Effect of crop morphology and density on crop and weed productivity

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Abstract

A field study was conducted at Lincoln University during the 1999-2000 growing season to evaluate the effect of crop type and crop density on weed and crop productivity. In the presence of a natural infestation of weeds, crops with a spreading habit (narrow-leafed lupin, (*Lupinus angustifolius* L.) and dwarf French bean, (*Phaseolus vulgaris* L.), rosette (turnip, (*Brassica campestris* L.) and forage rape, (*Brassica napus* L.)) and upright habit (maize, (*Zea mays* L.), and ryecorn, (*Secale cereale* L.)) expressed similar yields at sowing densities of 0, 0.5, 1.0, 2.0 and 4.0 times their recommended plant population. No other weed control measures were applied. Significant differences were found in the suppressive ability of the different crop types and different crop populations. Weed biomass was lowest in turnips and greatest in dwarf French bean. The ability to suppress weeds was independent of crop growth habit, but was related to leaf size and plant growth rate. Inclusion of large leaf size and rapid growth in the selection of crops as competitors to suppress weeds should be feasible in weed management.

Additional key words: narrow-leafed lupin, Lupinus angustifolius*, dwarf French bean,* Phaseolus vulgaris*, turnip,* Brassica campestris*, forage rape,* Brassica napus*, maize,* Zea mays*, ryecorn,* Secale cereale*.*

Introduction

Weeds are serious pests in crop production but environmental and economic concern has arisen when their control has been characterised by heavy inputs of herbicides in fragile ecosystems. Crops and weeds compete for resources such as light, water and nutrients. Weed control strategies should exploit the competitive ability of crops in suppressing weed growth. The competitive ability of the crop is enhanced by early emergence, high seedling vigour, high rate of leaf expansion, rapid formation of a dense canopy and tall stature. An understanding of weed-crop competition and weed population dynamics is essential in this type of management strategy because, with reduced use of herbicides, the capacity of the crop to compete with weeds becomes particularly important.

The crop has an important role to play in a weed control strategy since crop plants can suppress weed development in the same way that weeds interfere with crop growth. Sweet and Minotti (1980) demonstrated that different crops and cultivars could reduce weed biomass by 4 to 83 % during a full season of competition. Putnam (1986) reported that the intensity of weed suppression depended principally on the morphology and rate of growth of the crop, but that allelopathy could also be important. The plant density, choice of crop, time of sowing and other aspects of crop production may also influence the level of weed suppression (Christensen and Rasmussen, 1994). For example, potato has a vigorous growth habit that smothers weeds (Sweet and Yip, 1974).

Early establishment in all crops is important to achieve maximum weed suppression (Froud-Williams, 1997). Weeds grow unhindered when crop cover is poor, as there is a lack of crop competition. Decreased light transmission through the leaf canopy of crops planted in closely spaced rows, or at high populations, may suppress the growth and development of weeds considerably (Teasdale, 1995). Greater weed growth, in addition to contributing to yield losses, also exacerbates future weed problems as weed seed production is increased (Grundy *et al.*, 1999).

There have been only a few studies that have actually tested the effect of crop density on the abundance, productivity and species composition of associated weeds (Mohler and Liebman, 1987). Teasdale (1995) acknowledged the need for studies of the differential response of important weed species to high crop population, as did Seaver and Wright (1997). Grundy (1999) highlighted the relative dearth of information regarding the competitive ability of different crops with respect to their weed suppressing traits. These studies have centred on small grain cereals. By contrast there is little information for other crops. In Canterbury, Herbert *et al.* (1978) and McKenzie *et al.* (1986) reported weed suppression by increasing plant population in lupins and in lentils respectively.

This research was conducted to evaluate the ability of crops of different morphology, sown at varying densities, to suppress the emergence and growth of natural weed populations in the absence of other control measures in Canterbury. The other objectives were to compare weed emergence in the presence and absence of a crop and to identify crop morphological characteristics related to suppression of weed growth.

