approximated to 5g).

4.3. Results

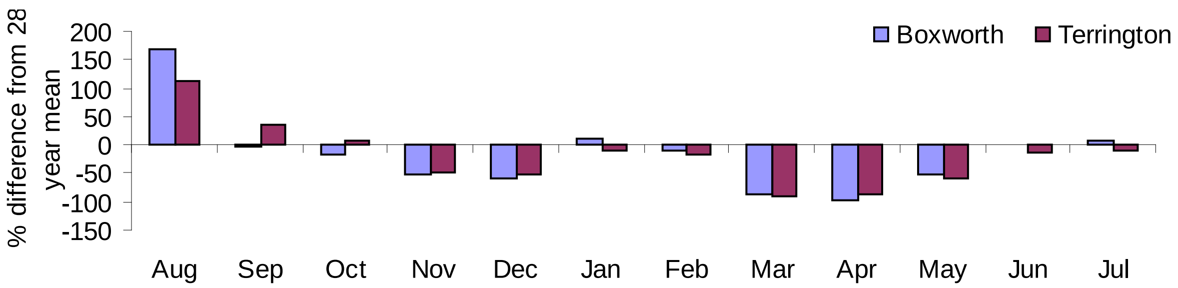
4.3.1. Weather

Establishment of the trials in autumn 2009 at Boxworth and Terrington was poor due to dry conditions at drilling (Figure 11 and Appendix 3). Rainfall was average during the winter months but April through to July was also dry. The winter months were colder than the 10 year average. In the autumn of 2010, establishment conditions were good and the crops at both sites established well. The spring (March, April and May) was dry, with only 22% and 29% of average rainfall falling at Boxworth and Terrington, respectively.

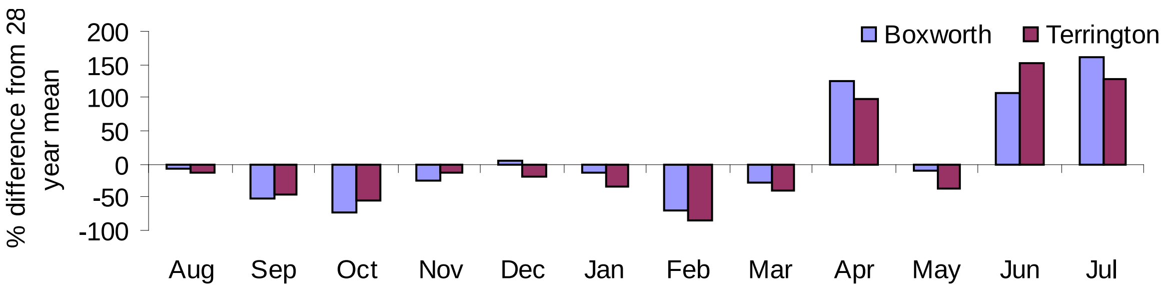
In autumn 2011 the crops established well and adequate rainfall fell during all months to maintain a good plant population. April was very wet with over twice the amount of average rainfall. This was followed by a very wet June and July. Harvest was delayed until the middle of August.



a) 2009–2010



b) 2010–2011



c) 2011–2012

Figure 11. Total monthly rainfall as the percentage difference from the 28 year mean for Boxworth and Terrington.

4.3.2. Plant establishment

Seed rate and row width had a significant effect on the number of plants that established. The percentage of seeds that established plants was lower at wider row widths and higher seed rates (Table 25 and Figure 12). The percentage of seeds sown that established plants was lower at Terrington in 2010 (Table 25) when the autumn was dry. Overall, plant establishment was lower at Boxworth compared with Terrington, except in the dry year of 2010. Over 70% of seeds sown failed to establish plants in the widest row width and highest seed rate.

Table 25. The effect of row width on the percentage of seeds sown that failed to establish plants at all sites and years

Seed rate (seeds/m²)	Seeds sown /m length of row	Row width (cm)	Boxworth 2011	Boxworth 2012	Terrington 2010	Terrington 2011	Terrington 2012
15	2	12	0	0		0	0
	4	24	0	0		0	0
	7	48	21	0		5	0
	11	72	32	14		10	0
20	2				0		
	5				7		
	10				56		
	14				56		
30	4	12	0	0		0	0
	7	24	3	0		0	0
	14	48	30	25		20	6
	22	72	46	35		20	16
40	5				0		
	10				42		
	19				63		
	29				66		
60	7	12	0	0		0	0
	14	24	20	9		3	2
	29	48	49	49		29	31
	43	72	58	61		42	42
80	10				19		
	19				64		
	38				71		
	58				73		
120	14	12	26	17		0	0
	29	24	50	38		25	31
	58	48	69	70		50	59
	86	72	79	77		59	72

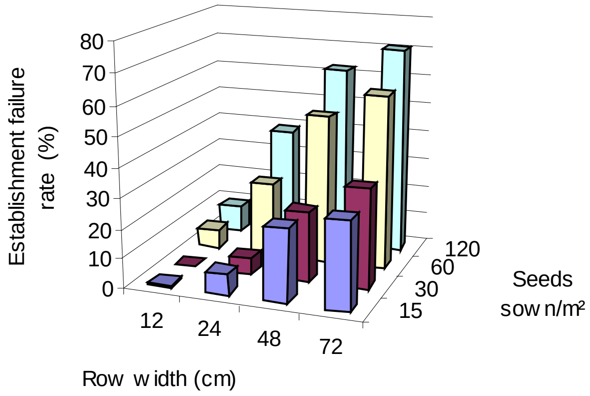


Figure 12. The effect of row width and seeds sown on the percentage of seeds sown that did not establish plants (establishment failure rate).

Curve fitting

Curves were fitted for Boxworth and Terrington 2011 and 2012 only.

There was a good fit when establishment failure rate was plotted against seeds sown per meter length of row (Figure 13). Regression of establishment failure rate was done using an exponential curve with the equation Y = A + B*(R**X) (Table 26). The variance accounted for was 93.2%.

A similar regression for plants/m accounted for 98.9% of the variation (Table 26). The probability of each plant surviving decreased when more than 7 seeds/m length of row were sown. This equates to a plant population of 58.3 plants/m² at a 12 cm row width and 29, 15 and 10 plants/m² at 24, 48 and 72 cm rows, respectively.

Table 26. Results for curve fitting

Y	R	A	B	se	p	% variance accounted for
Establishment failure rate (%)	0.989	0	-124.0	6.2	<0.001	93.2
Surviving plants (plants/m)	0.955	0	-24.77	0.74	<0.001	98.9

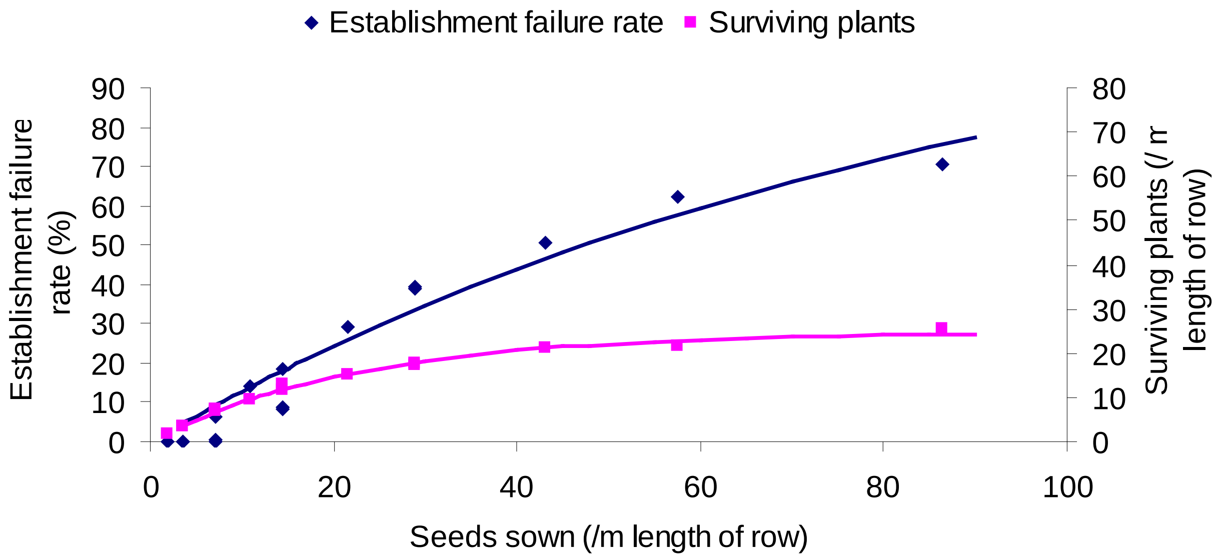


Figure 13. The effect of increasing plant population on establishment failure rate (%) and the number of surviving plants per meter length of row.

Winter kill

Plant counts were done in December and again in late February/March. There was no change in population between these dates (Figure 14), indicating that winter kill did not occur between 2009–2012 at Boxworth and Terrington.

There were no differences between the winter and spring plant populations so all references made to plant population will be from the spring (late February/March) counts.

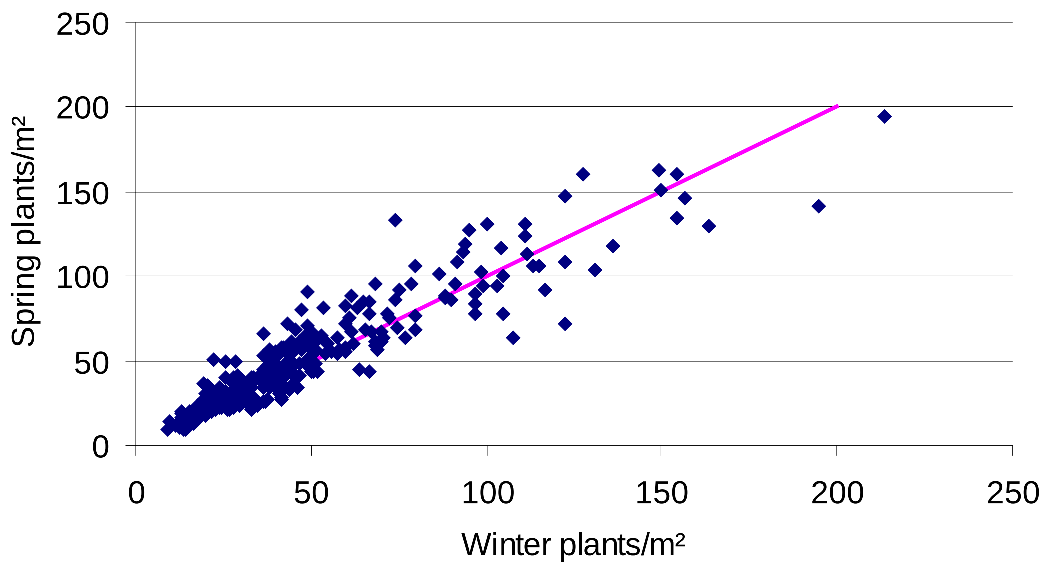


Figure 14. The relationship between winter and spring plant populations. The line denotes parity.

The combination of row width and seed rate treatments resulted in a wide range of plant densities per plot (3 to 195 plants/m²) being achieved during the 3 year series of experiments (Figure 15). The highest populations were achieved at Terrington in 2011 and 2012. Populations were low at Terrington and Boxworth in 2010 due to the drought during establishment. Some of the plant populations were greater than the number of seeds sown which was due to volunteer plants.

The crop at Boxworth never recovered from the poor establishment and yields were very low and as consequence the data set has not been included in the data analysis.

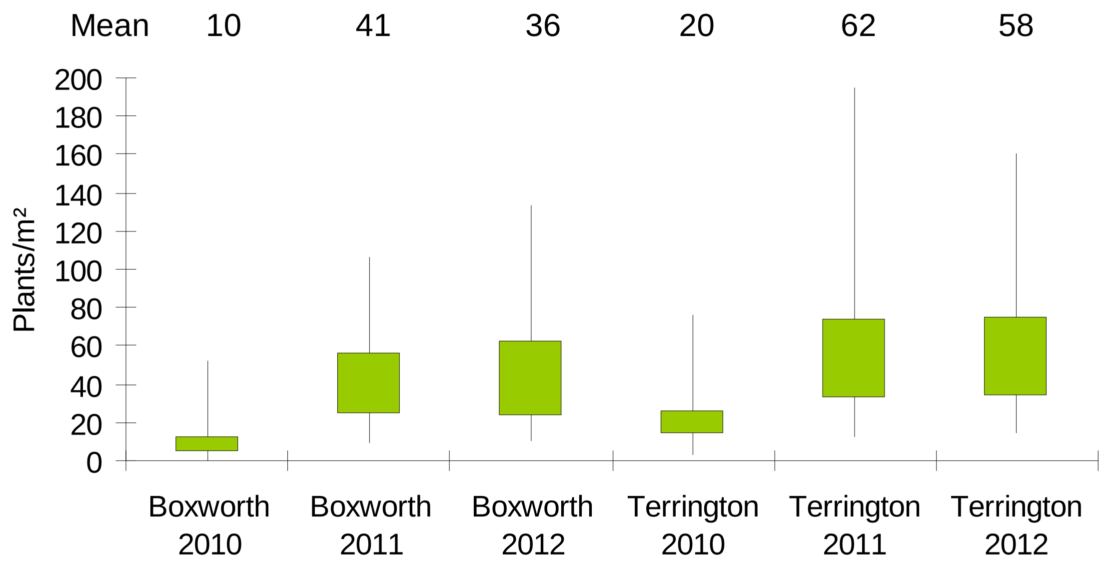
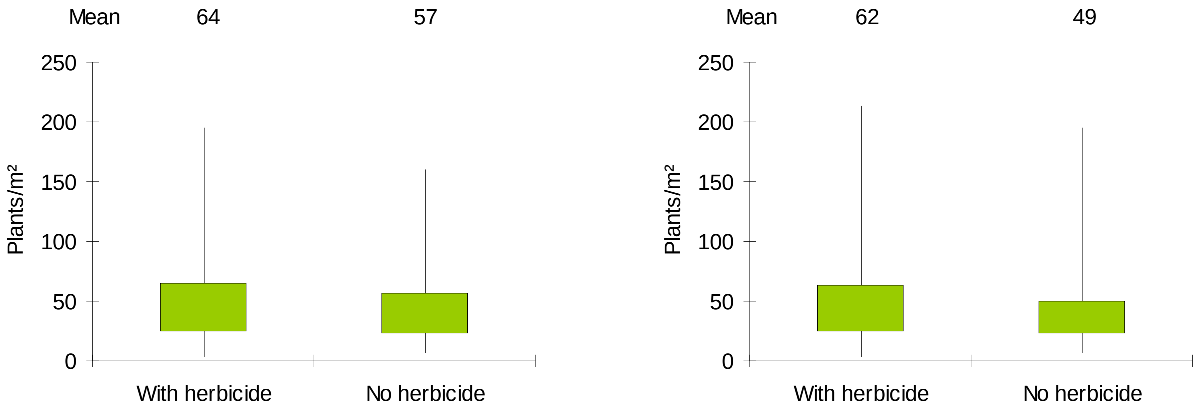


Figure 15. A box and whisker plot showing the range of spring plant populations achieved at Terrington and Boxworth 2010–2012. Upper and lower bars show the maximum and minimum values, the top of the darkened box marks 75% of the data and the lower 25%. The darkened box contains 50% of the data. Mean figures are in text.

The effect of herbicides on plant population

Over all sites and years the use of a comprehensive herbicide programme during the autumn and winter had no effect on plant population ($p>0.05$) (Figure 16). Due to the unbalanced nature of the trial design (4.2.3) and due to the effects of weeds on plant populations the analysis of plant population data has been restricted to herbicide treated plots only.



a) Winter b) Spring

Figure 16. A box and whisker plot showing the effect of use of herbicides on spring plant populations. Upper and lower bars show the maximum and minimum values, the top of the darkened box marks 75% of the data and the lower 25%. The darkened box contains 50% of the data. Mean figures are in text.

Row width

The range of spring populations achieved both per m² and per meter length of row were significantly ($p<0.001$) different between the row width treatments (Table 27). At any one site the highest populations/m^2 were achieved at the narrowest row width (12 cm) with the lowest populations in the 72 cm row widths (Table 27; Figure 17). The highest number of plants per metre row occurred in the widest rows. The maximum plant population achieved per m² was 117.5 for the treatment with 12.5 cm row width and 120 seeds/m^2 and in a metre length of row was 24.6 for the same seed rate but 72 cm row width (Figure 17a and b).

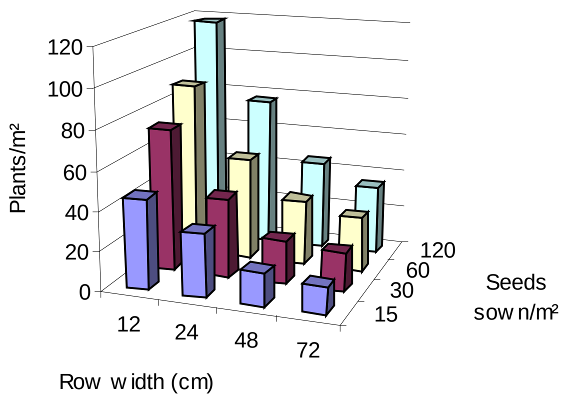
Table 27. The effect of site and row width on spring plants/m^2 and plants per meter length of row, mean of all seed rates (figures in parentheses are f probability and LSD)

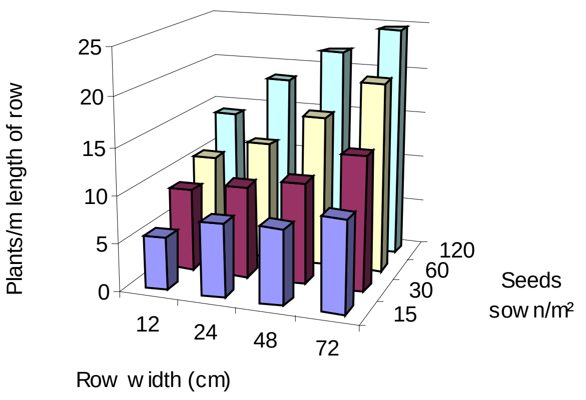
a) plants/m²

Row width (cm)	Boxworth 2011	Boxworth 2012	Terrington 2010	Terrington 2011	Terrington 2012
	(<0.001, 5.10)	(<0.001, 6.65)	(<0.001, 3.41)	(<0.001, 10.13)	(<0.001, 8.77)
12	65.6	77.5	46.3	95.7	100.6
24	42.0	51.5	22.9	60.1	60.3
48	25.1	27.5	15.6	35.9	36.1
72	19.3	21.0	14.7	31.5	28.8

b) Plants /m length of row

Row width (cm)	Boxworth 2011	Boxworth 2012	Terrington 2010	Terrington 2011	Terrington 2012
	(<0.001, 1.22)	(<0.001, 1.35)	(<0.001, 1.15)	(<0.001, 2.62)	(<0.001, 1.73)
12	7.9	9.3	5.6	11.5	12.1
24	10.1	12.4	5.5	14.4	14.5
48	12.1	13.2	7.5	17.2	17.3
72	13.9	15.1	10.6	22.0	20.7





a) per m² b) per m length of row

Figure 17. The effect of seed rate and row width on plant population and plants per meter length of row (mean of all sites).

There was an interaction between seeds sown/m² and row width on spring plant population (Figure 17), proportionally more plants established at the higher seed rates than at the low seed rates. Plant establishment (percentage of seeds sown that produced viable plants) decreased as row width and seed rate increased.

Plant spacing

The distance between plants decreased with increasing row width and increased numbers of plants in the row (Figure 18). At the highest seed rate and widest row spacing the distance between plants was 2.9 cm compared to 15.6 cm at the lowest seed rate.

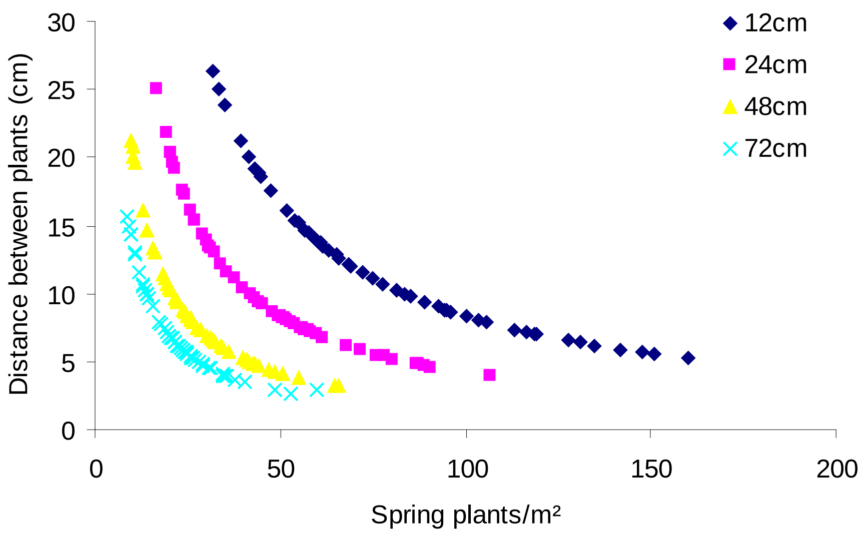


Figure 18. The effect of plant population and row width on the distance between plants in the spring (cm).

4.3.3. Plant size

Plant size was measured on the same date as the weed populations (winter and spring). There was a large variation in both plant height and width between sites and years. In the winter, plant height varied between 3 and 11 cm and width between 13 and 35 cm (Table 28). By the spring crops had increased in size, all were a similar width but height varied considerably (Table 28).

Table 28. Oilseed rape height and width in winter and spring (average across all treatments)

Site	Harvest year	Winter			Spring		
		Height (cm)	Width (cm)	Date	Height (cm)	Width (cm)	Date
Boxworth	2010	-	-	-	3.2	20.7	25 Feb 2010
	2011	3.3	13.9	14 Dec 2010	12.0	18.0	14 Mar 2011
	2012	11.4	34.5	26 Jan 2011	18.3	28.1	16 Mar 2012
Terrington	2011	4.6	15.8	15 Dec 2010	10.1	21.1	18 Mar 2011
	2012	6.4	19.7	17 Jan 2012	37.0	26.4	28 Mar 2012

Herbicides

Sometimes where herbicide was used, plant size was significantly affected but this effect was not consistent over all of the sites. Height of plants in the winter tended to be greater where no herbicide had been applied (Table 29). The width of the plants in the winter was unaffected by herbicide treatment.

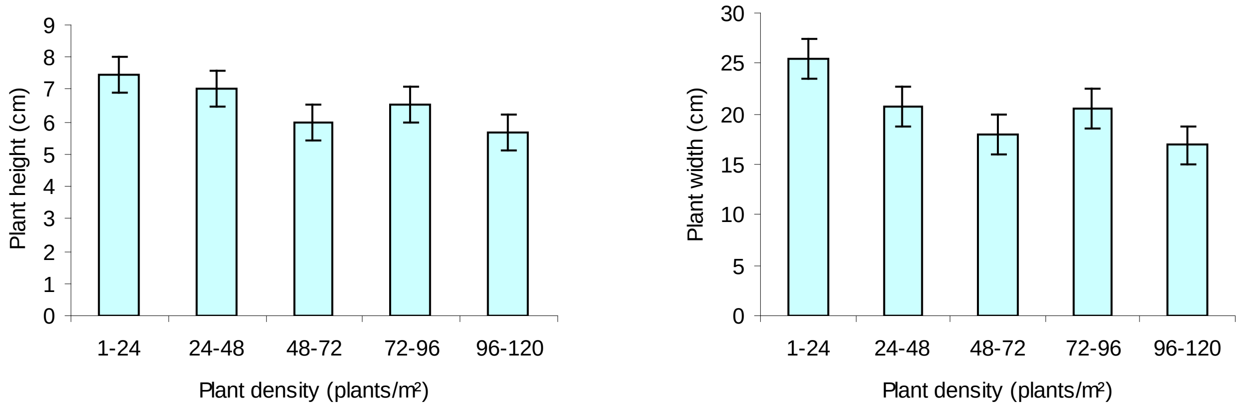
In the spring, plants were sometimes taller where herbicide had been used but sometimes shorter (Table 29). Plants were significantly wider where herbicide had been used.

Table 29. The effect of herbicide use on the size of oilseed rape plants

		No herbicide	With herbicide	F probability	LSD
a) Winter height					
Boxworth	2012	12.5	10.9	0.015	1.32
Boxworth	2011	3.7	3.2	<0.001	0.20
Terrington	2012	6.0	6.6	0.033	0.61
b) Spring height					
Boxworth	2012	21.0	17.0	<0.001	1.93
Boxworth	2011	11.0	12.6	0.003	1.00
Terrington	2011	11.3	9.4	<0.001	1.02
Boxworth	2011	15.4	19.3	<0.001	1.45
c) Spring width					
Boxworth	2012	31.1	36.6	0.002	0.27
Terrington	2011	20.1	21.5	0.002	0.52

__Plant density__

There was only a single effect of plant density on plant size in January; this was at Terrington in 2012. Plant height and width was significantly (p=0.007) smaller at the higher plant densities (Figure 19).

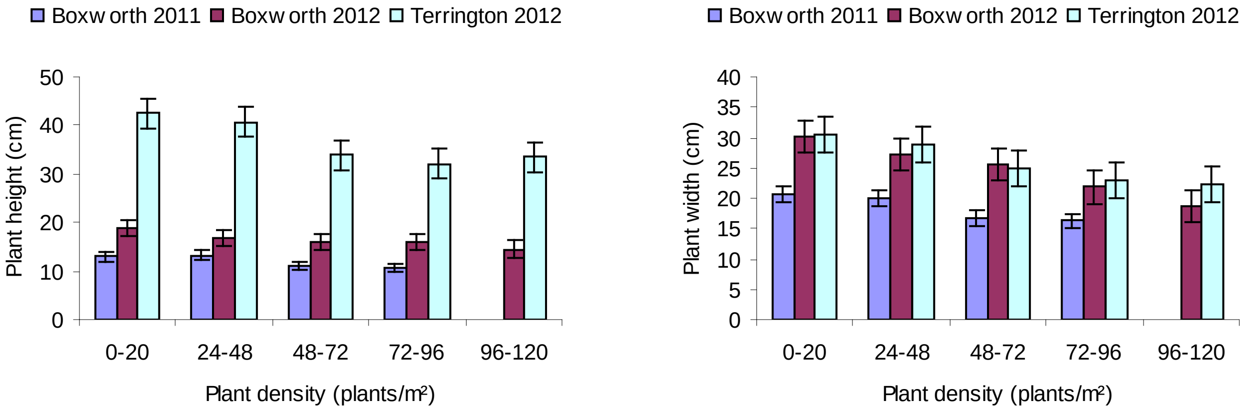


a) height **b) width**

Figure 19. The effect of plant density on oilseed rape plant height and width measured in January at Terrington, harvest year 2012.

In the spring, the plant density affected plant size more than in the winter. Plants were generally shorter at the higher plant density, this effect was significant at Boxworth in 2011 and 2012 (p=0.005 and 0.026) and Terrington in 2011 and 2012 (p=0.002) (Figure 20). At Terrington in spring 2010 the crops were very short (3cm) and unaffected by plant density.

Plant width was significantly reduced at 3 sites, Boxworth 2011 and 2012 (p=0.002 and p<0.001) and Terrington 2011 (p=0.021) at the higher plant densities (Figure 20).



a) height **b) width**

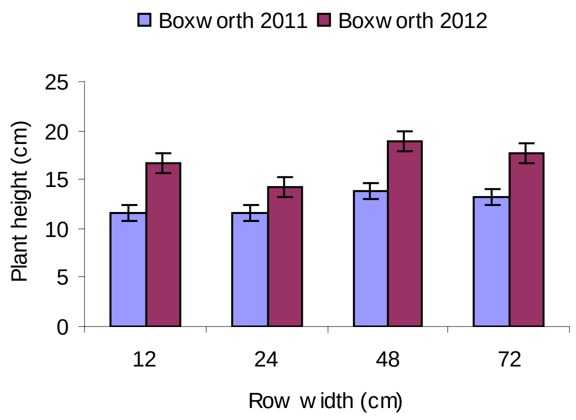
Figure 20. The effect of plant population on oilseed rape plant height and width measured in March at Boxworth and Terrington, harvest years 2011 and 2012.

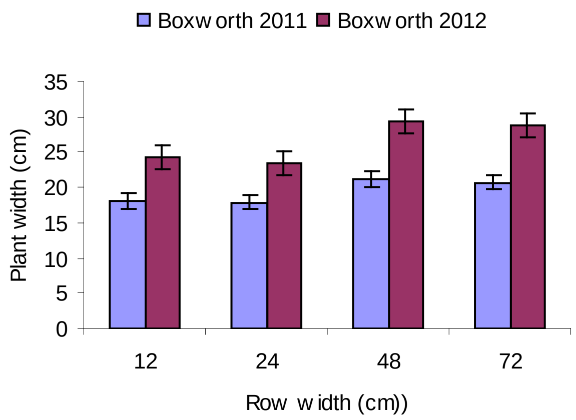
Row width

In the winter, row width only had an effect on crop height at Boxworth in 2011 (p=0.042) and Terrington in 2012 (p=0.008) where plants were shorter by 1 cm at the widest row width.

In the spring, plant height and width increased with increasing row width at Boxworth in 2011 and 2012 (p=0.013 and 0.002, Figure 21).

Plant width was also greater at the wider row widths at Boxworth in 2011 and 2012 (p=0.014 and p=0.008, Figure 21).





a) height **b) width**

Figure 21. The effect of row width on oilseed rape plant height and width measured in March at Boxworth and Terrington, harvest years 2011 and 2012. Average data across seed rates.

Plants per meter length of row

As number of plants in the row increased, plant height was unaffected but plant width tended to decrease (Figure 22). This was significant at Boxworth in 2011 and 2012 (p=0.002 and 0.012) and at Terrington in 2012 (p=<0.001).

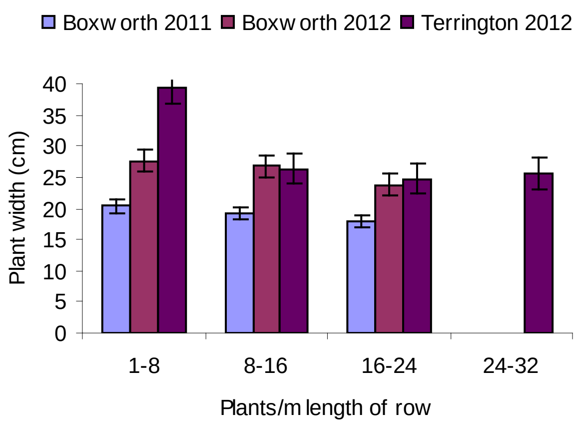
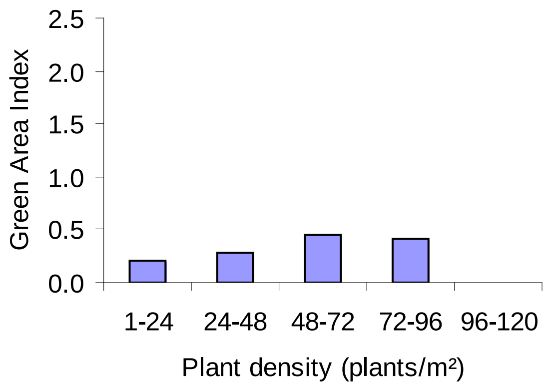


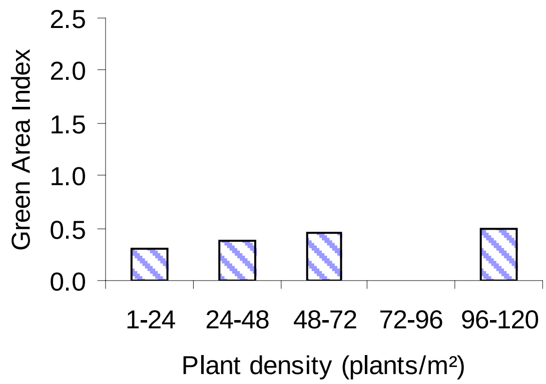
Figure 22. The effect of the number of plants per m length of row on oilseed rape plant width measured in March at Boxworth and Terrington, harvest years 2011 and 2012.

4.3.4. Green area index (GAI)

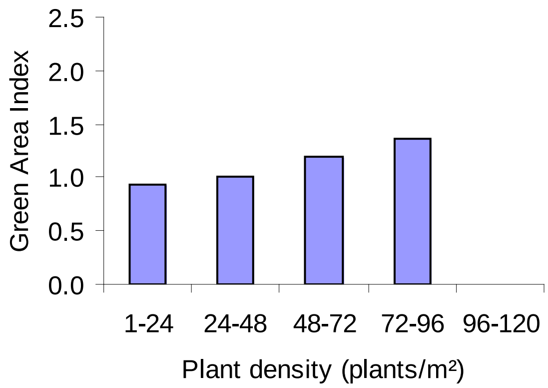
GAI in February/March was estimated from photographs of the crop for all treatments of replicate one in each experiment. It was 7% greater where no herbicides had been applied because this method does not distinguish between the green area of oilseed rape and weeds. GAI increased with increasing plant density (Figure 23) and with seed rate (data not shown). There was no difference in GAI for crops sown at 12 cm and 24 cm row widths (Figure 16). Increasing row width from 12 cm or 24 cm to 48 cm reduced the GAI by on average 20%. Increasing the row width further to 72 cm reduced the GAI by on average 30% (compared with the 12 cm or 24 cm row widths).



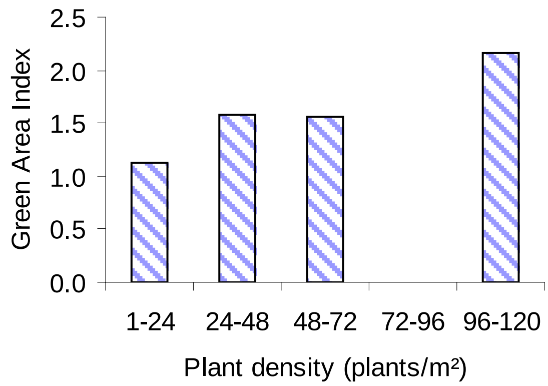
a) Boxworth 2011 – with herbicide



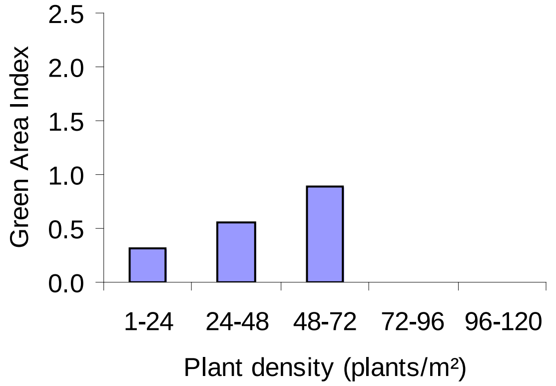
b) Boxworth 2011 – no herbicide



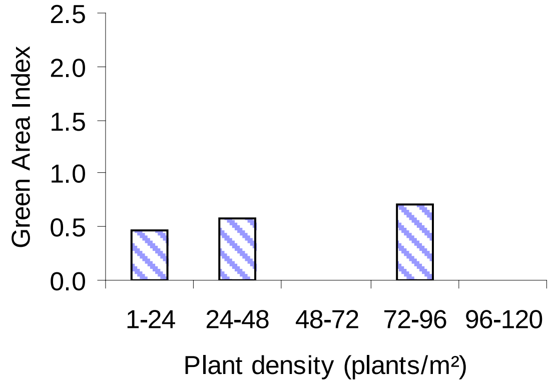
c) Boxworth 2012 – with herbicide



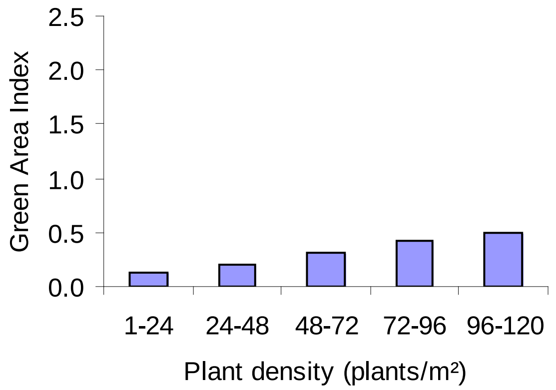
d) Boxworth 2012 – no herbicide



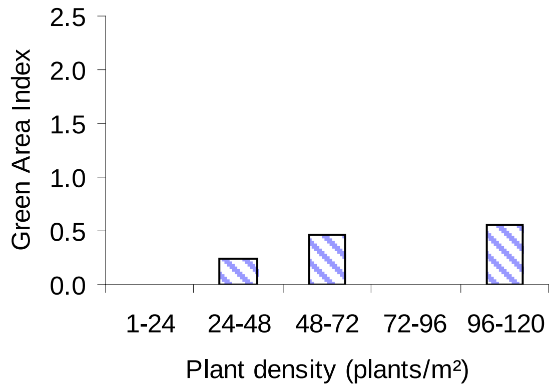
e) Terrington 2010 – with herbicide



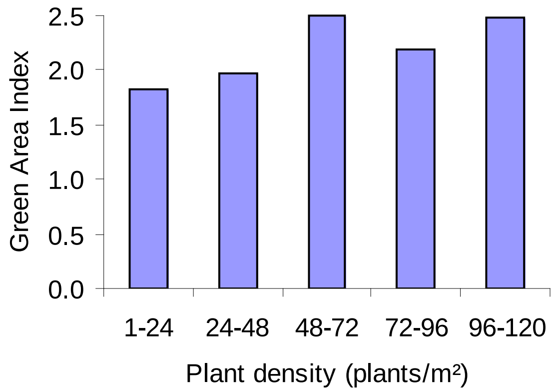
f) Terrington 2010 – no herbicide



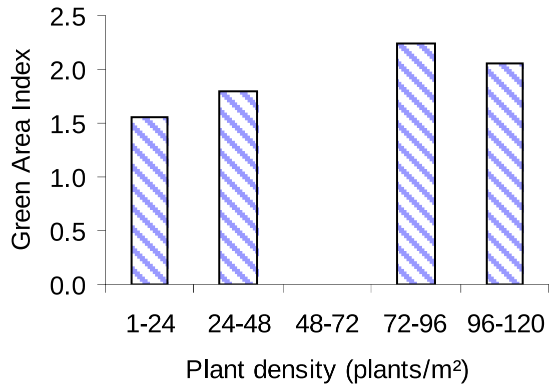
g) Terrington 2011 – with herbicide



h) Terrington 2011 – no herbicide

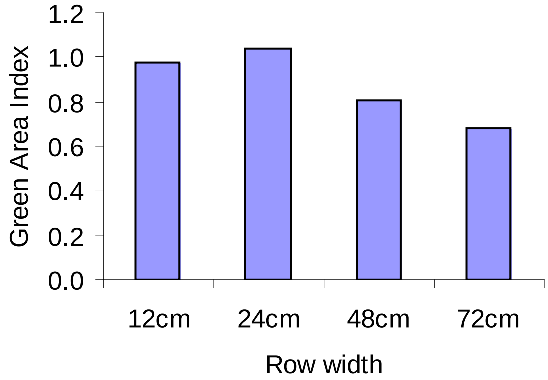


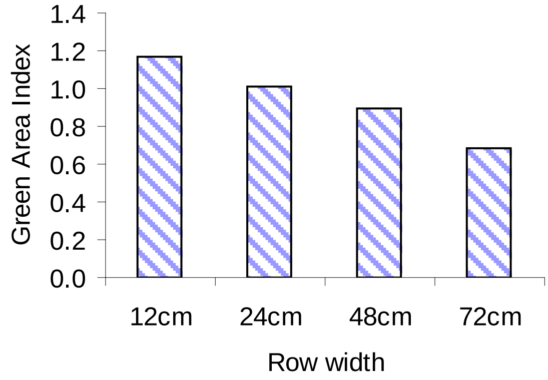
i) Terrington 2012 – with herbicide



j) Terrington 2012 – no herbicide

Figure 23. The effect of plant density on Green area index (GAI) oilseed rape with and without a comprehensive herbicide programme (unreplicated data).





a) with herbicide

b) no herbicide

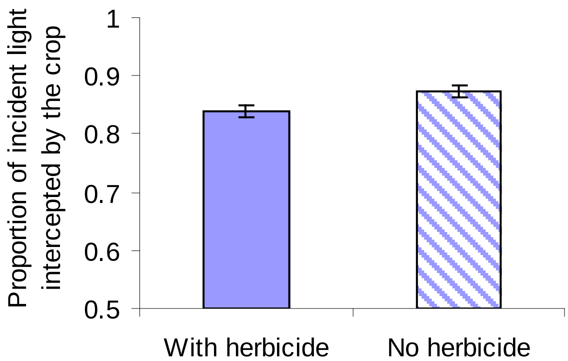
Figure 24. The effect of row width on Green area index (GAI) oilseed rape with and without a comprehensive herbicide programme, mean of all sites.

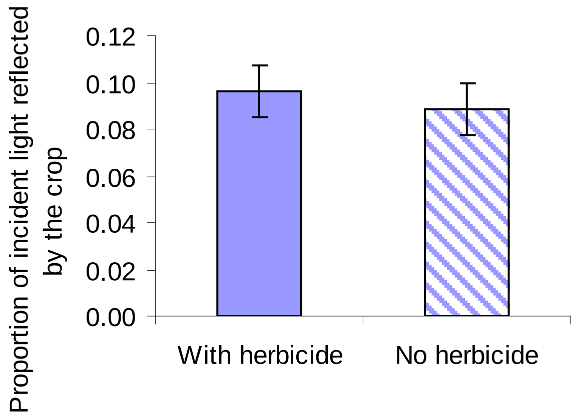
4.3.5. Light interception and reflection at mid-flowering

The amount of light reflected by a crop is an additional indicator of the proportion of ground covered by the crop, with more light reflected by crops that cover more ground.

Herbicides

There was four percent more light intercepted by crops untreated with herbicide (p=0.001) as a result of more weeds intercepting light. There was no effect on the amount of reflected light (Figure 25).





a) intercepted

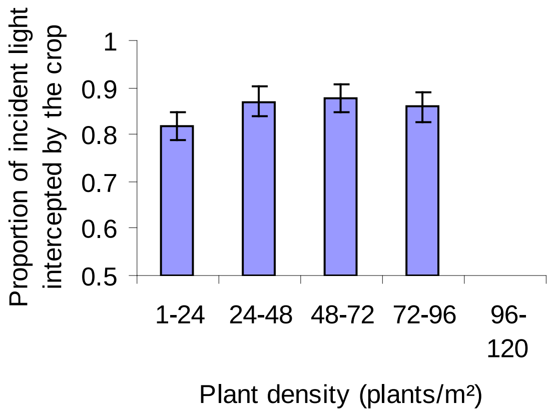
b) reflected

Figure 25. The effect of herbicide treatment on the proportion of light intercepted and reflected by oilseed rape crops.

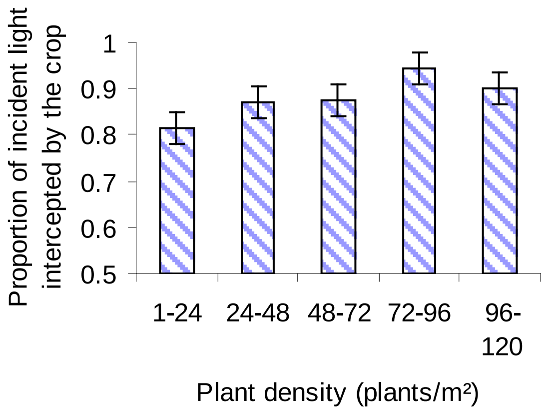
Plant density

In the herbicide treated crop the proportion of light intercepted by the crop was significantly increased by increasing plant density at Terrington in 2010 and 2011 ($p=<0.001$). In these two experiments crops with plant densities of 1–24 plants/m^2 intercepted significantly less light than crops with plant populations of over 24 plants/m^2 (Figure 26). In the other experiments, light interception was not reduced in crops with low plant populations of 1–24 plants/m^2.

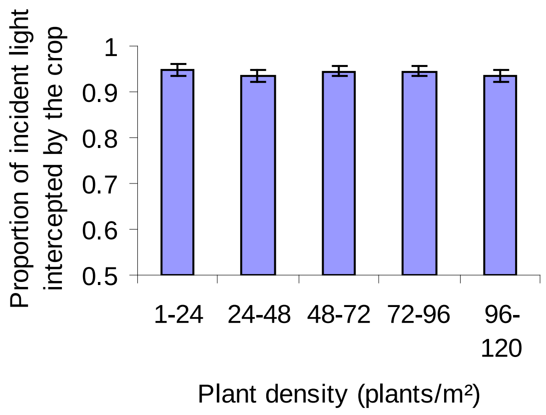
Without herbicide, the proportion of light intercepted by the crop was similar to that of the treated crop and there were no differences between the plant densities (Figure 26).



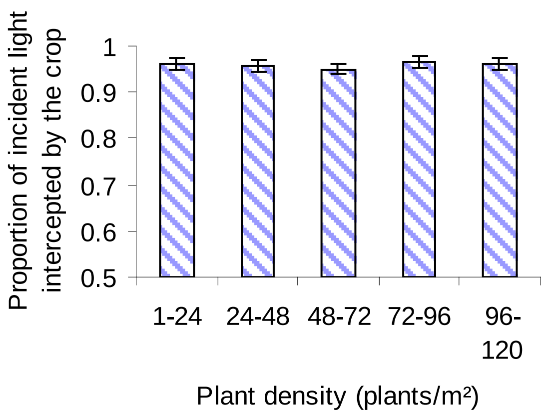
a) Boxworth 2011 – with herbicide



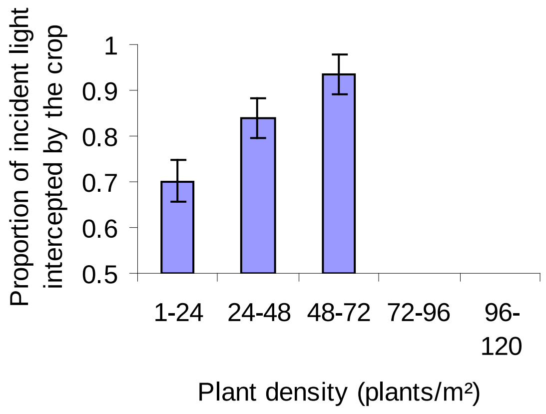
b) Boxworth 2011 –no herbicide



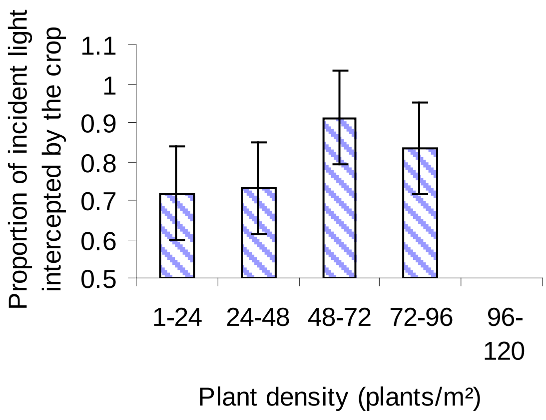
c) Boxworth 2012 – with herbicide



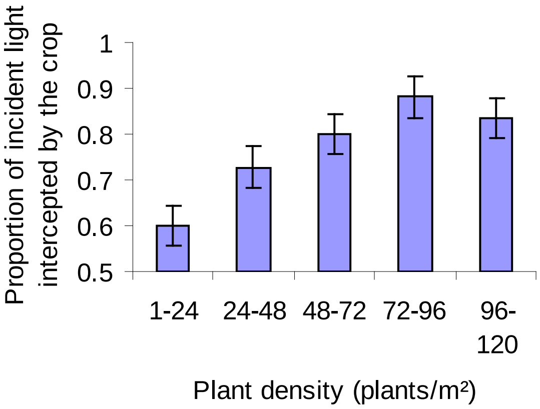
d) Boxworth 2012 – no herbicide



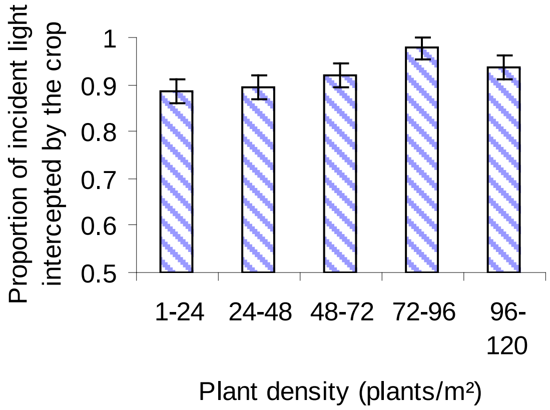
e) Terrington 2010 – with herbicide



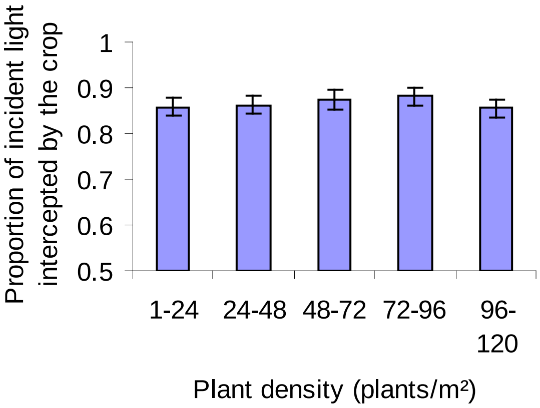
f) Terrington 2010 – no herbicide



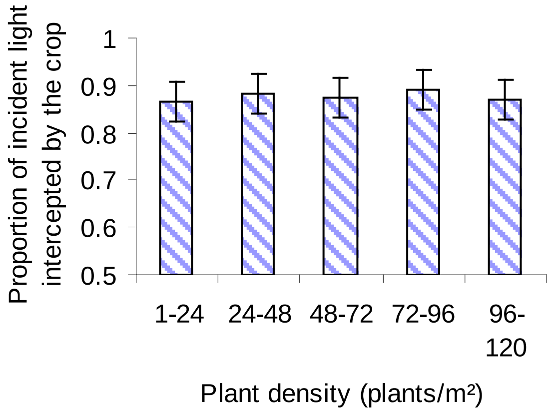
g) Terrington 2011 – with herbicide



h) Terrington 2011 – no herbicide



i) Terrington 2012 – with herbicide

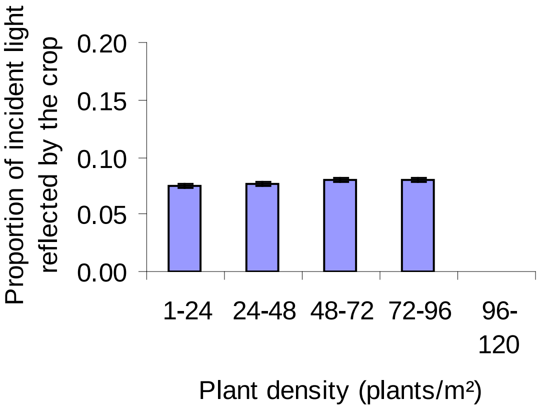


j) Terrington 2012 – no herbicide

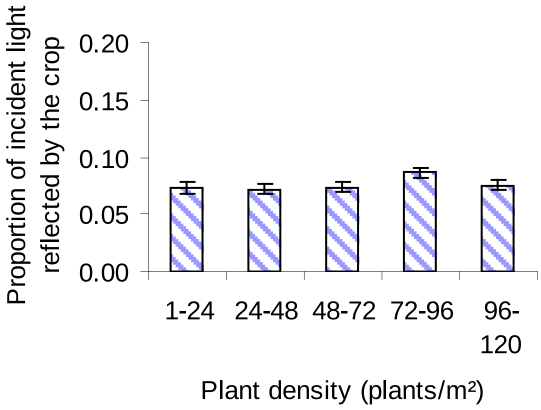
Figure 26. The effect of plant density on the proportion of light intercepted by oilseed rape with and without a comprehensive herbicide programme.

In herbicide-treated crops the proportion of light reflected by the crop increased with increasing plant population at Boxworth in 2011 and Terrington in 2010 (p=0.007 and 0.004). There was significantly more reflection where the population was greater than 48 plants/m² at Boxworth in 2011 and over 24 plants/m² at Terrington in 2010 (Figure 27). However, it should be recognised that the effects were quite small.

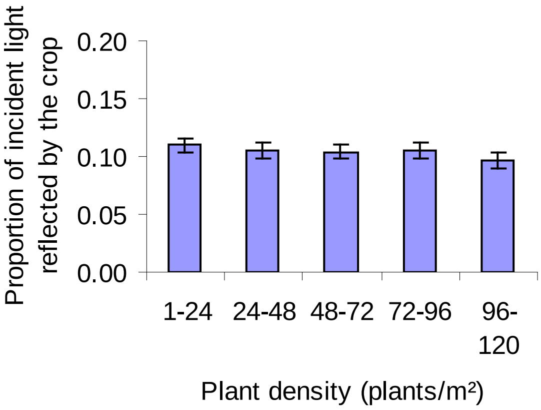
In the absence of herbicide there was a significant effect on the amount of light reflected only at Terrington in 2011. At this site, more light was reflected by the highest populations (p=<0.001, Figure 27).



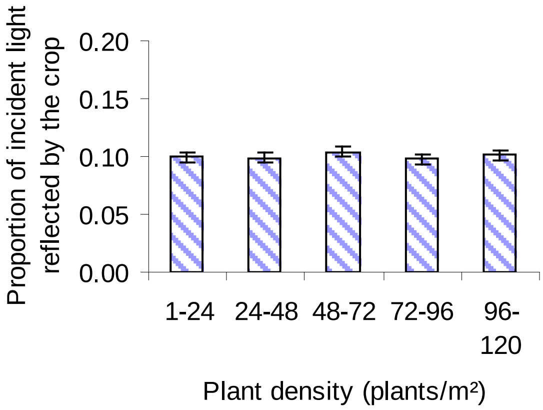
a) Boxworth 2011 – with herbicide



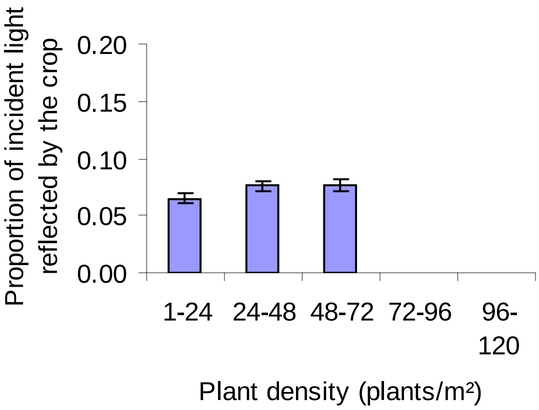
b) Boxworth 2011 – no herbicide



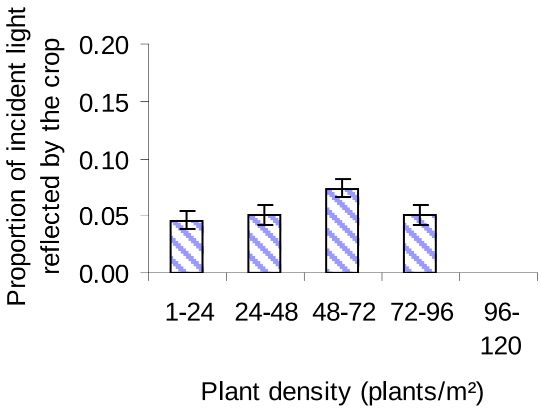
c) Boxworth 2012 – with herbicide



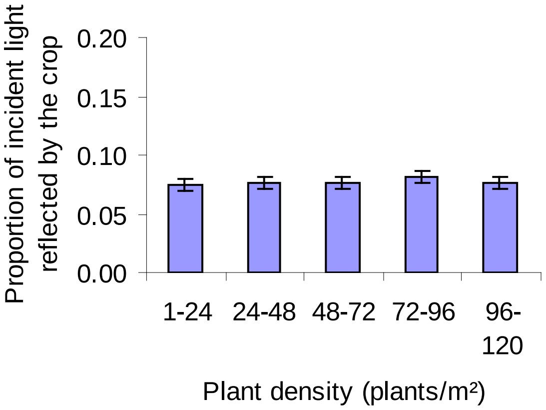
d) Boxworth 2012 – no herbicide

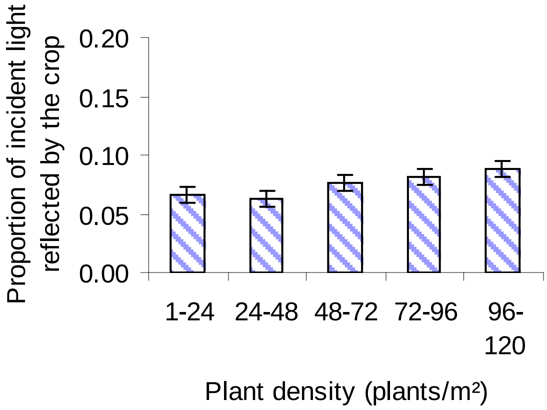


e) Terrington 2010 – with herbicide



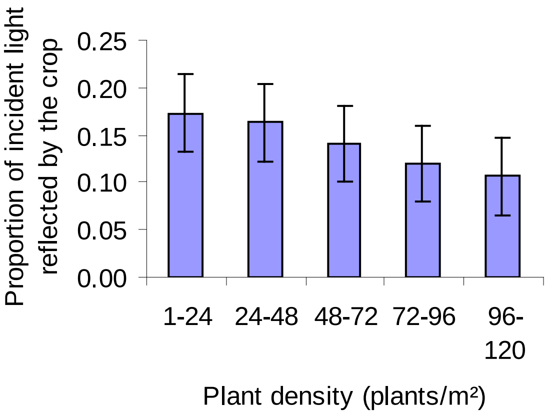
f) Terrington 2010 – no herbicide

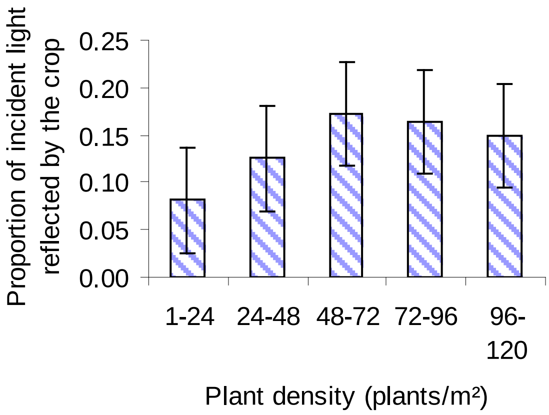




g) Terrington 2011 – with herbicide

h) Terrington 2011 – no herbicide





i) Terrington 2012 – with herbicide

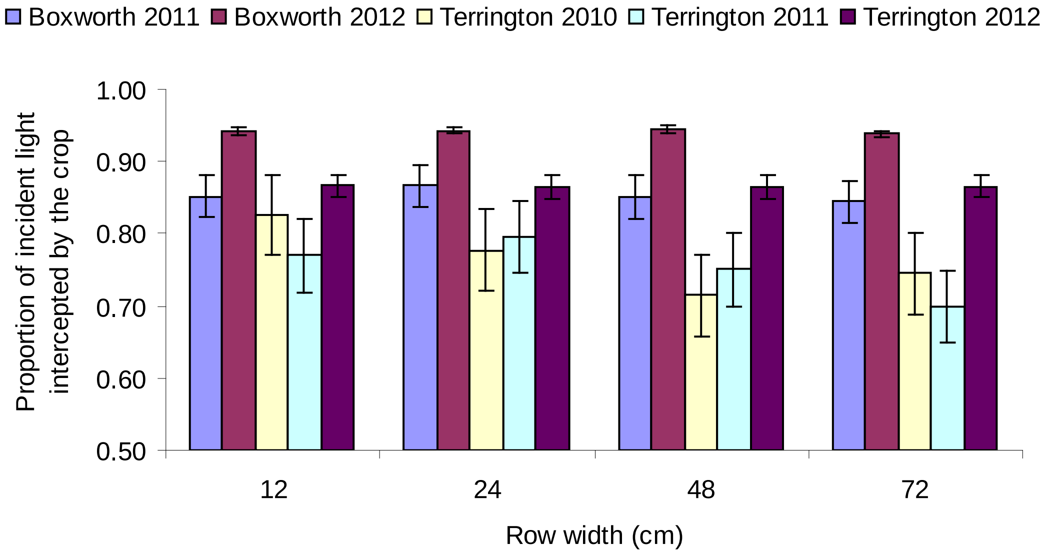
j) Terrington 2012 – no herbicide

Figure 27. The effect of plant density on the proportion of light reflected by oilseed rape with and without a comprehensive herbicide programme.

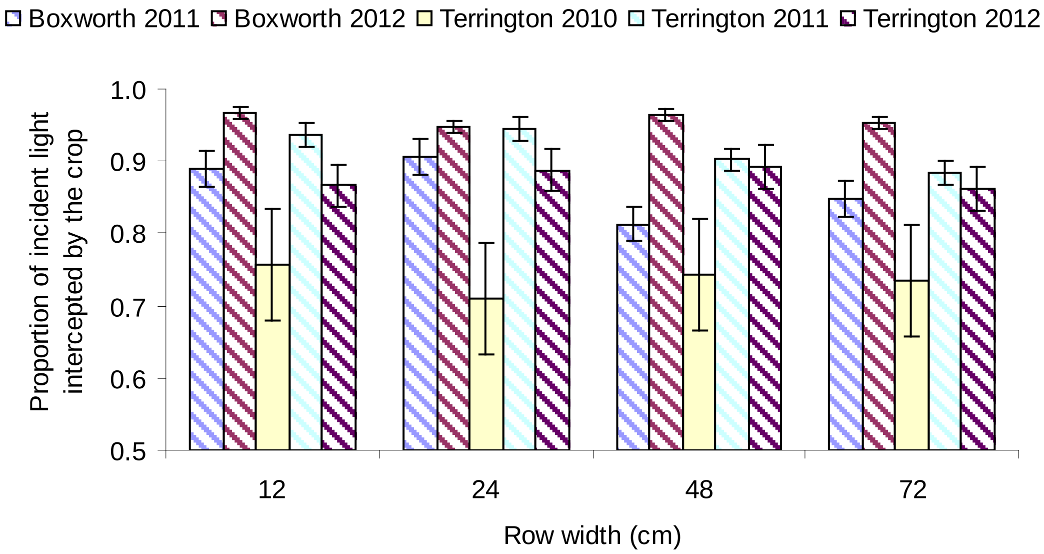
Row width

The row width treatments caused no differences in the amount of light intercepted by herbicide-treated crops (Figure 28a). Where crops received no herbicide, the row width had a significant effect on the proportion of light intercepted at Boxworth and Terrington in 2011($p=0.006$ and $p=0.004$); more light was intercepted by the narrowest rows (Figure 28b).

The row width treatments caused no differences in the amount of light reflected by herbicide-treated crops (Figure 29a). Where crops received no herbicide the proportion of light reflected was significantly lower at the widest row widths at Terrington in 2011 and 2012 ($p=0.025$ and $p=0.013$, Figure 29), which indicates that the widest row widths had a lower ground cover.

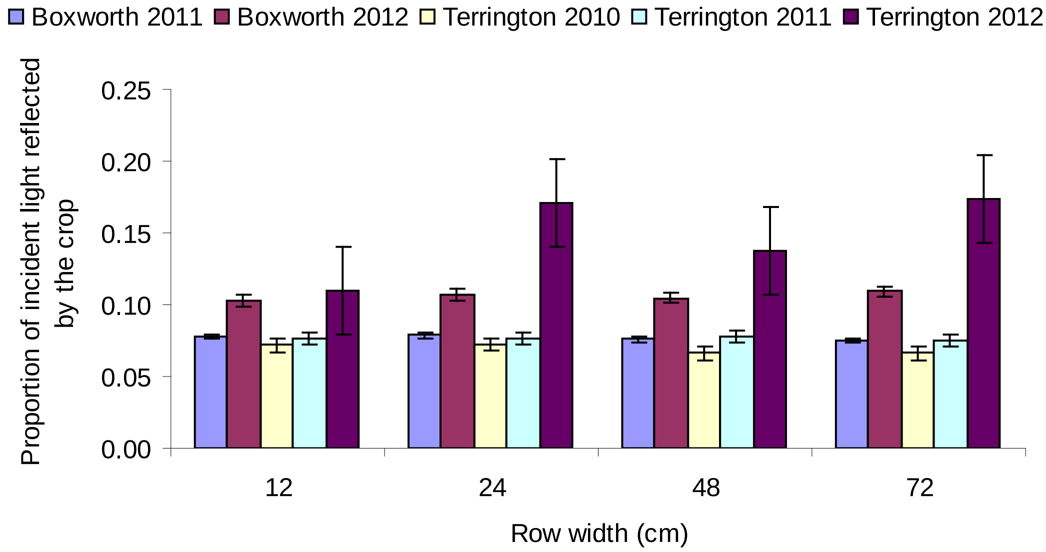


a) With herbicide

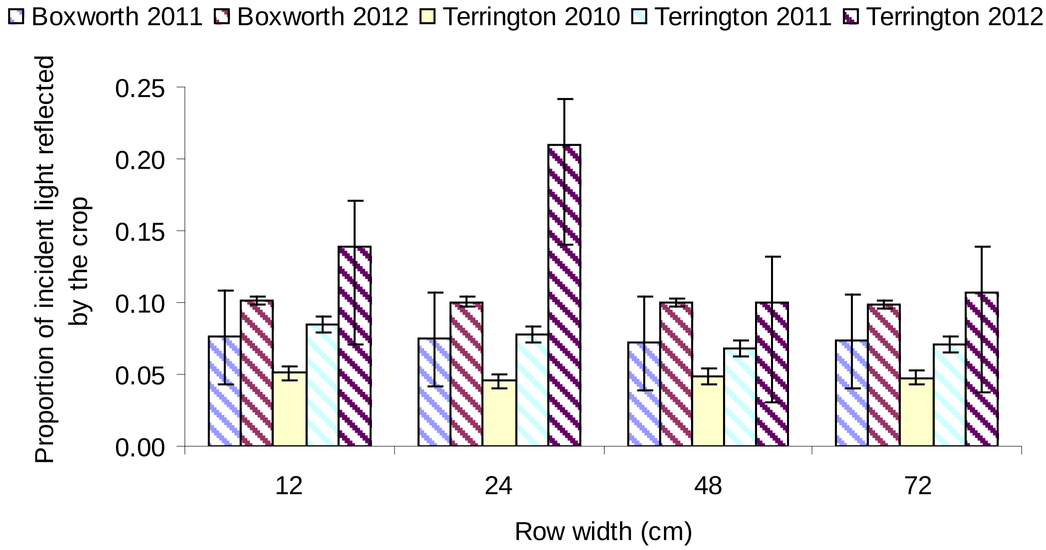


b) Without herbicide

Figure 28. The effect of row width on the proportion of light intercepted by oilseed rape, with and without a comprehensive herbicide programme.



a) With herbicide



b) Without herbicide

Figure 29. The effect of row width on the proportion of light reflected by oilseed rape with and without a comprehensive herbicide programme.

Overall effects on light interception and reflection at mid-flowering

As plant population increased, the proportion of photosynthetically active light intercepted by the crops reached a maximum. A split line regression was fitted to the data, X being the plant population at the point of intersection and Y the proportion of photosynthetically active light intercepted by the crop. For the whole dataset, the maximum light interception occurred at 27 plants/m^2 but only 16% of the variation was accounted for (Figure 30).

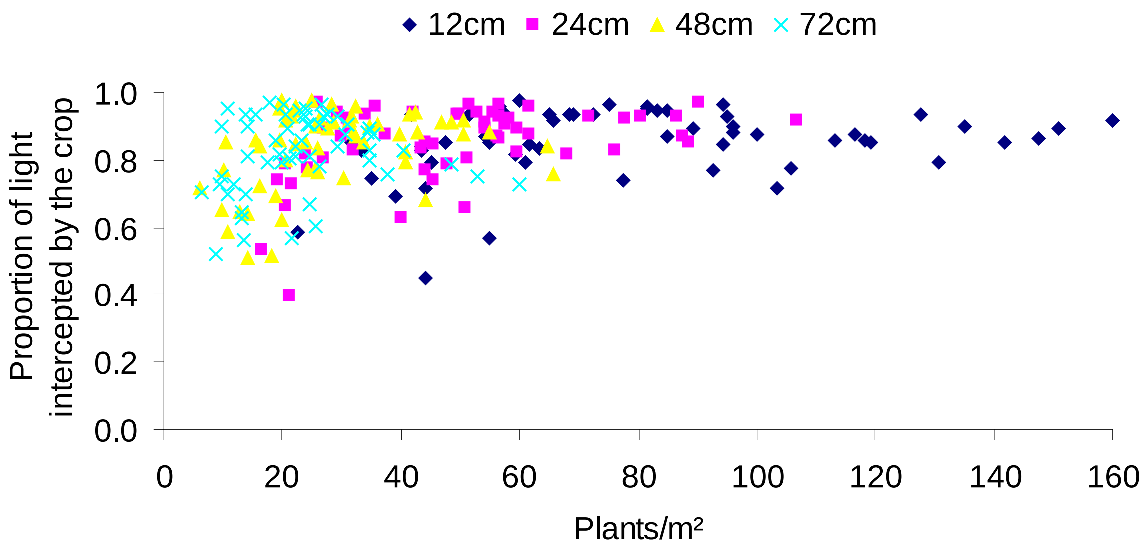


Figure 30. The proportion of light intercepted by the crop treated with herbicide.

The amount of light reflected by the crop was similar at all populations (Figure 31).

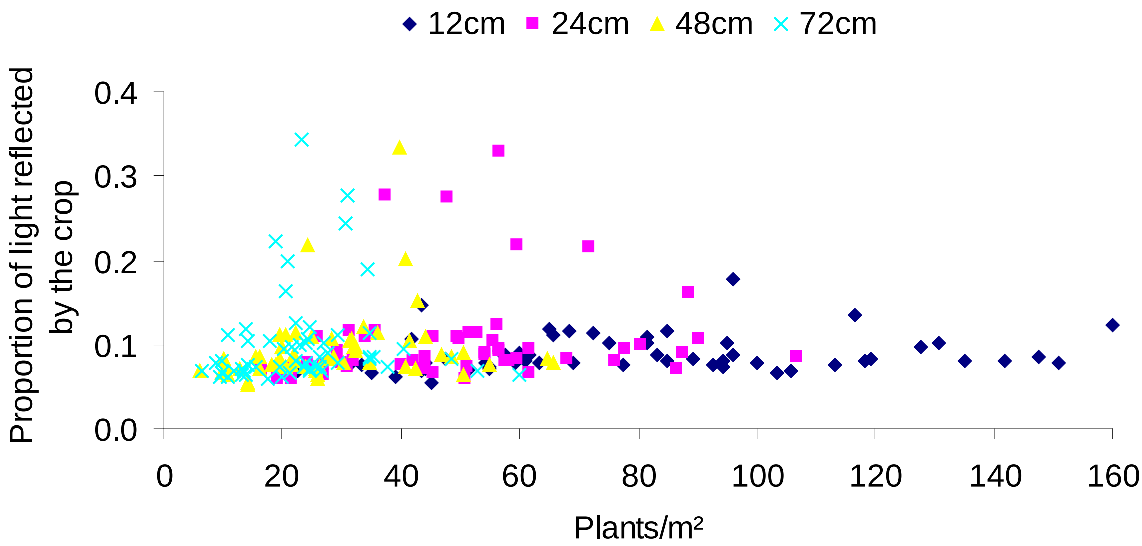


Figure 31. The proportion of light reflected by the crop treated with herbicide.

There were no interactions between row width and seed rate. In 12 cm rows the maximum light interception occurred at 65 plants/m² (Table 30), 26 plants/m² in 24 cm rows and 23 and 18 plants/m² in 48 and 72 cm rows, respectively. The proportion of light intercepted was similar at all row widths (0.85–0.88). This indicates that plants were able to compensate for low populations in wide row widths to intercept maximum light.

Table 30. Results for fitting a split line regression to plant population and the proportion of photosynthetically active light intercepted by the crop (54 degrees of freedom)

Row width	X	se	Y	se	% variance accounted for
12	65.0	2.55	0.88	0.014	20.8
24	25.8	0.20	0.88	0.012	41.2
48	22.7	2.46	0.87	0.017	29.4
72	17.9	0.52	0.85	0.016	12.6

4.3.6. Leaning and lodging

Generally the levels of leaning and lodging were low in the trials, apart from Terrington 2011 when all of the treatments leaned (Table 31). There was no significant effect of plant population or row width on leaning or lodging at any site.

Table 31. Degree of leaning and lodging at the trial sites (%)

Site and year	**Leaning**	**Lodging**
Boxworth 2011	0	0
Boxworth 2012	5	0
Terrington 2010	3	0
Terrington 2011	100	0
Terrington 2012	7	4

4.3.7. Yields

Herbicides

Yields with herbicide use were, on average, 0.7 t/ha higher at Terrington than Boxworth. The use of herbicide generally increased yields but at Boxworth and Terrington in 2012 there was no significant difference in yield, with or without herbicide (Table 32). The mean yield response to herbicide was 0.94 t/ha or 41%.

Table 32. Mean yield per site with and without herbicide and percentage yield increase due to herbicide use

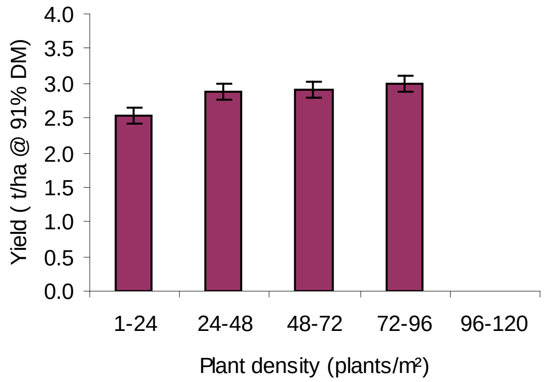
Site	Harvest year	With herbicide	No herbicide	% increase due to herbicide use
Boxworth	2010	1.38	1.08	28
	2011	2.78	2.22	25
	2012	3.01	3.02	0
Terrington	2010	3.26	0.90	262
	2011	3.62	1.89	92
	2012	3.58	3.50	2
Mean		3.25	2.31	41*

*does not include Boxworth 2010

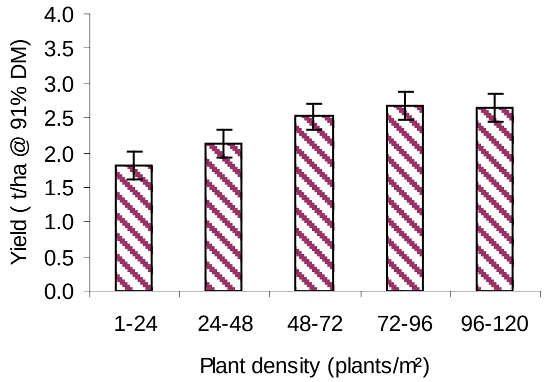
Plant density

The response of oilseed rape to increasing plant density varied between sites. At Boxworth in 2011 and Terrington in 2010 and 2011, yield was significantly lower at the lowest plant density ($p=<0.001$, <0.001 and 0.002, Figure 32). At Boxworth in 2012, yield tended to decrease with increasing plant density but this was not statistically significant ($p>0.05$).

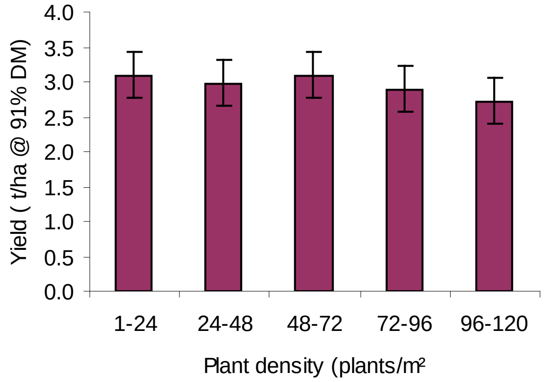
Where herbicide was not applied, the yield response to increasing plant density was greater than where herbicide was used. This was significant at Boxworth in 2011 and Terrington in 2010 and 2011 ($p=<0.001$, 0.032 and 0.004).



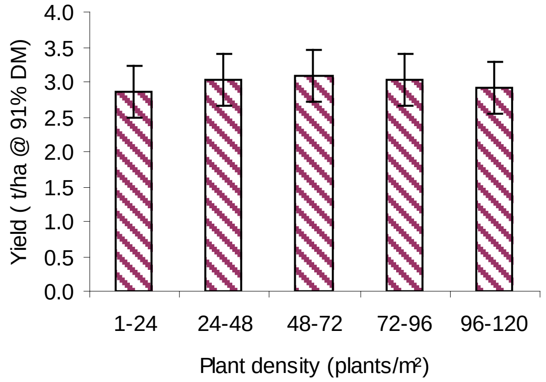
a) Boxworth 2011 – with herbicide



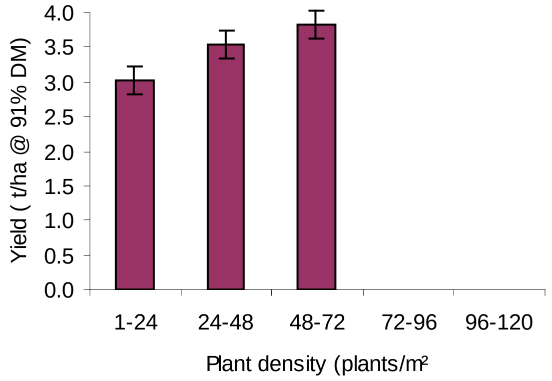
b) Boxworth 2011 – no herbicide



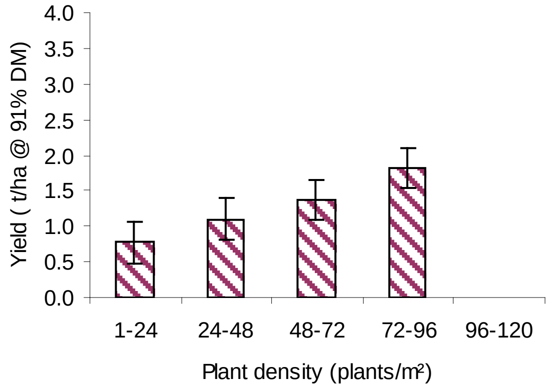
c) Boxworth 2012 – with herbicide



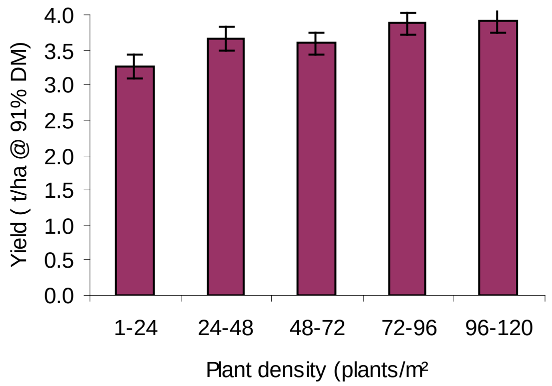
d) Boxworth 2012 – no herbicide



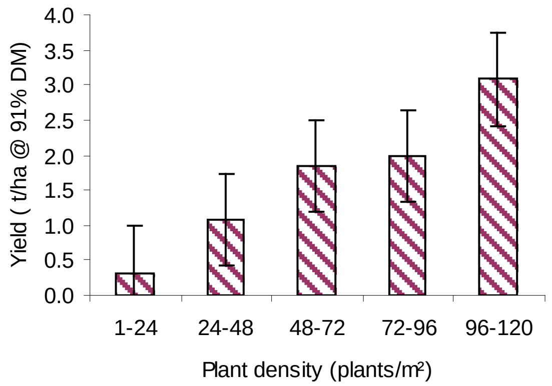
e) Terrington 2010 – with herbicide



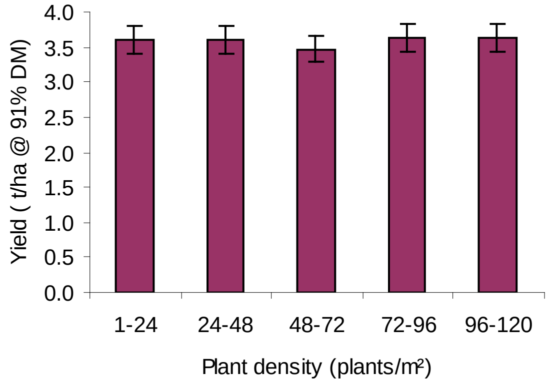
f) Terrington 2010 – no herbicide

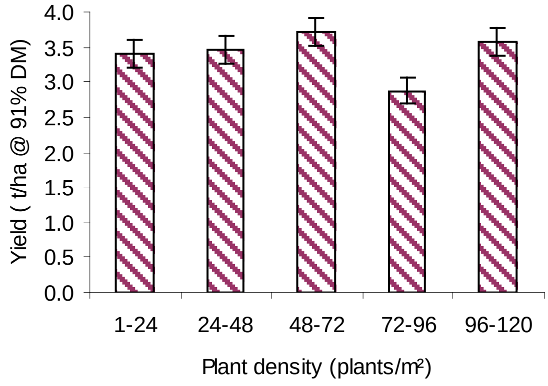


g) Terrington 2011 – with herbicide



h) Terrington 2011 – no herbicide





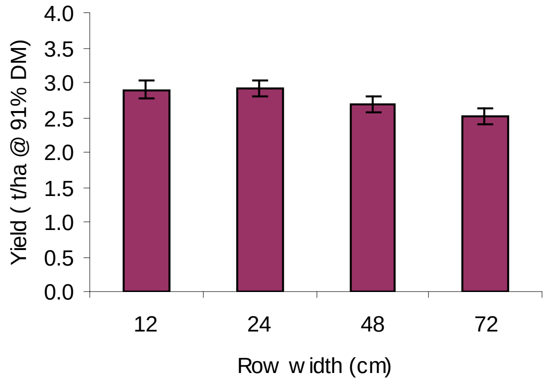
i) Terrington 2012 – with herbicide j) Terrington 2012 – no herbicide

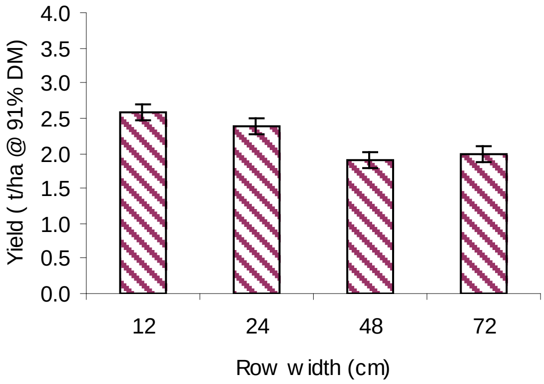
Figure 32. The effect of plant density on the yield of oilseed rape with and without a comprehensive herbicide programme.

Row width

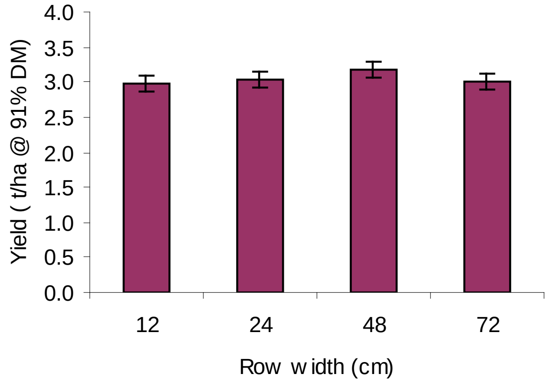
Where herbicides were used there was a significant (p=0.025) effect of row width on yield at Boxworth in 2011; yields were higher at row widths of 12 and 24 cm compared with 48 cm and 72 cm (Figure 33). In the absence of herbicides, yields were significantly higher at Boxworth and Terrington in 2011 (p=0.024 and 0.047) at the 12 and 24 cm row widths (Figure 33).

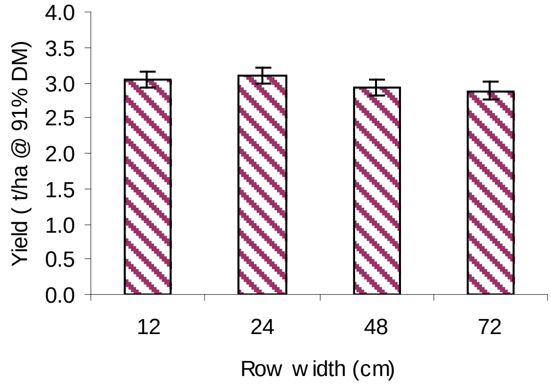
There were no interactions between row width and seed rate either with or without herbicide (Figure 34), but there was a close to significant interaction between row width and seed rate at Terrington in 2011 (P = 0.067). This interaction occurred because wider row spacing (72 cm) tended to have a lower yield at high seed rates (120 seeds/m^2).





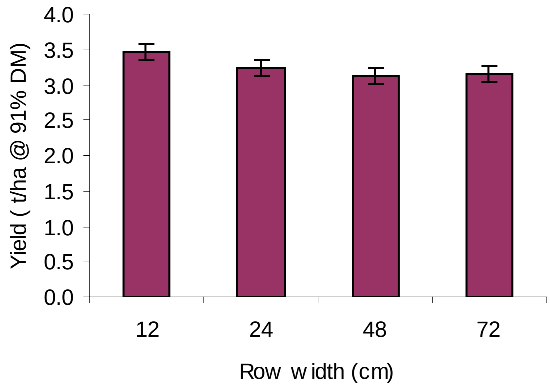
a) Boxworth 2011 – with herbicide b) Boxworth 2011 – no herbicide

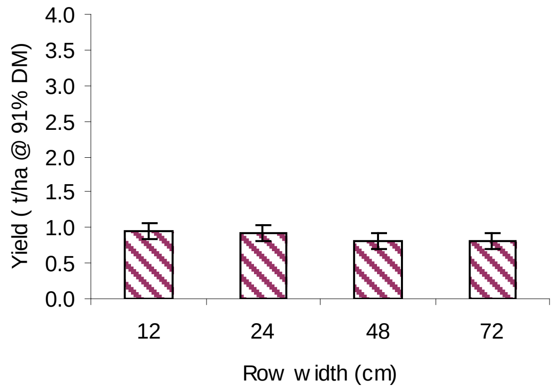




c) Boxworth 2012 – with herbicide

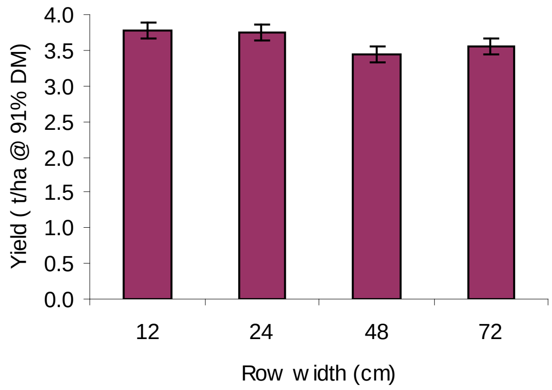
d) Boxworth 2012 – no herbicide

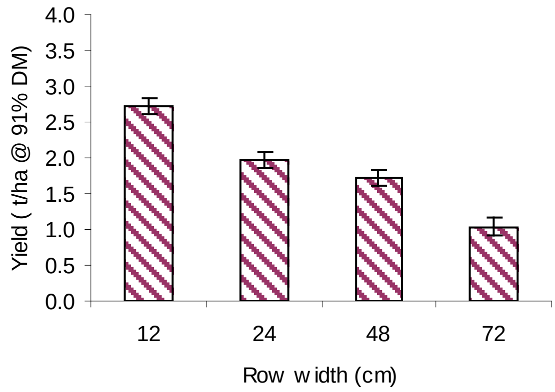




e) Terrington 2010 – with herbicide

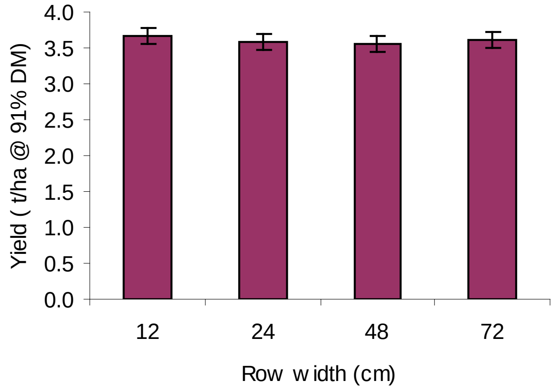
f) Terrington 2010 – no herbicide



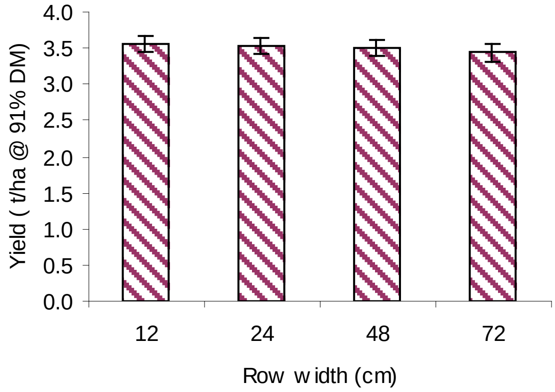


g) Terrington 2011 – with herbicide

h) Terrington 2011 – no herbicide

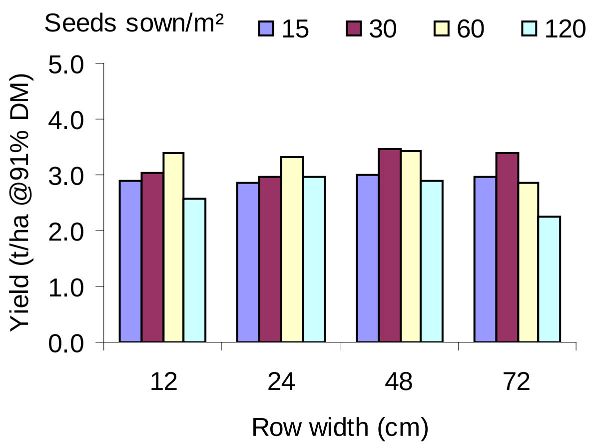


i) Terrington 2012 – with herbicide

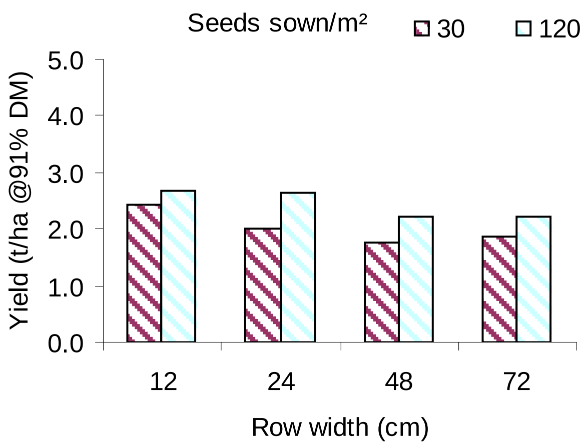


j) Terrington 2012 – no herbicide

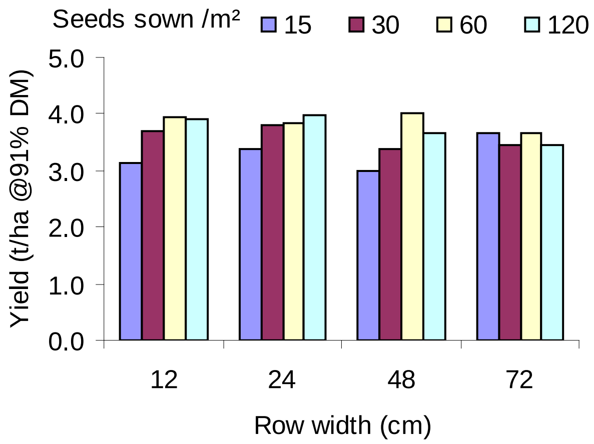
Figure 33. The effect of row width on the yield of oilseed rape with and without a comprehensive herbicide programme.