Materials and Methods

A field experiment sown on two dates during the 1999-2000 growing season was conducted on a Templeton silt loam soil (New Zealand Soil Bureau, 1968) at Lincoln University.

Treatments

There were six crop treatments: narrow-leafed lupin (*Lupinus angustifolius* L.), forage rape (*Brassica napus* L.), and ryecorn (*Secale cereale* L.) sown on 8 September 1999 (early spring) and dwarf French beans (*Phaseolus vulgaris* L.), turnip (*Brassica campestris* L.) and maize (*Zea mays* L.) sown on 4 November 1999 (late spring). The field was prepared using standard cultivation practices of ploughing, harrowing and rolling. Seeds were then drilled into a fine firm seedbed using an Öyjord cone seeder at 0.5, 1.0, 2.0, and 4.0 times the optimum sowing rates (defined as 100, 50, 200, 50, 50 and 12 plants/m^2 for lupin, rape, ryecorn, bean, turnip and maize respectively). Plots were 10 m long by 4.2 m wide. The area had previously been in a predominantly white clover (*Trifolium repens* L.) pasture for five years. One overhead dressing of superphosphate (0-9-0-12) at 250 kg/ha was broadcast over the trial area on the second week after sowing of the early spring crop.

Environment

One irrigation of 48 mm was applied to the entire trial area, by overhead sprinklers Bisley - hand shift) on 9 December 1999 (when the soil moisture level fell below 50 % of field capacity. For the rest of the growing season the trial was rain-fed. HOBO data loggers (Onset Computer Corporation, Bourne, MA, USA) were placed in the field throughout the growing season to record temperatures using four probes (one in the air, one in the crop canopy and two in the soil). These were transferred from plot to plot occasionally. Solar radiation levels were obtained from the Broadfields Meteorological Station, 3 km from the trial site.

Weeds

Weed observations were recorded fortnightly from 3 weeks after sowing from two quadrats of 0.25 by 0.25 m that remained fixed throughout the growing season in each plot. From these quadrats weed seedlings were counted and identified. Digital photographs of the plots were taken weekly for 5 weeks and were used to measure crop and weed cover. From 8 weeks after sowing randomly selected, destructive samples of 0.25 m^2 were taken at the same intervals until crop maturity of the respective crops to determine above ground weed biomass. Samples were cut with hand clippers at ground level and were dried to constant weight at 70°C for 24 h in a forced draught oven. Weeds were dissected by taxon (species or genus, depending on their similarity) with uncommon taxa pooled, and dry weights recorded.

Crop parameters

Plant heights were recorded for the first 8 weeks from 5 randomly selected plants in the plots. Leaf areas were measured, to derive leaf area index (LAI), by destructive sampling twice, and LAI was measured non-destructively weekly, from week 4 after sowing to final harvest using a LICOR LAI 2000 Plant Canopy Analyser. Four readings were taken above and beneath the crop canopy from each plot. Random quadrats of 0.25 m^2 were taken fortnightly from week 8 until final harvest to determine crop dry matter (DM) production. At final harvest, DM production was measured from an area of 1 m^2. Plant samples were clipped, along with the weeds, at ground level and oven dried to a constant weight at 70°C. At final harvest the plant material for all grain crops from the 1 m^2 quadrats was threshed and the grain yield recorded (not reported) and the harvest index calculated.

Statistics

Plots were arranged in a randomised complete block design with 3 replicates. An unweeded control, with no crop, was added to each sowing date giving a total of 78 plots. All data were subjected to analysis of variance (ANOVA). Means were separated at the 5 % level of significance using least significance difference (LSD) for crop main effect and the crop x sowing rate interaction.