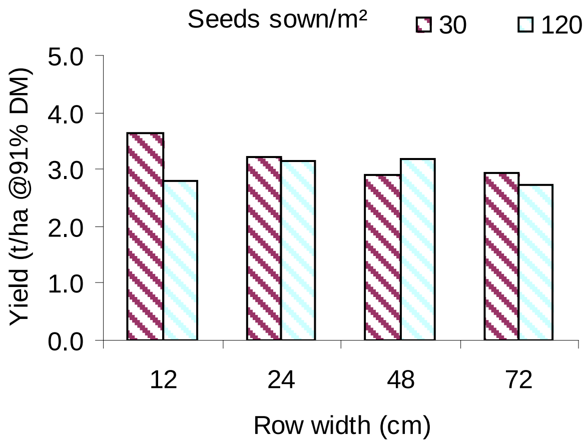
a) Boxworth 2011 – with herbicide



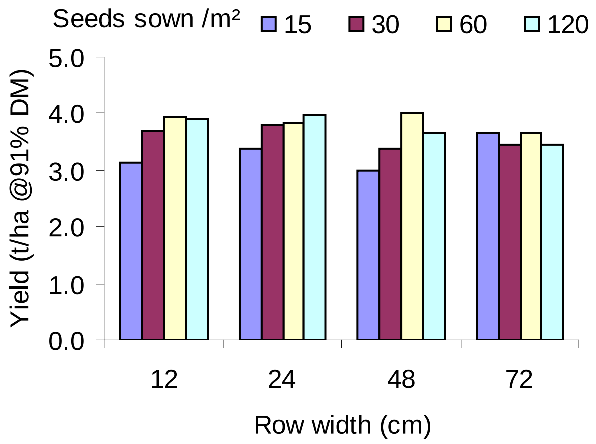
b) Boxworth 2011 – no herbicide

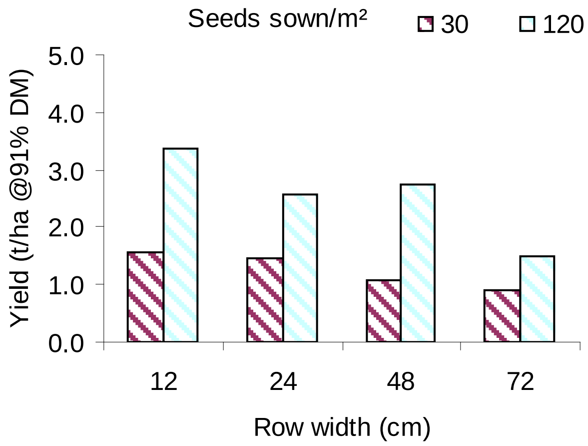


c) Boxworth 2012 – with herbicide



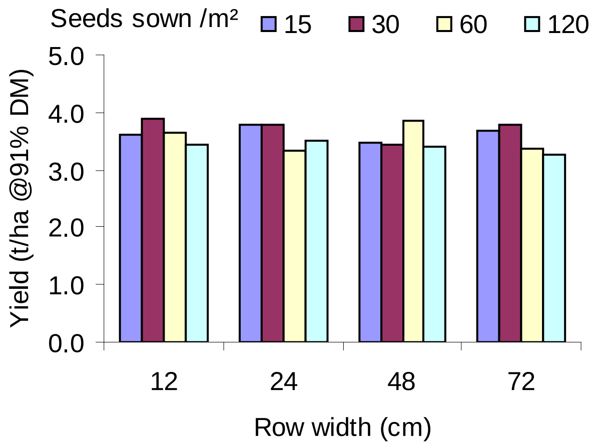
d) Boxworth 2012 – no herbicide

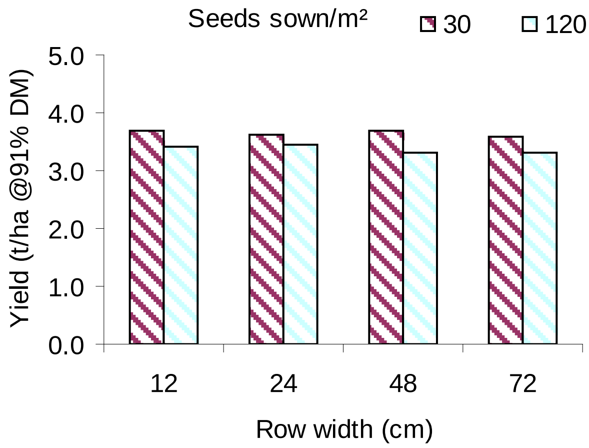




e) Terrington 2011 – with herbicide

f) Terrington 2011 – no herbicide





g) Terrington 2012 – with herbicide

h) Terrington 2012 – no herbicide

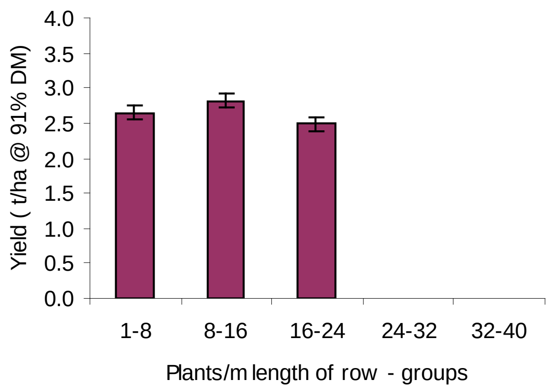
Figure 34. Effect of row width and seed rate on yield for Boxworth and Terrington 2011 and 2012, with and without a comprehensive herbicide programme.

Row width x seed rate interaction LSD

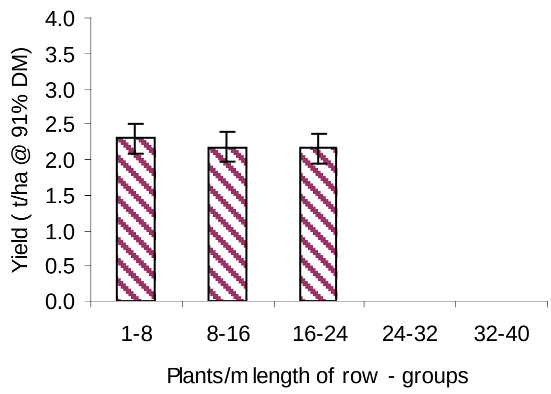
	With herbicide		**No herbicide**	
	2011	**2012**	**2011**	**2012**
Boxworth	**0.20**	**0.33**	**0.45**	**0.71**
Terrington	**0.46**	**0.54**	**0.96**	**0.41**

Plants per meter length of row

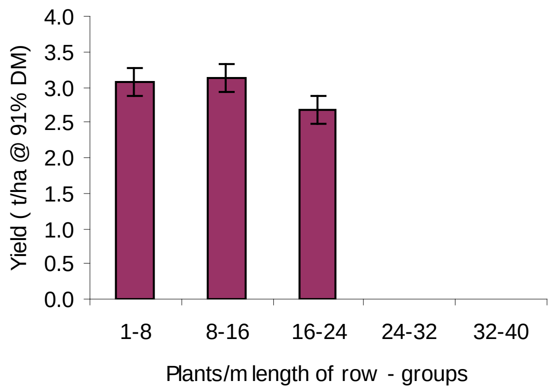
The number of plants per meter length off row had an effect on yield at 4 out of the 5 site years where herbicide was applied. At Boxworth in 2011 and 2012 and Terrington in 2012, yields were significantly (p=0.027, 0.02 and 0.03) higher where plant populations were between 1 and 16 plants per meter length of row compared with more than 16 plants per row (Figure 35). The treatments with the greatest plants per row generally had the widest row spacing. At Terrington in 2011 significantly (p=0.01) higher yields resulted from between 16 and 32 plants per meter length of row compared with 1–8 or 32–40 plants/m.



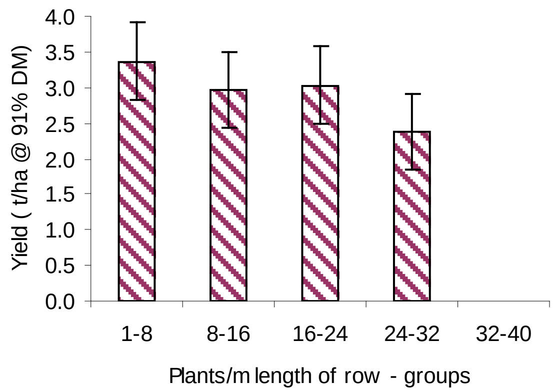
a) Boxworth 2011 – with herbicide



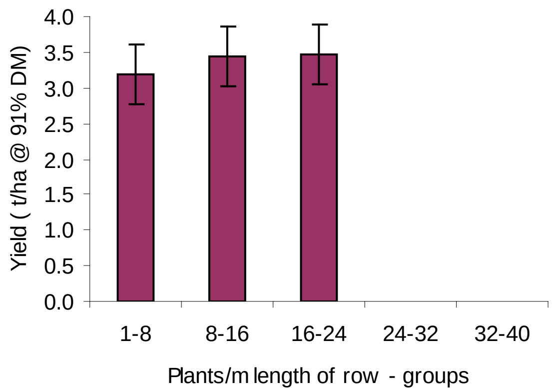
b) Boxworth 2011 – no herbicide

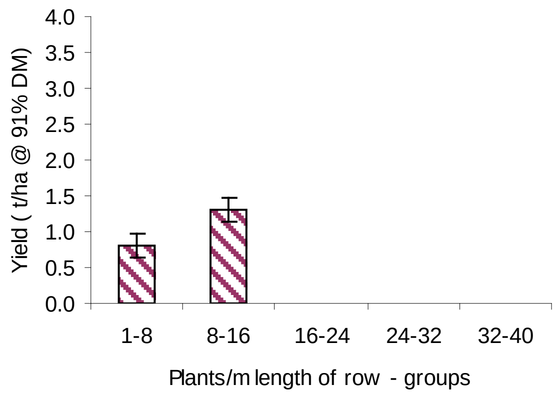


c) Boxworth 2012 – with herbicide

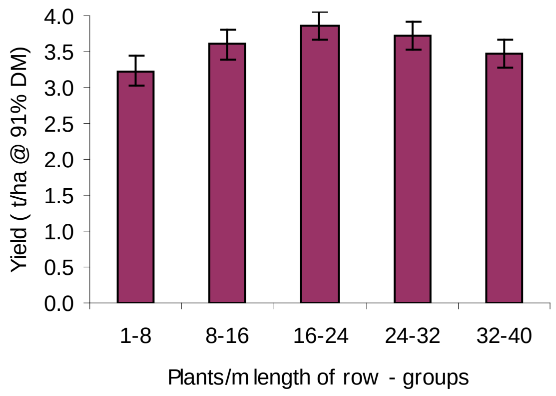


d) Boxworth 2012 – no herbicide

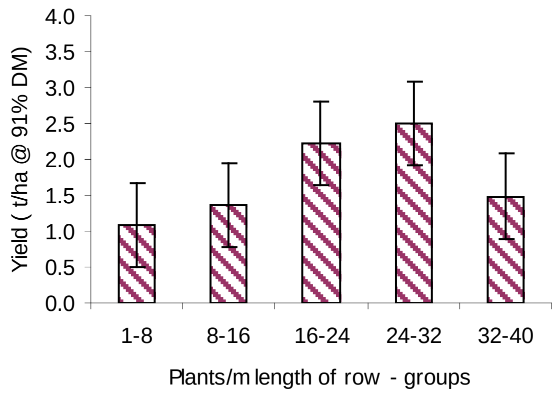




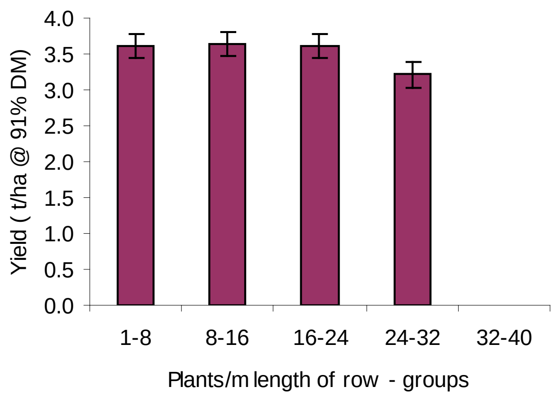
e) Terrington 2010 – with herbicide



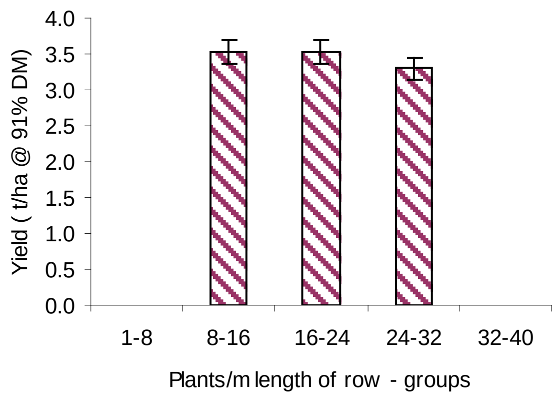
f) Terrington 2010 – no herbicide



g) Terrington 2011 – with herbicide



h) Terrington 2011 – no herbicide



i) Terrington 2012 – with herbicide

j) Terrington 2012 – no herbicide

Figure 35. The effect of the number of plants per meter length of row on the yield of oilseed rape with and without a comprehensive herbicide programme.

Overall yield effects

There was no response between spring plant population against yield (Figure 36), even for plant populations varying between 10 and 160 plants/m^2.

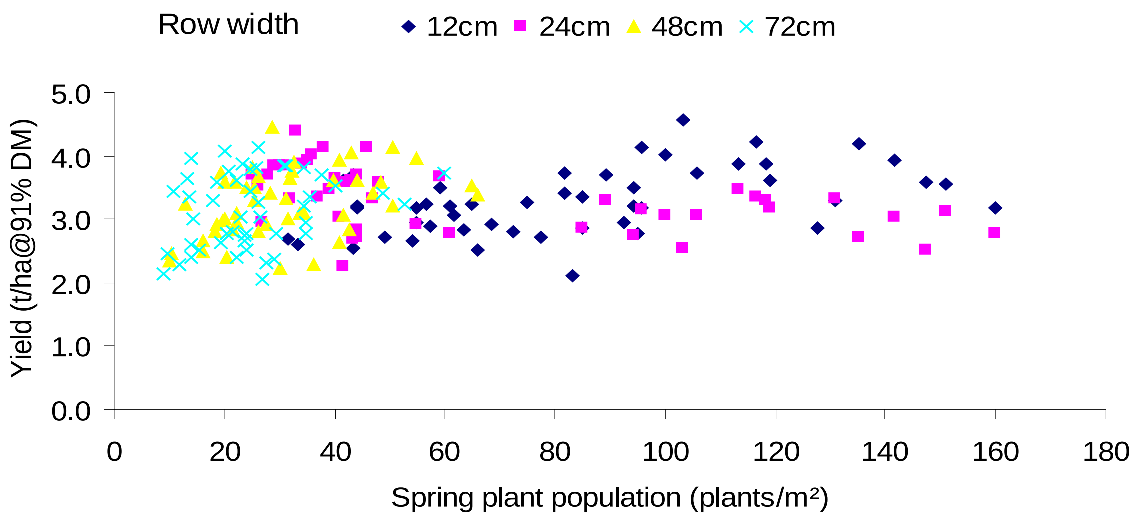


Figure 36. The effect of spring plant population on yield at all sites.

Regressions of plant population both as plants/m² and plants per meter length of row were done using exponential curves with the equation Y = A + B*R^X). Very little variance was accounted for through any of the curve fitting.

Fitting a single curve with spring plant population against yield across all sites did not give a good fit with only 8% of the variance accounted for. Fitting a single curve for each of the sites only produced significant curve fits for Boxworth and Terrington in 2011 (Table 33), but only a maximum of 34% of the variation was accounted for. This was the year of the very dry spring which resulted in less compensatory branching at low plant populations and low yields for the low plant population crops. For Boxworth 2011 the curve fitting process showed that fitting parallel curves for each row width accounted for significantly more variation (32%) (Table 34, Figure 37). The economically optimum plant population was 50 plants/m^2. There was no statistical evidence that different row widths require different plant populations (plants/m^2) to achieve maximum yield.

Table 33. Results for fitting a single curve for spring plant population (plants/m²) against yield for each site

Site	Year	R	B	A	opt	se	% variance accounted for
Boxworth	2011	0.8980	-1.735	2.913	68	21	34
	2012	No sensible fits					
Terrington	2010	No sensible fits					
	2011	0.9894	0.961	4.186	> max pop		15
	2012	No sensible fits					

Table 34. Results for fitting parallel curves for spring plant population against yield for Boxworth, harvest year 2011

Row width (cm)	R	B	A	opt	se	% variance accounted for
12	0.8396	-4.473	2.964	50	39	32
24		-4.473	3.001			
48		-4.473	2.803			
72		-4.473	2.693			

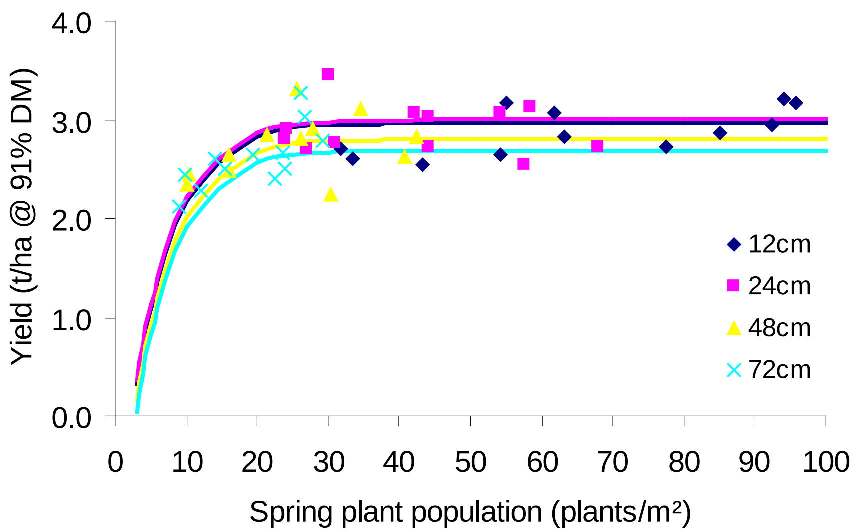


Figure 37. Parallel curves for spring plant population against yield for Boxworth, harvest year 2011.

For plants per meter length of row only 2% of the variation was accounted for at Boxworth in 2011 and 20% at Terrington in the same year (Table 35). Fitting parallel curves for each row width at each site only significantly increased the amount of variation accounted for at Boxworth in 2011 where 28% of the variance was accounted (Table 36). These curve fits were too poor to justify using them to estimate the optimum plants/m.

Table 35. Results for fitting a single curve for plants per m length of row against yield for each site

Site	Year	R	B	A	opt	se	% variance accounted for
Boxworth	2011	0.6783	-1.378	2.838	22	17	2
	2012	No sensible fits					
Terrington	2010	No sensible fits					
	2011	0.7861	-2.59	3.786	35	14	20
	2012	No sensible fits					

Table 36. Results for fitting parallel curves for each row width for plants per m length of row against yield for Boxworth 2011

Site	Year	Row width (cm)	R	B	A	opt	se	% variance accounted for
Boxworth	2011	12	0.8473	-1.014	3.180	44	31	28
		24		-1.014	3.135			
		48		-1.014	2.903			
		72		-1.014	2.746			

Boundary line analysis

The boundary line model was first proposed by Webb (1972). The concept is that a plot of the dependent variable (yield) against the independent variable (plant density) will reveal some upper boundary above which points cannot lay (except for some error). Points that are below the boundary line are limited by other factors. This type of analysis can be used to identify the maximum response (yield) to an independent variable (plant population /m length of row). Plant population/m² cannot be used for this analysis as it is a variate derived from plants /m length of row and row width.

For this analysis the method proposed by Milne *et al*. (2006) was used to fit a boundary line to the data. The method assumes that the data comply with a censored bivariate normal distribution, where the boundary line defines the censor. The form of the boundary line is first selected by the analyst and then maximum likelihood is used to estimate the distribution parameters. For this data a boundary line of the form Y=min[a(1-exp(-bx)), cx+d] was selected.

Where Y is yield, x is the number of plants\m length of row, and a,b,c and d are model parameters. The fitted parameters were a=4.27 (95% confidence interval [3.44, 5.11]), b=0.28 (95% confidence interval [0.17, 0.39), c=-0.04 (95% confidence interval [-0.11, 0.03]) and d=4.94 (95% confidence interval [2.93, 6.95]). Calculated from the above, the true maximum number of plants per meter length of row is 17 (Figure 38). The boundary line analysis indicates that the yield achieved can be subject to many variables. In this work, row width and site were important, but weather and soil type also played a part.

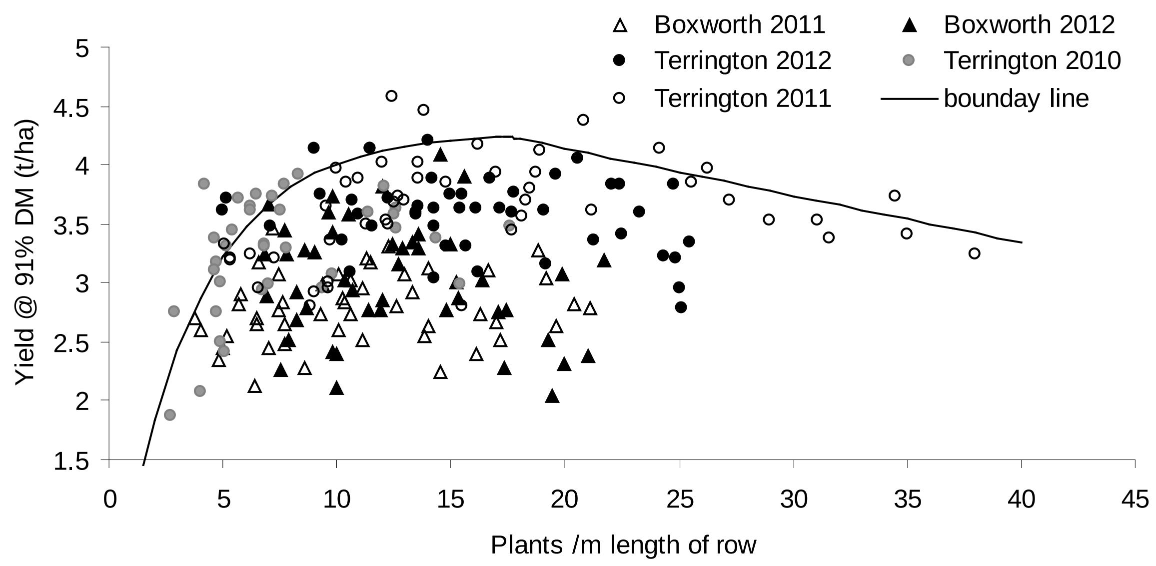
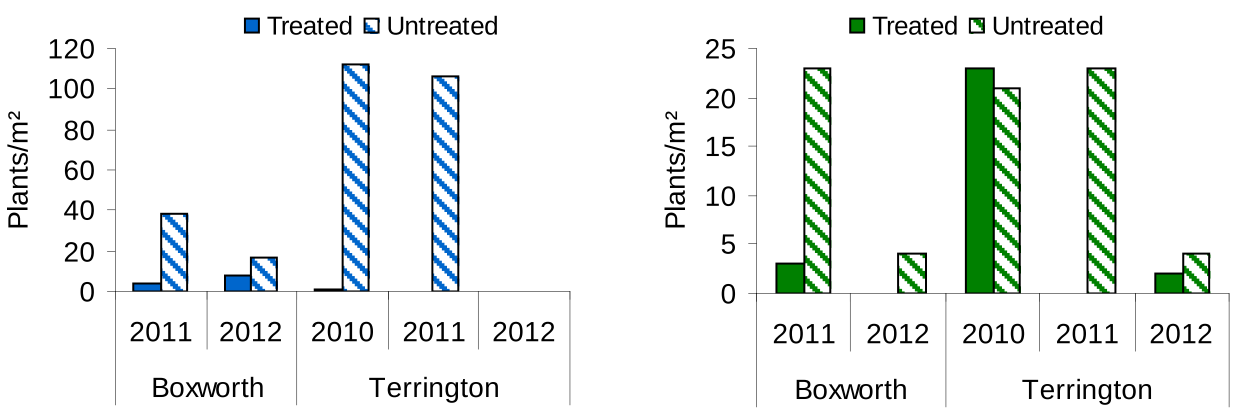


Figure 38. Boundary line analysis of yield and plant population\m length of row.

4.3.8. Weeds

A wide range of weeds commonly found in oilseed rape crops and typical for the soil types were recorded in the experiments (Table 37). Weed populations were highest at Terrington in 2010 and 2011 where common poppy, ivy-leaved speedwell (*Veronica hederifolia*) and volunteer winter wheat were commonly found. Only volunteer winter wheat was present at Terrington in 2012. Weed populations were lower at Boxworth and the most prevalent were black-grass and common chickweed. Overall, weed control from the herbicide programme was very good resulting in low populations with the exception of Terrington in 2010 where the crop was poor (Figure 39).



a) Broad-leaved weeds **b) Grass weeds**

Figure 39. **Mean broad-leaved and grass populations with and without herbicide at Boxworth and Terrington 2010–2012 from counts done in spring.**

Table 37. A summary of the weed species present at Boxworth and Terrington 2010–2012 with populations greater than 5 plants/m² (plants/m²)

Site	Harvest year	Assessment date		With herbicide	No herbicide
Boxworth	2011	14 December 2010	Black-grass	10	14
			Common chickweed		12
			Common field speedwell		6
			Total broad-leaved		21
			Total grass	11	15
			Total weeds	13	36
		14 March 2011	Black-grass		17
			Common chickweed		17
			Common field speedwell		1
			Total broad-leaved		38
			Total grass		23
			Total weeds	7	61
Boxworth	2012	26 January 2011	Black-grass		7
			Common chickweed		5
			Total broad-leaved	5	14
			Total grass		10
			Total weeds	8	23
		16 March 2012	Common chickweed		8
			Sow-thistle	6	3
			Total broad-leaved	8	17
			Total grass		4
			Total weeds	8	21
Terrington	2010	25 February 2010	Ivy-leaved speedwell		58
			Shepherd's purse		46
			Vol. winter wheat	23	21
			Total broad-leaved		112
			Total grass	23	21
			Total weeds	24	133
Terrington	2011	15 December 2010	Common poppy	No weeds	75
			Vol. winter wheat		22
			Ivy-leaved speedwell		15
			Total broad-leaved		91
			Total grass		24
			Total weeds		115
		18 March 2011	Common poppy	No weeds	90
			Vol. winter wheat		14
			Black-grass		10
			Common chickweed		8
			Common field speedwell		5
			Total broad-leaved		106
			Total grass		23
			Total weeds		129
Terrington	2012	17 January 2012	Vol. winter wheat	1	6
		28 March 2012	Vol. winter wheat	2	4

Other weeds present Boxworth 2011 – shepherds purse and annual meadow grass. Boxworth 2012 volunteer winter wheat, sow-thistle, black-grass, Shepherd's purse and cleavers. Terrington 2012 – black-grass

The effect of seed rate on weed populations

The area left untreated with herbicide was restricted to two seed rates each year. Within the plots weed counts were high but populations were variable over the area.

Consistently weed populations were higher at the low seed rate, this was the case for both broad-leaved and grass weeds (Table 38, Table 39, Table 40, Figure 40). There were no interactions between row width and seed rate.

Table 38. The effect of seed rate on total broad-leaved weed populations (plants/m^2)

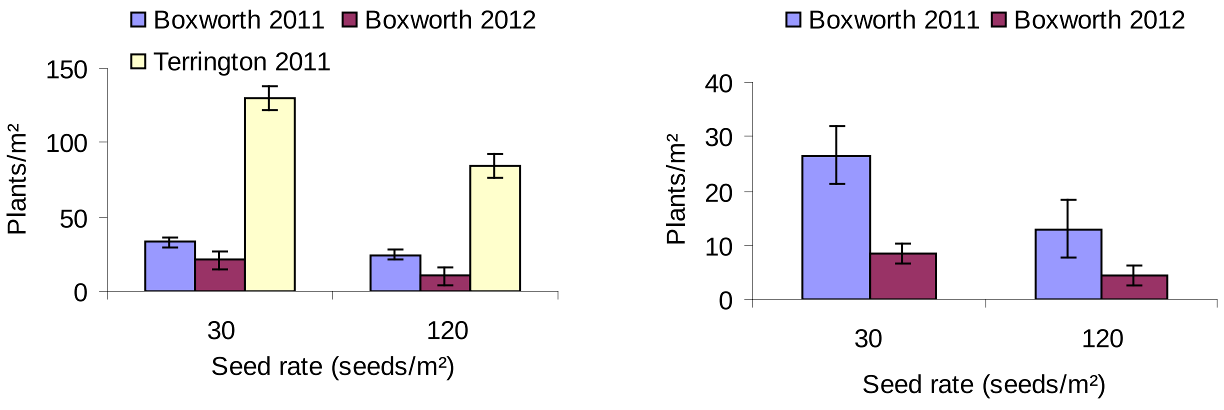
Site	Year	Seed rate		F prob	LSD	df	CV%
		30 seeds/m^2	120 seeds/m^2				
Boxworth	2011	33.2	24.7	0.016	6.83	62	57.9
Boxworth	2012	21.3	10.6	0.076	11.83	64	181.8
Terrington	2011	130.0	84.0	<0.001	16.58	54	37.9

Table 39. The effect of seed rate on total grass weed populations (plants/m^2)

Site	Year	Seed rate		F prob	LSD	df	CV%
		30 seeds/m^2	120 seeds /m^2				
Boxworth	2011	26.5	13.0	0.013	10.57	62	131.5
Boxworth	2012	8.3	4.4	0.034	3.63	64	140.9

Table 40. The effect of seed rate on total weed populations (broad-leaved and grass) (plants/m^2)

Site	Year	Seed rate		F prob	LSD	df	CV%
		30 seeds/m^2	120 seeds /m^2				
Boxworth	2011	59.6	37.6	<0.001	12.58	62	63.4
Boxworth	2012	29.6	15.0	0.030	13.16	64	144.8
Terrington	2011	157.8	106.7	<0.001	19.65	54	36.3



a) Total broad-leaved weeds b) Total grass weeds

Figure 40. The effect of oilseed rape seed rate on grass and broad-leaved weed populations.

The effects of seed rate on individual species followed the same pattern as for total weed numbers with significantly ($p<0.05$) fewer weeds at the higher seed rate (Table 41). At Boxworth in 2011 black-grass populations were reduced by 41% and chickweed by 28% by increasing the seed rate to 120 plants/m² (Figure 41). In 2012 sow-thistle and volunteer cereals were reduced by 57 and 76%, respectively, by the higher seed rate.

At Terrington a similar effect was seen on common poppy and ivy-leaved speedwell (Figure 41).

Table 41. The effect of seed rate on the population of individual species (plants/m²)

Site	Year	Weed species	Seed rate 30 seeds/m²	Seed rate 120 seeds/m²	F prob	LSD
Boxworth	2011	Black-grass	19.8	11.6	0.035	7.64
		Common chickweed	17.4	12.5	0.078	5.55
Terrington	2011	Common poppy	107.6	72.3	<0.001	15.52
		Ivy-leaved speedwell	15.7	6.0	0.019	8.10
Boxworth	2012	Sow-thistle	5.3	2.3	0.007	2.12
		Volunteer winter wheat	3.3	0.8	0.004	1.67

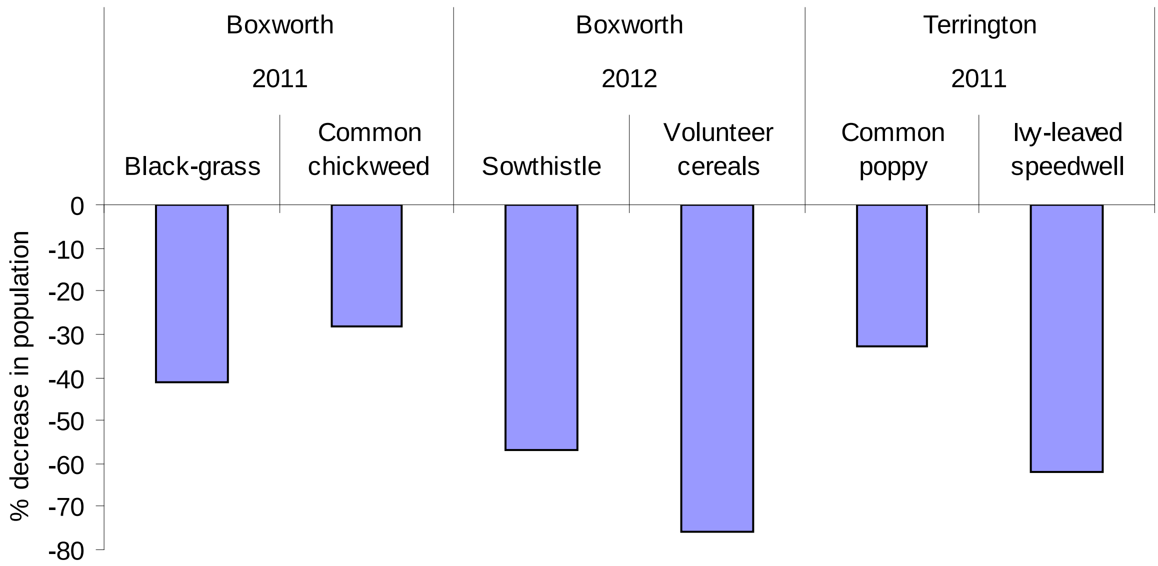


Figure 41. The effect of increasing seed rate from 30 seeds/m² to 120 seeds/m² on percent reduction in population of individual weed species.

The effect of row width on populations

Generally, changing the row width had no effect on the population of weeds. At Boxworth in 2012 there was an effect on ivy-leaved speedwell detected (Figure 42), here there were more weeds in at the 12 and 24 cm row widths than at the widest 72 cm rows.

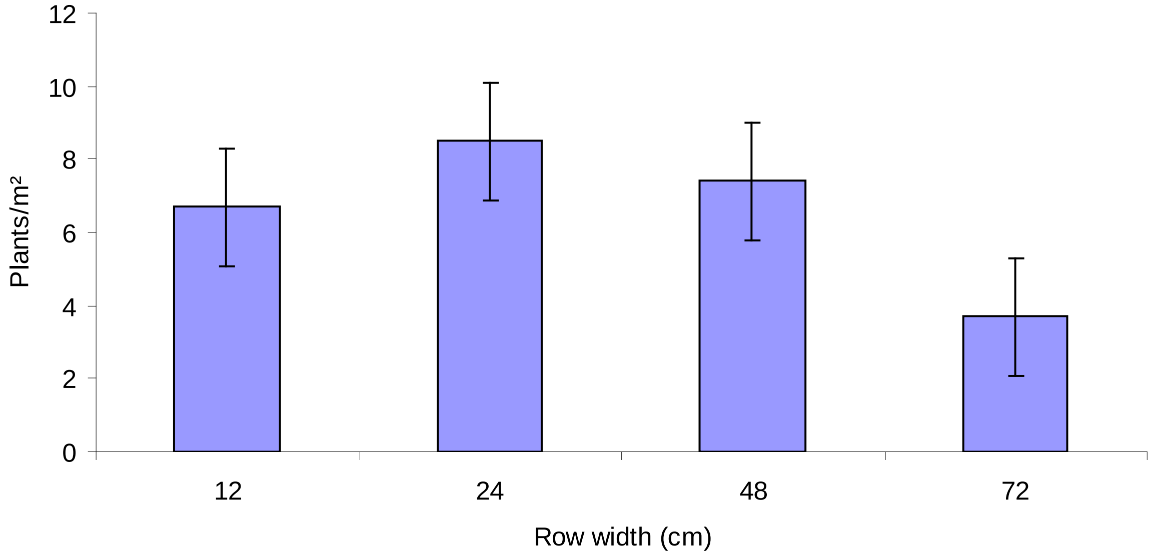


Figure 42. The effect of row width on the population of Ivy-leaved speedwell (plants/m²) at Boxworth 2012.

Location of weeds in relation to the oilseed rape plant

Counting weeds using the circular quadrat (Figure 9) was done to determine if the oilseed rape plant could influence the number and type of weeds that grew around it. Oilseed rape is a broad-leaved plant and can shade the soil around it possibly preventing weed growth. Generally there were no differences in the position that weeds were located but there were two instances where it did. At Terrington in 2012 there was a significantly higher number of volunteer winter wheat closer to the plant (Table 42). This could have been due, in part, to the plant shading the volunteer cereals from the herbicide. At Boxworth in 2012 there were higher numbers of common field speedwell 12–25cm from the plant (Table 43). The data indicated that fewer weeds germinated in close proximity to the oilseed rape plant than in the middle of the row.

Table 42. Location of volunteer winter wheat in relation to the oilseed rape plant (plants/m² within 12 cm or 12–25 cm)

Site	**Year**	**Location of weeds**		**F prob**	**LSD**	**df**	**Cv%**
		Within 12 cm diameter of OSR plant	**12–25 cm from OSR plant**				
Terrington	2012	13.81	2.09	<0.001	3.39	62	104.5

Table 43. Location of common field speedwell in relation to the oilseed rape plant (plants/m² within 12 cm or 12–25cm)

Site	Year	Location of weeds Within 12 cm diameter of OSR plant	12–25 cm from OSR plant	F prob	LSD	df	Cv%
Boxworth	2011	3.72	9.4	<0.001	2.29	62	85.4

Oilseed rape volunteers

The number of volunteers was counted at Boxworth and Terrington between the 72 cm rows in 2012 only (Table 44). At Boxworth there were 3.2 volunteers/m^2 where herbicide was not applied and 4.9 volunteers/m^2 where it had been, this difference was significant (p=0.01), at Terrington there were on average 6.4 volunteers/m² and no differences between the herbicide treatments. There were no differences in the number of volunteers at the different seed rates at either site. Plant populations were counted between the rows only, so assuming the number of volunteers is consistent within the row as between the rows and across all row widths they would account for 6–15% of the population at Boxworth and 8–16% of the population at Terrington.

Table 44. The number of oilseed rape volunteers between the 72 cm rows at Boxworth and Terrington in February 2012 (plants/m²)

Site	Herbicide	Seed rate (seeds sown/m²) 15	30	60	120	Mean
Boxworth						(0.01,1.207)
	With herbicide	4.8	3.9	5.2	5.6	4.9
	No herbicide	-	2.8	-	3.6	3.2
Terrington						(ns)
	With herbicide	5.5	3.9	5.9	6.1	5.3
	No herbicide	-	8.1	-	6.7	7.4

Weed seed contamination in grain

Generally grain samples were clean with most weed seeds being lost through the combine. At Boxworth in 2012, where no herbicide was applied, there was, on average 8% (range 2–13%) of the sample contaminated with weed seeds. These were predominantly cleavers.
At Boxworth in 2010 up to 50% of the weight of harvested seed was cleavers, this level of contamination was similar in both the herbicide and no herbicide treatments.

4.4. Discussion

Effect of row spacing on yield

In the absence of weeds, increasing row width from 12 cm to 72 cm did not affect yield in four of the five experiments. At one experiment (Boxworth 2011) increasing the row width from 24 cm to 72 cm reduced yield by 0.39 t/ha. In 2011 there was a very dry spring which reduced the plant's capacity to compensate in terms of greater branching and pods per branch. It is likely that this environmental effect contributed to the lower yields of the wide spaced rows in this experiment. This is supported by measurements of the amount of light intercepted by the crop at mid-flowering which showed that the increasing row width from 24 cm to 48 cm or 72 cm significantly reduced the amount of light intercepted from above 90% to 80–85%. Increasing row width was also shown to significantly reduce light interception at Terrington 2011. This indicates that the canopy of the wide row crops was too small to intercept all available light. It has shown that the crop must achieve an optimum GAI of 3 to 4 units at flowering in order to intercept the majority of incoming light to enable seed set to be maximised (Berry and Spink, 2006).

The response of yield to row width was not significantly affected by using different seed rates. There was a close to significant interaction between row width and seed rate at Terrington 2011 (P = 0.067). This interaction occurred because wider row spacing (72 cm) tended to have a lower yield at high seed rates (120 seeds/m^2).

In the presence of weeds, increasing row width from 12 cm to 72 cm did not affect yield in three of the five experiments. At Boxworth 2011 and Terrington 2011 increasing row width significantly reduced yield by more than in the experiments without weeds. At Boxworth 2011 increasing row width from 24 cm to 48 cm or 72 cm reduced yield by approximately 0.5 t/ha. At Terrington 2011 increasing row width from 12 to 24 cm reduced yield by approximately 0.7 t/ha and increasing row width to 72 cm reduced yield by a further 0.8 t/ha. In the presence of weeds the response of yield to row width was not significantly affected by using different seed rates.

These experiments therefore show that yield can be reduced by using rows of 72 cm in the absence of weeds in conditions which inhibit compensatory branching and pod formation. In situations with quite high levels of weeds, widening rows from 12 to 24 cm may reduce yield. Andersson & Bengtsson in Sweden (1989 and 1992) noted that yields were lower in 48 cm rows particularly when winters were colder or weed populations higher. In Agrovista Grow Crop Gold crop trials (Blake, 2011) yields were lower in wide rows when weed populations were high but generally row widths of up to 75 cm did not affect yield.

Open-pollinated varieties were grown at each of the Boxworth experiments and a hybrid was grown at each Terrington experiment. It is not possible to compare open-pollinated and hybrid varieties directly for their ability to perform with wide rows. However, there were no strong trends to indicate that open-pollinated varieties perform less well when sown in wide rows because

Boxworth 2012 showed no effect of row width on yield in the absence of weeds, and in the presence of weeds wide rows reduced yield at both Boxworth and Terrington in 2011. Ellis *et al.* (2013) found that open-pollinated varieties were able to compensate for low plant populations as well as hybrid varieties in all but the most severe spring drought conditions.

There was no evidence from the experiments in this project that wide spaced rows suffer from more pigeon damage compared with narrow spaced rows. However, it should be recognised that in these experiments the row width was manipulated by blocking of coulters which meant the space between the rows was cultivated. Current sub-casting systems generally do not disturb the soil between the rows, leaving the stubble erect. It is not certain whether this would increase or decrease the likelihood of pigeons landing between the rows and further work should investigate this. It should also be noted that there may be differences in the level of pigeon damage at the field scale with wide rows.

There were no significant effects of row width on leaning or lodging, however as the levels of lodging were generally low it is not possible to conclude with any certainty that row width does not affect lodging.

There was no evidence that more weeds established in the wide row treatments, with increasing seed rate causing a significant reduction in weed numbers.

Optimum seed rate for wide rows

In the absence of weeds there were no significant interactions between seed rate and row width on yield which indicates there was no evidence that the number of seeds/m^2 that should be drilled to maximise gross margin over seed costs should be adjusted for different row widths. This also held true in a no herbicide situation. Curves describing the yield response to plants/m^2 could be fitted for the Boxworth 2011 and Terrington 2011 data and showed no difference in the optimum plants/m^2 between the different row widths. However it should be recognised that yield response curves could not be fitted for the other 3 sites because there was only a very small yield response to increasing plants/m^2, therefore strong conclusions cannot be drawn. Observation of the yields at different seed rates and row widths does not reveal that different row widths have a large effect on the way that the yield responds to increasing seed rate. Therefore, overall, we conclude that for yield, in the presence or absence of weeds, there is no evidence that the optimum seeds/m^2 or plants/m^2 changes with different row widths.

Since 2009 there have been several seed rate response experiments carried out at narrow row spacing (12 to 15 cm) to investigate what the optimum seeds/m^2 and plants/m^2 is and whether this varies for open-pollinated and hybrid varieties (Ellis and Berry, 2012; Ellis *et al*., 2013). This data is summarised in Table 45 below and shows that the optimum plant number is usually less than 40 plants/m² and is similar for open-pollinated and hybrid varieties, except in 2011 when the very dry spring reduced the plant's capacity to compensate for low plant populations. This data helps to put the experiments carried out within this project into context as it shows that the dry spring of 2011 had a large effect on the crop's response to seed rate and that, in general, optimum plant numbers are low.

Table 45. Economically optimal plant populations for oilseed rape calculated from 8 seed rate experiments

Location	Harvest year	Conventional variety	*Hybrid variety*
†East Yorkshire, near High Mowthorpe	2009	28	*28*
†East Yorkshire, near High Mowthorpe	2010	32	*32*
Herefordshire, near Rosemaund	2011	36	*39*
Norfolk, near Terrington	2011	>159*	*63*
North Yorkshire, near High Mowthorpe	2011	98	*91*
Herefordshire, near Rosemaund	2012	48	*13*
Norfolk, near Terrington	2012	21	*21*
North Yorkshire, near High Mowthorpe	2012	21	*30*
Average		55	*40*
Average minus 2011		*31*	*27*

† Data from Ellis and Berry (2012)

*At one site, yield failed to reach a maximum over the range of plant populations tested. The figures quoted are the maximum plant population, grown from the maximum seed rate of 160 seeds/m^2.

Target plants/m^2 or plants/m row?

Whilst it appears that row width does not affect the optimum seeds that should be sown or the optimum number of plants/m² that should be established, the project did find that row width can have a significant effect on the percentage of seeds sown that establish plants. This was because oilseed rape plant establishment is very sensitive to crowding. This was clearly shown in this work with a lower rate of plant establishment found for the treatments where seeds were sown close together. The concept of seed rate or plants/m² is easy to understand if the row width remains constant, but increasing the row width decreases the number of rows/m² and increases seed number per meter length of row, this can be seen clearly in Figure 43 below.

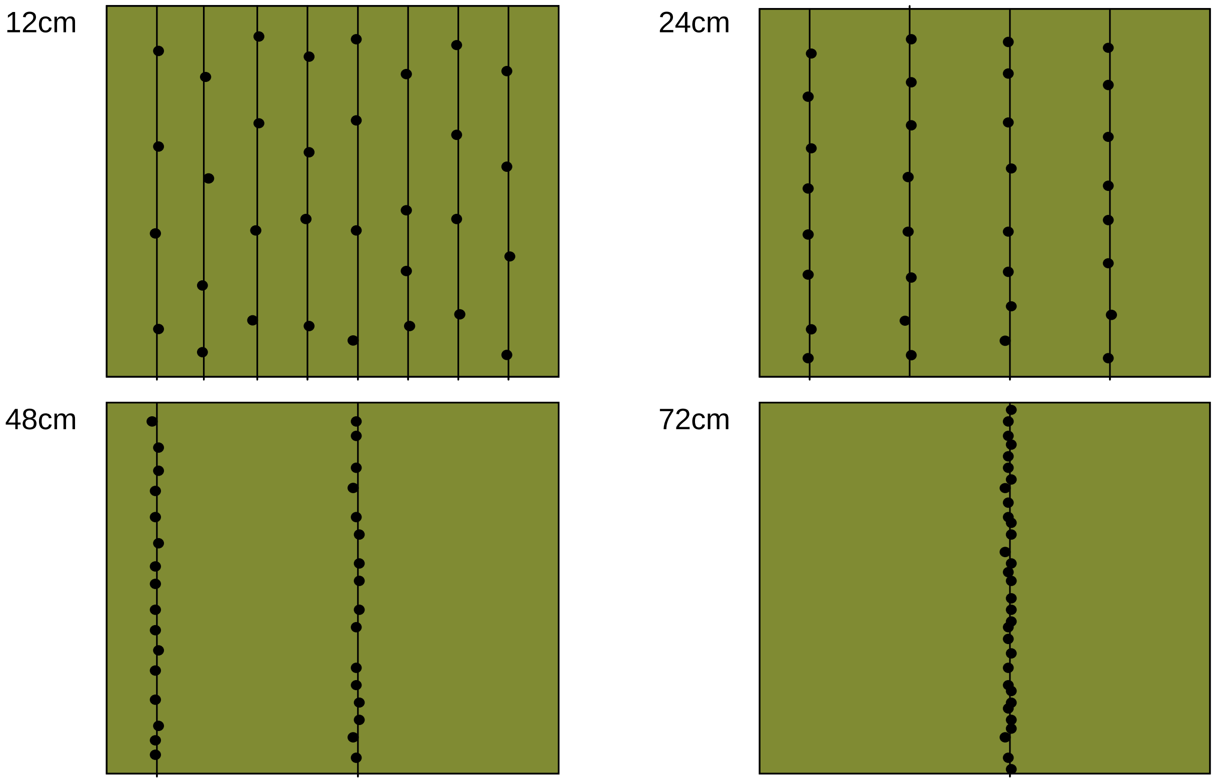


Figure 43. The effect of increasing row width on seeds sown per meter length of row (all are the same seed rate of 32 seeds/m²).

As the number of seeds per meter length of row increased there was a reduction in plant establishment rate (Figure 44). Increasing the number of seeds sown reduced the establishment rate, most probably due to intra-specific competition between close neighbour plants inhibiting seed germination and reducing seedling survival.

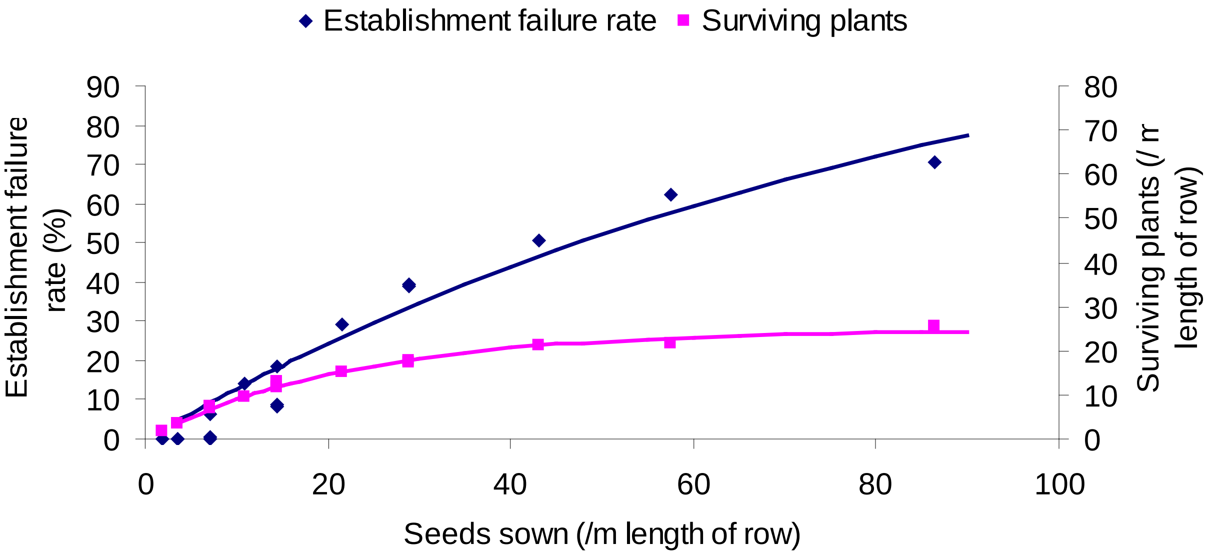


Figure 44. The effect of increasing plant population on seedling death (%) and the number of surviving plants per meter length of row in the spring.

This work has shown that where more than seven plants establish in a meter length of row the probability of each further plant surviving decreases. Populations per meter length of row only exceeded 20 plants in 14% of occasions, whilst on 86% of occasions populations are between 5 and 20 plants/m length of row. The maximum plant density per metre length of row was shown to be 25 plants/m and sowing more seeds did not increase this (Figure 44). This indicates that the minimum spacing between viable plants is about 4 cm. The boundary layer analysis indicated that maximum plants/m is 17, above which yield started to decrease. This may indicate that even at 5 cm spacing between plants there is inter-plant competition which reduces yield potential. There was evidence in the yield trials which showed that increasing seed rate at the widest row spacing tended to reduce yield more than at narrow row spacing. This effect may have been due to stronger inter-plant competition in the wide spaced row treatments. Work done by Agrovista between 2010 and 2012 has shown that sowing more than 15–20 seeds per meter length of row reduces the percentage establishment through competition (Casswell, 2012). The importance of avoiding intra-plant competition was also noted by Andersson & Bengtsson (1992).

The discovery that planting seeds close together within a row causes a marked reduction in establishment rate coupled with the observations that it is not possible to establish more than 25 plants/m and yield may start to drop off above 17 plants/m, have important implications for choice of seed rate with wide row establishment systems. This is because at 48 cm row spacing it may not be possible to establish more than 50 plants/m^2 and at 72 cm row spacings it may not be possible to establish more than 35 plants/m^2 (Table 46). This means that when buying seed, seed rates should be kept low for wide spaced row systems otherwise seed costs will be wasted and it is possible that yield will be reduced by excessive inter-plant competition.

Table 46. Effect of row width and target plants/m^2 on plants/m of row

	Row width			
Target Plants/m^2	12 cm	24 cm	48 cm	72 cm
10	1	2	5	7
20	2	5	10	14
30	4	7	14	22
40	5	10	19	29
50	6	12	24	36
60	7	14	29	43
70	8	17	34	50
80	10	19	38	58
90	11	22	43	65
100	12	24	48	72
110	13	26	53	79
120	14	29	58	86

The effect of weeds on the crop

Crop establishment was not affected by the presence of weeds even in untreated plots. The weed species in this work were those commonly found in oilseed rape crops on heavier soil types. Common poppy, ivy-leaved speedwell and volunteer winter wheat were predominant at Terrington and black-grass and common chickweed at Boxworth (these species do not tend to emerge with the crop). On the lighter soil types weeds are more likely to emerge with the crop and compromise establishment, here the application of a pre-emergence herbicide is important and delaying treatment can result in lower emergence and a reduction in plant size, compromising plant loss and yield.

Broad-leaved weeds numbers were higher than the grass weeds particularly on the silt soils at Terrington where common poppy was a particular problem. The weed population varied with the seasons mainly in response to less competitive oilseed rape crops which were seen in the drier seasons. Herbicide control relies, in part, on a vigorous crop out-competing weeds weakened by the herbicide application (Sansome, 1989 and 1991). At Terrington in 2010 there was poor control of volunteer cereals from the application of a graminicide due to the less competitive crop. Volunteer cereals establish quickly due to their large seed size, even in late drilling situations and dry autumns (Lutman, 1991). For crops drilled after 9 September the threshold is a 5% yield loss from 10 volunteers/m². In the competitive crop at Boxworth in 2012 there were 76% fewer volunteer cereals where oilseed rape population increased from 38 to 57 plants/m².

There were further results from this work that showed an effect of crop density on weed numbers: increasing the seed rate from 30 seeds/m² to 120 seeds/m² resulted in 37% fewer broad-leaved weeds and 49% fewer grass weeds. There was an effect on individual species, mainly the broadleaved ones, common chickweed and common poppy populations were 28 and 33% lower at the higher seed rate, ivy-leaved speedwell and sow-thistle were reduced by 62 and 57%, respectively. Sim *et al*. (2007) reported a 9% reduction in black-grass heads when oilseed rape population increased from 29–50 plants/m², in this work increasing population from 35 plants/m² to 57 plants/m² resulted in 41% fewer black-grass plants. The value of a vigorous crop was seen at Terrington in 2012, this crop contained very few broad-leaved weeds. At the wider row widths, this work has indicated that there is a limit to the population that can be established in a metre length of row. This indicates that there is less scope to out-compete weeds in wide row crops through increasing the seed rate.

The presence of weeds within the crop increased the GAI when measured from photographs and at mid-flowering the amount of light intercepted by the crop and weeds was 4% greater than in untreated crops. The presence of weeds should be taken into account when calculating nitrogen rates form GAI assessments.

The yield response to the presence of weeds varied between sites and years (Figure 45). In 2012, moisture was unlimited and crops grew well, overall weed numbers were low and yields were similar in both the herbicide-treated and untreated. In contrast, the autumn of 2009 was very dry and the crop at Terrington struggled to establish well. Spring plant populations were low; GAI was low and the proportion of light intercepted reduced. Weed populations were very high in the untreated and yields were reduced by 72%. In 2011 yields were reduced by the presence of weeds at both Boxworth and Terrington, numbers were higher at Terrington and yield was reduced by 48%.

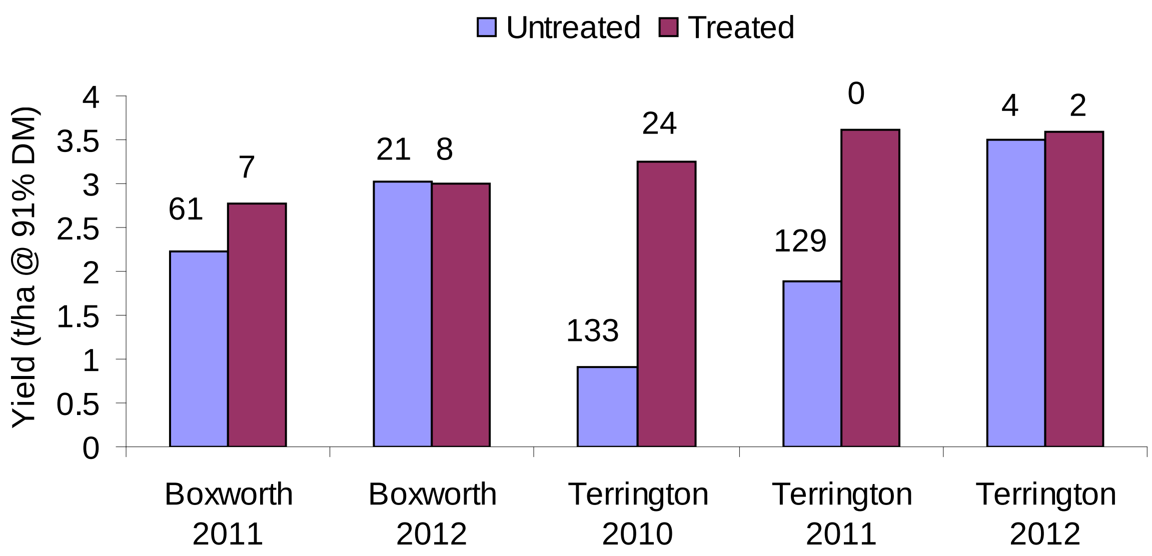


Figure 45. Yield of oilseed rape and total number of weeds present in the spring.

Sowing oilseed rape in wide rows can give an indication on the number of volunteers present in the crop; in 2012 6–15% of the plants at Boxworth and 8–16% of the crop at Terrington were volunteers.

The number of volunteer oilseed rape in a crop is determined by a range of factors including soil type, frequency of oilseed rape in the rotation, variety, number of seeds shed at harvest, secondary dormancy and cultivations. Volunteers can reduce the quality of harvested crops but they could also lead to yield reductions by reducing the predictability of emergence and increasing the plant population above the optimum. The project has shown that between 7–30% of the population could be due to unsown volunteers. To reduce volunteer numbers, immediate cultivation after harvest should be avoided giving seeds time to germinate or be predated. Cultivations should be delayed for 4 weeks where soil conditions are dry and 2 weeks when soils are moist (Lutman, 1999).

Currently there is a trend to establish oilseed rape using wider rows than the conventional drill width of 12 cm. Widening the rows would then offer the opportunity to mechanically weed using an inter-row hoe or band spray herbicides between or over the rows. This work shows that row width could be increased quite substantially without decreasing final yield. There was an indication that yield did decline at the widest row widths (72 cm) and it is postulated that extreme row widths could lead to lower yields in challenging seasons such as severe spring drought.

Economic implications

Manipulating the row width for oilseed rape can be done simply and without cost by shutting off coulters of a standard drill to achieve the required width. There has been a trend in recent years to establishing oilseed rape by subcasting, in this system the row spacing tends to be approximately 40 to 60cm, this system has been widely adopted because it reduces the time required for the drilling operation. The time taken for drilling will be dependent upon the width of the machinery rather than the number of rows sown.

Seed cost in oilseed rape accounts for approximately 12% of the total variable costs, which is similar to that of winter cereals (Nix, 2012).

This work has indicated that there was no evidence for altering the number of seeds/m^2 sown to maximise gross margin over seed costs for different row widths, but it was unlikely that more than 25 plants/m would establish. Yield was also likely to start to decrease when plants/m exceeded 17 plants/m. At 48 cm row spacing it may not be possible to establish more than 50 plants/m^2 and at 72 cm, more than 35 plants/m^2. Seed rates should not be super-optimal to save costs through excessive plant loss.

Herbicide use is a key factor in maximising the yield of oilseed rape, yields were increased an average of 41% (range 0–262) through the use of herbicides. Where rows are widened there is an opportunity to use inter-row cultivation or band spraying.

5. RD-2009-3605 New approaches to weed control in oilseed rape

5.1. Introduction

The actives propyzamide, carbetamide and metazachlor are important for controlling grass and broad-leaved weeds in the rotation, providing useful alternative modes of action to control resistant black-grass and other important weeds. However, their continued use by the farming industry is under threat as they have been proven to leach into water courses under certain conditions and breach the EU Water Framework Directive (WFD) and Drinking Water Directive (DWD). By reducing the impact of an individual active across the field using existing technology and current farming techniques, the concern of the water industry could be met.

The farming industry uses different systems for establishing oilseed rape. The use of wide row systems are now being employed to establish an increasing number of winter oilseed rape crops. Such systems provide the opportunity to use novel approaches to controlling weeds between the rows, potentially enabling the dependence on selective herbicides to be reduced.

Overall Aim

This research project aimed to evaluate new approaches to weed control in winter oilseed rape using carefully-directed control methods between (inter-row) crop rows. Such approaches are capable of minimising reliance on commonly-used selective residual herbicides.

Key Objectives

1. To assess the performance of inter-row application systems, the level of weed control achieved and the amount of crop damage. Increasing the width of the treated band is likely to increase the levels of weed control achieved, particularly if no over-the-row treatment is applied, but is also likely to increase crop damage.

Year one treatment lists for the experiments at SRUC and NIAB TAG are detailed in Table 47 and Table 48.

2. The aim of year two was to assess the most promising delivery nozzle configurations from year one (the treatments for year two are shown in Table 49 to Table 52), and integrate them with novel precision guidance systems (RTK GPS and Vision Guidance) as supplied by the project collaborators, John Deere and Tillett and Hague, respectively. The difference between the two guidance systems for RTK the crop was drilled using a GPS-guided drill whereas the Vision guidance simply follows the drill using a camera. NIAB TAG under took the precision guidance part of the project in year two, while SRUC looked at more aspects of delivery of glyphosate.

Narrow foot print nozzles are ideal for delivery of a targeted spray into the inter-row gap between crop rows where there was still the potential for drift under less than ideal conditions, especially as the crop grows, narrowing the gap between the rows. Drift and potential damage can be minimised by using ever narrower nozzles, using a shield or applying at an earlier growth stage of the crop. In the second year of the project SRUC looked at a combination of all three and tested the concepts on two contrasting varieties: a hybrid, Excalibur, and a conventional type, Catana. The SRUC treatments were taken to yield in year two.

3. To assess the comparison with mechanical weeding with conventional weed control as conducted by the ORC
4. To build on the more promising application guidance and delivery combinations from year two through the use of different shield types, the most promising and practical guidance systems, sequences of glyphosate inter-row with a residual partner intra-row. The impact of treatments on two contrasting varieties was also further evaluated. Treatment lists and protocols for year 3 are shown in Table 53 to Table 56.

The need for an official CRD approval for the use of glyphosate inter-row in winter rape requires residue work to GLP standard despite there being an existing approval for glyphosate as a desiccant in the crop. Monsanto, a collaborator in the project, in conjunction with Charles Rivers of Tranent, East Lothian and SRUC conducted a trial at Boghall to GLP standard in 2011–12 to generate residue data to support an application to CRD.

5.2. Materials and methods

5.2.1. Introduction

The aim of the research was to evaluate a range of delivery systems to apply glyphosate to the inter-row gap of rape grown on wide rows. To facilitate this, a test rig was constructed by NIAB TAG at Silsoe, see Appendix 5. The rig had two interchangeable booms and spray delivery systems mounted on a tool bar capable of attaching to the three point linkage of a tractor. One boom was capable of applying the treatments through the different hydraulic nozzles, with a second applying treatment through the Micron Varidome CDA nozzles. The nozzles were set up in such a way to apply treatments to the inter-row gaps within the plots drilled at 50 cm. Note the hydraulic nozzles used throughout the project are more commonly used in amenity and non-agricultural situations and are designed to deliver a narrow spray footprint compared to conventional flat fan nozzles. The Micron Varidome CDA system is commonly used in vegetable crops grown on wide rows.

The over-all metazachlor treatments were applied by a small plot sprayer at 1.8 m. In year one of the project, the treatment list for SRUC and NIAB TAG were similar, apart from the residual herbicide treatments and the NIAB TAG work was only carried out at a single row spacing. SRUC used straight metazachlor as Butisan S (BASF) and NIAB TAG propyzamide as Kerb Flo (Dow AgroSciences).

Growing rape on wide rows also provides the opportunity for the use of mechanical weeding. This may be important either in an organic crop or as in a situation where we lose chemical control measures. In year one of the research, the Organic Research Centre (ORC), a partner in the project, compared chemical weed control with mechanical weed control using a Vision Guided Garfords steerage hoe, Appendix 5.

5.2.2. Year one 2009–10, Variety Catana

The location of the trials in year one were

1. SRUC, Boghall Farm, Bush Estate (Grid Ref: NT250659)
2. TAG: MD Hamilton Farms, Model Farm, Ditchley Park, Enstone, Chipping Norton, OX7 4EZ
3. Elm Farm: Mr John Sanderson, South Elmham Hall, Harleston, Norfolk

The SRUC treatments list for year one are shown in Table 47.

Table 47. SAC Treatment List Year One 2009–10

CODE	Row width	Treatments pre-emergence	Treatment post-emergence	Spray type
1	50 cm	Untreated	Untreated	Untreated
2	50 cm	Metazachlor 1.5L	None	Standard
3	50 cm	Untreated	Roundup energy 2.0L	Micron hooded Varidome
4	50 cm	Untreated	Roundup energy 2.0L	Narrow “02”40° nozzle no hood
5	50 cm	Untreated	Roundup energy 2.0L	Flan Fan “01”110° twisted to give 80°
6	50 cm	Untreated	Roundup energy 2.0L	Even-spray 80° nozzle
7	50 cm	Untreated	Roundup energy 2.0L + Metazachlor 1.5L Over rows only	Micron hooded Varidome
8	12 cm	Untreated	Untreated	Untreated
9	12 cm	Metazachlor 1.5L	None	Standard
10	50 cm	Untreated	Metazachlor 1.5L+ Roundup energy 2.0L	Micron hooded Varidome
11	50 cm	Untreated	Metazachlor 1.0L + Roundup energy 2.0L	Micron hooded Varidome

12	50 cm	Untreated	Metazachlor 1.0L + Roundup energy 2.0L	Narrow “02”40° nozzle no hood

For site treatment notes – refer to Appendix 7

Micron Hooded Varidome is a spinning disc within a hood supplied by project collaborators Micron. The even-spray nozzle used was a “02”:80° with a narrow sprayfoot print compared to a 110°/120° conventional nozzle.

Narrow twisted was a twisted standard 110° hydraulic nozzle twisted to give an 80 degree spray footprint. Inter-row treatments were all applied with the experimental rig.

The NIAB TAG treatments list for year one are shown in Table 48.

Table 48. Treatment list for NIAB TAG experiment in Oxfordshire in year 1 (2009–10)

	Row width	Product	Band width	Comment
1	50 cm	Untreated	-	-
2	50 cm	Kerb Flo	Whole plot	Standard approach – wide row (FF110)
3	50 cm	Roundup Energy	30 cm inter-row band	Micron Hooded applicator (30 cm twist)
4	50 cm	Roundup Energy	30 cm inter-row band	‘Narrow’ nozzle (25°) with no hood
5	50 cm	Roundup Energy	30 cm inter-row band	Twisted nozzle (FF110 twisted to 45°)
6	50 cm	Roundup Energy	30 cm inter-row band	Even spray nozzle (80° nozzle twisted to 45°)
7	50 cm	Kerb fb Roundup Energy	Over row only fb Inter-row band only	Narrow nozzle (25°) Narrow nozzle (25°)
8	50 cm	Roundup Energy	20 cm inter-row band	Micron Hooded applicator (straight)
9	50 cm	Roundup Energy	20 cm inter-row band	Twisted nozzle (FF110 twisted to 80°)
10	50 cm	Roundup Energy	20 cm inter-row band	Even spray nozzle (40° nozzle twisted to 45°)
11	50 cm	Untreated	-	-

Notes:

Kerb Flo (propyzamide, 500 g/l SC, Dow) applied at 2.1 L/ha on the 25/01/10

Roundup Energy (glyphosate, 450 g/l SL, Monsanto) applied at 1.6 L/ha on the 25/01/10

5.2.3. Year two 2010–2011

Sites:

1. SRUC: Boghall Farm, Bush Estate, Penicuik, Edinburgh
2. NIAB TAG: Essex
3. ORC: South Elmham, Suffolk

SAC Protocol Year 2

Table 49. SAC Protocol 1. Variety: Catana. Winter rape inter-row herbicide trial 2010–11

	Treatment	Inter-row	Intra-Row	GS
1	“Commercial “12 cm spacing	Untreated		-
2	“Commercial “12 cm spacing	Metazachlor over-all		1,2
3	50 cm inter-row spacing	Untreated		1,2
4	50 cm inter-row spacing	Metazachlor over-all		1,2
5	Micron Varidome	Glyphosate	-	1,2
6	Micron Varidome	Glyphosate + Metazachlor	-	1,2
7	Micron Varidome	-	Metazachlor	1,2
8	Micron Varidome	Glyphosate	Metazachlor	1,2
9	‘Wide band’ - No Shield	Glyphosate	-	1,2
10	‘Wide band’ - With Shield	Glyphosate	-	1,2
11	‘Narrow band’ - No Shield	Glyphosate	-	1,2
12	‘Narrow band’ - With Shield	Glyphosate	-	1,2
13	‘Wide band’ - No Shield	Glyphosate	-	1,2 + 7–10 days
14	‘Wide band’ - With Shield	Glyphosate	-	1,2 + 7–10 days
15	‘Narrow band’ - No Shield	Glyphosate	-	1,2 + 7–10 days
16	‘Narrow band’ - With Shield	Glyphosate	-	1,2 + 7–10 days

Table 50. SAC Protocol 2. Catana vs Excalibur Year 2

	Treatment	Inter-row (2 leaf)
Catana	50 cm inter-row spacing	Untreated
Catana	50 cm inter-row spacing	MTZ (over-all)
Catana	Micron Varidome	Glyphosate
Catana	Narrow band – No Shield	Glyphosate
Catana	Narrow band – With shield	Glyphosate
Catana	Wide band – No shield	Glyphosate
Catana	Wide band – With shield	Glyphosate
Excalibur	50 cm inter-row spacing	Untreated
Excalibur	50 cm inter-row spacing	Metazachlor (over-all)
Excalibur	Micron Varidome	Glyphosate
Excalibur	Narrow band – No Shield	Glyphosate
Excalibur	Narrow band – With shield	Glyphosate
Excalibur	Wide band – No shield	Glyphosate
Excalibur	Wide band – With shield	Glyphosate

SRUC Trials Treatment notes year two refer to Appendix 7

Wide band refers to spray width of 300 mm using “02” 40° nozzle at 2 bar pressure.
Narrow band refers to a spray width of 150 mm using a “01” 25° nozzle at 2 bar pressure.
The commercial treatments were sprayed using a “03” 110° nozzle at 3 bar pressure.
Roundup Energy was applied at 1.6 L/ha.
Plots harvested using first a Haldrup Swather followed by Deutz small plot combine.

NIAB TAG Protocol Year 2

Research undertaken by NIAB TAG in year 2 in Essex integrated the use of narrow footprint nozzles with precision guidance systems (RTK and Vision Guidance) while also examining the potential for the incorporation of simple shielding approaches (pictured in Appendix 5). Two analogous experiments, one considering RTK and the other Vision Guidance, were located on the same farm in a field crop drilled using RTK guidance on wide rows as standard practice for the farm site (with the exception of herbicides all inputs were as farm practice). All glyphosate (Roundup Energy, Monsanto) applications were made on the same day (28/09/10) at an early growth stage (GS 1,2 – 1,3); where the crop rows were just apparent. The standard herbicide programme (propyzamide, Kerb Flo, Dow AgroSciences) was applied later in the season on the 22/11/10 (GS 1,6 – 1,8); as would be typical for this herbicide. Due to the long plot lengths needed to examine the use of the guidance systems, plots were set up as paired 'treated' and 'untreated' strips and all results are presented relative to the paired untreated plot with a standard error of the mean to give an indication of the variation across blocks. Assessments were undertaken pre- (22/10/10) and post-winter (07/02/11) to give an impression of treatment persistence and to look for any differences in crop loss over the winter period. Typical pictures of rows at application and post-treatment are presented in Appendix 6.

Table 51. Treatment list for NIAB TAG experiment year 2 (2010/11): Vision Guidance

	Treatment	Delivery	Nozzles Type	Pressure, Bar	Flow, L/min	Height, cm	Application Volume, L/ha	Chemicals Inter-row	Over-row	Guidance System
1.	Untreated	-						-	-	-
2.	Kerb Flo (over-all Oct)	-	"03" 110° Conventional	3.0	1.200	50.0	192	-	-	Standard
3.	Narrow band (150 mm)	No shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	None (Standard)
4.	Narrow band (150 mm)	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	None (Standard)
5.	Narrow band (150 mm)	No shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	Vision Guidance
6.	Narrow band (150 mm)	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	Vision Guidance

Notes:

Kerb Flo (propyzamide, 500 g/L SC, Dow) applied at 2.1 L/ha on the 29/09/10

Roundup Energy (glyphosate, 450 g/L SL, Monsanto) applied at 1.6 L/ha on the 22/11/10

Table 52. Treatment list for NIAB TAG experiment year 2 (2010/11): RTK DGPS

Treatment	Delivery	Nozzles				Application Volume, L/ha	Chemicals		Guidance System
		Type	Pressure, Bar	Flow, L/min	Height, cm		Inter-row	Over-row	
1 Untreated	-						-	-	-
2 Kerb Flo (over-all Oct)	-	“03” 110° Conventional	3.0	1.200	50.0	192	-	-	Standard
3 Narrow band (150 mm)	No shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	None (Standard)
4 Narrow band (150 mm)	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	None (Standard)
5 Narrow band (150 mm)	No shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	RTK
6 Narrow band (150 mm)	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	RTK
7 Narrow band (150 mm)	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	RTK
8 Narrow band (150 mm)	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate – late Sept	-	RTK

Notes:

Kerb Flo (propyzamide, 500 g/L SC, Dow) applied at 2.1 L/ha on the 28/09/10

Roundup Energy (glyphosate, 450 g/L SL, Monsanto) applied at 1.6 L/ha on the 22/11/10

ORC Treatments Year 2 (and 3) refer to Appendix 7

In both trials in years 2 and 3, four treatments were compared against each other:

1. Untreated control (no mechanical weeding and no herbicide applications)
2. Herbicide treatment (current farm practice)
3. Mechanical weed control in autumn, without Vision Guidance
4. Mechanical weed control as above, with Vision Guidance (Garford "Robocrop" hoe, Appendix 6).

The trial design was a randomized complete block design with 4 replicates. The four blocks were situated adjacent to each other, so that the trial layout consisted of 16 adjacent long strips (Figure 46). This trial design allowed an appropriate lead-in for the mechanical weed control treatments, where both accuracy and speed of the weeding process were expected to improve on the first few metres from starting in each strip. The length of the strips was ~120 m in the first year and ~60 m in the second year. The trial area was situated >20 m from field boundaries to reduced edge effects. Further details are shown in Figure 46. In the year 2 trial, tramlines ran perpendicular to the plots; therefore taking measurements in these areas was avoided.

Figure 46. Layout of ORC trials.

5.2.4. Measurements and assessments

Crop and weed assessments were done in autumn before and after the mechanical weeding and again in the following spring. Crop and weed cover (%) were estimated visually, using a 0.25 m^2 sectioned quadrat, placed diagonally in the row; track lines were avoided.
Crop and weed density (plants/m^2) were determined by counting crop and weed plants in two adjacent 1 m rows. Between 2 and 4 assessment points (subplots) per plot were used for cover assessments and counts. In addition, crop height was measured in 5 plants per sampling point. The crop growth stage at each assessment date was determined in 20 randomly selected plants for the whole trial area (i.e. not per plot). The 3 most dominant weed species were determined at each site and further notes were taken on other weed species.
Data in the ORC trials was subjected to one-factorial analysis of variance, using the programme R, version 2.14.2. Results are presented as relative treatment effects, i.e. using the relative difference D between each of the three treatments T_i and the untreated control C ($D = (T_i-C)/C*100\%$). All graphs presented in the results section show untransformed means and standard error.

5.2.5. Year three

SAC Year three of the project, 2011–12

The aim of year three of the SRUC study was to build on the need for shielding to minimise crop damage and to further evaluate different types of shielding. The Garfords all-round shield was compared with a simple horizontal, plate type shield at two timings GS 1,3 and GS 1,5. In some seasons a dry period followed by subsequent moisture can result in further flushes of weeds. To account for secondary flushes of weeds, sequences of glyphosate at GS 1,3 and then again at GS 1,5 were compared with single applications. Crops grown on wide rows are not competitive along the row due to the need for the lower plant populations. To account for this glyphosate, inter-row was compared with intra-row applications of metazachlor. By applying metazachlor intra-row the total dose/hectare is vastly reduced thus lowering the potential for losses to the environment. The SRUC trials in year three again looked to see if there were varietal differences in the potential for crop damage that may occur due to applications. The trial was compared with a standard over-all application of metazachlor.

Site:

SRUC: Boghall Farm, Bush Estate, Penicuik, Edinburgh

Table 53. SAC Protocol Year 3, Trial 1

	Treatment	Inter-row	Intra-row	GS applied	Nozzle size and angle, °
1	50 cm inter-row spacing	Untreated		-	-
2	50 cm inter-row spacing	Metazachlor over-all		1,2	"03" 110
3	Wide band – conventional shield	Glyphosate		1,3	"02" 40
4	Wide band – Garfords shield	Glyphosate		1,3	"02" 40
5	Wide band – no shield	Glyphosate		1,3	"02" 40
6	Wide band – convention shield	Glyphosate	Metazachlor	1,3	"02" 40
7	Narrow band – conventional Shield	Glyphosate		1,3	"01" 25
8	Narrow band– Garfords shield	Glyphosate		1,3	"01" 25
9	Narrow band – no shield	Glyphosate		1,3	"01" 25
10	Narrow band – convention shield	Glyphosate	Metazachlor	1,3	"01" 25
11	Narrow band – conventional shield	Glyphosate		1,5	"01" 25
12	Narrow band – Garfords shield	Glyphosate		1,5	"01" 25
13	Narrow band – no shield	Glyphosate		1,5	"01" 25
14	Narrow band – conventional shield	Glyphosate	Metazachlor	1,5	"01" 25
15	Wide band – conventional shield Fb Narrow band – conventional shield	Glyphosate Glyphosate		1,3 1,5	"02" 80

Table 54. SAC Protocol Year 3, Trial 2

Variety	Treatment	Inter-row (2 leaf)	GS applied	Nozzle size and angle, °
Catana	50 cm inter-row spacing	Untreated	-	-
Catana	50 cm inter-row spacing	Metazachlor (over-all)	1,2	"03" 110
Catana	Wide conventional shield	Glyphosate	1,5	"02" 40
Catana	Wide Garfords shield	Glyphosate	1,5	"02" 40
Catana	Metazachlor intra-row fb Narrow band – conventional shield	Metazachlor Glyphosate	1,3 1,5	"03" 110 "01" 25
Excalibur	50 cm inter-row spacing	Untreated		
Excalibur	50 cm inter-row spacing	Metazachlor (over-all)	1,2	"03" 110
Excalibur	Wide conventional shield	Glyphosate	1,5	"02" 40
Excalibur	Wide Garfords shield	Glyphosate	1,5	"02 40
Excalibur	Metazachlor intra-row fb Narrow band conventional shield	GS 13 GS 15	1,3 1,5	"03" 110 "01" 25

Note: Fb = followed by

NIAB TAG Year three 2011–12

Research undertaken in year 3 by NIAB TAG was carried out in Cambridgeshire. Two experiments were located on the same farm in a field crop drilled using RTK guidance on wide rows (as standard practice for the farm site). Both experiments used RTK guidance within subsequent application treatments, which were again based around glyphosate (Roundup Energy, Monsanto) and propyzamide (Kerb Flo, Dow). With the exception of herbicides all inputs were as farm practice. Research in year 3 included techniques examining aspects of shielding, application timing and the use of multiple or combination strategy approaches.

Study 1 considered the use of three application timings (September, November and January – resulting in three differing crop canopy characteristics), with and without the use of a simple shielding approach (as used in season 2) and included specific combined approaches (i.e. repeated applications to the inter-row gap at a series of timings and the use of combined inter-row (glyphosate) and over-row (propyzamide) treatments).

Study 2 compared three approaches to shielding (unshielded, the simple shielding used in year 2 and a new Garford hooded shield) across two application timings (September and November) and also included a specific combined approach to apply inter-row glyphosate and over-row propyzamide. Pictures of the shield types are provided in Appendix 6.

Table 55. Treatment list for NIAB TAG study 1 in year 3 (2011/12) using RTK DGPS

		Nozzles				Application	Chemicals		
	Treatment	**Type**	**Bar Pressure**	**Flow, l/min**	**Height cm**	**Volume, L/ha**	**Inter-row**	**Over-row**	**Timing**
1	Untreated						-	-	-
2	Kerb Flo (over-all Oct)	“03” 110° Conventional	3.0	1.200	50.0	192	-		Standard
3	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Mid-Sept
4	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Early-Nov
5	Garford shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Mid-Sept
6	Garford shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Early-Nov
7	No shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Mid-Sept
8	No shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Early-Nov
9	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Mid-Sept
10	With shield	“01” 25° Even spray	2.0	0.327	33.8	175	-	Kerb Flo	Early-Nov

Table 56. Treatment list for NIAB TAG study 2 in year 3 (2011/12) using RTK DGPS

	Treatment	Nozzles Type	Bar Pressure	Flow, l/min	Height cm	Application Volume, L/ha	Chemicals Inter-row	Over-row	Timing
1	Untreated						-	-	-
2	Kerb Flo (over-all Oct)	"03" 110° Conventional	3.0	1.200	50.0	192	-		Standard
3	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Late-Sept
4	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Mid-Nov
5	Garford shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Early-Jan
6	Garford shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Late-Sept
7	No shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Mid-Nov
8	No shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Early-Jan
9	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate	-	Late-Sept
10	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate		Mid-Nov
11	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	Glyphosate		Early-Jan
12	With shield	"01" 25° Even spray	2.0	0.327	33.8	175	-	Kerb Flo	Early-Nov

ORC treatments Year three

Refer to Appendix 6 for ORC treatment list in year three.

The aim of the study in year three was to repeat the trial of the previous year, this time at the NIAB TAG research farm in Cambridge. The aim was to further evaluate the use of Vision Guidance as a means of guiding a mechanical hoe as means of replacing herbicides in winter rape grown on wide rows. This had proved effective in the first year of the study. Three treatments were compared against each other:

1. Untreated control (no mechanical weeding and no herbicide applications)
2. Herbicide treatment (current farm practice)
3. Mechanical weed control in autumn, without camera

Data was subjected to one-factorial analysis of variance, using the programme R, version 2.14.2. Results are presented (Figures 57–65) as relative treatment effects, i.e. using the relative difference, D, between each of the three treatments, T_i, and the untreated control, C ($D = (T_i - C)/C*100\%$). All graphs presented in the results section show untransformed means and standard errors.

5.3. Results

5.3.1. SAC results

SAC Results Year 1 2009–10

The aim of the project in year one was to screen a range of approaches to applying glyphosate to the inter-row gap of a winter rape crop grown on wide rows and to both assess any crop damage and compare the weed control and with current standard herbicide practice. The treatments are as set out in Table 53 and results are presented in Table 57, Table 58, Table 59, and Table 60. Table 57 compares a standard pre-emergence (metazachlor) herbicide at 12 cm and 50 cm. As expected, the standard metazachlor treatments significantly improved weed control compared to the untreated at both spacings ($P < 0.05$). Comparing the untreated at the 50 cm spacing to the untreated at the 12 cm row spacing there was a significant improvement in weed control at the October assessment, but this was not reflected in the spring assessment timing. The LAI of the treatments was measured using a Delta T Sun Scanner on the 22nd April at early flower, Table 60 and Table 61. As expected, the untreated showed a high LAI as the ground cover was more than 100%. There was no difference within a treatment or between the 12 and 50 cm row spacing ($P<0.05$).

Table 57. Impact of row spacing on weed control and crop damage

Treatment	Damage, % leaf tipping 31st October	% Weed cover 31st October inter-row	Damage, % leaf tipping 18th March	% Weed cover 18th March inter-row	% Weed cover 22nd April inter-row	Weed free gap cm, 22nd April	Over-all weed cover as a % 25th May
Untreated @ 50 cm	5	71	47	85	87	3	70
MTZ over-all @ 12 cm spacing	7	15	33	3	18	12	5
MTZ over-all a @ 50 cm spacing pre-em	7	13	45	15	30	17	15
Narrow (01:25) Nozzle + RDP 2.0 L/Ha	17	31	36	28	38	15	60
Even spray 02:80 degree nozzle + RDP 2.0 L/ha	22	13	47	12	19	38	65
Micron Hood + 2.0 L/ha RDP	20	11	47	33	62	12	50
Twisted 02:110 Tapered (twisted) nozzle	15	27	57	23	29	30	70
LSD $P<0.05$	6.9	10.7	21	17.4	23	8.6	n/a

Note: MTZ = Butisan containing 500g/L metazachlor

RDP = Roundup Energy 450g/L glyphosate

Table 57 shows that all glyphosate treatments applied inter-row caused a significant degree of tipping compared to metazachlor applied over-all ($P<0.05$), although all treatments had evened out by March. Two weeks after treatment there was some separation in the effectiveness of the nozzle types. The 25 degree nozzle delivered too narrow a spray footprint to give effective weed control in a 50 cm inter-row gap. Both the Micron and the 80 degree even-spray nozzles gave the best initial weed control due their wide spray footprints, Table 57. In the March assessment, the even-spray 80 degree nozzle showed similar levels of weed control to the standards (over-all metazachlor), Table 57. At this assessment, the Micron system showed significantly poorer weed control within the inter-row gap compared to the standard treatment at ($P<0.05$). This is partially explained by the non-standard way this equipment was mounted and the less than ideal seed bed which resulted in small spray droplets from the spinning discs within the Micron shield escaping out the sides of the shield as the spray rig went over bumps. The 80 degree even-spray nozzle stood out above the others, assessment on the 22nd April (Table 57) gave the widest weed-free gap in the inter-row space followed by the twisted 110 degree standard nozzle. By 22nd April the crop would have been well into stem extension and early flower. Interestingly all treatments had broken down by the 25th May compared to the standard. This is a reflection on the replacement of a residual herbicide with a contact herbicide. Depending on the weed flora in a particular field this would be important.

The addition (a tank-mix) of a residual herbicide, such as metazachlor, to glyphosate should have improved weed control to the inter-row gap to control further flushes of weeds, Table 59. However there was no significant benefit at ($P<0.05$) of tank-mixing metazachlor to glyphosate as shown in the March and April assessments. The application of metazachlor intra-row gave poor results. This may have been due to timing when there were emerged weeds. Metazachlor works best pre-emergence. By the 25th of May all the glyphosate treatments had broken down compared to the over-all metazachlor even where metazachlor had been applied intra-row. Metazachlor has little post-emergence activity hence the poor results from the intra-row treatment as shown in Table 58.

The Leaf Area Index (LAI) assessments are shown in Table 61, assessed on the 22nd April at GS 3.6–3.7 using a Delta T Sun Scanner. The HGCA Oilseed rape guide 2012 indicates that a LAI of 3.5 is optimum at flowering. The metazachlor standards shown in Table 59 are about optimum LAI at GS 3.7. The measurements for crop plus weed LAI relate to the level of weed control shown in Table 57 and Table 59. The higher the weed count the higher the crop plus weed LAI. When you remove the effect of the weeds and compare nozzle types there are some big reductions in LAI, with the metazachlor combinations showing the biggest reductions. The standard over-all metazachlor applications gave good weed control as indicated by the consistent figures in both columns.

The narrow 25 degree nozzle stands out with a high crop and weed LAI due to the narrow spray footprint of this nozzle. The low figures for the twisted nozzle and even-spray 80 degree nozzles were due to the amount of damage incurred from these application systems although they did give good weed control, as indicated in the crop plus weed assessments. There was a significant benefit at ($P<0.05$) of the addition of metazachlor applied intra-row compared to glyphosate on its own inter-row on crop LAI and comparable to the standards.

Table 58. Comparing different nozzle types for damage and weed control

Treatment	**Damage, % leaf tipping 31st October**	**% Weed cover 31st October inter-row**	**Damage, % leaf tipping 18th March**	**% Weed cover 18th March inter-row**	**% Weed cover 22nd April inter-row**	**Weed free gap cm, 22nd April**	**Over-all % weed control 25th May**
Narrow (01:25) nozzle + RDP 2.0 L/Ha	17	31	35	28	38	15	60
Even spray 02:80 degree nozzle + RDP 2.0 L/ha	22	13	47	11	19	38	65
Micron Hood + 2.0 L/ha RDP	20	11	47	33	62	12	50
Twisted 02:110 tapered nozzle	15	27	57	23	29	30	70
Untreated @ 50 cm	5	71	47	85	87	3	70
LSD P<0.05	6.9	10.7	21	17.4	23	8.6	n/a

Note: RDP = Roundup Energy containing 450 g/L glyphosate

Table 59. Comparing the impact of adding metazachlor at different rates to glyphosate inter- and intra-row in comparison straight Roundup on weed control

Treatment	% Weed cover 31st October inter-row	% Weed cover 18th March inter-row	% Weed cover 22nd April inter-row	Weed free gap cm, 22nd April
Untreated At 50 cm spacing	72	85	87	3
Even-spray With 80 degree nozzle No hood	13	11	19	38
RDP 2.0 L/ha Micron Hood	17	19	53	17
RDP 2.0L/ha inter-row MTZ 1.5 L/ha Over-row With Micron Hood	12	33	62	12
RDP 2.0 L/ha + MTZ 1.5 L/ha With Micron Sprayer Inter-row	17	26	43	10
RDP 2.0 L/ha + MTZ 1.0 L/ha Inter-row With Micron Sprayer	17	25	57	13
LSD $P < 0.05$	10.7	17	23	8.6

Note: RDP= Roundup Energy 450 g/L glyphosate and MTZ = Butisan 500 g/L metazachlor

Table 60. Impact of row spacing on LAI early spring and the benefits of herbicide

Treatment	Crop LAI above weeds 22nd April	Crop + weed LAI 22nd April
Crop at 12 cm row Spacing + 1.5 L/ha MTZ	2.8	3.1
Crop at 50 cm row spacing + 1.5 L/ha MTZ	2.7	2.9
Untreated 50 cm spacing	1.5	7.3
Untreated 12 cm spacing	2.4	6.8
LSD P < 0.05	0.46	1.2

Table 61. Impact of nozzle type with and metazachlor treatments at early stem extension on Leaf Area Index (LAI)

Treatment	Crop LAI above weeds 22nd April	Crop + weed LAI 22nd April
Untreated at 50 cm spacing	1.5	7.3
Narrow (01:25) nozzle + RDP 2.0 L/ha	2.7	3.3
Even spray 02:80 degree nozzle + RDP 2.0 L/ha	1.4	1.5
Micron Hood + 2.0 L/ha RDP	1.8	2.2
Twisted 02:110° tapered (twisted) nozzle	1.2	1.5
Even spray With 80° nozzle No hood	1.0	1.5
RDP 2.0 L/ha inter-row MTZ 1.5 L/ha over-row With Micron hood	3.0	3.3
RDP 2.0 L/ha+ MTZ 1.5 L/ha With Micron sprayer Inter-row	2.0	2.2
RDP 2.0 L/ha + MTZ 1.0 L/ha Inter-row With Micron sprayer	2.0	2.8
LSD	0.46	1.2

Note: RDP is Roundup. MTZ = Novall (metazachlor 400g/L + quinmerac 100g/L)

SAC Year 2, 2010–11

Research in year two of the project augmented the narrow even-spray nozzles though the additions / use of a simple shield. The results from year one indicated that the narrow even-spray nozzle and the Micron Varidome, both of which have a narrower spray footprint compared to a convention 110 degree flat fan nozzle, reduced the potential for crop damage. The research also examined different application timings as there was an indication from year one that damage was to some extent related to growth stage (crop development) and could be reduced with earlier applications to smaller crops. There was also a need to look at the impact on different variety types with different growth habits that may or may not increase the risk of damage from an inter-row application. The need for sequences to account for further flushes of weeds and the use of sequences of selective and non-selective herbicides inter-row and intra-row was also seen as promising in year one and was evaluated further in year two. The results are shown in Table 62 to Table 66.

Table 62. Comparison between row spacing and herbicide treatment

Treatment	Number of plants/m^2 6/10/10	Plant damage 6/10/10 0–9 scale, 9 = no damage	Plant damage 28/10/10 0–9 scale, 9 = no damage	Weed control 28/10/10 Percent (%)	Weed cover 30/03/11 Percent (%)	Yield t/ha
Untreated at 12 cm row spacing	98	9	9	85.5	33	5.95
Untreated at 50 cm row spacing	37	9	9	74.4	67	5.59
MTZ over-all at 12 cm row spacing	98	9	9	96.7	8.3	5.99
MTZ over-all at 50 cm row spacing	47	9	9	92.2	6.7	5.76
LSD P<0.05	15.3	1.8	1.4	10.3	21.9	0.82

Note: MTZ = Novall, 400 g/L (metazachlor + 100 g/L quinmerac @ 1.5 L/ha)

Table 62 shows the benefit on row spacing and the standard herbicide application. As expected, increasing the inter-row spacing significantly reduced the number of plants/m^2 ($P<0.05$). The pre-emergence application of a metazachlor-based treatment (Novall, BASF) gave almost 100% weed control. There was no significant yield benefit from increasing the row spacing or from using a herbicide application.