Results

Environment

Rainfall was mostly adequate and timely for crop growth throughout the growing season. However, in December 1999 with decreasing soil moisture content because of reduced rainfall, 30 mm of irrigation was applied to maintain soil moisture at or near field capacity. Minimum temperatures (Table 1) were very low, particularly in November 1999 (9 °C) compared with long-term means and this stunted the early growth of the beans in particular and caused slight necrosis in the maize. The mean monthly solar radiation received over this period (538 MJ/m^2) was higher than the long-term mean of 502 MJ/m^2 (Table1).

Weed spectrum

There was no significant interaction between the crop type and the weed species identified. Most weed species were present in all of the crop treatments. The major weeds were mainly annuals. These annuals included scarlet pimpernel (*Anagallis arvensis*) (34 % by weed biomass), twin cress (*Coronopus didymus*) (15 %), field pansy (*Viola arvensis*) (3 %), shepherd's purse (*Capsella bursa-pastoris*) (2 %), fathen (*Chenopodium album*) (2 %), black nightshade (*Solanum nigrum*), field speedwell (*Veronica arvensis*), sheep's sorrel (*Rumex acetosella*), curled dock (*Rumex crispus*), hawksbeard (*Crepis capillaris*), wireweed (*Polygonum aviculare*), field bindweed (*Polygonum convolvulus*), parsley piert (*Aphanes arvensis*), vetch (*Vicia sativa*), nodding thistle (*Carduus nutans*) and others. Perennial weeds were white clover (*Trifolium repens*) (13 %), Californian thistle (*Cirsium arvense*), storksbill (*Erodium cicutarium*), scentless mayweed (*Tripleurospermum inodora*) and yarrow (*Achillea millefolium*). There were also a number of grass weeds present such as annual poa (*Poa annua*), barley grass (*Hordeum leporinum*) and perennial ryegrass (*Lolium perenne*). These species are typical of cereal cropping land in Canterbury (Bourdôt *et al.*, 1998).

Increasing crop density did not suppress weed numbers in the first six weeks after sowing but weed DM was substantially decreased with increasing density for all crop types from eight weeks after sowing to final

Table 1. Weather pattern for the September to April experimental period, 1999-2000 from Broadfields Meteorological station, Lincoln.

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Max.	15	17	17	19	20	22	20	19
Temp (°C)	(14)	(17)	(18)	(21)	(23)	(22)	(20)	(18)
Ave.	9.5	12.5	13	14	16	17	15	14
Temp. (°C)	(9)	(12)	(13)	(16)	(17)	(17)	(15)	(13)
Min.	4	8	9	9	11	11	9	8
Temp (°C)	(4)	(6)	(8)	(10)	(11)	(11)	(10)	(7)
Rain	27	51	61	35	85	20	52	19
(mm)	(40)	(55)	(56)	(61)	(50)	(51)	(59)	(52)
Solar Radiation	417	522	602	743	661	553	517	293
(MJ/m^2)	(339)	(508)	(603)	(673)	(670)	(515)	(421)	(288)

*Numbers in parentheses refer to the long-term mean (LTM) from 1975–91 harvest (Table 2). From three to six weeks after sowing, weed numbers increased until canopy closure for all crops except forage rape. The main weed flush occurred after crop sowing and continued until crop cover was able to suppress the weeds physically. Turnips suppressed weeds the most in terms of both weed emergence and biomass. Where crop cover was sparse and patchy the opportunity for weed emergence was enhanced considerably.

Individual weed species differed in their responses to increasing sowing rate (2.0 and 4.0x sowing rate) for lupin, turnip, maize and ryecorn. However, scarlet pimpernel and twin cress were present in all crop treatments. Californian thistle, considered as one of the worlds worst weeds (Holm *et al.*, 1977), was also considerably suppressed by turnips at all plant populations and by all other crops at their higher densities with the exception of the beans.

Weed biomass

In the absence of any crop at final harvest weed DM was 920 g/m^2 in the early sowing and 560 g/m^2 in the

Table 2. The effect of crop population (plants/m^2) on maximum crop and weed biomass and harvest index.