Table 63. Comparison of glyphosate (RDP) inter-row at GS 1,2 with or without combinations or sequences of Novall (MTZ) inter- or intra-row, all at 250 mm spray footprint

Treatment	Number of plants/m^2 6/10/10	Plant damage 6/10/10, 0–9 scale, 9 = no damage 39DAT	Plant damage 28/10/10, 0–9 scale, 9 = no damage 58DAT	Weed control 28/10/10 Percent (%) 59DAT	Weed cover 30/03/11 Percent (%)	Yield t/ha
MTZ over-all at 50 cm row spacing	98	9	9	96.7	8.3	5.99
MTZ 1.5 L over-all at 12 cm	86	9	9	96.7	8.3	6.01
RDP 1.6 L + MTZ 1.5 L with Micron Hood, inter-row	35	5.3	5.3	70	56.7	4.84
RDP 1.6 L with Micron Hood, inter-row	39	5.7	6.3	66.7	66.7	4.59
MTZ 1.5 L intra-row Micron Hood	19	9	9	77.7	26.7	5.85
RDP 1.6 L inter-row, MTZ 1.5 L intra-row	37	6.3	6.0	81.1	33.3	5.00
LSD P<0.05	15.3	1.8	1.4	10.3	21.9	0.82

Table 63 shows the application of glyphosate using the Micron Varidome shield caused significant crop damage compared to the standards at (P<0.05). There was a significant benefit from the sequence of glyphosate inter-row followed by metazachlor intra-row on weeds 59 DAT, although this was not reflected in March assessment. All treatments where glyphosate was used and applied using the Micron Varidome alone or in the combination with metazachlor reduced yield significantly at (P<0.05).

Table 64. Comparison of shielding with two different even spray nozzles, a "01" 25° to give a 150 mm footprint and a "02"40° to give a 300 mm footprint with glyphosate applied inter-row at GS 1,3 (3 true leaves)

Treatment	Number of plants/m^2	Plant damage 6/1010 0–9 scale, 9 = no damage	Plant damage 28/10/10 0–9 scale, 9 = no damage	Weed control 28/10/10 Percent (%)	Weed cover 30/03/11 Percent (%)	Yield t/ha
Untreated	37	7	9	60.3	66.7	5.59
MTZ over-all	47	9	9	92	6.7	5.76
Narrow 150 mm, even-spray nozzle, unshielded	35	9	9	81.1	36.7	5.65
Narrow 150 mm, even-spray nozzle, shielded	36	9	9	81.1	33.3	5.82
Wide, 300 mm, even-spray nozzle, unshielded	43	6.7	7	77.1	50.0	5.12
Wide, 300 mm, even-spray nozzle, shielded	44	8.7	9	86.6	26.7	5.62
LSD P <0.05	15.3	1.8	1.4	10.3	21.9	0.82

Note: All planted at 50 cm spacing

MTZ = Novall (metazachlor 400g/L + quinmerac 100g/L)

Table 64 describes the effect of shielding and nozzle type at the early GS 1,3 timing. The early timing at GS 1,3 should result in less crop damage as the inter-row gap is the widest at this point in the growth of the crop. The results show a significant (P<0.05) reduction in damage from using a shield when using the wider footprint nozzle ("02" 40°). When using the narrow ("01" 25°) nozzle there was no benefit from using the shield in terms of crop damage with similar levels to the control.

The best overall spring weed control (lowest cover of weeds) was from the standard Novall treatment but the use of the shield with the wide nozzle was at least as good at (P<0.05) as the standard over all application of metazachlor. The shielded and wide nozzle gave significantly better weed control than the unshielded narrow nozzle.

Apart from the unshielded “02” 40° nozzle all treatments significantly increased weed control compared to the untreated. However there was no significant benefit in yield from any treatment at (P<0.05). There was an indication that the unshielded wide “02” 40° nozzle that showed early crop damage checked yield.

Table 65. Comparison of shielding with two different even spray nozzles, a “01” 25° to give a 150 mm footprint and a “02”40° to give a 300 mm footprint with glyphosate applied inter-row at 5 true leaves of the crop (GS 1,5)

Treatment	Number of plants/m^2	Plant damage 6/1010 0–9 scale, 9 = no damage	Plant damage 28/10/10 0–9 scale, 9 = no damage	Weed control 28/10/10 Percent (%)	Weed cover 30/03/11 Percent (%)	Yield t/ha
Untreated	37	7	9	60.3	66.7	5.59
MTZ Over-all	47	9	9	92	6.7	5.76
Narrow 150 mm, even-spray nozzle, unshielded	41	7	9	88.9	8.3	5.71
Narrow 150 mm, even-spray nozzle, shielded	36	9	8.7	81.1	27.7	5.87
Wide, 300 mm, even-spray nozzle, unshielded	36	9	7	85.6	15	4.98
Wide, 300 mm, even-spray nozzle, shielded	37	9	8.7	88.9	13.3	5.83
LSD P <0.05	15.3	1.8	1.4	10.3	21.9	0.82

Table 65 shows results at the later timing of GS 1,5. At GS 1,5 the inter-gap is reduced as leaves start to fill in the rows. The results show a clear benefit from the use of the shield compared to the unshielded treatments in a reduction in crop damage at the 28th October assessment, some 61 days after application. This was significant at (P<0.05) with the wider “02” 40° nozzle.
All treatments gave significant increases in weed control compared to the untreated at the spring assessment. The inter-row treatments were not significantly different from the standard over-all application of metazachlor.

The results showed that the wide unshielded “02” 40° nozzle significantly lowered yield at (P<0.05) compared to the shielded nozzle at the GS 1,5 timing. This reflected the low damage scores in the autumn and despite good weed control scores.

Table 66. Comparison between variety types, different nozzles to give different spray footprints (mm) and shields with a conventional over-all application of metazachlor (unshielded Figures are shown in brackets)

Treatment	**MTZ over-all**		**Varidome at 250 mm**		**Even-spray nozzle, Shielded at 150 mm**		**Even-spray nozzle, shielded at 300 mm**	
Variety	**Castille**	**Excalibur**	**Castille**	**Excalibur**	**Castille**	**Excalibur**	**Castille**	**Excalibur**
Plant damage 6/1010, 0–9 scale, 9 = no damage LSD 2.1	9	9	3.3	5	9 (9)	9 (9)	9 (5.3)	4.7 (5.3)
Plant damage 28/10/10, 0–9 scale, 9 = no damage, LSD 1.60	8.3	9	3.3	5	9 (9)	9 (9)	9 (7.3)	6.3 (7.3)
Weed control 28/10/10, 0–9 scale, 9 = no damage, LSD 0.88	8.7	8.7	6.7	7	7.3 (8.3)	7.7 (8)	7.7 (8)	7 (7.7)
Weed cover 30/03/11 Percent (%), LSD 21.6	8.3	8.3	30.0	40.0	26.7 (20)	33.3 (23.3)	26.7 (16.7)	33.3 (26.7)
Yield t/ha LSD 1.00(t/ha) P<0.05	5.46	5.83	2.97	3.58	5.33 (5.6)	5.40 (5.49)	5.48 (4.91)	4.45 (4.59)

Note: The even-spray nozzles are “01” 25° to give a narrow 150 mm footprint and a “02” 40° to give a wider spray footprint

Table 66 compares two different varieties with treatments applied at GS 1,5. Application of glyphosate inter-row using the Varidome CDA system caused significantly more crop damage than even-spray nozzles. Comparing the even-spray nozzles there was no significant difference in crop damage between and within varieties using the narrow nozzle, shielded or unshielded at ($P<0.05$) for both Castile and Excalibur. With the wider footprint even-spray nozzle there was significantly more damage from the Excalibur with no benefit from shielding.

The over-all application of metazachlor gave the best weed control at the spring assessment. There was no significant difference in spring weed control between the over-all metazachlor standard and unshielded inter-row treatments for both even-spray nozzle types at ($P<0.05$). There was also no significant difference in weed control from shielding and no shielding within a variety and across the two varieties, although there was slightly better weed control when the nozzles were not constrained by the shield.

In terms of yield, the Varidome treatment significantly reduced yield across both varieties compared to the standard and other inter-row treatments at ($P<0.05$). There was no significant yield difference between the standard and the narrow nozzles whether shielded or unshielded with both varieties. Excalibur benefited from shielding and narrow nozzle. The wide nozzle is not suited to Excalibur, whether shielded or not, indicating there are differences in growth structure between varieties and the timing of an inter-row application of glyphosate

SAC Year 3, 2011–12

Table 67. Comparison of shield type, nozzle (“01” 25° v “02” 40°) and metazachlor sequences on weed control and yield (t/ha) applied at GS 1,3

Treatment	**Plant damage, 0–9 scale, 18/11/11**	**Weed control, 0–9 scale, 18/11/11**	**% Weed cover inter-row, 23/03/12**	**% Weed cover intra-row 23/03/12**	**Over-all weed control 0–9, scale 15/05/12**	**Yield t/ha**
Untreated	9	1	166.7	166.7	1	3.27
Elk 2.5 L (50 cm spacing) @ GS 1,2	9	2.3	48.3	65	3.7	4.43
Narrow band – no shield “01” 25°	9	7.7	3.3	47	6.7	4.17
Narrow band – conv. shield, “01” 25°	9	5.7	30.0	73	4.3	3.9
Narrow band “01” 25° Garford shield	9	7.7	3.3	63	5.3	4.20
Wide band – No shield “02” 40°	2	8.7	3.3	25	5.3	1.87
Wide conv shield,“02” 40°	8	7.7	3.3	38	7.3	4.10
Wide Garford shield, “02” 40°	8.7	6.3	3.3	67	4.7	4.33
RDP, wide band inter-row – conv. shield, “02” 40° + MTZ intra-row @ GS 1,3	7.3	7.3	1.7	38	6.3	4.53
RDP, narrow conv. shield, ”01” 25° + MTZ intra-row @ GS 1,3#	9	6.7	93.3	35	6.3	3.23
LSD	1.1	1.2	42.4	36	3.0	0.77

Note: MTZ was Elk 2.5 L/ha (metazachlor + dimethenamid-p + quinmerac)

RDP was Roundup Max 1.5 L/ha

This treatment was applied in reverse in error. The MTZ was applied at GS 1,2 and the glyphosate at GS 1,3

Table 68. Comparison of shield type at the later timing of GS 1,5 and glyphosate sequences

	Plant damage, 0–9 scale, 18/11/11	Weed control, 0–9 scale, 18/11/11	% Weed cover inter-row, 23/03/12	% Weed cover intra-row 23/03/12	Over-all weed control 0–9, scale 15/05/12	Yield t/ha
Untreated	9	1	166.7	166.7	1	3.27
Elk 2.5 L (50 cm spacing)@ GS 1,2	9	2.3	48.3	65	3.7	4.43
Narrow band						
Conventional shield	9	5.7	40	67	5.7	4.27
“01” 25° nozzle						
Narrow band						
Garfords shield	9	5.3	25	90	3.7	3.93
“01 25° nozzle						
Narrow band No shield “01” 25°	9	5	15	87	5	3.87
RDP & wide band						
Conventional shield with						
“02” 40° @ GS 1,3	7.7	8	0	38	6.3	3.8
fb RDP & narrow band						
with “01” 25° @ GS 1,5						
LSD	1.1	1.2	42.4	36	3	0.77

Table 69. The comparison between shield type and nozzle on two contrasting varieties applied at GS 15

	Untreated		MTZ Over-all applied @GS 1,2, (Elk))		Narrow nozzle, ("01" 25°) &conventional shield		Wide nozzle ("02" 40°) & Garfords shield		MTZ (Elk) intra-row@ GS 1,3 followed by narrow band, conventional shield @ GS 1,5	
	Catana	**Excalibur**	**Catana**	**Excalibur**	**Catana**	**Excalibur**	**Catana**	**Excalibur**	**Catana**	**Excalibur**
Plant damage, 0–9 scale, 27/10/11, LSD 0	9		9	9	9	9	9	9	9	9
Plant damage, 0–9 scale, 18/11/11, LSD 0	9	9	9	9	9	9	9	9	9	9
Weed control, 0–9 scale, 18/11/11, LSD 1.10	1.3	1.3	2	2	5	5	4	4	6.7	5.3
% Weed cover. Intra-row, 26/03/12, LSD 33.7	160	150	28.3	33.3	30.0	30.0	50.0	33.3	3.3	8.3
% Weed cover. Inter-row, 26/03/12, LSD 32.1	160	150	70	76.7	103	93.3	113.3	113.3	46.7	73.3
Yield, t/ha, LSD 0.832	2.57	2.53	3.73	3.67	2.90	2.83	2.77	2.70	3.87	3.93

Note: MTZ is Elk (metazachlor + dimethenamid-p + quinmerac)

SAC Results Year 3

Having identified that even-spray nozzles could deliver glyphosate successfully to the inter-row gap of rape grown on wide rows and that shielding was beneficial, particularly at the later timings, the next step was to look at shield types. A simple plate type was used in year two but an all-round shield, as produced by Garfords, might be better especially in more adverse conditions or on different varieties which were previously identified as a problem. Year three looked at two timings, at 3 leaves and 5 leaves of the crop and two even-spray nozzles, an “01” 25° and an “02” 40° and the two shield types, the Garfords and the simple plate.

The yield (t/ha) results in year three were substantially lower than in year two. The standard herbicide, Elk (metazachlor + dithenamid-P +quinmerac) was applied early post-emergence in year three as opposed to pre-emergence in year two and did not give as good weed control as the glyphosate treatment but still yielded (Table 67). This illustrated the benefits of a contact herbicide in some years compared to a residual herbicide and that it is possible to make the substitution in some circumstances where the weed spectrum allows. The benefits of shielding were clear but there was no significant distinction between shield types, although there was some tendency for better weed control with the conventional shield at the later timings and a slight but not significant yield benefit at ($P<0.05$) (Table 67 and Table 68). Comparing the two nozzles types there was a clear benefit from using a shield when using the wider nozzle but not necessarily with the narrower “01” 25° nozzle (Table 67). The glyphosate sequence, Table 68, gave the better over-all weed control both in the autumn and spring with a yield as good as the standards but no better than single applications. In the second year of the study there was a tendency for Excalibur to show more damage than Catana due to different growth habit but this proved not to the case in year three of the study. Although there was no difference in damage between the two varieties compared to the standard, the trial did show a reduction in yield compared to the standard (Elk) across the two nozzle types (Table 69). This is possibly due to variation across the field as the yield results were equal if not better than the standard where Elk was applied intra-row in sequence with glyphosate inter-row across the two varieties (Table 69).

5.3.2. NIAB TAG Results Years 1 – 3

NIAB TAG Year 1, 2009/10

Research was undertaken by NIAB TAG in a farm crop in Oxfordshire in year 1 to test a range of systems for the delivery of a defined glyphosate (Roundup Energy, Monsanto) footprint to the inter-row gap in a wide row oilseed rape crop; treatments are as presented in Table 24. It should be noted that several of the techniques employed used a range of novel approaches, including the use of nozzles that would not be used commonly in agricultural scenarios and the non-standard use of existing specialised delivery systems (including the Micron Varidome).

Glyphosate application was delayed until January due to inclement autumn weather followed by protracted snow cover over the winter. Consequently, applications scheduled for October / November were made in January in cooler conditions, which may have inhibited the speed of activity of the glyphosate and given less time for the propyzamide to take effect prior to spring assessments; this should be considered within the evaluation of data from this experiment.

Crop damage (on a 1–9 scale where 9 is no damage) and row integrity (on a 1–9 scale where 9 represents complete / intact rows) were assessed approximately 6 weeks (04/03/10) and 10 weeks (01/04/10) post application; data is presented in Table 70.

Table 70. The effect of treatment on row integrity (1–9 where 9 represents complete rows over the plot), crop damage (1–9 where represents 9 no herbicide damage) in the NIAB TAG experiment in Oxfordshire in year 1 (2009/10)

	Product	*Band width*	*Comment*	*Row integrity (1–9)*		*Crop damage (1–9)*	
				04/03/10	01/04/10	04/03/10	01/04/10
1.	Untreated	-	-	7.7	8.0	8.7	7.3
2.	Kerb Flo	Whole plot	Standard approach – wide row (FF110)	8.0	8.0	8.3	7.7
3.	Roundup Energy	30 cm inter-row band	Micron Hooded applicator (30 cm twist)	7.3	7.3	8.3	6.3
4.	Roundup Energy	30 cm inter-row band	'Narrow' nozzle (25°) with no hood	6.7	5.0	4.3	4.7
5.	Roundup Energy	30 cm inter-row band	Twisted nozzle (FF110 twisted to 45°)	3.0	1.0	1.3	1.3
6.	Roundup Energy	30 cm inter-row band	Even spray nozzle (80° nozzle twisted to 45°)	2.0	1.0	1.7	1.3
7.	Kerb fb Roundup Energy	Over row only fb Inter-row band only	Narrow nozzle (25°) Narrow nozzle (25°)	4.7	4.3	4.3	4.7
8.	Roundup Energy	20 cm inter-row band	Micron Hooded applicator (straight)	7.0	4.7	6.3	4.7
9.	Roundup Energy	20 cm inter-row band	Twisted nozzle (FF110 twisted to 80°)	3.7	2.0	2.7	2.3
10.	Roundup Energy	20 cm inter-row band	Even spray nozzle (40° nozzle twisted to 45°)	7.7	4.7	4.0	4.3
11.	Untreated	-	-	8.3	8.7	8.7	8.3
LSD				2.17	2.00	1.96	2.28
P value				P=0.0001	P=0.0001	P=0.0001	P=0.0001
CV (%)				21.2	22.1	23.2	27.8

Table 71. The effect of treatment on oilseed rape plant population within the row and black-grass, other grass weeds and other broadleaf weeds between the row. All counts per m^2 taken on 04/03/10. NIAB TAG experiment in Oxfordshire in year 1

Product	Band width	Comment	OSR (per m^2)	Black-grass (per m^2)	Other grasses (per m^2)	Other broadleaf (per m^2)
Untreated	-	-	63.1	8.0	3.6	24.9
Kerb Flo	Whole plot	Standard approach – wide row (FF110)	55.1	12.9	5.8	25.3
Roundup Energy	30 cm inter-row band	Micron Hooded applicator (30 cm twist)	46.2	17.8	1.8	10.7
Roundup Energy	30 cm inter-row band	'Narrow' nozzle (25°) with no hood	48.9	5.8	1.3	29.3
Roundup Energy	30 cm inter-row band	Twisted nozzle (FF110 twisted to 45°)	20.0	4.9	2.2	6.22
Roundup Energy	30 cm inter-row band	Even spray nozzle (80° nozzle twisted to 45°)	31.1	6.7	1.8	14.2
Kerb fb Roundup Energy	Over row only fb Inter-row band only	Narrow nozzle (25°) Narrow nozzle (25°)	41.3	6.2	1.8	16.5
Roundup Energy	20 cm inter-row band	Micron Hooded applicator (straight)	45.3	6.2	5.3	13.8
Roundup Energy	20 cm inter-row band	Twisted nozzle (FF110 twisted to 80°)	28.0	8.0	3.6	7.1
Roundup Energy	20 cm inter-row band	Even spray nozzle (40° nozzle twisted to 45°)	37.3	9.8	12.0	12.0
Untreated	-	-	51.1	15.6	2.2	9.8
LSD			26.65	10.04	6.30	15.69
P Value			NS (P= 0.09)	NS (P=0.59)	P=0.05	NS (P=0.18)
CV			36.8	68.8	80.3	48.1

The highest degree of row integrity and lowest levels of crop damage were associated with untreated plots (treatments 1 and 11) and the ‘standard’ propyzamide-based (Kerb Flo, Dow) approach (treatment 2) on both dates. Of the ‘inter-row’ footprint approaches, the greatest levels of crop damage and reduction in row integrity were generally associated with the simple twisted nozzle-based approaches (treatments 5, 6 and 9). The lower levels of damage and greatest retention of row integrity from the ‘inter-row’ approaches were associated with the use of narrow footprint even-spray nozzles and the Micron hooded sprayer (treatments 3, 4, 8 and 10). Treatment 7, the combined approach for inter-row glyphosate and over row propyzamide, was similar to the other narrow footprint even-spray nozzles at the second assessment timing, although did appear slightly more damaging at the first assessment timing.

Further data were also collected on the 04/03/10 and are presented in Table 71. At this timing while there were no significant differences in the oilseed rape populations there were some marked reductions in populations that were worthy of note; these were typically associated with the treatments where greater crop damage and reduced row integrity had been apparent. With regard to grass and broadleaf weed species, there were no meaningful changes in the numbers recorded between treatments; but this is probably a reflection of the late application and relatively short timeframe to assessment. A series of photographs of the crop effects observed with specific treatments and the equipment used are presented in Appendix 6.

Table 72. The effect of the presence or absence of a precision guidance system (± RTK) and simple shielding (± S) for the inter-row application of glyphosate on oilseed rape plant populations (plants per m²) within and between the rows on the 22/10/10 and 07/02/11. Treatments are compared to 'paired untreated' areas on both dates and to a standard treatment of propyzamide (Kerb Flo, Dow) on the second date.

	22/10/10								07/02/11							
	In row (per m²)				Between row (per m²)				In row (per m²)				Between row (per m²)			
	Treated plot	*SEM*	*Untreated plot*	*SEM*	*Treated plot*	*SEM*	*Untreated plot*	*SEM*	*Treated plot*	*SEM*	*Untreated plot*	*SEM*	*Treated plot*	*SEM*	*Untreated plot*	*SEM*
+S +RTK	29.4	3.79	35.2	3.88	0.4	0.30	6.4	1.25	25.4	2.30	25.7	2.94	1.3	0.99	4.0	0.82
+S - RTK	28.7	3.90	31.9	2.61	0.6	0.37	7.0	0.64	23.7	2.39	24.4	2.79	1.0	0.57	3.4	0.53
-S + RTK	25.9	2.12	26.8	2.20	0.6	0.43	9.1	1.00	19.9	1.33	22.1	1.19	0.7	0.42	6.1	0.55
-S - RTK	28.2	2.48	26.3	2.35	1.0	0.53	9.2	1.28	19.7	1.32	17.8	1.19	2.2	1.37	6.6	1.17
Average	*28.1*		*30.1*		*0.65*		*7.93*		*22.2*		*22.5*		*1.3*		*5.0*	
Kerb Flo									24.1	1.37	24.1	1.21	5.0	0.92	3.8	0.67

Table 73. The effect of the presence or absence of a precision guidance system (± Vision Guidance, VG) and simple shielding (± S) for the inter-row application of glyphosate on oilseed rape plant populations (plants per m^2) within and between the rows on the 22/10/10 and 07/02/11. Treatments are compared to 'paired untreated' areas on both dates and to a standard treatment of propyzamide (Kerb Flo, Dow) on the second date.

	22/10/10								**07/02/11**							
	In row (per m^2)				**Between row (per m^2)**				**In row (per m^2)**				**Between row (per m^2)**			
	Treated plot	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***
+S +VG	24.7	2.06	23.3	1.06	0.4	0.21	3.9	0.35	12.8	0.13	16.0	0.89	0.5	0.35	3.3	0.43
+S - VG	19.5	0.93	19.1	0.24	1.9	0.17	4.7	0.05	17.4	0.39	14.2			0.13	2.6	0.16
-S + VG	16.1	1.56	23.0	3.20	0.5	0.53	5.1	1.53	15.3	1.38	14.6	0.81	0.7	0.51	2.8	0.89
-S - VG	18.6	0.31	17.9	0.20	0.2	0.04	2.8	0.19	15.6	0.47	12.8	0.13	1.1	0.07	2.8	0.10
Average	19.7		20.8		0.7		4.1		15.3		14.4		0.9		2.9	
Kerb Flo									15.3	0.28	18.1	0.08	3.0	0.18	1.6	0.07

NIAB TAG Year 2 Results summary

Following the inter-row application of glyphosate, in both the RTK and Vision Guidance studies, comparing paired treated and untreated plots there was no strong indication of any loss of oilseed rape crop plants within the row at either assessment timing, regardless of the presence or absence of guidance or shielding approaches (Table 72 and Table 73 respectively). In the RTK study the mean within row oilseed rape populations across all treatments was 28 plants per m^2 (treated plots) and 30 plants per m^2 (untreated plots) in October and around 22 plants per m^2 (in treated and untreated plots) by February. In the Vision Guidance study the mean oilseed rape populations across all treatments were 20 plants per m^2 (treated plots) and 21 plants per m^2 (untreated plots) in October and 15 plants per m^2 (treated plots) and 14 plants per m^2 (untreated plots) by February. Where inter-row glyphosate was applied there was clear evidence of a reduction in volunteer oilseed rape populations between the rows for both RTK and Vision Guidance approaches (Table 72 and Table 73 respectively); although there was little indication of any influence of impact of guidance or shielding on the reduction achieved. In the RTK study the oilseed rape populations between the rows, mean across all treatments, were <1 plant per m^2 in treated plots compared to 8 plants per m^2 in untreated plots in October. An analogous comparison in February revealed around 1 plant per m^2 in treated plots and 5 plants per m^2 in untreated plots post winter. Similarly in the Vision Guidance study the oilseed rape population between the rows, mean across all treatments, was <1 plants per m^2 in treated plots compared to 4 plants per m^2 in untreated plots in October, while the analogous February assessment indicated <1 plants per m^2 in treated plots and 3 plants per m^2 in untreated plots.

The effect of treatment on grass weeds (Table 74 pertaining to RTK and Table 75 Vision Guidance) and broadleaf weeds (Table 76 pertaining to RTK and Table 77 Vision Guidance) are also presented. It should be noted that the level of control achieved was from a single glyphosate treatment, which was intended to examine primarily the capability of the positioning systems. Where inter-row glyphosate was applied, for both grass and broadleaf weeds, there were no strong indications of any influence of guidance system or shielding on the levels of weed reduction achieved. With regard to grass weeds there was evidence of a reduction in the level of grass-weeds between the rows where a single glyphosate treatment had been applied (relative to the populations in untreated plots that had not received such an application). This reduction also appeared to be retained between the October and February assessment dates. While the effect was less marked with broadleaved weeds, a similar pattern was observed. While this finding is indicative of encouraging levels of weed control from a single application of glyphosate it also suggests that timing and / or the number of applications of a non-residual herbicide (e.g. glyphosate) will be a factor in the effective management weeds over the winter period should such a system be employed. For both grass and broadleaf weeds the level of control delivered by propyzamide was limited; although it is likely that the February assessment timing was too early to pick out the full effect of this herbicide treatment.

Table 74. The effect of the presence or absence of a precision guidance system (± RTK) and simple shielding (± S) for the inter-row application of glyphosate on grass weed populations (plants per m^2) within and between the rows on the 22/10/10 and 07/02/11. Treatments are compared to 'paired untreated' areas on both dates and to a standard treatment of propyzamide (Kerb Flo, Dow) on the second date.

	22/10/10								**07/02/11**							
	In row (per m^2)				**Between row (per m^2)**				**In row (per m^2)**				**Between row (per m^2)**			
	Treated plot	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***
+S +RTK	7.5	2.29	11.8	3.17	2.8	0.45	6.9	1.34	6.7	1.86	6.0	2.51	4.1	1.29	5.3	1.68
+S - RTK	7.6	2.64	10.7	3.41	14.6	4.35	27.3	6.06	5.6	1.61	4.1	1.61	1.8	0.51	3.4	1.33
-S + RTK	12.9	5.96	7.9	1.91	3.7	2.30	9.1	1.76	15.4	3.10	6.1	1.18	2.9	1.66	5.4	1.23
-S - RTK	12.9	2.24	13.2	3.10	6.0	1.91	14.5	2.54	12.7	2.32	5.1	1.10	5.3	1.43	5.0	0.67
Average	10.2		10.9		6.8		14.4		10.1		5.3		3.5		8.3	
Kerb Flo									0.9	0.32	1.6	0.62	0.2	0.15	2.2	1.28

Table 75. The effect of the presence or absence of a precision guidance system (± Vision Guidance, VG) and simple shielding (± S) for the inter-row application of glyphosate on grass weed populations (plants per m^2) within and between the rows on the 22/10/10 and 07/02/11. Treatments are compared to 'paired untreated' areas on both dates and to a standard treatment of propyzamide (Kerb Flo, Dow) on the second date.

	22/10/10								**07/02/11**							
	In row (per m^2)				**Between row (per m^2)**				**In row (per m^2)**				**Between row (per m^2)**			
	Treated plot	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***
+S +VG	3.7	1.31	7.0	0.92	0.7	0.33	5.4	1.19	3.0	0.81	1.9	1.50	1.2	0.76	2.5	1.19
+S - VG	2.8	0.11	1.8	0.11	0.9	0.06	2.8	0.14	1.4	0.13	1.4	0.10	0.5	0.05	0.9	0.11
-S + VG	4.2	1.83	6.1	3.37	1.2	0.45	2.5	0.58	2.1	0.45	0.5	0.57	0.5	0.21	1.2	0.66
-S - VG	2.1	0.10	2.1	0.10	0.4	0.08	3.7	0.14	1.6	0.13	1.8	0.14	0.4	0.05	1.2	0.15
Average	3.2		4.3		0.8		3.6		2.0		1.4		0.7		1.5	
Kerb Flo									0.5	0.05	0.5	0.08	0.9	0.09	1.2	0.08

Table 76. The effect of the presence or absence of a precision guidance system (± RTK) and simple shielding (± S) for the inter-row application of glyphosate on broad-leaf weed populations (plants per m^2) within and between the rows on the 22/10/10 and 07/02/11. Treatments are compared to 'paired untreated' areas on both dates and to a standard treatment of propyzamide (Kerb Flo, Dow) on the second date.

	22/10/10								**07/02/11**							
	In row (per m^2)				**Between row (per m^2)**				**In row (per m^2)**				**Between row (per m^2)**			
	Treated plot	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***
+S +RTK	25.4	6.12	24.5	5.23	9.8	1.62	21.6	4.55	26.9	7.41	22.5	4.76	10.1	1.91	19.4	4.78
+S - RTK	33.5	9.44	31.9	8.85	14.6	4.35	27.3	6.06	26.2	7.87	23.1	7.08	17.0	4.65	21.5	4.79
-S + RTK	26.5	6.79	24.2	5.27	11.1	2.47	22.5	2.86	34.1	8.16	19.2	5.74	17.7	3.79	13.5	3.23
-S - RTK	32.8	10.14	22.4	5.91	13.0	2.02	20.3	5.76	20.2	5.58	10.4	2.26	7.8	1.77	8.2	1.50
Average	29.6		25.8		12.1		22.9		26.9		18.8		13.2		15.7	
Kerb Flo									17.1	6.77	15.4	4.33	12.7	5.53	11.6	4.25

Table 77. The effect of the presence or absence of a precision guidance system (± Vision Guidance, VG) and simple shielding (± S) for the inter-row application of glyphosate on broad-leaf weed populations (plants per m^2) within and between the rows on the 22/10/10 and 07/02/11. Treatments are compared to 'paired untreated' areas on both dates and to a standard treatment of propyzamide (Kerb Flo, Dow) on the second date.

	22/10/10								**07/02/11**							
	In row (per m^2)				**Between row (per m^2)**				**In row (per m^2)**				**Between row (per m^2)**			
	Treated plot	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***	***Treated plot***	***SEM***	***Untreated plot***	***SEM***
+S +VG	4.0	1.99	2.1	0.59	0.5	0.35	2.3	0.35	3.0	1.22	3.2	0.90	1.1	0.51	0.9	0.28
+S - VG	0.5	0.08	0.9	0.09	0.9	0.06	1.1	0.24	0.4	0.05	0.4	0.05	0.5	0.08	1.2	0.15
-S + VG	4.4	3.14	0.2	0.18	2.5	2.03	1.4	1.40	2.1	1.13	0.0	0.00	0.9	0.28	0.7	0.43
-S - VG	1.1	0.14	1.6	0.24	0.2	0.04	1.6	0.13	2.1	0.24	0.9	0.15	1.1	0.07	0.7	0.07
Average	2.5		1.2		1.0		1.6		1.9		1.1		0.9		0.9	
Kerb Flo									0.7	0.07	2.1	0.24	0.4	0.05	1.6	0.14

Oilseed rape population within the row in NIAB TAG Study 1 in 2011/12 assessed in March ranged from 20 to 33 plants/m^2 (Figure 47). Differences between treatments were small and, with the exception of the treatment applied in January in the absence of shielding (labelled Glyphosate – S, Jan), all populations were higher than the untreated. Considering the number of volunteer oilseed rape plants found between the rows, in keeping with findings from year 2, compared to untreated and propyzamide-only treatments, there was a general tendency for the use of inter-row glyphosate treatments to reduce the number of oilseed rape volunteers between the rows (Figure 48). There was some suggestion of a lesser reduction associated with the January application; it is possible that this is just an anomaly in the data or perhaps is an indication that cooler conditions had restricted the activity of the January inter-row glyphosate application.

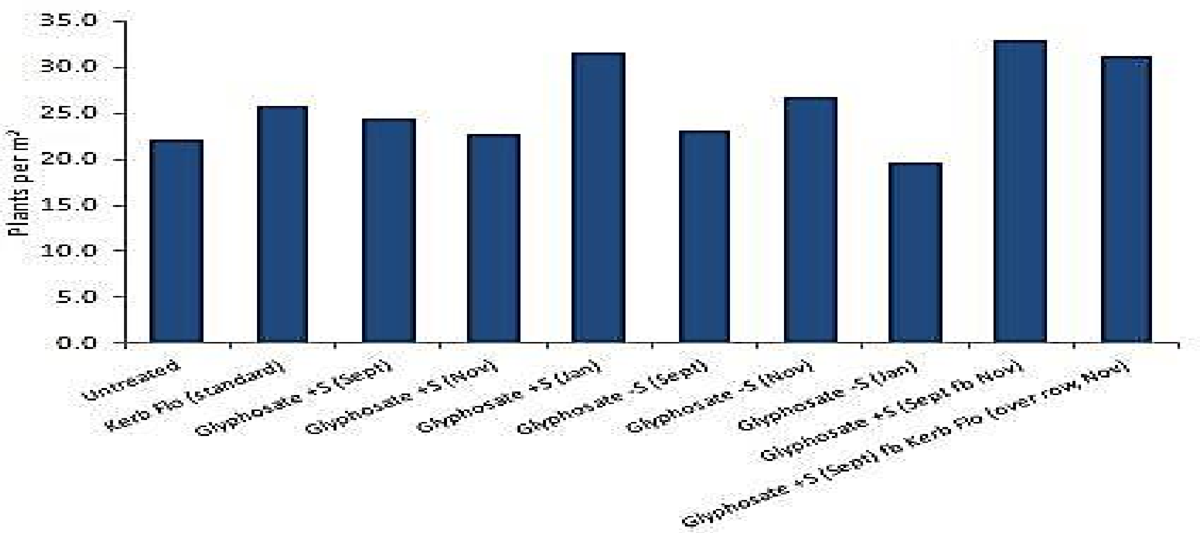


Figure 47. The effect of inter-row glyphosate application treatment, with or without simple shielding (±S), on oilseed rape plant populations within the row (plants per m^2). Assessment was undertaken on the 14/03/12 and the bracketed dates indicate application timing (Study 1 in Cambridgeshire).

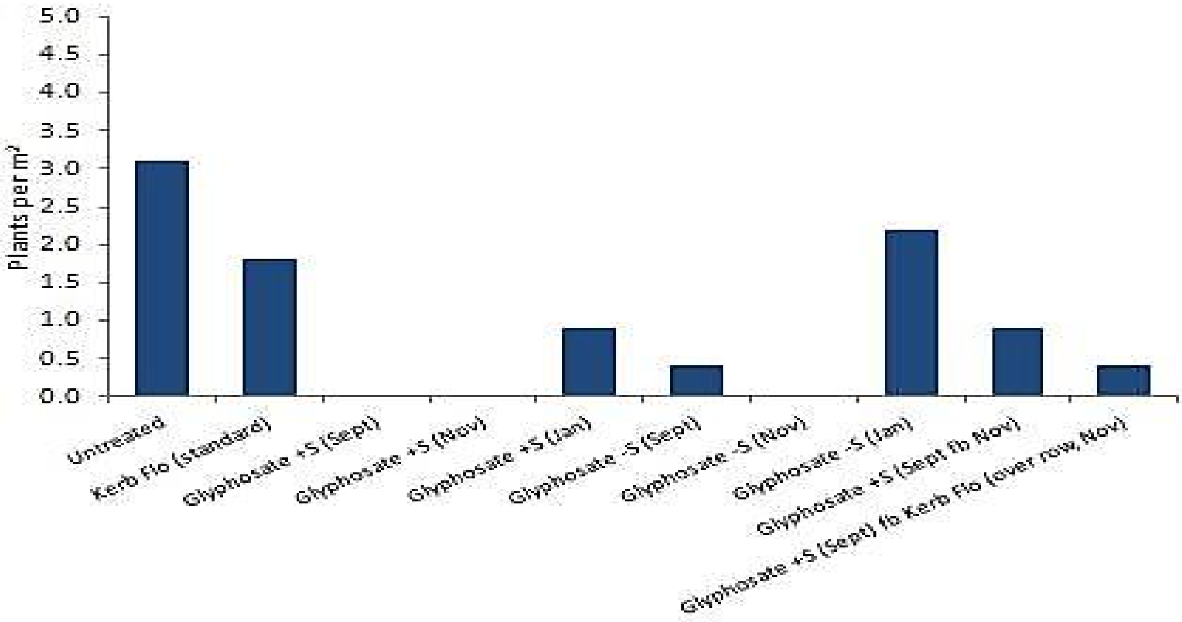


Figure 48. The effect of inter-row glyphosate application treatment, with or without simple shielding (±S), on oilseed rape plant populations between the rows (plants per m^2). Assessment was undertaken on the 14/03/12 and the bracketed dates indicate application timing (Study 1 in Cambridgeshire).

Some crop damage was noted in particular assessments (Figure 49 and Figure 50). A January assessment (made around the time of the January glyphosate application) indicated damage from inter-row glyphosate treatments applied in November; although it should be noted that the level of crop damage was reduced where simple shielding was used. Similarly, an assessment of crop damage made in March indicated damage associated primarily with the inter-row glyphosate treatments made in January; again damage was greater where shielding had not been used. There was no appreciable crop damage associated with any other treatment at either assessment timing.

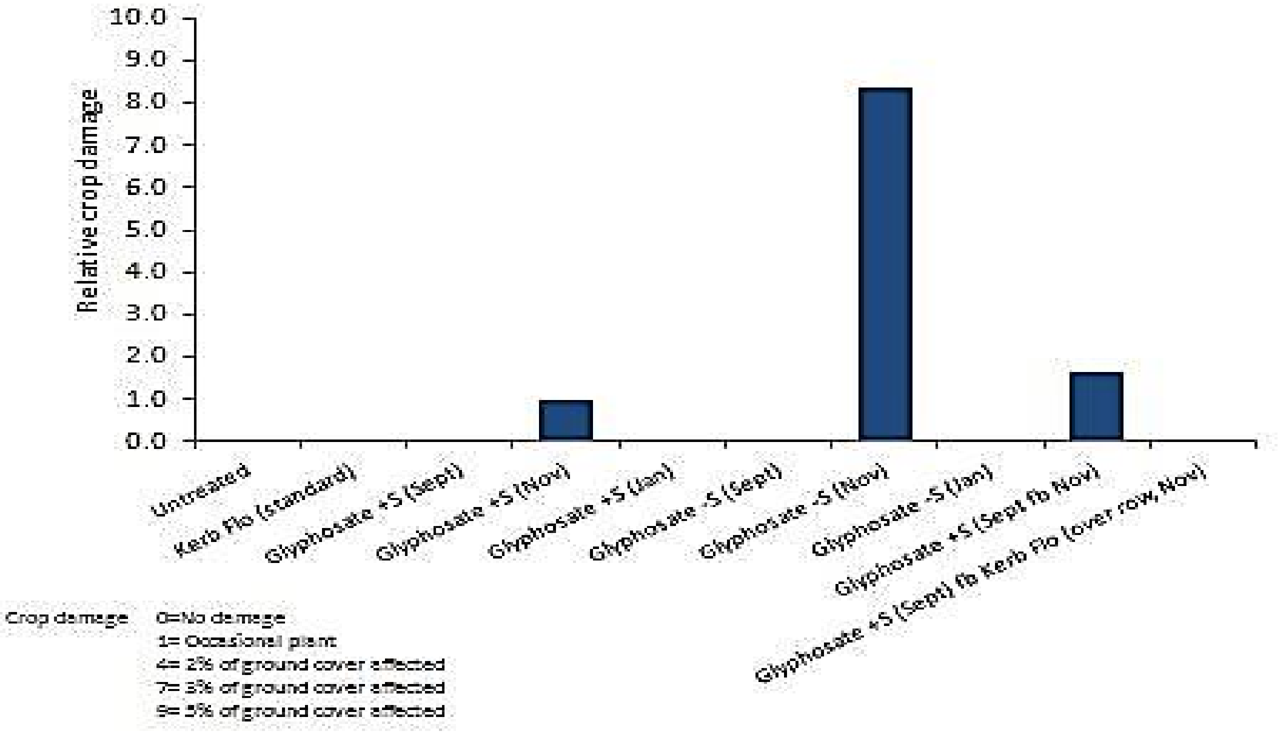


Figure 49. The effect of inter-row glyphosate application treatment, with or without simple shielding (±S), on crop damage (relative score). Assessment was undertaken on the 27/01/12 and the bracketed dates indicate application timing (Study 1 in Cambridgeshire).

Weed levels between the rows were assessed in March, as a percentage ground cover of weeds; levels were generally low (Figure 51). The highest ground cover was associated with untreated plots; peaking at around 10% ground cover. Weed levels from the September inter-row glyphosate timings were marginally higher than those of other treatment (perhaps suggesting that this early timing was not maintaining persistence as well as other timings), however, in general all other timings and approaches gave similar levels of weed control to the standard treatment based on propyzamide (Kerb Flo, Dow). Considering weed control ‘within rows’, data collected in March also compared the untreated plots, with a standard propyzamide-based approach over the entire plot, and a treatment where propyzamide had only been applied over the rows using RTK guidance (in conjunction with an inter-row glyphosate application). Weed ground cover levels within the row in these scenarios were: 8.3% (untreated), 4.0% (propyzamide, full plot) and 4.7% (propyzamide, over-row); indicating that both approaches with the propyzamide reduced weed levels similarly.

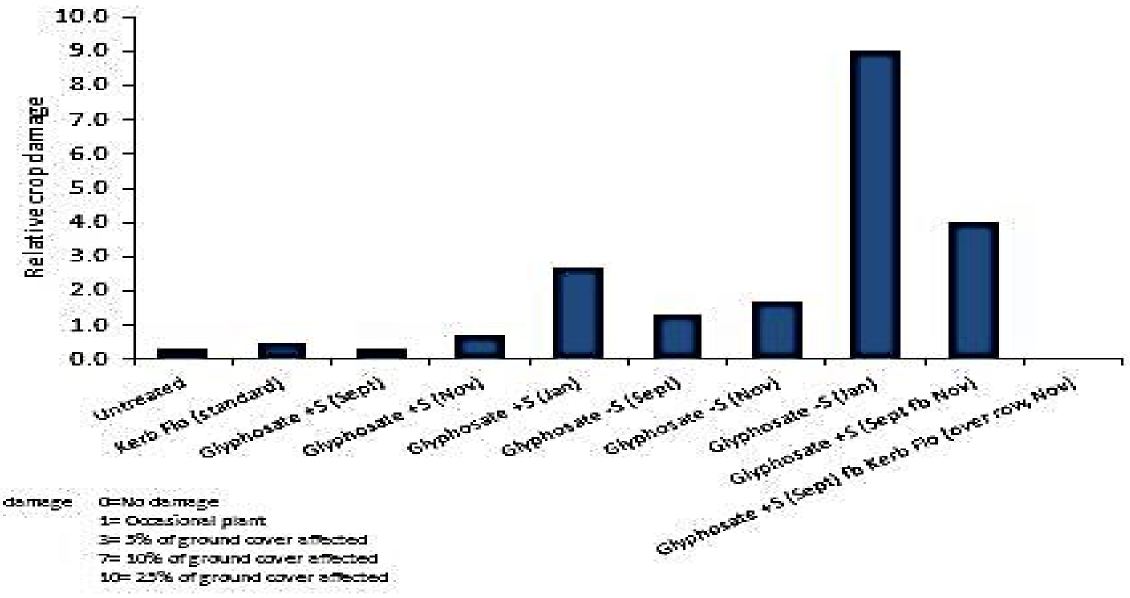


Figure 50. The effect of inter-row glyphosate application treatment, with or without simple shielding (±S), on crop damage (relative score). Assessment was undertaken on the 14/03/12 and the bracketed dates indicate application timing (Study 1 in Cambridgeshire).

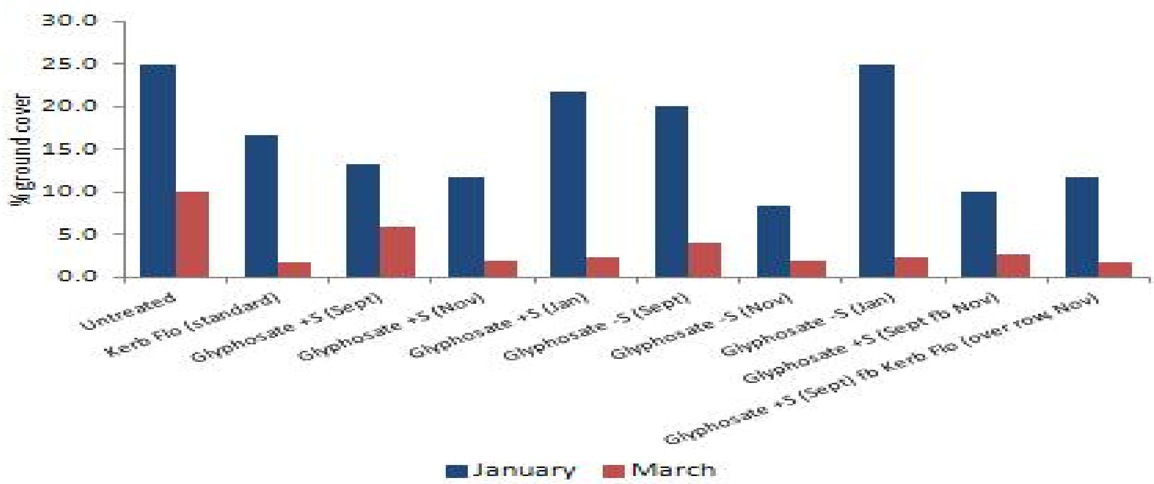


Figure 51. The effect of inter-row glyphosate application treatment, with or without simple shielding (±S), on weed populations between the rows (plants per m^2). Assessment was undertaken on the 09/01/12 and the 14/03/12 and the bracketed dates indicate application timing (Study 1 in Cambridgeshire).

Yields from Study 1 are presented in Figure 52; yields were good and typically around 5 t/ha. None of the treatments resulted in any significant yield differences compared to either untreated plots or the propyzamide-based (standard) approach. The highest yield, around 5.5 t/ha, was associated with a repeat September and November application of glyphosate to the inter-row gap while using a simple shielding system, the lowest yield of around 4.5 t/ha was associated with an unshielded inter-row application of glyphosate made in November.

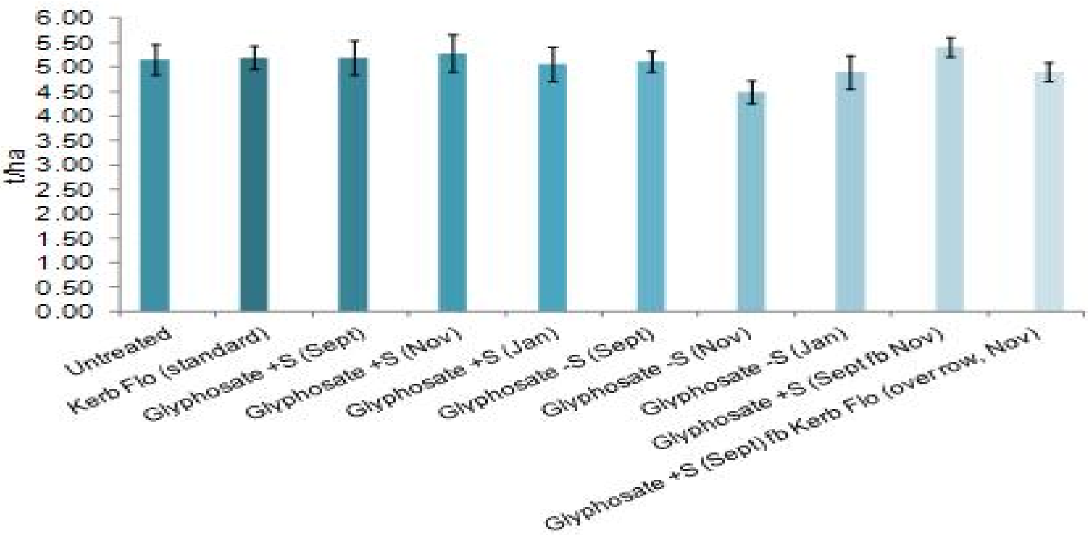


Figure 52. The effect of inter-row glyphosate application treatment, with or without simple shielding (±S), on oilseed rape yield (t/ha), data presented ± SEM. Bracketed dates indicate application timing (Study 1 in Cambridgeshire).

Oilseed rape populations within the row in NIAB TAG Study 2 in 2011/12, assessed in March, ranged from around 40 to 60 plants/m^2 (Figure 53). All populations in treated plots were higher than those in untreated plots, although there were no clear differences between treatments. With regard to oilseed rape volunteers between the rows (Figure 54), while data in Study 2 was very variable and levels were low in untreated plots, results were broadly in keeping with those from year 2; specifically compared to the standard propyzamide-based approach there was some tendency for inter-row glyphosate treatments to reduce the number of volunteers.

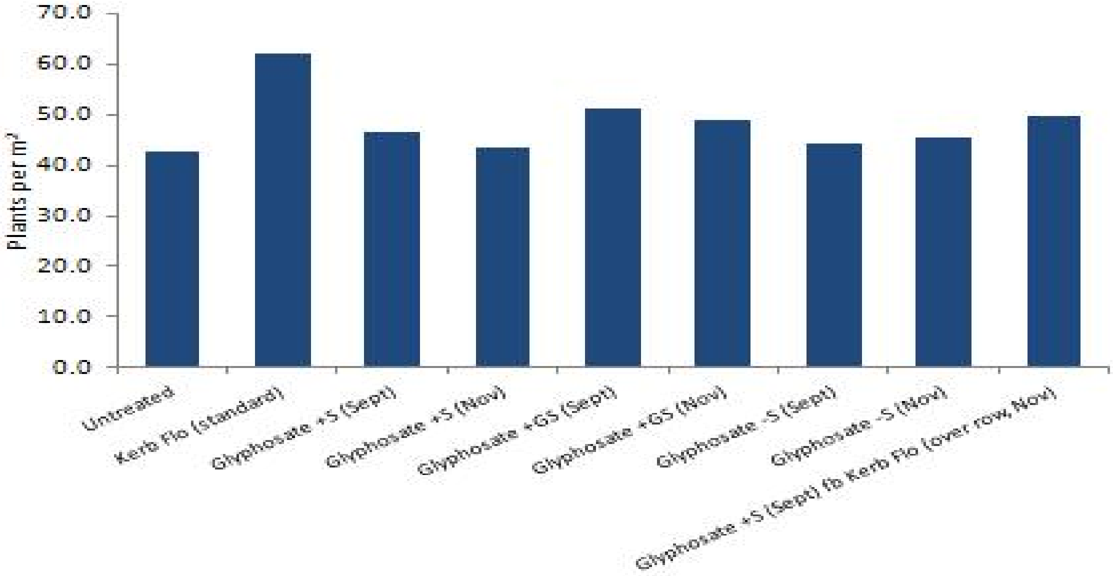


Figure 53.The effect of inter-row glyphosate application treatment, with or without shielding (simple shielding (±S) and Garford shield (±GS)) on oilseed rape plant populations within the row (plants per m²). Assessment was undertaken on the 14/03/12 and the bracketed dates indicate application timing (Study 2 Cambridgeshire).

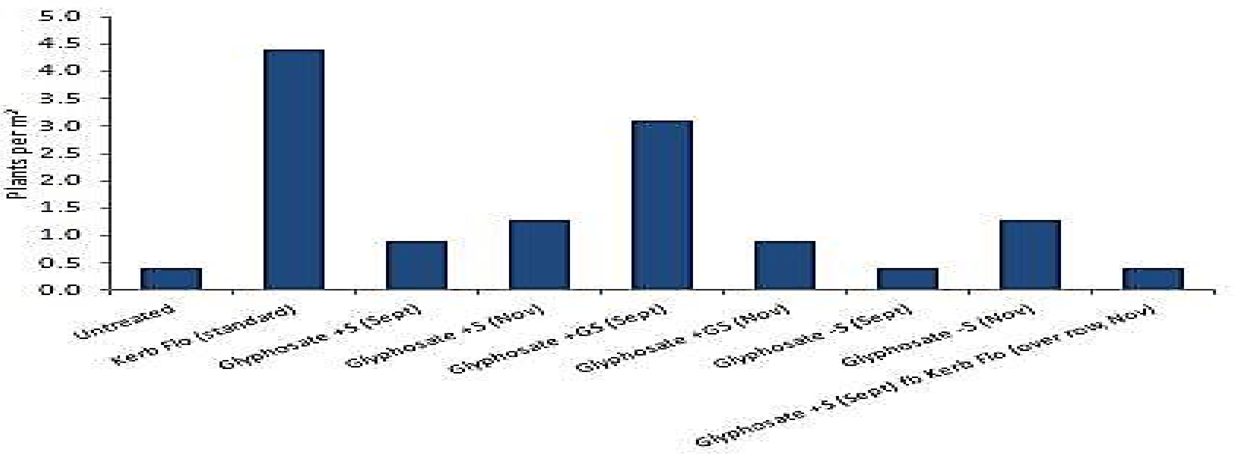


Figure 54. The effect of inter-row glyphosate application treatment, with or without shielding (simple shielding (±S) and Garford shield (±GS)), on oilseed rape plant populations between the rows (plants per m²). Assessment was undertaken on the 14/03/12 and the bracketed dates indicate application timing (Study 2 in Cambridgeshire).

Some crop damage was noted within this experiment (Figure 55). A January assessment indicated damage from inter-row glyphosate treatments applied in November; although the level of crop damage was reduced where either a Garford shield or the simple shielding approach was used as compared to an unshielded nozzle. A further assessment for crop damage was also made in March; by this point levels were very low and there was little apparent difference between treatments (data not shown).

Weed levels in Study 2 were assessed as a percentage ground cover score in January and March. On both occasions weed levels remained very low (0–2.5% ground cover) and no differences were apparent between any treatments (data not shown). Yields in Study 2 were also more variable than those is Study 1. Yields were typically around 3.5 – 4.5 t/ha and there were no differences between treatments (Figure 56).

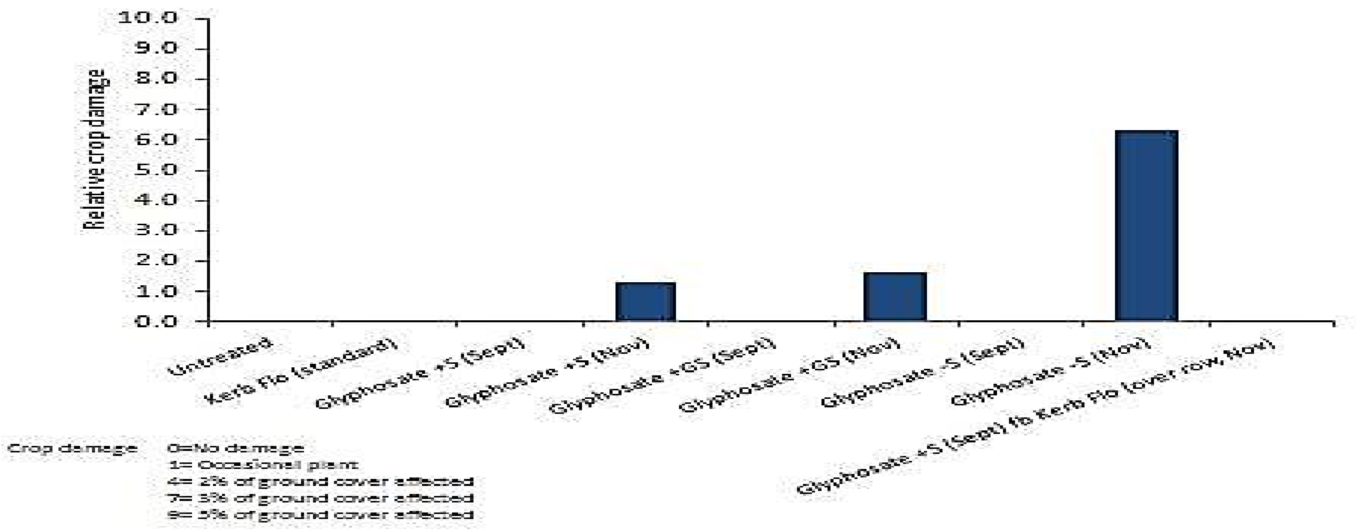


Figure 55. The effect of inter-row glyphosate application treatment, with or without shielding (simple shielding (±S) and Garford shield (±GS)), on crop damage (relative score). Assessment was undertaken on the 27/01/12 and the bracketed dates indicate application timing (Study 2 in Cambridgeshire).

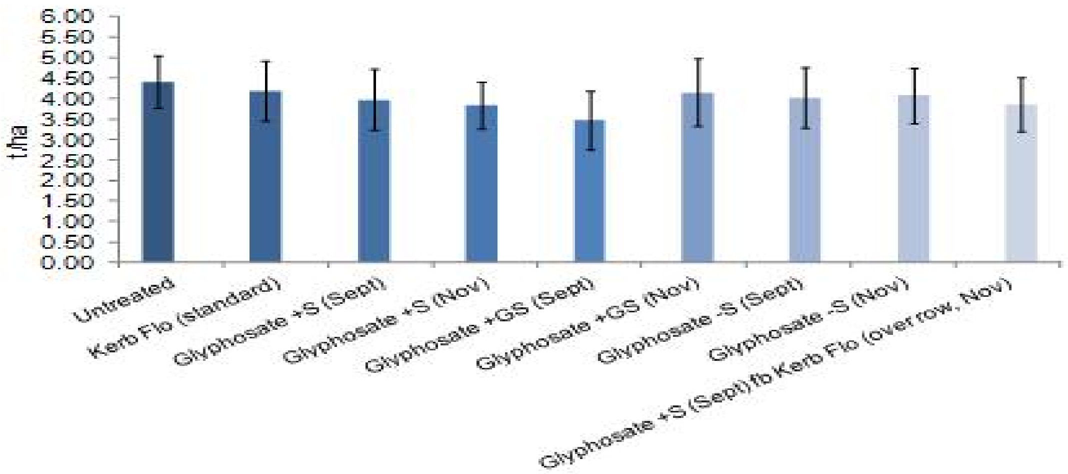


Figure 56. The effect of inter-row glyphosate application treatment, with or without shielding (simple shielding (±S) and Garford shield (±GS)), on oilseed rape yield (t/ha), data presented ± SEM. Bracketed dates indicate application timing (Study 2 in Cambridgeshire).

5.3.3. ORC Years 2 (2010–11) and 3 (2011–12)

The accuracy of removing weeds by means of mechanical weeding can be improved by using vision guidance (camera systems). Both unguided and guided mechanical weeding treatments were compared with an untreated control and current practice of herbicide application.

Assessments showed that weed cover was much higher in the year 2 trial than in year 1 trial (Figure 57). Interestingly, weed cover increased from autumn to spring in year 1, but declined from over this period in year 2. Prior to the mechanical weeding treatment, there were no significant differences between the treatments and the control (Figure 58).

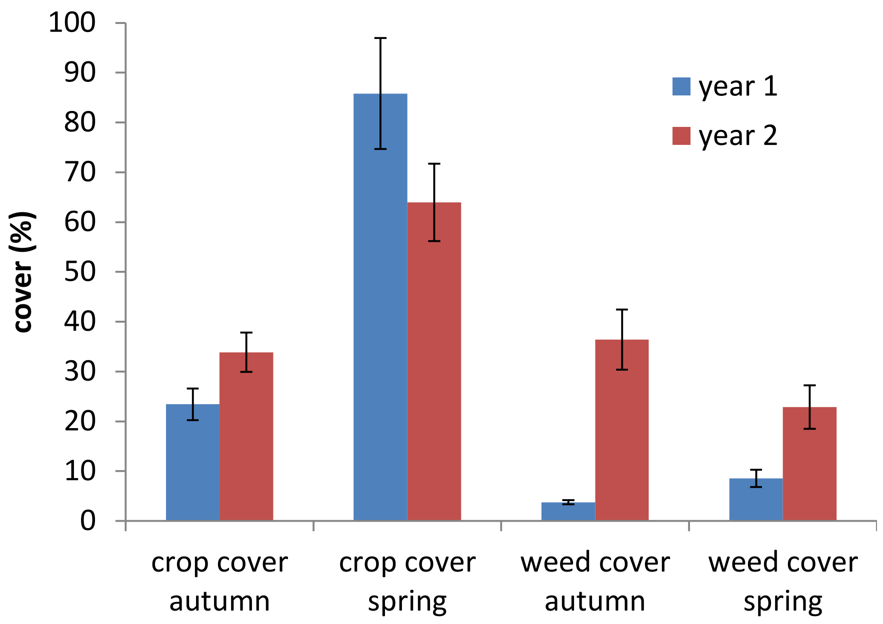


Figure 57. Crop and weed cover in the untreated control in the two trial years.

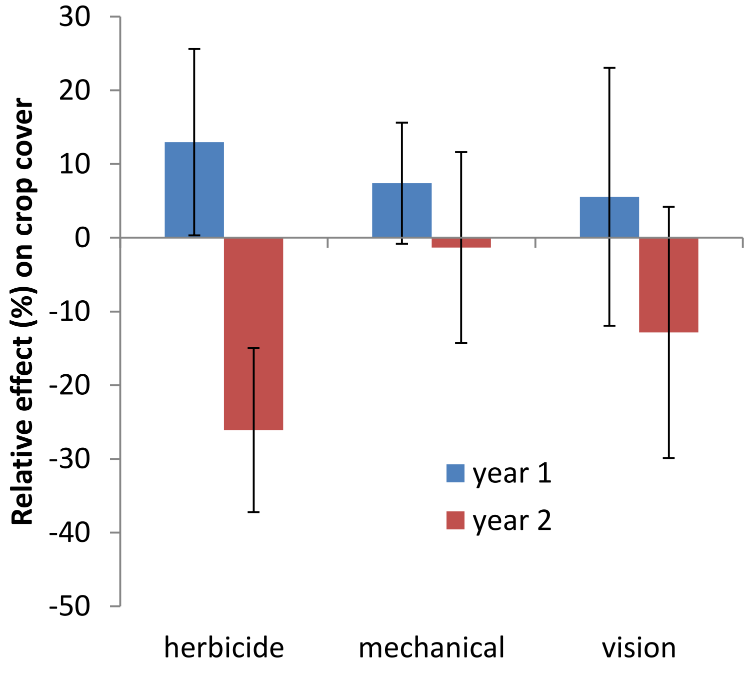


Figure 58. Pre-treatment crop cover. There were no significant treatment effects.

Crop performance

Post-treatment, the OSR crop suffered slightly under mechanical weed control but not from herbicide spraying (Figure 59). The effect of using the vision guidance was inconsistent between the two years; in year 1, the vision guided hoeing caused less damage to the crop than unguided weeding, whereas the opposite was the case in the year 2. In both years, the autumn crop cover was reduced by around a third in the vision guided system. However, all treatment effects had disappeared by the following spring (Figure 60).

Similarly, crop density in spring was not significantly affected by any of the treatments (Figure 61). Finally, there were no treatment effects on crop height in spring (Figure 62).

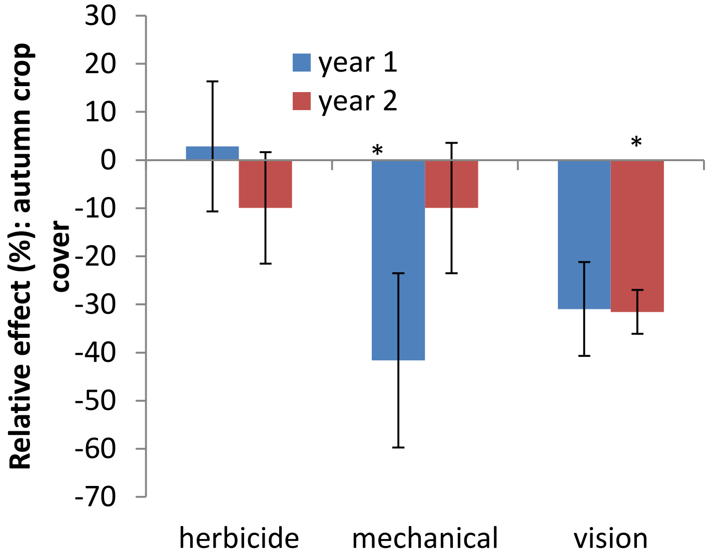


Figure 59. Crop cover in autumn after the mechanical weeding. Statistical significance (p<0.05) is indicated by the asterisks.

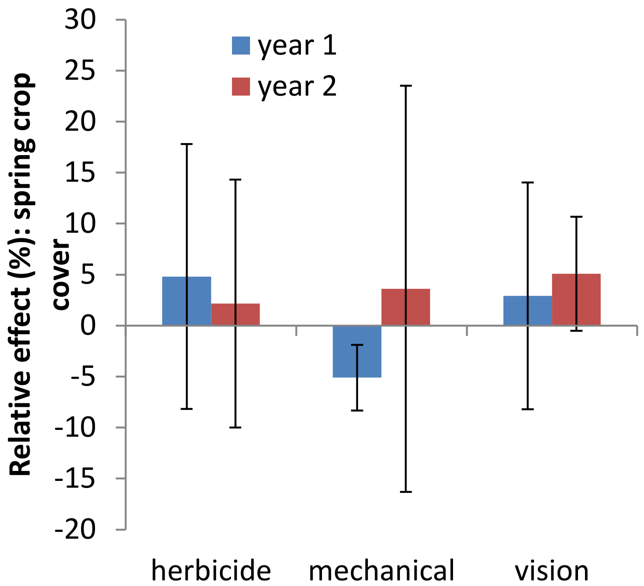


Figure 60. Crop cover in spring following the mechanical weeding in the previous autumn. There were no significant treatment effects.

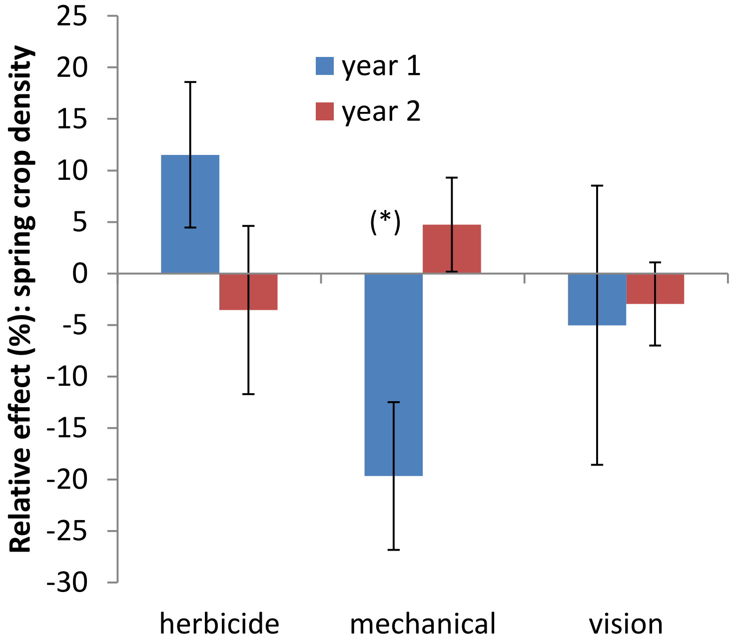


Figure 61. Effect of weeding treatments on spring crop density. Significance (*): 0.05<p < 0.10.

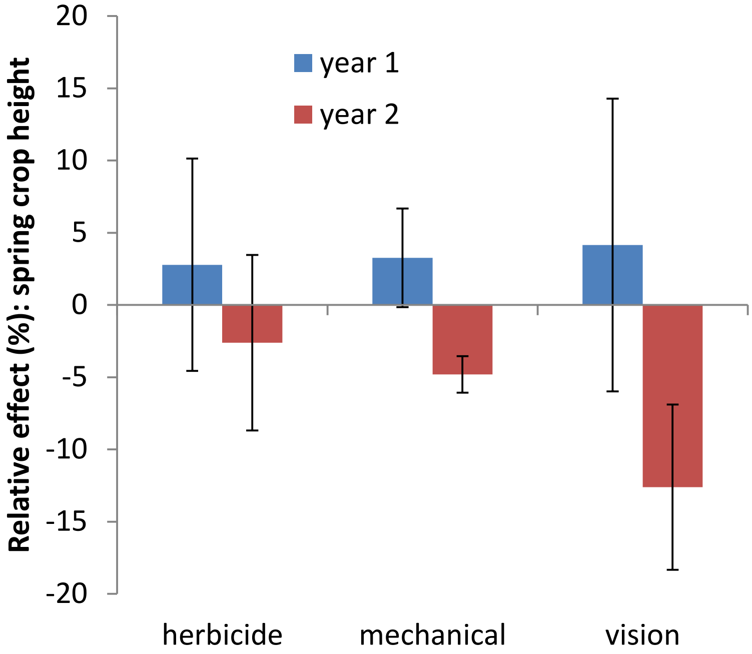


Figure 62. Effect of weeding treatments on crop height in spring

Weeds

None of the treatments had any significant impact on weed cover in autumn (Figure 63). However, there were pronounced effects of the treatments in the following spring (Figure 64), where the residual herbicides led to a significant reduction of weed cover. Effects of the mechanical weeding consistently reduced spring weed cover over both years (Figure 64) and was at least as good as the vision guidance.

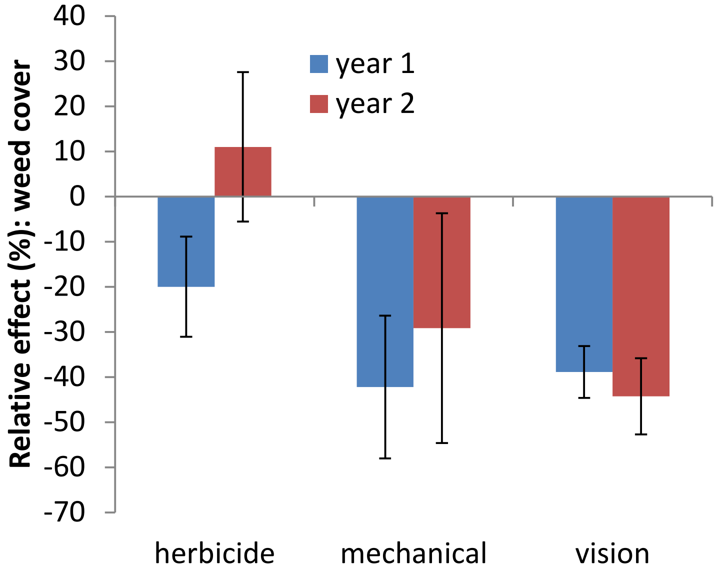


Figure 63. Effect of weeding treatments on weed cover in autumn, after mechanical weeding.

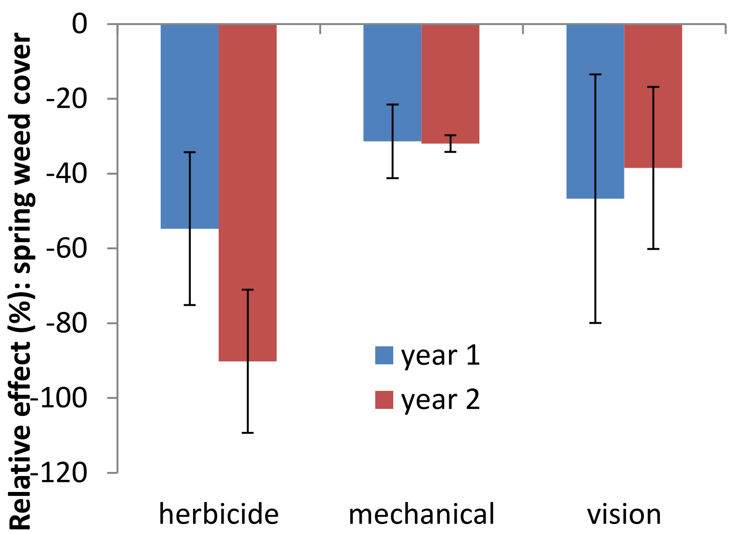


Figure 64. Effect of weeding treatments on spring weed cover in oilseed rape. Significance (*): 0.05< p < 0.10, *: p<0.05; **: p<0.01.

In the year 2 trial, assessments were conducted separately for broad-leaved weeds (dicots) and grasses (monocots). As Figure 65 shows, dicots were not significantly affected by any of the treatments, but grass cover in spring was reduced by all three treatments.

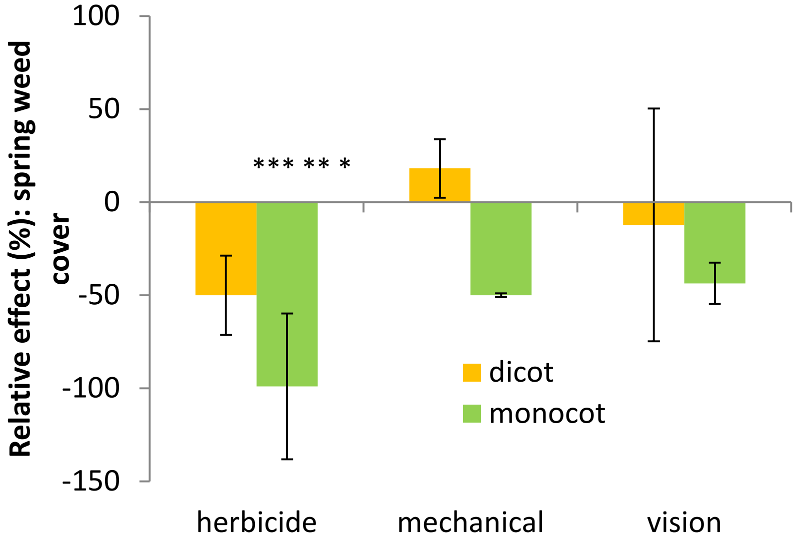


Figure 65. Effect of weeding treatments on spring weed cover in oilseed rape, year 2. Significance: *: p<0.05; **: p<0.01; ***: p<0.001.

In year 1 of the results, the dominant weeds were groundsel (*Senecio vulgaris*), cleavers (*Galium aparine*), field pansy (*Viola arvensis*) as well as various grass species annual meadow grass (*Poa annua)* and black-grass *(Alopecurus myosuroides*). Further species encountered in year 1 were creeping thistle (*Cirsium arvense*), crane's-bill, docks (*Rumex crispus*), sow-thistle, chickweed and speedwell (*Veronica persica*). In the year 2 trial, the weed community was dominated by grasses (annual meadow grass and other) and volunteer wheat (*Triticum aestivum*).

A survey of German and French literature on mechanical weed control in OSR showed that several trials on mechanical weeding have been conducted with good results, providing evidence that mechanical weed control in OSR is a viable option (Lucas 2006, Becker & Leithold 2007a, b, Anonymous 2008, Daniels *et al*. 2008, Lieven *et al*. 2008, Grünig 2009, Stumm *et al*. 2009, Dierauer *et al*. 2010, Arnold 2011, Böhm *et al*. 2011). However, high competitiveness of OSR against weeds was highlighted in this survey; therefore, frequently there is no effect of weeding on yield. In conclusion, hoeing is seen as a successful strategy especially in autumn when OSR follows cereals, but it requires wider row widths (e.g. 24–50 cm). With wider rows it is recommended to use a reduced seed density to reduce competition within the crop.

5.4. Discussion

The winter rape crop is the most widely grown combinable break crop in the UK and is particularly important in regions where other crops such as potatoes or sugar beet are not grown. It is also seen as a cleaning crop to control black-grass. Establishment of the crop is very important as it is not competitive at the seedling stage and can suffer from winter kill and pest damage which opens the crop allowing weeds such as chickweed, shepherd's purse, mayweeds and grass weeds such as annual meadow, bromes or black-grass to take hold. It is increasingly grown on wide rows of up to 50 cm which can, depending on circumstances, exacerbate all these issues. The importance of early crop competition was highlighted in the early years of the study. The impact of good early establishment was shown in years one and two of the study and showed that there was no response to a standard metazachlor-based herbicide on 12 cm or 50 cm row spacing. This is shown in Table 65 from the SRUC work where an untreated yield of 5.59 t/ha compared to an overall treated yield with metazachlor of 5.76 t/ha, was not significant. Thus where the crop is competitive, perhaps due to early drilling it can quickly cover the ground and compete with the weeds.

In years where the crop is less competitive, perhaps late sown or in areas of key weeds such black-grass or cleavers, the application of a well-timed residual herbicide is more important and yield responses are more likely. This is shown in Table 67 of the SRUC work in year 3 where the untreated yield was 3.27 t/ha and the overall herbicide 4.43 t/ha giving a response to the herbicide of 35%. This magnitude of response was corroborated by the results from project 3652, 'Improving Oilseed Rape crops for Effective Weed Control' where over two years and two sites there was an average of 41% increase in yield from a herbicide on less competitive crops.

An aim of this study was to look at novel ways of reducing the dependency on standard herbicides by replacing them with an application of a total/systemic herbicide such as glyphosate applied to the inter-row gap, between the crop rows. The early year of the study showed that it can give as effective weed control as standards. However, glyphosate is a systemic product and drift has the potential to kill young plants. To overcome this, year one of the study looked at applying the glyphosate using even-spray nozzles, which give a more defined spray footprint than standard 110/120 degree or reduced drift nozzles. The study looked at 25 degree and 80 degree nozzles. The 80 degree gives a wider spray footprint which in the study caused slightly more damage when used at 5–6 leaves of the crop than the 25 degree nozzle with a narrower spray footprint although the wider nozzle did give improved weed control due to better coverage. The concept of using even spray nozzles was the foundation of further study.

CDA sprayers can produce smaller droplets than conventional hydraulic nozzles which are more prone to drift but do give better coverage, which is advantageous for a contact/systemic herbicide such as glyphosate when targeting small weeds. The CDA nozzle is held inside a shield (see

Appendix 5). However, the Varidome (used in this circumstance) proved difficult to set in year one and proved susceptible to uneven fields partly due to the mounting arrangement used in the trials. It was thus no different to using an 80 degree nozzle in terms of crop damage and weed control.

A single application of glyphosate does not provide total weed control in many crops. It does not cater for further flushes of weeds and takes no account of weeds growing in the row. Applying a tank mix of glyphosate + metazachlor applied inter-row should in theory combine the benefits of both a total and a residual herbicide. However the study found this not to be the case. An alternative to tank-mixing was to sequence glyphosate inter-row with metazachlor across the row (intra-row). The first year of the study suggested that the combinations of glyphosate applied inter-row in sequence with a low rate of metazachlor intra-row was beneficial. The concept of sequencing glyphosate and metazachlor was considered again in the final year of the study on both Catana and Excalibur and was found to be beneficial (Table 67).

From a farmer's perspective, drilling on wide rows, often done by one pass, or reduced tillage systems, such as sub-soilers working at reduced depths than normal, or the more complex drill plus cultivators systems as available from Simba or Claydon, have become increasingly popular. The results can be faster speeds of drilling and purported improved soil structure in the long run. However in this study there was no significant yield response in the second year of the study to growing winter rape on wide rows of 50 cm compared to 12 cm (Table 62). There was also no significant response to an over-all application or the application of a residual herbicide at either row spacing. The crop was sufficiently vigorous to out compete the weeds. This was from established plant populations of 98/m^2 from treatments planted at 12 cm and around 37/m^2 established on the 50 cm spacing (unreported figures). Work from project 3652 corroborates these typical plant populations showing that to maintain yield, plant populations on a 50 cm spacing need to be reduced compared to planting at 12 cm.

The concept of shielding using the Micron Shielding with a CDA nozzle and more simple plate shields with even-spray nozzles was further evaluated in year two of the study. As in year one there was perhaps indications that the Micron system was not ideal for applying glyphosate to the inter-row gap in winter rape in this study; this system tended to result in more crop damage and reductions in yield, although it should be noted the equipment was mounted and used in a non-standard way (Table 63).

The more simple plate shields were more effective, particularly where wider even-spray nozzles are used at the later spray timings of 5–6 leaves (Table 64). The study shows a well-timed application at 3–4 leaves with a narrow even spray nozzle was as effective in terms of yield as an overall residual herbicide despite slightly inferior weed control. The wider nozzle gave slightly better weed control than the narrow nozzles but benefited from the shielding when used at 3 or 5 leaves (Table 64 and Table 65). In some years there is an advantage of leaving the herbicide application to 5 leaves of the crop to take out any secondary flushes of weeds and indeed this later timing did give longer term weed control (Table 64 and Table 65).

This project indicated that growing winter rape on wide rows facilitates the application of a targeted low dose total herbicide such as glyphosate to the inter-row gap. By using off the shelf technologies such as even spray nozzles and basic plate type shields that could easily be constructed in the farm work shop, or all-round shield such as produced by Micron and Garfords crop damage can be significantly reduced (Table 67). Having established this approach the project sought to resolve:

1. How could we increase both the accuracy and the speed of delivery of the glyphosate to the crop? To do this, the project looked at both RTK GPS and Vision Guidance (Table 50 and Table 51). Both systems produced good results in controlling broad leaved weeds and volunteer rape plants in the inter-row gap but the RTK GPS system proved easier to set up, particularly on farms where this system is being used for other applications. Both systems increased the speed and accuracy of delivery. However with the RTK system it would rely on the crop being drilled using GPS to give the accuracy of delivery and to supply co-ordinates. The costs of RTK GPS systems remain high. To kit out a tractor with GPS costs around £10–15K (personal communication from Soil Essentials). Depending on the system used, RTK correction signals can be provided by a mobile phone network but is better provided by a base station or a network of base stations. If using a mobile phone network, the annual cost is around £750. The best combination is to use a trailed sprayer thus using the same tractor to pull the drill and sprayer. For a self-propelled sprayer the cost of kitting it out with GPS is around £15K.
2. The costs associated with RTK GPS on farm are thus high. An analysis of precision farming techniques by NIAB TAG, sponsored by HGCA, gave a figure of kitting out two on-farm vehicles with RTK GPS at around £20/ha for a 500ha farm as it is unlikely that £20/ha would be economic on anything less than 500ha. Despite the high cost of RTK GPS, the concept is being used by leading farmers at home and abroad to improve the accuracy of drilling combinable crops and reduce trafficking.

   Vision Guidance Systems, as developed by Tillett and Hague and marketed by Garford Farm Machinery, has been developed for use in high value row crops such as lettuce, onions and transplanted brassica crops to provide inter-row weed and intra-row weed control. It is has also been looked at in sugar beet to control black-grass by a progressive grower Mr Ed Banks of Thomas Banks and Partners. At a basic level vision guidance can be used to guide inter-row cultivators, as successfully tested in this project.

3. How can we provide season long weed control and control late flushes of weeds? The limitations of contact herbicides are that they provide no residual weed control. While the project did find that a single well timed application of glyphosate applied inter-row can be as good as a standard over all conventional herbicide (Table 67), the project has shown that often secondary flushes of weeds are not controlled from a single application. The solution is to apply sequential applications of glyphosate to the inter-row gap or combinations of glyphosate and a residual herbicide. The other option is to delay the application of glyphosate so that late flushes of weeds are controlled. This project looked at all the options. Where the reliance is on total and, in this case, a systemic herbicide such as glyphosate, there were benefits of multiple applications on weed control but this was not always translated into a significant yield response as shown in (Table 68). The benefits of tank-mixing glyphosate with a metazachlor-based product applied inter-row were less clear and perhaps were antagonistic. This needs further clarification.

   There were clear benefits in terms of weed control from late (November) applications of glyphosate as long as shielding and narrow nozzles were used as illustrated in Figure 5, although where you have a competitive crop there may not be a clear yield benefit.

   The additional benefits of sequences of a well-timed glyphosate application(s) applied inter-row followed by a residual herbicide intra-row were less clear in this project, especially where Kerb was applied. The benefits would be control of grass weeds in the rotation at the same time reducing the total herbicide loading per hectare. There were, however, benefits from applying a metazachlor-based product (Elk) intra-row early at GS 1,3 followed by glyphosate inter-row at GS 1,5 (Table 69). Crops grown on wide rows are less competitive due to lower plant numbers and benefit from weed control.

Over the three years of this project we have successfully provided a new approach to weed control in winter rape grown on wide rows while reducing the impact of herbicides that are causing concern to the water industry through EU Directives. With few herbicide options, those that are available tend to be expensive. By adopting the technologies developed in this study, the grower would make significant cost savings in herbicide use as shown in Table 78. It should be noted that the figures in Table 78 do not include application costs and that the use of more specialised machines with work rates that are generally less than those of conventional sprayers could involve higher costs.

Table 78. Cost comparison herbicides used in the study at over-all and when applied in the band

	Approx. cost £/L	Application rate over-all application	Over-all application £/ha	Banded application 15 cm band £/ha	Banded application 30 cm band £/ha	Banded application @ 15 cm intra 1 cm band £/ha
Roundup Energy	5.40	1.6 L	8.64	1.30	2.60	-
Butisan	21.00	1.5 L/ha	31.50	4.73	9.45	6.03
Novall	24.40	2.5 L/ha	61.00	9.15	18.30	-
Elk/Shadow	26.00	2.5 L/ha	65.00	9.75	19.50	11.05
Kerb	16.00	2.1 L/ha	33.60	5.04	10.11	5.17
Carbetamex	11.00	3.5 kg	38.50	5.78	11.55	7.08

The use of glyphosate as a desiccant in winter rape or indeed other row crops has a full label approval. However its use as a herbicide applied to the inter-row gap of crops grown on wide rows, using targeted application technology, requires a change in the label. SRUC has been working with Monsanto, a partner in this project, to help generate this appropriate data to support a new label. Data from this study will help support a new label.

The increasing reliance on winter rape being drilled by reduced tillage techniques, especially when using a sub-soiler technique potentially creates a slot which may be a conduit to the drains for residual herbicides especially in a wet autumn. This could be mitigated by the technologies used in this project and the use of glyphosate applied inter-row. However, if followed by a residual herbicide intra-row the same potential issues may apply. Thus, this requires further study.

Regarding the effect of mechanical weed control with hoeing on weeds, the field trials showed that mechanical weed control in autumn was better able to control weeds than with herbicides, but this trend was reversed in spring, because of the longer term (residual) effect of the herbicides. All treatments had a stronger effect on grasses than on dicots, but reasons for this effect are currently unclear. There were no consistent differences between the vision guided and non-guided hoeing with regard to weed control. In year 1, the vision guided hoe achieved similar weed control as herbicide treatment. Relative to the untreated control, the herbicide treatment had the highest level of weed control in spring 2011, followed by the vision guided hoe. In the autumn (relatively soon after the mechanical weeding), the weed control effect was similar between the two mechanical control options (with vs. without guidance). However, in the following spring relative weed control was greater in the vision guided hoe than when no camera was used.

With regard to effects on crops, mechanical weeding was observed to damage the crop in the autumn but due to compensatory growth of the oilseed rape plants, any negative effects were lost by the following spring. While the vision guidance hoe was shown to have the potential to reduce damage to the crop (as observed in year 1), this was not the case in year 2; however, in the year 2 trial, the vision guidance allowed the weeding operation to be carried out faster than the unguided mechanical weeding. Importantly, the benefits of using vision guidance will be apparent on larger scale application in practice.

6. Conclusions

6.1. RD-2009-3652

- In situations where weeds are well controlled there is scope to increase row widths up to 48 cm without reducing yield potential. There is also scope to increase row width to 72 cm without reducing yield potential, but only in conditions which allow the plant to compensate fully in terms of branching and pods per branch. Row widths of 72 cm were shown to have a reduced yield following a severe spring drought compared with row widths of 48 cm or less.
- In situations where weeds are not well controlled, coupled with factors which limit the plants potential for compensation (e.g. spring drought), increasing row width from 24 cm to 48 cm and 72 cm was shown to reduce yield potential.
- There was no evidence that row width affects the optimum seeds/m² sown or the optimum plants/m². However it was shown that, as a result of inter-plant competition limiting plant establishment, it is not possible to establish more than 25 plants per metre of row and yields may decrease above 17 plants per metre of row. This means that it may not be possible to establish more than 50 plants/m² for 48 cm row widths or more than 35 plants/m² for 72 cm row widths.
- In conditions where growth was not limited, open-pollinated varieties were shown to compensate as well as hybrids against wide row widths and low plant populations.
- There was no evidence that plants in wide rows are attacked more by pigeons, although more work is required to test whether or not cultivating between rows affects this.
- There were only low levels of lodging in the experiments so it was not possible to conclude about the effect of row width on lodging risk.
- Increasing row width did not affect the weed population.
- In the absence of herbicides higher seed rates reduced weed populations and usually increased yields.
- Reducing weeds by increasing seed rate is less effective in wide row crops because there is a limit to the number of plants that can be established per m length of row, which means the maximum plants/m² is smaller in wide row crops.

6.2. RD-2009-3605

- It was found that when winter rape is established on wide rows there is an opportunity to apply targeted applications of a non-selective herbicide such as glyphosate to the inter-row gap, thus reducing or eliminating the use of residual herbicides and their impact on the environment.
- Damage to the crop using glyphosate in the inter-row gap can be limited by the use of even spray nozzles coupled with simple plate type shields that can be produced in the farm workshop or all-round shields from Garfords.
- Timing of application of glyphosate at the young plant stage, GS 1,3 compared to GS 1,5 limits the potential for damage. As the crop grows the inter-row gap becomes narrower.
- A sequence of glyphosate applied at GS 1,5 followed by a second application may be necessary to account for a second flush of weeds.
- It was found that there was no difference between hybrid and conventional variety types in terms of potential for crop damage from glyphosate applied inter-row.
- The targeting of a non-selective herbicide such as glyphosate can be improved using Vision Guidance and RTK GPS, technologies that are currently used in agriculture. Both were successful but RTK GPS in more simple to set up and is currently installed in many tractors.
- It was found that Vision Guidance coupled to an inter-row cultivator gave weed control equivalent to standard weed control (metazachlor). This result would be particularly useful in an organic system.
- It was found in fields with high levels of volunteer rape the use of glyphosate inter-row improved the homogeneity of the crop by controlling volunteer rape plants.
- Using RTK GPGS allows for the application of glyphosate inter-row in sequence with a sequence with a selective herbicide such as propyzamide intra-row. This is useful to control grass weeds such as black-grass.

7. Recommendations for future work

- Test the benefit of using wide row establishment systems with band applied herbicides in commercial situations.
- Develop optimum crop management strategies for wide row crops including fertiliser and PGR strategies. For example, lower soil disturbance may increase the requirement for fertiliser especially N and P fertiliser in autumn or the need for band applying fertilisers. The greater reliance on branching may increase the requirement for PGRs that enhance branching.
- Investigate whether commercially used wide row establishment systems (e.g. sub casting/ direct drilling) that do not disturb the soil between the rows affect the crop's vulnerability to pigeon damage.
- Investigate whether wide rows are more or less prone to lodging.
- Investigate the effect of wide row establishment systems on the risk of leaching to drains of pesticides.
- To test other non-selective herbicides for application inter-row such as diquat and carfentrazone.
- To test other residual herbicides for application both intra-row and inter-row.
- To provide further residue work to support a full label application of glyphosate applied intra-row on a range of crops grown on wide rows (winter rape, beans).

8. Acknowledgements

We thank farmer John Sanderson for collaboration and hosting year 1 trial. The authors are grateful for input from Cyril Bigot who helped with the retrieval and translation of French source. The ADAS, NIAB TAG and SRUC trials teams.