Crop	Sowing rate (x optimal)[a]	Plants/m^2	Maximum Crop DM (t/ha)	Maximum Weed DM (t/ha)	Harvest Index
Narrow leafed lupin[1]	0.5	58	16.9	3.1	0.44
	1.0	126	17.9	2.3	0.36
	2.0	224	19.5	1.4	0.35
	4.0	441	18.4	1.5	0.29
Ryecorn[1]	0.5	69	9.5	2.5	0.21
	1.0	141	11.2	1.6	0.22
	2.0	309	11.2	0.4	0.14
	4.0	810	11.4	0.1	0.18
Forage rape[1]	0.5	30	8.1	2.0	-
	1.0	63	9.6	1.1	-
	2.0	91	9.7	0.6	-
	4.0	181	9.0	0.3	-
Maize[2]	0.5	7	30.3	2.7	0.50
	1.0	14	32.6	1.7	0.45
	2.0	23	34.3	0.7	0.36
	4.0	40	27.8	0.0	0.24
Beans[2]	0.5	14	6.1	3.5	0.54
	1.0	33	7.6	2.4	0.48
	2.0	71	9.3	1.7	0.46
	4.0	136	8.3	0.5	0.42
Turnip[2]	0.5	44	6.7	1.6	-
	1.0	57	7.6	0.2	-
	2.0	139	9.3	0.0	-
	4.0	234	8.1	0.0	-
Significant Interactions (Crop x sowing rate)		***	NS	**	**
LSD		44.9	5.7	1.2	.07

[a]Sowing rate (0.5, 1.0, 2.0 and 4.0x) recommended sowing rate. Plants/m^2 indicate actual density, which were higher than intended sowing rates.

[1] and [2] indicate early and late sown crops respectively.

*, **, *** Significant at the 0.05, 0.01 and 0.001 probability levels, respectively, NS, non significant.

late sowing. There were significant crop x sowing rate differences in weed biomass among the different crop types tested (p<0.05) (Table 2). Generally, there was a reduction in weed DM at higher crop plant populations. Turnips reduced weed cover by more than 95 %. Maize, lupin and ryecorn also suppressed most of the weeds present, particularly at high densities. Beans and forage rape were less effective at suppressing weed DM even at high densities. Beans were the least competitive of the crops and were virtually eliminated by the weeds at the 0.5x sowing rate. In all the crops except for turnip, increasing the crop sowing rate from 0.5 to 4.0x reduced weed yields (Fig. 1c and 1d). Turnips however gave nearly complete weed control at all sowing rates.

Crop biomass

Increasing plant population did not significantly affect the maximum dry matter (DM) and final DM in all