9. References

Abram M (2011) Clearfield to bring agronomic flexibility Crops 25 June 2011 pp 10

Andersson, B. & Bengtsson, A. (1989) The influence of row spacing, seed rate and sowing time on overwintering and yield in winter oilseed rape (*Brassica napus*) Swedish Journal of Agricultural Research **19**, 129-134 http://agris.fao.org/agris-search/search/display.do?f=1990%2FSE%2FSE90007.xml%3BSE9010201 Accessed 5 March 2013

Andersson, B. & Bengtsson, A. (1992) Influence of row spacing, tractor hoeing and herbicide treatment on weeds and yield in winter oilseed rape (*Brassica napus* L.) Swedish Journal of Agricultural Research **22**, 19-27 http://agris.fao.org/agris-search/search/display.do?f=1992%2FSE%2FSE92020.xml%3BSE9210983 Accessed 5 March 2013

Anonymus (2008) Bauern zeigen die kalte Schulter. Land und Forst http://landundforst.agrarheute.com/index.php?redid=214758 :

Arnold B (2011) Raps Mechanische Unkrautregulierung. http://wwwagrigatech/de/pflanzenbau/ ackerbau/oel/sorten/. Accessed 15 November 2011.

Banhardt A, Gruber S, & Claupein W(2011) Seed eaters on our fields – how many rapeseeds are consumed by what creatures? 13th International rapeseed congress, Prague, Czech Republic, pp 295-298

Becker K, Leithold G (2007a) Ausweitung des Anbaukonzeptes Weite Reihe bei Winterweizen auf Roggen, Hafer, Raps und Körnerleguminosen. Eine pflanzenbauliche und betriebswirtschaftliche Untersuchung unter Berücksichtigung von Vorfruchtwirkungen. Endbericht. Bundesprogramm Ökologischer Landbau. Available from http://orgprints.org/14858/. Giessen: Justus Liebig Universität.

Becker K, Leithold G (2007b) Effekte der Anbausystem Weite Reihe im Ökologischen Landbau auf Ertrag und Qualität von Getreide und Raps. Mitteilungen der Gesellschaft für Pflanzenbauwissenschaften 19:16-17.

Berry, P.M. & Spink, J.H. (2006). A physiological analysis of oilseed rape yields: Past and future. Journal of Agricultural Science, Cambridge **144**, 381-392.

Berry, P.M. & Spink, J.H. (2009). 'Canopy Management' and late nitrogen applications to improve yield of oilseed rape. Home-Grown Cereals Authority Project Report No 447*.* HGCA, London, 212 pp.

Berry, P.M. (2011). Predicting the optimum rate and timing of nitrogen fertiliser for winter oilseed rape. 13th International Rapeseed Congress. Prague, 5-9 June 2011.

Blake J, Spink J & Bingham I (2006) Management of oilseed rape to balance root and canopy growth. HGCA project report 402, 22p, HGCA, London.

Blake, A (2011) Wider OSR row widths are feasible with right management. Farmers weekly 14 November 2011. http://www.fwi.co.uk/articles/14/11/2011/130072/wider-osr-row-widths-are-feasible-with-right-management.htm Accessed 5 March 2013

Böhm H, Aulrich K, Sauermann W, Alpers G (2011) Sortenwahl und Schädlingsdruck im ökologischen Rapsanbau. In: Es geht ums Ganze: Forschen im Dialog von Wissenschaft und Praxis - 11 Wissenschaftstagung Ökologischer Landbau, Band 1: Boden, Pflanze, Umwelt, Lebensmittel und Produktqualität (Leithold, G, Becker, K, Brock, C, Fischinger, S, Spiegel, A-K, Spory, K, Wilbois, K-P and Williges, U, eds) Gießen, Germany: Verlag Dr. Köster, Berlin.

Bond W, Turner R J, Grundy A C (2003) A review of non-chemical weed management. HDRA http://www.gardenorganic.org.uk/organicweeds/downloads/updated_review.pdf accessed 13 January 2010.

Bowman G (1997) Steel in the field: A farmer's guide to weed management tools. Burlington VT: Sustainable Agriculture Publications, University of Vermont, Vermont, USA. http://www.sare.org/publications/steel/steel.pdf accessed 13 January 2010

Brachaczek A & Salas M (2011) Ethametsulfuron-methyl (SALSATM 75WG) - a new active and the first postemergent herbicide that controls Brassica and Geranium species in oilseed rape. 13th International rapeseed congress, Prague, Czech Republic, pp 1189-1192

Casswell, L. (2012) Be brave and cut oilseed rape seed rates. Farmers weekly 22 November 2012 http://www.fwi.co.uk/articles/22/11/2012/136361/be-brave-and-cut-oilseed-rape-seed-rates.htm. Accessed 4 March 2013

CETIOM (2008) Guide simplifié des techniques alternatives de désherbage des cultures http://www.cetiom.fr/fileadmin/cetiom/kiosque/desherbage_alternatif_sept08.pdf**.** Accessed 2 February 2012.

Chicouene D (2007) Mechanical destruction of weeds A review Agron. Sustain. Dev. 27, 19-27

Clarke, J., Wynn S, Twining S, Berry P. Cook S, Ellis S and Gladders P (2009) HGCA Research Project 70 Pesticide availability for cereals and oilseeds following revision of Directive 91/414/EEC; effects of losses and new research priorities.

Clarke J H, Cook S K, Harris, D. Wiltshire J J J,, Henderson I G , Jones N E, Boatman N D, Potts S G, Westbury D B , Woodcock B A , Ramsay A J , Pywell R F, Goldsworthy P E , Holland J M , Smith B M, Tipples J , Morris A J , Chapman P and, Edwards P (2007). The SAFFIE Project Report. ADAS Boxworth, UK

Daniel C, Dierauer H, Schärer F, Ramseier H, Bovigny C, Jossi W, Humphrys C (2008) Raps – die Königsdisziplin im Bioackerbau. bioaktuell 6/08:10-12.

Davies G, Turner B & Bond B (2008) Weed management for organic farmers, growers and smallholders, a complete guide. HDRA, Crowood press, Marlborough. 270 pages

Dierauer H, Früh B, Humphrys C, Hebeisen T (2010) Merkblatt Bioraps. pp 5: Forschungsinstitut für Biologischen Landbau, Frick, Switzerland.

Dow (2008) Kerb Flow and agronomists guide to effective management of resistant grass weeds. http://www.dowagro.com/PublishedLiterature/dh_0177/0901b80380177fea.pdf?filepath=/uk/pdfs/noreg/011-01562.pdf&fromPage=GetDoc Accessed 14 December 2011.

Ellis, S.A. and Berry P.M. (2012). Re-evaluating thresholds for pollen beetle in oilseed rape. Home-Grown Cereals Authority Research Project No 495. HGCA, Stoneleigh, Warwickshire, 76pp.

Ellis, S.A., Berry P.M., Kendall, S. and White, C. (2013). Assessing tolerance to slugs in winter wheat and oilseed rape by stimulating pest damage. Defra Project Report PS2805, 52pp**.**

Freeman S E & Lutman & P J W (2004) The effects of timing of control of weeds on the yield of winter oilseed rape (*Brassica napus*), in the context of the potential commercialisation of herbicide tolerant winter rape. J. Ag. Sci, 142, 263-272

Freer B (2002) Non-tillage establishment of oilseed rape using the "autocast" technique. HGCA Project report OS55, HGCA, London.

Froud-Williams RJ & Chancellor RJ (1987) A survey of weeds in oilseed rape in central southern England. Weed Research 27, 187-194

Garthwaite, D. G, Thomas M. R, Heywood E &. Battersby. A Pesticide Usage Survey Team Central Science Laboratory. Sand Hutton, York UK. YO41. 1LZ Pesticide Usage Survey Report 213 Arable Crops on Great Britain

Goodman A M, Crook M J & Ennos A R (2001) Anchorage mechanics of the tap root system of winter –sown oilseed rape (*Brassica napus* L.). Annals of Botany 87, 397-404

Grundy A (2007) Mechanical weed control for integrated and organic salad and brassica production. FV 266 HL0173 Final report. Horticultural Development Council.

Grünig K (2009) Hier wächst Schweizer Bioraps-Saatgut. Die Grüne 9/2009:20-21

Heckendorn, P. Hillmann, F, Klocke, E, Lüscher P,, Riedel A,, Stolze S,, Strasser M,, van der Heijden F, & Willer, H, eds), pp 193-196 ETH Zürich: Verlag Dr. Köster

HGCA (2012) Oilseed rape guide, Summer 2012

Huguet B, Bizot E, Kister C (2007) Désherbage colza: des pistes alternatives - Note commune SRPV - Fredon - Chambre Agriculture 77. pp 6pp. Rungis, France: Service Regional de la Protection des Vegetaux Ile de France.

Hull R, Marshall R, Tatnell L, Moss SR (2008) Herbicide-resistance to mesosulfuron + iodosulfuron in Alopecurus myosuroides (black-grass). Communication in Agricultural and Applied Biological Sciences 73:903-912

Humphrey NCB, Breach B, Goldsworthy P, Hamilton C, Hillier D, Keyse P, Knapp M, Littlejohn J, Mooney M, Welland G (2007) The Voluntary Initiative Pilot Catchment Project - UKWIR Report Ref. No. 07/WR/26/2. (UK Water Industry Research Ltd, ed).

Knight S, Miller P, Orson J (2009) An up-to-date cost benefit analysis of precision farming techniques to guide growers of cereals and oilseeds, Research Review No 71. May 2009

Leisen E (1999) Anbaustrategien zur Erzeugung von Winterraps: hier: Hackeinsatz zur Unkrautregulierung. In: Leitbetrieb Ökologischer Landbau Nordrhein-Westfalen, pp 46-50.

Lieven J & Lucas J L (2009) Contribution des méthodes de lutte mécanique au désherbage intégré des grandes cultures oléagineuses. Oléagineux, Corps Gras, Lipides. Volume 16, Number 3, 169-81, MAI-JUIN 2009

Lieven J, Quere L, Lucas JL (2008) Oilseed rape weed integrated management: concern of mechanical weed control. In: ENDURE International Conference: Diversifying crop protection, La Grande-Motte, France.

Lucas JL (2006) Désherber le colza autrement. In: Rapport d'activité 2006, (CETIOM, ed) pp 16-17

Lunn G D, Spink J J, Stokes D T, Wade A. Clare R & Scott R K (2001) Canopy management in winter oilseed rape. HGCA Project report OS49, HGCA, London.

Lunn, G. D., Spink, J., Wade, A.and Clare, R. W. (2003). Spring remedial treatments to improve canopy structure and yield in oilseed rape. Project Report No. OS64, pp. 97. HGCA, London.

Lutman P (1991) Weeds in oilseed crops. Oilseeds research review OS2, HGCA, London

Lutman P (1999) Dormancy and persistence of volunteer oilseed rape. Topic sheet No 24, HGCA, London.

Lutman P J W & Dixon F L (1991). The competitive effects of volunteer barley (*Hordeum vulgare*) on the growth of oilseed rape (*Brassica napus*). *Annals of Applied Biology* 117, 633-644.

Lutman P J W, Bowerman P, Palmer G M & Whytock G P (2000) Response of oilseed rape to interference from *Stellaria media*. *Weed Research*, 40, 255-270.

Lutman P J W, Bowerman P, Palmer G M, Andrews F & Whytock G P (1995) Cost effective weed control in winter oilseed rape. HGCA Project report OS15, HGCA, London.

Lutman, P. (1999) Dormancy and persistence of volunteer oilseed rape. Topic sheet 24, HGCA, Stoneleigh.

McKinlay R G, Davies D H K, Langley A, McGregor M & Tillet N (1994) Field vegetables: Mechanical and mulching weed control techniques. Final report on horticultural development council project FV/107. SAC Edinburgh.

Melander B (2006) Current achievements and future directions of physical weed control in Europe. AFPP 3rd international conference on non-chemical crop protection methods. Lille France, 49-58

Melander B, Rasmussen I A and Bàrberi P. (2005) Integrating physical and cultural methods of weed control: examples from European research, Weed Science, 53, 369-381.

Milne, A E, Wheeler, H C and Lark, R.M. (2006) On testing biological data for the presence of a boundary, Annals of Applied Biology, **149**, 213

Moss SR, Anderson-Taylor G, Beech P, Cranwell S, Davies D, Ford I, Hamilton I, Keer J, Mackay J, Paterson E, Spence E, Tatnell L, Turner M (2005) The current status of herbicide resistant grass and broad-leaved weeds of arable crops in Great Britain. In: Proceedings of the BCPC International Congress, pp 139-144.

Nix, J. (2012) The John Nix farm management pocket book. Impress, Corby.

O'Donovan J T, Blackshaw R E, Harker K N, Clayton G W, Moyer J R, L M Dosdall, Maurice D C & Turkington T K (2007) Integrated approaches to managing weeds in spring-sown crops in western Canada. Crop Protection 26, 390-398

Ogilvy S E (1989) The effects of severity and duration of volunteer barley competition on the yield od winter oilseed rape – a review of ADAS trials. 1986-87. Aspects of Applied Biology 23, Production and Protection of Oilseed rape and other Brassica crops, 237-246

Ogilvy S E (2000) Link Integrated Farming Systems (a field scale comparison of arable rotations) Volume I: Experimental work. *HGCA Project report 173*, HGCA, London.

Pretty, J. N., Brett, C., Gee, D., Hine, R. E., Mason, C. F., Morison, J. I. L., Raven, H., Rayment, M. D & Van der Bijl, G. (2000). An assessment of the total external costs of UK agriculture. Agricultural systems, 65(2), 113-136.

Reyer W (2009a) BASF advisor survey. Personal communication.

Reyer W (2009b) How to cope without trifluralin in oilseed rape http://www.farminguk.com/news/How-to-cope-without-trifluralin-in-oilseed-rape_16807.html. accessed 16 December 2011.

Sansome G (1989) Effect of crop populations on the performance of herbicidesin winter oilseed rape. Aspects of Applied Biology 23, Production and protection of oilseed rape and other brassica crops, 257-262.

Sansome G (1991) The effect of oilseed rape populations on weeds, herbicide performance and crop yields. Proceedings 1991 Brighton Crop Protection Conference (Weeds), 1225-1232.

Sansome, G. (1989) Effect of crop populations on the performance of herbicides in winter oilseed rape. Aspects of Applied Biology **23**, Production and protection of oilseed rape and other brassica crops, 257-262.

Sansome, G. (1991) The effect of oilseed rape populations on weeds, herbicide performance and crop yields. Proceedings 1991 Brighton Crop Protection Conference (Weeds), 1225-1232.

Sim L C, Froud-Williams R J, & Gooding M J (2007) The influence of winter oilseed rape (*Brassica napus* ssp. *Oleifera* var *biennis*) canopy size on grass weed growth and grass weed seed return. J. Agric. Sci. 145, 313-327

Slaughter D C, Giles D K, & Downey D (2008) Autonomous robotic weed control systems: a review. Computers and electronics in agriculture, 61 63-78.

Stokes D T, Scott R K, Bullard M J, Clare R W & Lunn G D (2000) Establishment of oilseed rape. HGCA R&D conference 'Crop management into the Millennium', 9.1-9.9 http://www.hgca.com/document.aspx?fn=load&media_id=1019&publicationId=32. Accessed 2 February 2012.

Stokes, D. T., Scott, R. K., Clare, R. W., Spink, J. H., Bullard, M. J.and Sylvester-Bradley, R. (1998). Establishment and canopy management in oilseed rape. In *Proceedings of the Sixth Home-Grown Cereals Authority Research and Development Conference*, Robinson College, Cambridge, HGCA, London, 6.1-6.12.

Stumm C (2007) Winterraps im Ökologischen Landbau Prüfung praxisüblicher Anbausysteme und gesteigerter Frühjahrsdüngung mit RecyKal SF. In: Leitbetrieb Ökologischer Landbau Nordrhein-Westfalen, pp 46-50.

Stumm C (2009) Anbau und Düngung von Winterraps im Ökologischen Landbau. In: Leitbetriebe Ökologischer Landbau Nordrhein-Westfalen, pp 24-32.

Stumm C, Berg M, Köpke U (2009) Anbau und Düngung von Winterraps (Brassica napus L.) im Ökologischen Landbau. In: Werte - Wege - Wirkungen: Biolandbau im Spannungsfeld zwischen Ernährungssicherung, Markt und Klimawandel Beiträge zur 10 Wissenschaftstagung Ökologischer Landbau, Band 1: Boden, Pflanzenbau, Agrartechnik, Umwelt- und Naturschutz, Biolandbau international, Wissensmanagement, (Mayer, J, Alföldi, T, Leiber, F, Dubois, D, Fried, P, Heckendorn, F, Hillmann, E, Klocke, P, Lüscher, A, Riedel, S, Stolze, M, Strasser, F, van der Heijden, M and Willer, H, eds), pp 193-196 ETH Zürich: Verlag Dr. Köster.

Stumm C, Berg M, Köpke U (2009) Anbau und Düngung von Winterraps (Brassica napus L.) im Ökologischen Landbau. In: Werte - Wege - Wirkungen: Biolandbau im Spannungsfeld zwischen Ernährungssicherung, Markt und Klimawandel Beiträge zur 10 Wissenschaftstagung Ökologischer Landbau, Band 1: Boden, Pflanzenbau, Agrartechnik, Umwelt- und Naturschutz, Biolandbau international, Wissensmanagement, (Mayer, J, Alföldi, T, Leiber, F, Dubois, D, Fried,

Tan S, Evans R, Dahmer M, Singh B & Shaner D. (2005) Imidazolinone-tolerant crops: history, current status and future. Pest Manag Sci 61: 246–257

Van der Schans D, Bleeker P, Molendijk L, Plentinger M & van der Weide R (2006) Practical weed control in arable farming and outdoor vegetable cultivation without chemicals. Wageningen UR, Applied Plant Research, Wageningen.

Van der Weide, R Y, Bleeker, P O, Achten, V T J M, Lotz, L A P, Fogelberg, F & Melander, B (2008), Innovation in mechanical weed control in crop rows. Weed Research, 48: 215–224. doi: 10.1111/j.1365-3180.2008.00629.x

Webb, R. A. (1972). Use of the boundary line in analysis of biological data. Journal of Horticultural Science **47**:309-319.

Welsh J P, Tillett N D, Home M & King J A (2002) A review of knowledge: Inter-row hoeing and its associated agronomy in organic cereal and pulse crops. Final report from Defra-funded project OF0312 http://randd.defra.gov.uk/Document.aspx?Document=OF0312_2234_FRP.doc Accessed 14 January 2012.

Whitehead R & Wright H C (1989) The incidence of weeds in winter oilseed rape in Great Britain. Aspects of Applied Biology – Production and protection of oilseed rape and other brassica crops, 23, 211-218

Young J E B, Griffin M. Alford D V, & Ogilvy S E (2001) Reducing agrochemical use on the arable farm, the TALISMAN and SCARAB projects. Edited by. Defra, London. 416 pages

Zand E & Beckie H J (2002) Competitive ability of hybrid and open pollinated canola (*Brassica napus*) with wild oat (*Avena fatua*). Canadian Journal of Plant Science 82, 473-480.

10. Appendices

Appendix 1. Inputs at each site

Drilling date, variety and treatment herbicides

Site	Boxworth 2010	Boxworth 2011	Boxworth 2012	Terrington 2010	Terrington 2011	Terrington 2012
Cropping year	2009–2010	2010–2011	2011–2012	2009–2010	2010–2011	2011–2012
Drill trial	07/09/2009	05/09/2010	01/09/2011	09/09/2009	17/09/2010	09/09/2011
Variety	Castille	Catana	Catana	Excalibur	Excalibur	Excalibur
Pre-emergence herbicide						
Application date	09/09/2009	05/9/2010	15/9/2010	11/09/2009	05/9/2010	15/09/2011
Product and rate (L/ha)	Springbok 2.5	Springbok 2.5	Shadow 2.5	Novall 1.5	Novall 1.5	Shadow 2.5
Post-emergence herbicide						
Application date	10/03/2010	12/10/11	19/09/2011	13/10/2009	28/10/2010	15/10/2012
Product and rate (L/ha)	Aramo 1.0 Whole trial	Aramo 1.0 whole trial	Aramo 1.0 Whole trial	Falcon 1.5 whole trial	Aramo 1.0 whole trial	Aramo 1.0 whole trial
Application date	10/03/2010	11/11/2010	25/11/2011	13/10/2009	08/10/2010	12/12/2011
Product and rate (L/ha)	Dow shield 0.5 Whole trial	Kerb Flo 2.1	Kerb Flo 2.1	Novall 1.0	Novall 1.0	Kerb Flo 2.1
Application date				29/12/2009	20/10/2010	
Product and rate (L/ha)				Kerb 1.75	Kerb Flo 2.1	

Terrington 2010

Drilling and emergence		**Soil analysis**			
Drilled	09/09/09	pH	8.20		
First emergence	18/09/09	K (mg/l)	16	K Index	2-
50% emergence	29/09/09	P (mg/l)	10	P Index	1
100% emergence	22/10/09	Mg (mg/l)	54	Mg Index	2
		OM (%)	2.0		
Cultivations					
Date	**Equipment**				
09/09/2009	Delta Drag				
09/09/2009	Flat Lift				
10/9/09	rolled				
Pesticides					
Date	**Product name**	**Rate**	**Units**	**Growth stage**	**Type**
13/10/2009	Falcon	1.5	L/ha	1,0 – 1,4	Herbicide
13/10/2009	Novall	1	L/ha	1,0 – 1,4	Herbicide
29/01/2009	Kerb Flo	1.75	L/ha		Herbicide
10/03/2010	Capitan	0.6	L/ha	1,8 – 1,9	Other
10/03/2010	P.Curser	1	L/ha	1,8 – 1,9	Other
11/8/10	Harvest				
Fertilisers					
Date	**Product name**	**Nutrient**	**Rate(/ha)**	**Units**	**Nutrients (kg/ha)**
17/04/2010	OMEX	N	-	Kg/ha	100
14/06/2010	OMEX	N	-	Kg/ha	40

Boxworth 2010

Drilling and emergence		Soil analysis			
Drilled	07/09/2009	pH	7.8		
First emergence	15/10/209	K (mg/l)	249	K Index	3
		P (mg/l)	13	P Index	1
		Mg (mg/l)	83.	Mg Index	2
		Organic matter (%)	3.9		

Cultivations Date	Equipment
01/09/2009	Disced
04/09/2009	Power harrowed
07/09/2009	Combination drilled
08/09/2009	Rolled

Pesticides Date	Product name	Rate	Units	Growth stage	Type
09/09/2010	Springbok	2.5	L/ha	Pre-em	Herbicide
10/03/2010	Aramo	1	L/ha	1,5	Herbicide
	Dow Shield	0.5	L/ha	1,5	Herbicide
Harvest	29/07/10				

Fertilisers Date	Product name	Nutrient & % age	Rate(/ha)	Units	Nutrients (kg/ha)
08/03/2010	AS	N 21% S60%	125	Kg/ha	N26 S75
18/03/2010	TSP	N 46%	220	Kg/ha	100
18/03/2010	Urea	N 46%	150	Kg/ha	69
27/04/2010	Urea	N 46%	225	Kg/ha	104

Boxworth 2011

Drilling and emergence		Soil analysis			
Drilled	05/09/2010	pH	7.4		
First emergence	12/09/2010	K (mg/l)	276	K Index	3
		P (mg/l)	19.4	P Index	2
		Mg (mg/l)	104	Mg Index	3
		OM (%)	2.9		

Cultivations Date	Equipment
16/08/2010	Sumo
19/08/2010	Power harrow
30/08/2010	Tines
02/03/2010	Power harrow
05/09/2010	Sulky drilled
05/09/2010	Rolled

Pesticides Date	Product name	Rate	Units	Growth stage	Type
17/09/2010	Slug pellets	8	Kg/ha	Emergence	Molluscicide
12/10/2010	Aramo	1	L/ha	1,4	Herbicide
08/02/2011	Plover	0.3	L/ha	1,4	Fungicide
08/02/2011	Sanction	0.4	L/ha	1,7	Fungicide
04/07/2011	Glyphosate	?	L/ha		Herbicide

Fertilisers Date	Product name	Nutrient & % age	Rate(/ha)	Units	Nutrients (kg/ha)
16/02/2011	Ammonium sulphate	N 21% S60%	100	Kg/ha	N 21 S60
09/03/2011	Urea	N 46%	130	Kg/ha	60
24/03/2011	Urea	N 46%	215	Kg/ha	100

Terrington 2011

Drilling and emergence		Soil analysis			
Drilled	17/09/10	pH	8.2		
First emergence	27/09/10	K (mg/l)	250	K Index	3
		P (mg/l)	12	P Index	1
		Mg (mg/l)	119	Mg Index	3
		OM (%)	2.8		
Cultivations					
Date	**Equipment**				
13/09/2010	Disced				
14/09/2010	Flat lifted				
18/09/2010	Rolled				
Pesticides					
Date	**Product name**	**Rate**	**Units**	**Growth stage**	**Type**
28/10/2010	ARAMO	1	L/ha	1,03	Herbicide
23/11/2010	Capitan	0.4	L/ha	1,04	Fungicide
12/07/2011	Glyphosate	4	L/ha	9,9	Herbicide
Fertilisers					
Date	**Product name**	**Nutrient & % age**	**Rate(/ha)**	**Units**	**Nutrients (kg/ha)**
04/03/2011	Omex	N 30%	333	L/ha	100
11/04/2011	Omex	N 30%	333	L/ha	100
20/05/2011	All seed extra	N 18%	225	L/ha	40

Boxworth 2012

Drilling and emergence		Soil analysis			
Drilled	01/09/2011	pH	7.6		
First emergence	09/09/2011	K (mg/l)	226	K Index:	2+
		P (mg/l)	18.6	P Index:	2
		Mg (mg/l)	96	Mg Index:	2
		OM (%)	3.0		
Cultivations					
Date	**Equipment**				
17/08/2011	Spring tined				
22/08/2011	Power harrowed				
30/08/2011	Power harrowed				
01/09/2011	Sulky drilled				
01/09/2011	Rolled				
Pesticides					
Date	**Product name**	**Rate**	**Units**	**Growth stage**	**Type**
15/09/2011	Cypermethrin	0.1	L/ha	Cotyledon	Insecticide
03/11/2011	Corinth	0.6	L/ha	Not recorded	Fungicide
03/11/2011	Karate	0.1	L/ha	Not recorded	Insecticide
03/04/2012	Priory Extra	0.7	L/ha	Not recorded	Fungicide
03/04/2012	Boron	1.25	L/ha	Not recorded	Other
03/04/2012	Hallmark	0.075	L/ha	Not recorded	Insecticide
12/05/2012	Prosaro	0.6	L/ha	Not recorded	Fungicide
12/05/2012	Hallmark	0.075	L/ha	Not recorded	Insecticide
Fertilisers					
Date	**Product name**	**Nutrient & % age**	**Rate(/ha)**	**Units**	**Nutrients (kg/ha)**
14/09/2011	Urea	N 46%	60	Kg/ha	28
27/02/2012	AS	N 21% S60%	191	Kg/ha	N40 S115
14/03/2012	Urea	N 46%	130	Kg/ha	60
29/03/2012	Urea	N 46%	184	Kg/ha	85

Terrington 2012

Drilling and emergence		**Soil analysis**			
Drilled	09/09/11	pH	8.2		
		K (mg/l)	244	K Index:	3
		P (mg/l)	21	P Index:	2
		Mg (mg/l)	100	Mg Index:	2
		OM (%)	2.6		

Cultivations

Date	**Equipment**
08/09/2011	Disced
09/09/2011	Flat lifted
09/09/2011	Power harrowed
09/09/2011	Drilled
10/09/2011	Rolled

Pesticides

Date	**Product name**	**Rate**	**Units**	**Growth stage**	**Type**
13/04/2012	Sunorg-Pro	0.6	L/ha	4,3	Fungicide
13/04/2012	Rapitrel	3	L/ha	4,3	Other
13/04/2012	Markate	0.25	L/ha	4,3	Insecticide
17/05/2012	Filan	0.25	Kg/ha	5,9	Fungicide
17/05/2012	Galileo	1	L/ha	5,9	Fungicide

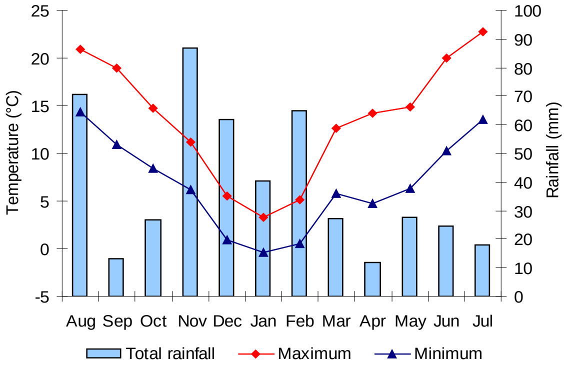
Fertilisers

Date	**Product name**	**Nutrient & % age**	**Rate (/ha)**	**Units**	**Nutrients (kg/ha)**
06/03/2012	Liquid	N 30%	333	L/ha	100
10/04/2012	Liquid	N 30%	266	L/ha	80
13/06/2012	Liquid	N 18%	222	L/ha	40

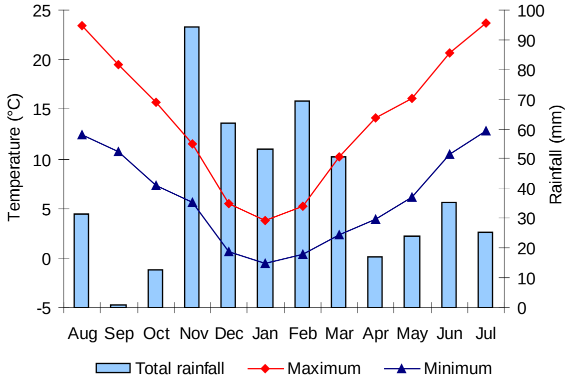
Appendix 2. Assessment dates at each site

Site	Boxworth 2010	Terrington 2010	Boxworth 2011	Boxworth 2012	Terrington 2011	Terrington 2012
Cropping year	2009–2010	2009–2010	2010–2011	2011–2012	2010–2011	2011–2012
Winter plant count	Not done due to poor emergence	25/02/2010	14/12/2010	07/12/2011	15/12/2010	05/12/2011
Winter weed assessment	Not done due to poor emergence	25/02/2010	14/12/2010	26/01/2012	15/12/2010	17/01/2012
Spring plant count	17/05/2010	25/02/2010	24/02/2011	Stubble count	03/03/2011	28/02/2012
Volunteer count				15/02/2012		20/02/2012
Canopy assessment before stem extension	12/05/2010	29/03/2010	24/02/2011	07/03/2012	03/03/2011	22/03/2012
Spring weed assessment	28/05/2010	Not done	14/03/2011	16/03/2012	18/03/2011	28/03/2012
Light interception measurements mid-flower	Not done	17/05/2010	03/05/2011	17/05/2012	26/04/2011	11/05/2012
Visual assessment of weed biomass				19/06/2012		26/06/2012
Lodging end of flowering	25/06/2010	29/07/2010	16/05/2011	13/06/2012	21/06/2011	Not done
Lodging at harvest	29/07/2010	11/08/2010	25/07/2011	12/08/2012	14/08/2011	17/08/2012
Stubble count				17/08/2012		
Harvest	29/07/2010	11/08/2010	25/07/2011	12/08/2012	14/08/2011	17/08/2012
Weed seed analysis	05/08/10	Clean	Clean	Clean	14/11/12	14/11/12

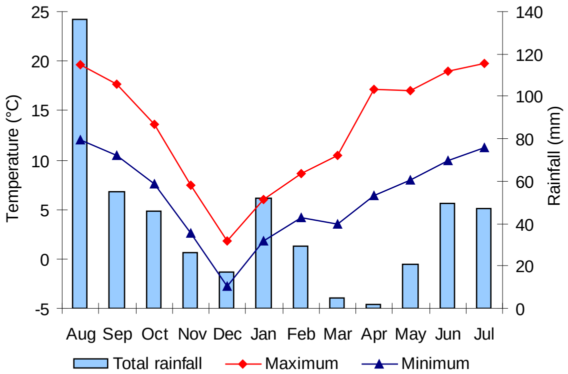
Appendix 3. Weather



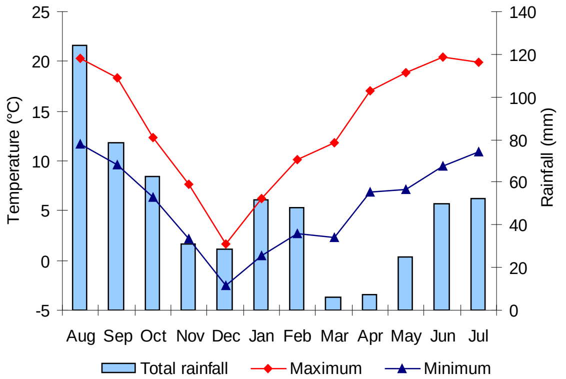
a) Boxworth 2009–2010



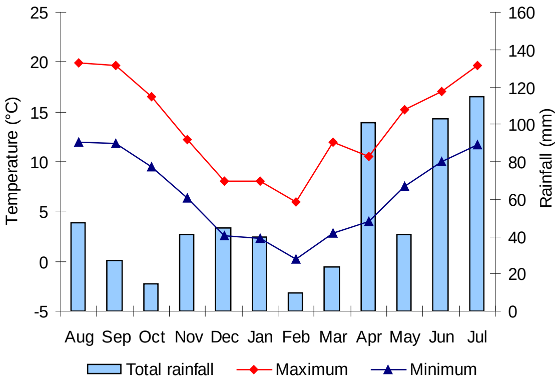
b) Terrington 2009–2010



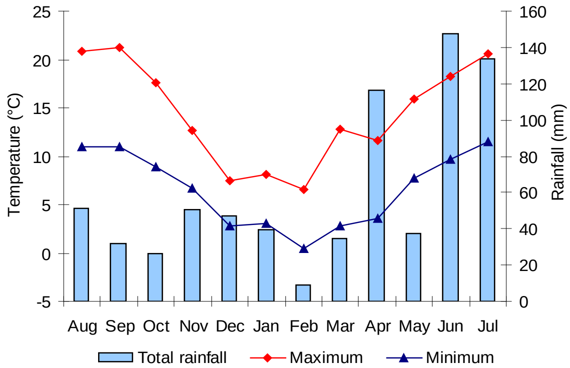
c) Boxworth 2010–2011



d) Terrington 2010–2011



e) Boxworth 2011–2012



f) Terrington 2011–2012

Average maximum and minimum temperatures and rainfall for Boxworth and Terrington

Appendix 4. Data

Oilseed rape plants/m length of row (winter)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	Not done	30	7.6	13.6	6.6	11.4
	24				8.6	13.0	6.9	12.0
	48				10.3	15.2	10.3	13.3
	72				13.5	19.0	12.2	14.3
	12	80		120	13.1	20.7	11.5	16.8
	24				14.4	20.4	12.2	15.8
	48				18.3	30.0	15.4	25.2
	72				22.5	31.7	19.2	27.4
With herbicide	12	20		15	4.7	6.3	4.9	5.7
	24				5.2	7.9	5.2	10.4
	48				6.6	7.8	8.2	12.0
	72				8.3	10.4	8.5	13.9
	12	40		30	5.3	11.3	5.7	9.9
	24				8.3	10.6	6.0	12.8
	48				9.3	14.1	11.0	13.5
	72				12.3	17.3	12.3	15.6
	12	80		60	8.5	13.8	7.4	12.5
	24				9.8	15.3	9.2	10.9
	48				13.1	19.1	14.1	15.7
	72				19.7	23.6	18.0	26.2
	12			120	11.6	20.0	10.4	15.0
	24				15.8	18.7	10.7	16.7
	48				20.6	24.4	14.3	22.2
	72				23.5	30.9	21.3	31.0

Oilseed rape plants/m² (winter)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	Not done	30	63.61	113.61	55.28	95.00
	24				109.44	172.22	95.56	140.00
	48				35.83	54.17	28.75	49.83
	72				60.14	84.86	50.83	66.02
	12	80		120	21.36	30.49	21.53	27.78
	24				38.19	62.50	32.15	52.50
	48				18.75	26.34	16.99	19.86
	72				31.20	43.98	26.62	38.10
With herbicide	12	20		15	39.17	52.22	40.56	47.78
	24				44.44	94.44	47.50	82.50
	48				70.56	115.00	61.39	104.44
	72				96.94	166.39	86.67	124.72
	12	40		30	21.53	33.06	21.81	43.47
	24				34.72	44.31	25.00	53.19
	48				40.97	63.61	38.47	45.42
	72				65.83	77.78	44.44	69.72
	12	80		60	13.68	16.18	17.15	25.07
	24				19.44	29.38	22.85	28.13
	48				27.29	39.79	29.45	32.64
	72				42.99	50.76	29.86	46.18
	12			120	11.57	14.40	11.76	19.31
	24				17.13	24.03	17.04	21.67
	48				27.41	32.78	25.00	36.39
	72				32.59	46.57	29.63	43.01

Winter oilseed rape plant height (cm)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	Not done	30	3.80	13.73	4.47	5.85
	24				4.10	10.87	4.77	4.45
	48				3.57	11.57	4.13	5.60
	72				3.83	11.30	4.53	5.21
	12	80		120	3.27	12.57	4.97	5.97
	24				3.37	14.20	5.00	6.82
	48				3.80	12.90	4.20	6.42
	72				3.90	13.07	5.50	7.43
With herbicide	12	20		15	2.90	11.67	4.37	6.20
	24				2.90	10.47	4.53	7.30
	48				3.20	9.97	4.10	5.38
	72				3.10	12.93	5.03	5.48
	12	40		30	3.33	11.20	4.03	6.55
	24				3.37	8.60	4.33	5.85
	48				3.07	9.07	4.57	6.33
	72				3.27	8.87	4.43	6.12
	12	80		60	3.13	8.47	4.47	6.22
	24				3.07	16.10	4.53	7.53
	48				3.03	8.73	4.43	6.08
	72				3.03	10.83	3.93	6.75
	12			120	3.30	8.83	4.23	7.82
	24				3.33	13.07	4.67	8.03
	48				3.10	12.57	4.80	7.63
	72				3.80	13.73	4.47	5.85

Winter oilseed rape plant width (cm)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	Not done	30	15.80	39.80	15.87	22.68
	24				14.23	30.57	15.40	13.33
	48				13.20	35.20	16.77	21.12
	72				14.07	32.50	14.57	15.68
	12	80		120	13.73	37.57	13.23	22.00
	24				14.00	34.47	14.23	15.90
	48				14.93	36.93	17.43	21.67
	72				14.57	33.47	14.67	17.52
With herbicide	12	20		15	14.00	37.40	16.80	22.80
	24				13.07	34.37	17.20	23.83
	48				14.10	32.70	16.27	18.65
	72				12.47	33.37	14.97	13.85
	12	40		30	14.67	38.33	15.77	22.22
	24				13.80	32.93	16.73	18.87
	48				14.43	28.60	16.50	19.10
	72				13.63	30.57	14.34	17.48
	12	80		60	12.73	35.97	15.80	23.47
	24				13.17	41.30	16.40	24.73
	48				14.43	31.83	16.13	19.52
	72				12.53	33.10	19.11	16.77
	12			120	14.43	34.50	15.00	25.45
	24				13.40	39.33	15.83	23.40
	48				12.67	30.60	15.97	18.25
	72				15.13	33.43	14.80	15.60

Spring oilseed rape plant height (cm)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	3.50	30	12.13	25.57	11.05	36.83
	24		3.10		9.73	17.73	12.00	27.50
	48		2.97		11.50	24.29	11.90	32.97
	72		3.03		10.37	17.37	10.93	31.27
	12	80	3.00	120	11.47	20.67	10.64	41.13
	24		3.33		11.63	18.53	11.00	33.30
	48		3.03		9.90	21.67	10.94	44.73
	72		3.27		11.20	22.27	11.92	38.30
With herbicide	12	20	3.33	15	13.43	18.93	8.57	39.50
	24		3.03		12.40	16.87	8.85	34.97
	48		3.27		12.30	15.23	10.10	37.30
	72		3.43		9.40	16.50	10.57	28.83
	12	40	3.33	30	12.30	14.90	7.75	39.93
	24		3.00		11.37	16.03	9.07	36.63
	48		3.23		12.03	12.90	10.22	34.37
	72		3.57		9.67	15.10	10.15	31.73
	12	80	3.33	60	14.07	19.10	8.70	36.20
	24		3.17		13.30	21.27	9.42	40.43
	48		3.27		14.47	17.17	9.61	42.50
	72		3.47		12.10	16.37	9.40	35.90
	12			120	13.23	17.07	8.67	42.30
	24				14.33	18.68	8.63	45.67
	48				11.17	19.10	10.20	43.47
	72				15.23	16.43	11.18	33.30

Spring oilseed rape plant width (cm)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	20.73	30	17.97	37.33	21.05	26.90
	24		21.63		13.07	25.23	18.53	19.37
	48		20.60		16.20	34.89	22.15	25.00
	72		21.97		13.33	24.83	19.37	20.07
	12	80	21.49	120	15.63	34.50	20.88	29.77
	24		22.27		16.63	27.50	19.02	24.87
	48		20.33		15.17	34.00	20.77	30.80
	72		22.80		14.83	30.50	19.08	27.70
With herbicide	12	20	22.87	15	21.77	29.83	20.32	39.30
	24		18.93		19.00	27.00	21.35	26.27
	48		19.93		17.87	23.17	22.22	24.33
	72		20.03		14.87	20.17	20.92	19.17
	12	40	18.87	30	20.13	28.17	19.77	29.67
	24		20.77		17.87	26.00	21.82	22.57
	48		14.60		18.20	22.07	22.57	25.27
	72		21.97		14.67	19.77	22.25	20.83
	12	80	19.77	60	20.67	31.00	22.02	22.94
	24		23.73		23.77	33.83	21.65	30.87
	48		23.10		20.37	25.27	22.18	27.30
	72		18.40		18.47	26.17	19.63	22.77
	12			120	21.23	27.83	22.57	34.43
	24				22.20	30.26	20.78	32.23
	48				16.40	28.83	23.37	27.07
	72				21.13	25.83	21.60	23.60

Spring oilseed rape plants /m length of row

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	2.63	30	7.93	7.90	10.37	11.77
	24		7.23		12.07	13.13	20.73	16.27
	48		3.10		8.40	10.67	14.73	13.33
	72		6.40		15.17	14.00	21.27	17.07
	12	80	3.27	120	10.27	10.17	16.50	13.17
	24		10.13		16.97	17.00	29.33	22.43
	48		5.10		12.43	13.43	20.37	15.27
	72		11.95		21.40	19.27	39.10	26.93
With herbicide	12	20	3.87	15	4.33	7.20	6.40	5.77
	24		5.77		6.90	8.90	10.30	11.90
	48		7.75		9.57	8.87	12.13	14.23
	72		4.50		10.70	12.23	17.10	16.37
	12	40	5.53	30	6.30	7.57	8.53	11.87
	24		6.95		8.10	10.83	12.07	11.97
	48		4.23		11.57	13.10	15.50	14.23
	72		7.03		14.37	17.90	21.57	19.83
	12	80	11.23	60	5.83	9.90	8.00	11.77
	24		6.37		10.10	10.77	11.47	14.43
	48		9.67		14.57	14.80	20.43	19.77
	72		15.80		17.77	17.40	28.97	23.37
	12			120	7.33	9.33	9.73	15.43
	24				11.73	14.07	17.37	18.30
	48				18.14	16.97	24.90	25.10
	72				18.33	20.13	35.83	24.13

Spring oilseed rape plant population (plants/m²)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	21.94	30	66.11	65.83	86.39	98.06
	24		60.28		100.56	109.44	172.78	135.56
	48		12.92		35.00	44.44	61.39	55.56
	72		26.67		63.19	58.33	88.61	71.11
	12	80	6.81	120	21.39	21.18	34.38	27.43
	24		21.11		35.35	35.42	61.11	46.74
	48		7.08		17.27	18.66	28.29	21.20
	72		16.60		29.72	26.76	54.31	37.41
With herbicide	12	20	32.22	15	36.11	60.00	53.33	48.06
	24		48.06		57.50	74.17	85.83	99.17
	48		64.58		79.72	73.89	101.11	118.61
	72		18.75		89.17	101.94	142.50	136.39
	12	40	23.06	30	26.25	31.53	35.56	49.44
	24		28.96		33.75	45.14	50.28	49.86
	48		8.82		48.19	54.58	64.58	59.31
	72		14.65		59.86	74.58	89.86	82.64
	12	80	23.40	60	12.15	20.63	16.67	24.51
	24		8.84		21.04	22.43	23.89	30.07
	48		13.43		30.35	30.83	42.57	41.18
	72		21.94		37.01	36.25	60.35	48.68
	12			120	10.19	12.96	13.52	21.44
	24				16.30	19.54	24.12	25.42
	48				25.19	23.56	34.58	34.86
	72				25.46	27.96	53.76	33.52

Oilseed rape GAI assessed by destructive sampling

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	0.04	30	0.29	2.07	0.22	0.52
	24		0.19		0.62	1.98	0.40	0.69
	48		0.02		0.39	1.27	0.24	0.84
	72		0.20		0.32	1.34	0.60	0.38
	12	80	0.03	120	0.33	1.03	0.12	0.70
	24		0.09		0.37	2.26	0.58	0.42
	48		0.05		0.31	0.76	0.14	0.71
	72		0.20		0.33	1.38	0.36	0.71
With herbicide	12	20	0.13	15	0.33	0.83	0.05	0.07
	24		0.26		0.22	1.58	0.14	3.85
	48		0.68		0.30	1.55	0.28	0.69
	72		0.32		0.29	1.59	0.29	0.74
	12	40	0.38	30	0.26	1.17	0.06	0.65
	24		0.53		0.25	1.26	0.13	0.74
	48		0.11		0.38	1.30	0.18	0.73
	72		0.24		0.45	2.02	0.18	0.39
	12	80	0.32	60	0.08	1.83	0.09	0.46
	24		0.26		0.21	1.12	0.05	0.30
	48		0.22		0.42	1.41	0.31	0.60
	72		0.42		0.35	1.65	0.34	0.66
	12			120	0.14	1.12	0.03	0.98
	24				0.15	1.40	0.16	0.43
	48				0.28	1.11	0.17	0.67
	72				0.27	1.75	0.32	0.62

Oilseed rape GAI assessed by analysis of photograph

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	0.47	30	0.47	1.67	0.47	2.57
	24		0.71		0.50	2.16	0.64	2.05
	48		0.55		0.44	1.31	0.56	2.32
	72		0.58		0.46	1.44	0.53	1.93
	12	80	0.47	120	0.25	1.17	0.39	1.73
	24		0.50		0.41	1.85	0.44	1.74
	48		0.40		0.36	0.90	0.09	1.39
	72		0.42		0.31	1.30	0.38	1.33
With herbicide	12	20	0.34	15	0.34	0.85	0.25	1.96
	24		0.53		0.36	1.13	0.28	2.30
	48		0.89		0.40	1.10	0.44	2.50
	72		0.45		0.43	1.36	0.49	2.62
	12	40	0.51	30	0.35	0.68	0.25	2.48
	24		0.82		0.36	1.18	0.30	2.87
	48		0.18		0.51	1.18	0.44	2.62
	72		0.21		0.46	1.72	0.41	2.19
	12	80	0.47	60	0.16	0.89	0.16	2.36
	24		0.19		0.24	1.28	0.10	2.22
	48		0.32		0.27	1.11	0.16	1.39
	72		0.36		0.22	1.13	0.28	2.57
	12			120	0.14	0.80	0.12	1.28
	24				0.21	0.73	0.12	2.47
	48				0.25	0.97	0.16	1.52
	72				0.28	0.99	0.21	1.74

Proportion of incident radiation reflected

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	0.04	30	0.07	0.11	0.08	0.12
	24		0.06		0.08	0.10	0.09	0.16
	48		0.04		0.07	0.10	0.07	0.16
	72		0.05		0.08	0.10	0.09	0.26
	12	80	0.04	120	0.07	0.10	0.06	0.11
	24		0.05		0.07	0.10	0.08	0.09
	48		0.04		0.07	0.10	0.07	0.12
	72		0.05		0.07	0.10	0.08	0.09
With herbicide	12	20	0.07	15	0.07	0.10	0.08	0.11
	24		0.07		0.08	0.11	0.08	0.14
	48		0.08		0.08	0.11	0.07	0.08
	72		0.06		0.08	0.10	0.08	0.10
	12	40	0.06	30	0.07	0.11	0.07	0.14
	24		0.09		0.08	0.11	0.07	0.17
	48		0.07		0.08	0.10	0.08	0.21
	72		0.06		0.08	0.11	0.08	0.16
	12	80	0.07	60	0.08	0.10	0.07	0.09
	24		0.06		0.08	0.11	0.07	0.15
	48		0.07		0.08	0.10	0.09	0.23
	72		0.07		0.08	0.11	0.08	0.09
	12			120	0.07	0.11	0.07	0.23
	24				0.07	0.12	0.08	0.19
	48				0.08	0.10	0.08	0.12
	72				0.08	0.10	0.07	0.16

Proportion of incident radiation intercepted

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	0.63	30	0.87	0.97	0.94	0.86
	24		0.89		0.91	0.97	0.93	0.87
	48		0.73		0.91	0.96	0.94	0.84
	72		0.69		0.90	0.93	0.95	0.94
	12	80	0.73	120	0.78	0.97	0.90	0.88
	24		0.76		0.84	0.96	0.90	0.91
	48		0.72		0.84	0.95	0.87	0.86
	72		0.75		0.85	0.95	0.90	0.86
With herbicide	12	20	0.67	15	0.84	0.94	0.60	0.86
	24		0.86		0.85	0.94	0.82	0.88
	48		0.94		0.85	0.95	0.78	0.87
	72		0.65		0.87	0.94	0.88	0.86
	12	40	0.77	30	0.84	0.92	0.59	0.84
	24		0.91		0.84	0.94	0.81	0.84
	48		0.65		0.90	0.96	0.90	0.91
	72		0.67		0.88	0.95	0.89	0.88
	12	80	0.83	60	0.78	0.94	0.62	0.86
	24		0.71		0.89	0.97	0.72	0.83
	48		0.72		0.86	0.95	0.83	0.86
	72		0.80		0.88	0.92	0.84	0.90
	12			120	0.72	0.93	0.64	0.84
	24				0.85	0.96	0.67	0.89
	48				0.87	0.94	0.73	0.86
	72				0.94	0.93	0.76	0.87

Oilseed rape leaning at harvest (%)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	23.33	30	0.00	3.33	71.67	0.00
	24		3.33		0.00	35.67	100.00	8.33
	48		26.67		0.00	10.00	75.00	8.33
	72		6.67		0.00	50.00	96.67	6.67
	12	80	26.67	120	0.00	0.00	68.33	0.00
	24		0.00		0.00	36.67	100.00	1.67
	48		20.00		0.00	36.67	71.67	0.00
	72		8.33		0.00	52.33	66.67	15.00
With herbicide	12	20	6.67	15	0.00	0.00	100.00	5.00
	24		3.33		0.00	0.00	100.00	0.00
	48		0.00		0.00	0.00	100.00	1.67
	72		6.67		0.00	33.33	100.00	11.67
	12	40	1.67	30	0.00	0.00	100.00	10.00
	24		1.67		0.00	0.00	100.00	1.67
	48		8.33		0.00	0.00	100.00	6.67
	72		1.67		0.00	6.67	100.00	3.33
	12	80	1.67	60	0.00	0.00	100.00	0.00
	24		1.67		0.00	0.00	100.00	8.33
	48		3.33		0.00	0.00	100.00	1.67
	72		1.67		0.00	3.33	100.00	18.33
	12			120	0.00	0.00	100.00	0.00
	24				0.00	10.00	100.00	6.67
	48				0.00	9.00	100.00	8.33
	72				0.00	20.00	100.00	33.33

Oilseed rape lodging at harvest (%)

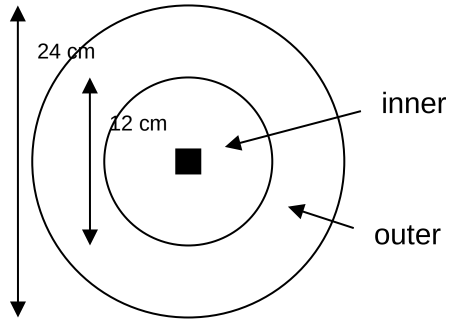
Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Terrington 2011	Boxworth 2012	Terrington 2012
No herbicide	12	20	0.00	30	0.00	0.00	28.33	0.00
	24		0.00		0.00	0.00	0.00	6.67
	48		0.00		0.00	0.00	25.00	0.00
	72		0.00		0.00	0.00	3.33	0.00
	12	80	0.00	120	0.00	0.00	31.67	0.00
	24		0.00		0.00	0.00	0.00	0.00
	48		0.00		0.00	0.00	28.33	0.00
	72		0.00		0.00	0.00	33.33	0.00
With herbicide	12	20	0.00	15	0.00	0.00	0.00	0.00
	24		0.00		0.00	0.00	0.00	0.00
	48		0.00		0.00	0.00	0.00	0.00
	72		0.00		0.00	0.00	0.00	6.67
	12	40	0.00	30	0.00	0.00	0.00	0.00
	24		0.00		0.00	0.00	0.00	0.00
	48		0.00		0.00	0.00	0.00	0.00
	72		0.00		0.00	0.00	0.00	0.00
	12	80	0.00	60	0.00	0.00	0.00	0.00
	24		0.00		0.00	0.00	0.00	23.33
	48		0.00		0.00	0.00	0.00	0.00
	72		0.00		0.00	0.00	0.00	26.67
	12			120	0.00	0.00	0.00	0.00
	24				0.00	0.00	0.00	0.00
	48				0.00	0.00	0.00	0.00
	72				0.00	0.00	0.00	3.33

Oilseed rape yield (t/ha @ 91% DM)

Herbicide	Row width (cm)	Seeds sown (/m²)	Terrington 2010	Seeds sown (/m²)	Boxworth 2011	Boxworth 2012	Terrington 2011	Terrington 2012
No herbicide	12	20	0.65	30	2.43	3.44	1.55	3.68
	24		1.23		2.67	2.81	3.35	3.42
	48		0.62		2.02	3.21	1.44	3.61
	72		1.22		2.63	3.16	2.55	3.44
	12	80	0.58	120	1.77	2.70	1.06	3.68
	24		1.13		2.21	3.18	2.74	3.31
	48		0.76		1.88	2.95	0.91	3.58
	72		1.00		2.20	2.72	1.48	3.29
With herbicide	12	20	2.96	15	2.62	2.88	3.12	3.60
	24		3.60		2.89	3.04	3.70	3.90
	48		3.82		2.96	3.41	3.93	3.64
	72		2.82		3.04	2.58	3.89	3.45
	12	40	3.19	30	2.83	2.87	3.39	3.78
	24		3.70		2.97	2.97	3.79	3.77
	48		2.64		3.07	3.32	3.83	3.33
	72		3.41		2.79	2.95	3.97	3.49
	12	80	3.42	60	2.42	2.99	2.99	3.49
	24		3.12		2.93	3.45	3.39	3.44
	48		3.14		2.72	3.44	4.01	3.86
	72		3.28		2.79	2.89	3.68	3.41
	12			120	2.29	2.95	3.65	3.69
	24				2.58	3.38	3.46	3.78
	48				2.56	2.85	3.68	3.37
	72				2.99	2.25	3.46	3.27

Weed populations

In the tables below, the weed counts refer to the areas of the circular quadrat, see section 4.2.4



Boxworth 2011

Autumn count 14 December 2010

Common chickweed (*Stellaria media*) (plants/m^2)

	Quadrat area	Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		11.8		0.0		13.8		8.8		13.3		6.6
	24		23.6		14.7		7.9		13.8		11.8		14.0
	48		8.8		23.6		12.8		15.7		11.8		17.7
	72		23.6		2.9		13.8		8.8		16.2		7.4
With herbicide	12	0.0	0.0	0.0	5.9	1.0	0.0	0.0	1.0	0.7	0.0	0.0	2.2
	24	0.0	0.0	0.0	2.9	1.0	2.0	0.0	1.0	0.7	1.5	0.0	1.5
	48	0.0	0.0	0.0	0.0	2.0	4.9	0.0	1.0	1.5	3.7	0.0	0.7
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7

Black-grass (*Alopecurus myosuroides*) (plants/m^2)

	Quadrat area	Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		8.8		11.8		32.4		12.8		26.5		12.5
	24		23.6		11.8		18.7		12.8		19.9		12.5
	48		11.8		14.7		8.8		8.8		9.6		10.3
	72		14.7		8.8		6.9		7.9		8.8		8.1
With herbicide	12	11.8	14.7	5.9	5.9	10.8	10.8	7.9	12.8	11.1	11.8	7.4	11.1
	24	17.7	5.9	2.9	11.8	22.6	3.9	4.9	3.9	21.4	4.4	4.4	5.9
	48	8.8	17.7	17.7	5.9	5.9	11.8	9.8	9.8	6.6	13.3	11.8	8.8
	72	11.8	2.9	8.8	8.8	12.8	8.8	10.8	17.7	12.5	7.4	10.3	15.5

Common field speedwell (*Veronica persica*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.2		0.0		10.8		6.9		11.8		5.2
	24		0.1		0.0		6.9		6.9		7.4		5.9
	48		0.0		0.1		7.9		4.9		5.9		5.2
	72		0.0		0.1		2.0		5.9		2.2		7.4
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.7	0.0	0.7
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.5

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		29.5		2.9		29.5		15.7		29.5		12.5
	24		38.3		23.6		17.7		20.6		22.8		21.4
	48		11.8		29.5		21.6		22.6		19.2		24.3
	72		29.5		17.7		17.7		20.6		20.6		19.9
With herbicide	12	2.9	0.0	0.0	5.9	1.0	0.0	0.0	1.0	1.5	0.0	0.0	2.2
	24	0.0	0.0	0.0	2.9	1.0	2.0	1.0	1.0	0.7	1.5	0.7	1.5
	48	0.0	2.9	2.9	2.9	2.0	5.9	0.0	2.9	1.5	5.2	0.7	2.9
	72	0.0	0.0	0.0	2.9	0.0	0.0	0.0	4.9	0.0	0.0	0.0	4.4

Shepherds purse (*Capsella bursa-pastoris*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		0.0		4.9		0.0		4.4		0.0
	24		0.1		0.1		2.9		0.0		3.7		1.5
	48		0.0		0.0		1.0		2.0		0.7		1.5
	72		0.0		0.0		2.0		5.9		2.2		5.2
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0
	48	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.7	0.0	1.5
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.5

Total grass weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		23.6		11.8		33.4		13.8		30.9		13.3
	24		23.6		14.7		19.6		15.7		20.6		15.5
	48		11.8		14.7		9.8		8.8		10.3		10.3
	72		14.7		8.8		7.9		7.9		9.6		8.1
With herbicide	12	14.7	17.7	8.8	5.9	13.8	11.8	8.8	12.8	14.0	13.3	8.8	11.1
	24	17.7	5.9	2.9	11.8	23.6	5.9	4.9	3.9	22.1	5.9	4.4	5.9
	48	8.8	17.7	17.7	5.9	5.9	16.7	9.8	9.8	6.6	16.9	11.8	8.8
	72	11.8	2.9	11.8	8.8	12.8	8.8	11.8	17.7	12.5	7.4	11.8	15.5

Total weed number (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		53.0		14.7		62.9		29.5		60.4		25.8
	24		61.9		38.3		37.3		36.3		43.5		36.8
	48		23.6		44.2		31.4		31.4		29.5		34.6
	72		44.2		26.5		25.5		28.5		30.2		28.0
With herbicide	12	17.7	17.7	8.8	11.8	14.7	11.8	8.8	13.8	15.5	13.3	8.8	13.3
	24	17.7	5.9	2.9	14.7	24.6	7.9	5.9	4.9	22.8	7.4	5.2	7.4
	48	8.8	20.6	20.6	8.8	7.9	22.6	9.8	12.8	8.1	22.1	12.5	11.8
	72	11.8	2.9	11.8	11.8	12.8	8.8	11.8	22.6	12.5	7.4	11.8	19.9

Boxworth 2011

Spring counts 14 March 2011

Black-grass (*Alopecurus myosuroides*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		29.5		23.6		33.4		20.6		32.4		21.4
	24		26.5		5.9		17.7		4.9		19.9		5.2
	48		8.8		14.7		8.8		17.7		8.8		16.9
	72		44.2		2.9		22.6		5.9		28.0		5.2
With herbicide	12	0.0	0.0	2.9	8.8	2.0	1.0	3.9	6.9	1.5	0.7	3.7	7.4
	24	2.9	2.9	0.0	0.0	5.9	2.9	0.0	0.0	5.2	2.9	0.0	0.0
	48	0.0	2.9	2.9	0.0	0.0	6.9	0.0	0.0	0.0	5.9	0.7	0.0
	72	0.0	5.9	2.9	2.9	5.9	3.9	1.0	3.9	4.4	4.4	1.5	3.7

Common chickweed (*Stellaria media*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		23.6		11.8		19.6		13.8		20.6		13.3
	24		11.8		11.8		14.7		16.7		14.0		15.5
	48		17.7		14.7		17.7		19.6		17.7		18.4
	72		38.3		8.8		19.6		13.8		24.3		12.5
With herbicide	12	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.7	0.7	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7
	72	0.0	0.0	2.9	0.0	0.0	2.9	0.0	1.0	0.0	2.2	0.7	0.7

Common field speedwell (*Veronica persica*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		14.7		2.9		7.9		9.8		9.6		8.1
	24		14.7		5.9		20.6		12.8		19.2		11.1
	48		5.9		14.7		11.8		13.8		10.3		14.0
	72		0.0		0.0		11.8		9.8		8.8		7.4
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		38.3		14.7		40.3		31.4		39.8		27.3
	24		38.3		20.6		51.1		41.3		47.9		36.1
	48		32.4		38.3		39.3		44.2		37.6		42.7
	72		53.0		20.6		42.2		30.5		44.9		28.0
With herbicide	12	0.0	0.0	2.9	20.6	1.0	2.0	7.9	3.9	0.7	1.5	6.6	8.1
	24	8.8	17.7	0.0	0.0	4.9	11.8	1.0	0.0	5.9	13.3	0.7	0.0
	48	2.9	5.9	0.0	5.9	0.0	1.0	2.0	4.9	0.7	2.2	1.5	5.2
	72	0.0	5.9	5.9	5.9	2.0	8.8	2.9	8.8	1.5	8.1	3.7	8.1

Total grass weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		58.9		26.5		55.0		21.6		56.0		22.8
	24		38.3		8.8		32.4		5.9		33.9		6.6
	48		11.8		20.6		8.8		18.7		9.6		19.2
	72		47.2		2.9		26.5		5.9		31.7		5.2
With herbicide	12	0.0	0.0	2.9	8.8	2.9	1.0	3.9	6.9	2.2	0.7	3.7	7.4
	24	2.9	2.9	0.0	0.0	5.9	2.9	1.0	0.0	5.2	2.9	0.7	0.0
	48	0.0	2.9	2.9	0.0	0.0	6.9	0.0	0.0	0.0	5.9	0.7	0.0
	72	0.0	5.9	5.9	2.9	5.9	3.9	1.0	3.9	4.4	4.4	2.2	3.7

Total weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		97.3		41.3		91.4		51.1		92.8		48.6
	24		73.7		29.5		77.6		42.2		76.6		39.0
	48		41.3		56.0		44.2		57.0		43.5		56.7
	72		91.4		23.6		62.9		32.4		70.0		30.2
With herbicide	12	0.0	0.0	5.9	29.5	3.9	2.9	11.8	10.8	2.9	2.2	10.3	15.5
	24	11.8	20.6	0.0	0.0	10.8	14.7	2.0	0.0	11.1	16.2	1.5	0.0
	48	2.9	8.8	2.9	5.9	0.0	7.9	2.0	3.9	0.7	8.1	2.2	4.4
	72	0.0	11.8	11.8	8.8	7.9	11.8	2.9	10.8	5.9	11.8	5.2	10.3

Boxworth 2012

Autumn weeds counts 26 January 2011

Black-grass (*Alopecurus myosuroides*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		5.9		0.0		8.8		9.8		8.1		7.4
	24		0.0		2.9		5.9		5.9		4.4		5.2
	48		5.9		11.8		16.7		2.9		14.0		5.2
	72		8.8		8.8		4.9		3.9		5.9		5.2
With herbicide	12	0.0	2.9	0.0	0.0	1.0	1.0	0.0	0.0	0.7	1.5	0.0	0.0
	24	2.9	2.9	0.0	2.9	2.0	0.0	2.0	1.0	2.2	0.7	1.5	1.5
	48	0.0	5.9	0.0	5.9	0.0	0.0	2.0	2.0	0.0	1.5	1.5	2.9
	72	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.7	1.5	0.0	0.0

Common chickweed (*Stellaria media*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		5.9		0.0		1.0		0.0		2.2
	24		8.8		2.9		6.9		1.0		7.4		1.5
	48		5.9		2.9		5.9		28.5		5.9		22.1
	72		2.9		0.0		1.0		2.9		1.5		2.2
With herbicide	12	5.9	2.9	0.0	0.0	2.0	13.8	0.0	0.0	2.9	11.1	0.0	0.0
	24	2.9	2.9	0.0	2.9	1.0	2.9	1.0	2.0	1.5	2.9	0.7	2.2
	48	0.0	0.0	0.0	2.9	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.7
	72	2.9	2.9	0.0	0.0	2.0	1.0	0.0	2.9	2.2	1.5	0.0	2.2

Volunteer winter wheat (*Triticum aestivum)* (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		0.0		2.9		2.0		2.2		1.5
	24		5.9		0.0		4.9		0.0		5.2		0.0
	48		0.0		0.0		3.9		2.0		2.9		1.5
	72		5.9		0.0		2.9		2.0		3.7		1.5
With herbicide	12	8.8	0.0	0.0	0.0	2.0	2.0	2.0	2.0	3.7	1.5	1.5	1.5
	24	0.0	0.0	2.9	0.0	1.0	5.9	2.9	1.0	0.7	4.4	2.9	0.7
	48	0.0	0.0	0.0	0.0	3.9	0.0	2.0	0.0	2.9	0.0	1.5	0.0
	72	2.9	0.0	0.0	0.0	2.0	1.0	2.0	0.0	2.2	0.7	1.5	0.0

Sow-thistle (*Sonchus* spp.) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		5.9		2.9		4.9		1.0		5.2		1.5
	24		0.0		0.0		5.9		4.9		4.4		3.7
	48		8.8		0.0		6.9		3.9		7.4		2.9
	72		8.8		0.0		2.0		4.9		3.7		3.7
With herbicide	12	0.0	2.9	0.0	2.9	6.9	6.9	2.0	0.0	5.2	5.9	1.5	0.7
	24	2.9	0.0	2.9	0.0	2.9	1.0	2.9	2.0	2.9	0.7	2.9	1.5
	48	0.0	2.9	0.0	2.9	6.9	0.0	0.0	0.0	5.2	0.7	0.0	0.7
	72	0.0	8.8	2.9	2.9	4.9	2.9	1.0	2.9	3.7	4.4	1.5	2.9

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		5.9		8.8		12.8		2.9		11.1		4.4
	24		8.8		5.9		17.7		11.8		15.5		10.3
	48		14.7		5.9		16.7		38.3		16.2		30.2
	72		20.6		8.8		4.9		15.7		8.8		14.0
With herbicide	12	5.9	5.9	2.9	5.9	10.8	20.6	3.9	0.0	9.6	16.9	3.7	1.5
	24	5.9	5.9	2.9	2.9	4.9	4.9	3.9	4.9	5.2	5.2	3.7	4.4
	48	0.0	2.9	0.0	8.8	8.8	0.0	0.0	1.0	6.6	0.7	0.0	2.9
	72	2.9	14.7	2.9	2.9	7.9	3.9	1.0	5.9	6.6	6.6	1.5	5.2

Total grass weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		5.9		0.0		11.8		11.8		10.3		8.8
	24		5.9		2.9		10.8		5.9		9.6		5.2
	48		5.9		11.8		20.6		4.9		16.9		6.6
	72		14.7		8.8		7.9		5.9		9.6		6.6
With herbicide	12	8.8	2.9	0.0	0.0	2.9	2.9	2.0	2.0	4.4	2.9	1.5	1.5
	24	2.9	2.9	2.9	2.9	2.9	5.9	4.9	2.0	2.9	5.2	4.4	2.2
	48	0.0	5.9	0.0	5.9	3.9	0.0	3.9	2.0	2.9	1.5	2.9	2.9
	72	2.9	0.0	0.0	0.0	2.9	2.9	2.0	0.0	2.9	2.2	1.5	0.0

Total weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		11.8		8.8		24.6		14.7		24.6		14.7
	24		14.7		8.8		28.5		17.7		28.5		17.7
	48		20.6		17.7		37.3		43.2		37.3		43.2
	72		35.4		17.7		12.8		21.6		12.8		21.6
With herbicide	12	14.7	8.8	2.9	5.9	13.8	23.6	5.9	2.0	13.8	23.6	5.9	2.0
	24	8.8	8.8	5.9	5.9	7.9	10.8	8.8	6.9	7.9	10.8	8.8	6.9
	48	0.0	8.8	0.0	14.7	12.8	0.0	3.9	2.9	12.8	0.0	3.9	2.9
	72	5.9	14.7	2.9	2.9	10.8	6.9	2.9	5.9	10.8	6.9	2.9	5.9

Boxworth 2012

Spring weed counts 16 March 2012

Black-grass (*Alopecurus myosuroides)* (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		5.9		2.9		2.0		0.0		2.9		0.7
	24		2.9		2.9		2.0		1.0		2.2		1.5
	48		0.0		0.0		2.9		2.0		2.2		1.5
	72		17.7		0.0		6.9		5.9		9.6		4.4
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	1.0	0.0	2.0	1.0	0.7	0.0	1.5	0.7

Common chickweed (*Stellaria media*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		0.0		2.9		2.0		2.2		1.5
	24		82.5		0.0		3.9		2.9		23.6		2.2
	48		2.9		2.9		20.6		17.7		16.2		14.0
	72		2.9		0.0		2.9		2.0		2.9		1.5
With herbicide	12	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.7	1.5	0.0	0.0
	24	0.0	0.0	2.9	0.0	2.0	2.9	2.0	1.0	1.5	2.2	2.2	0.7
	48	0.0	0.0	0.0	0.0	1.0	1.0	2.9	0.0	0.7	0.7	2.2	0.0
	72	0.0	2.9	0.0	2.9	1.0	0.0	0.0	1.0	0.7	0.7	0.0	1.5

Shepherd's purse (*Capsella bursa-pastoris*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		0.0		2.0		1.0		1.5		0.7
	24		5.9		2.9		1.0		0.0		2.2		0.7
	48		0.0		0.0		2.0		2.0		1.5		1.5
	72		0.0		0.0		0.0		1.0		0.0		0.7
With herbicide	12	0.0	0.0	0.0	0.0	4.9	0.0	1.0	1.0	3.7	0.0	0.7	0.7
	24	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.7	1.5
	72	0.0	0.0	0.0	0.0	3.9	0.0	1.0	1.0	2.9	0.0	0.7	0.7

Sow-thistle (*Sonchus* spp.) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		8.8		0.0		2.9		2.9		4.4		2.2
	24		5.9		5.9		2.0		2.0		2.9		2.9
	48		11.8		0.0		2.9		2.9		5.2		2.2
	72		2.9		2.9		3.9		2.9		3.7		2.9
With herbicide	12	2.9	0.0	5.9	11.8	7.9	11.8	3.9	12.8	6.6	8.8	4.4	12.5
	24	0.0	0.0	2.9	0.0	2.9	3.9	3.9	3.9	2.2	2.9	3.7	2.9
	48	0.0	5.9	0.0	2.9	14.7	3.9	6.9	3.9	11.1	4.4	5.2	3.7
	72	2.9	5.9	0.0	0.0	5.9	9.8	1.0	5.9	5.2	8.8	0.7	4.4

Cleavers (*Gallium aparine*) (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		2.9		2.9		1.0		2.0		1.5		2.2
	24		14.7		2.9		1.0		2.0		4.4		2.2
	48		8.8		0.0		1.0		3.9		2.9		2.9
	72		14.7		0.0		6.9		0.0		8.8		0.0
With herbicide	12	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
	24	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		11.8		2.9		8.8		9.8		9.6		8.1
	24		109.0		11.8		7.9		6.9		33.2		8.1
	48		26.5		2.9		40.3		26.5		36.8		20.6
	72		20.6		2.9		13.8		7.9		15.5		6.6
With herbicide	12	2.9	0.0	8.8	11.8	13.8	15.7	4.9	14.7	11.1	11.8	5.9	14.0
	24	0.0	2.9	5.9	0.0	9.8	6.9	5.9	5.9	7.4	5.9	5.9	4.4
	48	0.0	5.9	0.0	2.9	16.7	4.9	12.8	6.9	12.5	5.2	9.6	5.9
	72	2.9	8.8	0.0	2.9	11.8	10.8	2.9	7.9	9.6	10.3	2.2	6.6

Total grass weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		5.9		2.9		3.9		0.0		4.4		0.7
	24		2.9		2.9		2.0		2.0		2.2		2.2
	48		2.9		0.0		6.9		2.0		5.9		1.5
	72		17.7		0.0		6.9		7.9		9.6		5.9
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	2.9	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.7
	48	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.7	0.7	0.0	0.0
	72	0.0	0.0	0.0	0.0	1.0	0.0	2.0	1.0	0.7	0.0	1.5	0.7

Total weeds (plants/m^2)

		Inner				Outer				Both			
	Seed sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		14.0		8.8		17.7		5.9		12.8		9.8
	24		35.4		10.3		112.0		14.7		9.8		8.8
	48		42.7		22.1		29.5		2.9		47.2		28.5
	72		25.0		12.5		38.3		2.9		20.6		15.7
With herbicide	12	11.1	11.8	5.9	14.0	2.9	0.0	8.8	11.8	13.8	15.7	4.9	14.7
	24	7.4	5.9	6.6	5.2	0.0	2.9	5.9	2.9	9.8	6.9	6.9	5.9
	48	13.3	5.9	9.6	5.9	0.0	5.9	0.0	2.9	17.7	5.9	12.8	6.9
	72	10.3	10.3	3.7	7.4	2.9	8.8	0.0	2.9	12.8	10.8	4.9	8.8

Terrington 2010

Winter weed assessment 25 February 2010

Ivy-leaved speedwell (*Veronica hederifolia*) (plants/m^2)

		Inner			Outer			Both		
	Seeds sown/m²	10	20	40	10	20	40	10	20	40
Herbicide	Row width (cm)									
No herbicide	12	56.0		53.0	58.9		50.1	58.2		50.8
	24	53.0		53.0	44.2		60.9	46.4		58.9
	48	106.1		82.5	62.9		56.0	73.7		62.6
	72	82.5		58.9	61.9		43.2	67.0		47.1
With herbicide	12	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.7	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	5.9	0.0	0.0	1.0	0.0	0.0	2.2	0.0	0.0
	72	2.9	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0

Volunteer winter wheat (*Triticum aestivum*) (plants/m^2)

		Inner			Outer			Both		
	Seeds sown/m²	10	20	40	10	20	40	10	20	40
Herbicide	Row width (cm)									
No herbicide	12	23.6		17.7	38.3		9.8	34.6		11.8
	24	5.9		38.3	24.6		12.8	19.9		19.2
	48	14.7		32.4	15.7		16.7	15.5		20.6
	72	20.6		26.5	25.5		24.6	24.3		25.0
With herbicide	12	11.8	23.6	23.6	13.8	15.7	14.7	13.3	17.7	16.9
	24	17.7	17.7	82.5	23.6	12.8	76.6	22.1	14.0	78.1
	48	29.5	8.8	11.8	15.7	9.8	5.9	19.2	9.6	7.4
	72	35.4	50.1	5.9	27.5	27.5	13.8	29.5	33.2	11.8

Shepherd's purse (*Capsella bursa-pastoris*) (plants/m^2)

		Inner			Outer			Both		
	Seeds sown/m²	10	20	40	10	20	40	10	20	40
Herbicide	Row width (cm)									
No herbicide	12	82.5		29.5	51.1		29.5	58.9		29.5
	24	26.5		41.3	58.9		60.9	50.8		56.0
	48	29.5		23.6	61.9		51.1	53.8		44.2
	72	35.4		8.8	49.1		34.4	45.7		28.0
With herbicide	12	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	1.5
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	2.0	0.0	0.0	1.5	0.0	0.0

Total broad-leaved weeds (plants/m^2)

		Inner			Outer			Both		
	Seeds sown/m²	10	20	40	10	20	40	10	20	40
Herbicide	Row width (cm)									
No herbicide	12	144.4		94.3	110.0		91.4	118.6		92.1
	24	82.5		97.3	108.1		128.7	101.7		120.8
	48	144.4		109.0	131.6		113.0	134.8		112.0
	72	159.1		76.6	125.7		82.5	134.1		81.0
With herbicide	12	0.0	2.9	0.0	0.0	10.8	2.0	0.0	8.8	1.5
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	5.9	0.0	0.0	2.0	0.0	0.0	2.9	0.0	0.0
	72	2.9	0.0	0.0	2.0	0.0	0.0	2.2	0.0	0.0

Total grass weeds (plants/m^2)

		Inner			Outer			Both		
	Seeds sown/m²	10	20	40	10	20	40	10	20	40
Herbicide	Row width (cm)									
No herbicide	12	23.6		17.7	38.3		9.8	34.6		11.8
	24	5.9		38.3	24.6		12.8	19.9		19.2
	48	14.7		32.4	15.7		16.7	15.5		20.6
	72	17.7		26.5	25.5		24.6	23.6		25.0
With herbicide	12	11.8	23.6	23.6	13.8	15.7	14.7	13.3	17.7	16.9
	24	17.7	17.7	82.5	23.6	12.8	76.6	22.1	14.0	78.1
	48	29.5	8.8	11.8	15.7	9.8	5.9	19.2	9.6	7.4
	72	35.4	50.1	5.9	27.5	27.5	13.8	29.5	33.2	11.8

Total weeds (plants/m^2)

		Inner			Outer			Both		
	Seeds sown/m²	10	20	40	10	20	40	10	20	40
Herbicide	Row width (cm)									
No herbicide	12	168.0		112.0	148.3		101.2	153.2		103.9
	24	88.4		135.6	132.6		141.5	121.6		140.0
	48	159.1		141.5	147.4		129.7	150.3		132.6
	72	176.8		103.1	151.3		107.1	157.6		106.1
With herbicide	12	11.8	26.5	23.6	13.8	26.5	16.7	13.3	26.5	18.4
	24	17.7	17.7	82.5	23.6	12.8	76.6	22.1	14.0	78.1
	48	35.4	8.8	11.8	17.7	9.8	5.9	22.1	9.6	7.4
	72	38.3	50.1	5.9	29.5	27.5	13.8	31.7	33.2	11.8

Terrington 2011

Winter weed assessment 15 December 2010

Common poppy (*Papaver rhoeas*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		100.2		35.4		68.8		33.4		76.6		33.9
	24		50.1		76.6		114.9		69.7		98.7		71.5
	48		53.0		47.2		91.4		51.1		81.8		50.1
	72		182.7		44.2		123.8		51.1		138.5		49.4
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Volunteer winter wheat (*Triticum aestivum*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		67.8		5.9		2.9		6.9		19.2		6.6
	24		32.4		38.3		40.3		24.6		38.3		28.0
	48		8.8		14.7		8.8		27.5		8.8		24.3
	72		26.5		20.6		18.7		29.5		20.6		27.3
With herbicide	12	2.9	0.0	0.0	5.9	2.0	2.9	0.0	7.9	2.2	2.2	0.0	7.4
	24	0.0	0.0	2.9	20.6	0.0	6.9	2.9	5.9	0.0	5.2	2.9	9.6
	48	2.9	0.0	11.8	5.9	1.0	0.0	9.8	4.9	1.5	0.0	10.3	5.2
	72	0.0	11.8	8.8	2.9	0.0	0.0	4.9	0.0	0.0	2.9	5.9	0.7

Ivy-leaved speedwell (*Veronica hederifolia*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		32.4		11.8		6.9		2.9		13.3		5.2
	24		35.4		8.8		7.9		6.9		14.7		7.4
	48		53.0		8.8		35.4		15.7		39.8		14.0
	72		29.5		0.0		16.7		9.8		19.9		7.4
With herbicide	12	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		132.6		47.2		75.6		36.3		89.9		39.0
	24		85.5		100.2		124.8		76.6		114.9		82.5
	48		106.1		56.0		129.7		68.8		123.8		65.6
	72		212.2		44.2		141.5		60.9		159.1		56.7
With herbicide	12	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	2.9	1.0	0.0	0.0	2.2	0.7
	48	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.7	0.0
	72	0.0	0.0	0.0	0.0	2.0	1.0	0.0	1.0	1.5	0.7	0.0	0.7

Total grass weeds (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		67.8		5.9		2.9		6.9		19.2		6.6
	24		35.4		58.9		40.3		29.5		39.0		36.8
	48		8.8		17.7		16.7		27.5		14.7		25.0
	72		26.5		20.6		18.7		29.5		20.6		27.3
With herbicide	12	2.9	0.0	0.0	5.9	2.0	2.9	0.0	7.9	2.2	2.2	0.0	7.4
	24	0.0	0.0	2.9	20.6	0.0	6.9	2.9	5.9	0.0	5.2	2.9	9.6
	48	2.9	0.0	11.8	5.9	1.0	0.0	9.8	4.9	1.5	0.0	10.3	5.2
	72	0.0	11.8	8.8	2.9	0.0	0.0	4.9	0.0	0.0	2.9	5.9	0.7

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		200.4		53.0		78.6		43.2		109.0		45.7
	24		120.8		159.1		165.0		106.1		154.0		119.3
	48		114.9		73.7		146.4		96.3		138.5		90.6
	72		238.7		64.8		160.1		90.4		179.7		84.0
With herbicide	12	2.9	0.0	0.0	5.9	2.9	2.9	0.0	7.9	2.9	2.2	0.0	7.4
	24	0.0	0.0	2.9	20.6	0.0	6.9	5.9	6.9	0.0	5.2	5.2	10.3
	48	2.9	0.0	11.8	5.9	1.0	0.0	10.8	4.9	1.5	0.0	11.1	5.2
	72	0.0	11.8	8.8	2.9	2.0	1.0	4.9	1.0	1.5	3.7	5.9	1.5

Terrington 2011

Spring weed assessment 18 March 2011

Common poppy (*Papaver rhoeas*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		126.7		61.9		122.8		43.2		123.8		47.9
	24		141.5		141.5		105.1		99.2		114.2		109.8
	48		109.0		56.0		108.1		56.0		108.3		56.0
	72		112.0		44.2		111.0		50.1		111.2		48.6
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Volunteer winter wheat (*Triticum aestivum*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
None	12		14.7		11.8		16.7		8.8		16.2		9.6
	24		11.8		20.6		11.8		6.9		11.8		10.3
	48		38.3		14.7		13.8		20.6		19.9		19.2
	72		11.8		5.9		10.8		11.8		11.1		10.3
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	5.9	0.0	0.0	0.0	0.0	2.9	0.0	0.0	1.5	2.2	0.0
	48	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.2	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Common field speedwell (*Veronica persica*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		2.9		6.9		4.9		5.2		4.4
	24		11.8		2.9		2.0		5.9		4.4		5.2
	48		2.9		8.8		2.0		4.9		2.2		5.9
	72		2.9		0.0		5.9		4.9		5.2		3.7
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Common chickweed (*Stellaria media*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		8.8		5.9		2.0		9.8		3.7		8.8
	24		5.9		2.9		10.8		12.8		9.6		10.3
	48		2.9		2.9		14.7		2.0		11.8		2.2
	72		20.6		8.8		6.9		9.8		10.3		9.6
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Black-grass (*Alopecurus myosuroides*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		8.8		0.0		7.9		5.9		8.1		4.4
	24		20.6		17.7		20.6		2.9		20.6		6.6
	48		17.7		0.0		8.8		3.9		11.1		2.9
	72		0.0		8.8		13.8		12.8		10.3		11.8
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total broad-leaved weeds (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		138.5		73.7		135.6		59.9		136.3		63.4
	24		159.1		153.2		123.8		120.8		132.6		128.9
	48		117.9		67.8		131.6		65.8		128.2		66.3
	72		138.5		56.0		126.7		64.8		129.7		62.6
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total grass weeds (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		23.6		11.8		24.6		14.7		24.3		14.0
	24		32.4		38.3		32.4		9.8		32.4		16.9
	48		56.0		14.7		22.6		24.6		30.9		22.1
	72		11.8		14.7		24.6		24.6		21.4		22.1
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	5.9	0.0	0.0	0.0	0.0	2.9	0.0	0.0	1.5	2.2	0.0
	48	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.2	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total weeds (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		162.1		85.5		160.1		74.7		160.6		77.4
	24		191.6		191.6		156.2		130.7		165.0		145.9
	48		173.9		82.5		154.2		90.4		159.1		88.4
	72		150.3		70.7		151.3		89.4		151.0		84.7
With herbicide	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24	0.0	5.9	0.0	0.0	0.0	0.0	2.9	0.0	0.0	1.5	2.2	0.0
	48	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.2	0.0	0.0
	72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Terrington 2012

Winter weed count 17 January 2012

Volunteer winter wheat (*Triticum aestivum*) (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		14.7		14.7		0.0		0.0		3.7		3.7
	24		23.6		23.6		0.0		0.0		5.9		5.9
	48		29.5		20.6		0.0		0.0		7.4		5.2
	72		26.5		32.4		1.0		0.0		7.4		8.1
With herbicide	12	2.9	0.0	2.9	2.9	0.0	0.0	0.0	0.0	0.7	0.0	0.7	0.7
	24	5.9	2.9	11.8	2.9	0.0	0.0	0.0	0.0	1.5	0.7	2.9	0.7
	48	0.0	8.8	0.0	2.9	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.7
	72	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0

Terrington 2012

Spring weed count 28 March 2012

Volunteer winter wheat (*Triticum aestivum*) GS11–13 (plants/m^2)

		Inner				Outer				Both			
	Seeds sown/m²	15	30	60	120	15	30	60	120	15	30	60	120
Herbicide	Row width (cm)												
No herbicide	12		0.0		14.7		4.9		2.0		3.7		5.2
	24		5.9		5.9		8.8		2.9		8.1		3.7
	48		0.0		0.0		5.9		1.0		4.4		0.7
	72		5.9		2.9		2.9		3.9		3.7		3.7
With herbicide	12	0.0	0.0	0.0	2.9	5.9	1.0	5.9	2.9	4.4	0.7	4.4	2.9
	24	5.9	0.0	2.9	0.0	2.0	1.0	9.8	0.0	2.9	0.7	8.1	0.0
	48	2.9	0.0	0.0	0.0	1.0	2.0	2.0	0.0	1.5	1.5	1.5	0.0
	72	0.0	0.0	2.9	0.0	0.0	2.9	0.0	2.0	0.0	2.2	0.7	1.5

Appendix 5. Test Rigs

Figure 66. Test rig as developed by NIAB TAG at Silsoe.

The rig shown in Figures 66 and 67 was mounted on the tractor three-point linkage with height control from the tractor hydraulics. Spray liquid was supplied to the nozzles from pressurised containers that were supplied with air from a small 12 v d.c. compressor mounted on the rig. Pressure at the nozzles was controlled by adjusting the supply pressure to the liquid canisters. While the height control proved to be adequate for the conventional and twisted nozzle arrangements used, operation on rough terrain gave conditions where the shrouded Micron "Varidome" was not consistently close to the soil surface and some spray in small droplets may then have escaped under the shroud.

Figure 67. Test rig in action at SAC site in year one of the project.

Appendix 6. Year 2 NIAB TAG Using RTK and Vision Guidance.

Also pictured are the Garford shield and simple plate shield

Figure 68. Application systems used in Year 2 of the work.

The vision guidance system (Figure 68 – Upper left) uses forward facing cameras to capture images of the crop that are then analysed to determine row positions and directions. For the experiments conducted in this project, an existing front-mounted rig developed for targeted spot and patch application in vegetable crops was adapted such that the system could operate with shielded nozzles – see Figure 68. The presence of volunteer plants in the inter-row makes the row less visually distinct and the set up for vision guidance is then more critical. The conditions in Year 2 of this study with a substantial inter-row volunteer population gave testing conditions for the vision guidance but despite this the system was able to follow rows throughout all plots.

The RTK GPS system used in Year 2 was tractor-based with a separate base station mounted on a tripod in the field. The field had been drilled using a different RTK system and therefore the co-ordinates from the drill system were transferred manually to the tractor system used for the trial. In the parts of the field where this did not give the correct row alignment, a new A-B line was established with the trials tractor and used for all plot treatments. The shielded sprayer unit was mounted behind the tractor on the three-point linkage with the linkage tight such that the row following components followed the guidance determined from the tractor. In Year 3, the RTK system was on the same tractor system as used to establish the crop and hence the co-ordinates for the guidance system were transferred directly to the tractor used for the field trials.

Untreated

With RTK / with shield

With VG / with shield

Vision Guidance on Mechanical Hoe

Shows the vision guidance system mounted on Garfords inter-row Robocrop inter-row cultivator. The winter rape was drilled using a GPS controlled drill on 50 cm wide drills.

Appendix 7.

Treatment Notes SRUC Year one

SAC Trials Treatment Notes:

Trial design: Randomised Block, 20 m long x 2 m wide x 3 reps

Drilled: 28 August 2009

Variety: Catana.

Pre-em residual herbicide applied: 02/09/09

Post-em inter-row treatments applied: 15/10/09 at GS 1,5

Roundup energy is a 450g/l glyphosate supplied by project collaborator Monsanto

Butisan S is 500g/l formulation of metazachlor

Treatment Notes SRUC Year Two

Design: Replicated randomised block x 3 reps. Plot size 22 m x 2.0 m

Varieties: Catana and Excalibur

Seed Rate: 90 seeds/m² for 12 cm, 40 for 50 cm spacing

Drilled: 27/08/10

Pre-em applied: Novall as 400g/L metazachlor 100g/L quinmerac

Post-em applied: GS 1,2

Treatments Notes ORC, Years 2 and 3

In both trial years 2 and 3, four treatments were compared against each other:

1) Untreated control (no mechanical weeding and no herbicide applications)
2) Herbicide treatment (current farm practice)
3) Mechanical weed control in autumn, without camera

Mechanical weed control as above, with camera (Garford Vision-Guided hoe)

ORC Treatment Notes Year 2

Parameter	Year 2 trial (2010/11)
Location	South Elmham, Suffolk
Soil type	Beccles series, Sandy Clay Loam
Row width (centre-centre)	25 cm
Oilseed rape variety	Bravour
Seed rate	5kg/ha
Plot width	4 m
Plot length	150 m
Treatment width (herbicides)	4 m
Herbicide application	0.96L/ha Rapsan 500SC applied 12/10/10; 1.21 L/ha Megaflo 13/12/10; 1.5L/ha Laser 4/3/11; 0.75 L/ha Dow Shield 12/3/11
Conditions at spraying	Not recorded
Key dates	
Drilling date	24/08/2010
Assessment autumn (pre-treatment)	11/10/2010
Mechanical weeding date	22/10/2010
Assessment autumn (post treatment)	04/11/2010
Assessment spring	07/04/2011

ORC Treatment Notes Year 3

Parameter	Year 3 trial (2011/12)
Location	Cambridge, Cambs.
Soil type	
Row width (centre-centre)	50 cm (Cultivated width: 23 cm)
Oilseed rape variety	Excalibur (hybrid)
Seed rate	3 kg/ha (30–40 seeds/m^2)
Plot width	4 m
Plot length	60 m
Treatment width (herbicides)	3 m
Herbicide application	Kerb Flow (propyzamide): 2.1 L/ha @ 3 bar pressure
Conditions at spraying	Air temp. 13°C; soil – moist; foliage – damp drying on day; wind speed – 8 mph; wind direction – easterly; cloud cover – 50%; Crop growth stage 1,10–1,12 (15–20 cm diameter)
Key dates	
Drilling date	19/08/2011
Assessment autumn (pre-treatment)	21/10/2011
Mechanical weeding date	21/10/2011
Assessment autumn (post treatment)	30/11/2011
Assessment spring	19/03/2012

Note: Rapsan is 500g/L metazachlor, Laser is 200g/L cycloxydim, Megaflo is 400g/L propyzamide

SAC Trials Treatment Notes Year 3

Site: Boghall Farm, Bush Estate, Penicuik, Edinburgh

Design: Replicated randomised block x 3 reps, 22 x 2 m

Seed Rate: 70 m^2

Drilled: 31/08/2011
Pre-em applied: GS 1,3 as Elk 2.5 L/ha
Post–em applied: GS 1,5
Wide band refers to spray width of 300 mm using “02” 40° nozzle at 2 bar pressure

Narrow band refers to a spray width of 150mm using a “01” 25° nozzle at 2 bar pressure

The commercial treatments were sprayed using a “03” 110°nozzle at 3 bar pressure

Roundup Energy was applied at 1.6 L/ha

Metazachlor treatment applied as Elk (200 g/l metazachlor + 200 g/l dimethenamid-p + 100g/l quinmerac).