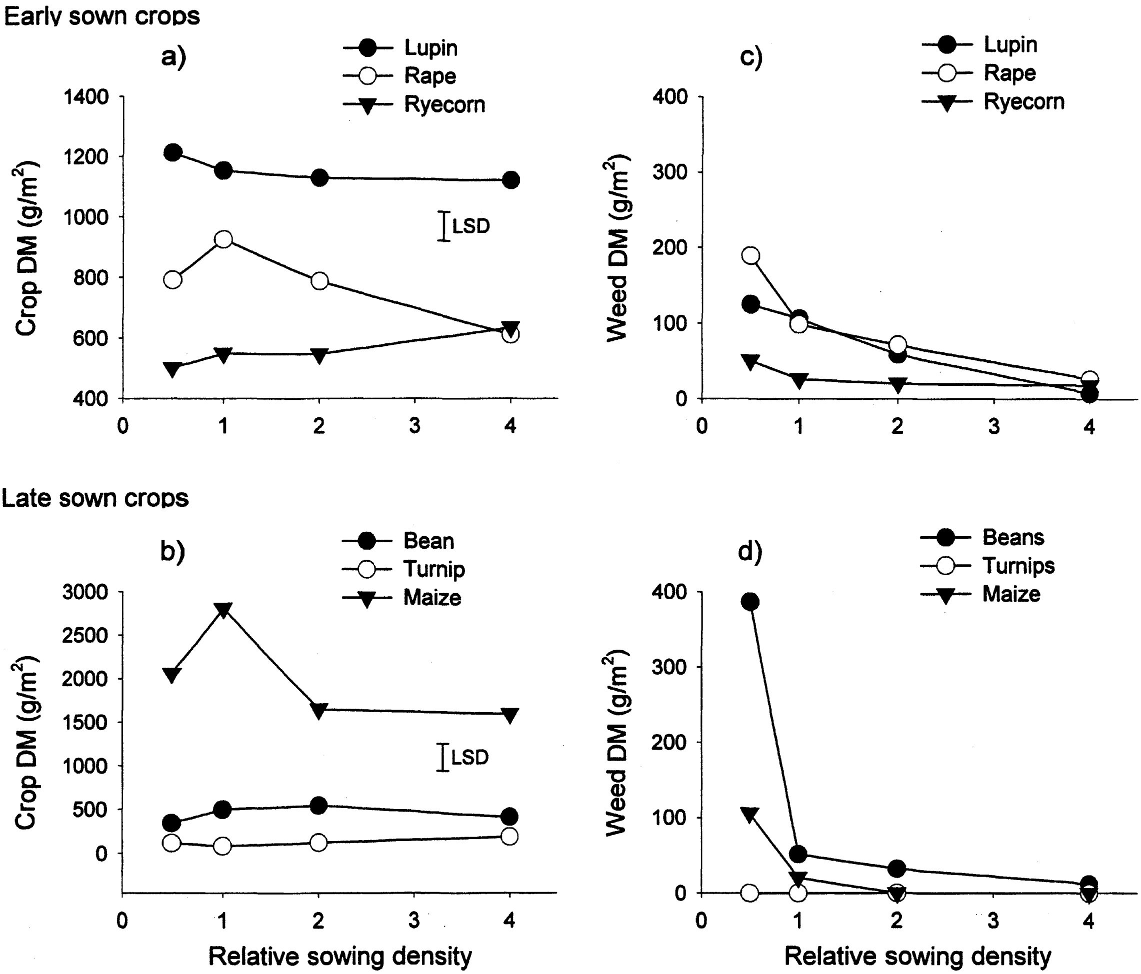

Figure 1. Crop (a, b) and weed (c, d) dry matter (g/m^2) means at final harvest from the relative sowing densities (0.5, 1.0, 2.0, and 4.0x recommended sowing rate) for the early and late sown crops. Bar = LSD at p< 0.05.

crops (Table 2 and Fig. 1a, b). At 60 days after sowing (DAS) turnips (397 g/m^2) had achieved the most DM production. This was followed by maize, lupin, rape, ryecorn and bean, which had produced 213, 174, 168, 121 and 69 g/m^2, respectively. The climatic conditions throughout the growing season were favourable for all crops, resulting in high DM production. Of all the crops, maize produced the highest amount of DM (30.3 t/ha) at the 0.5x sowing rate and gave a maximum DM yield of 34.3 t/ha at the 2.0x sowing rate (Fig. 1b). Lupins produced 14.1 t DM/ha at the 0.5x sowing rate and their highest DM yield was at the 2.0x sowing rate (19.5 t/ha) (Fig. 1a). The turnips (shoot DM only) produced the lowest amount of crop DM, with 6.7 t/ha at the 0.5x sowing rate and 8.1 t/ha at the 4.0x sowing rate (Fig. 1b). At final harvest, crop DM produced by the early sown crops was highest in lupins followed by rape and ryecorn (Fig. 1a). For the late sown crops, crop DM was highest in maize followed by beans and turnips (Fig. 1b). Figure 2 compares weed and crop DM in the most suppressive crop (turnips) and the least (beans) at the 0.5 and the 4.0x sowing rate. Turnips effectively suppressed weeds at both the highest and lowest population. Beans were however an ineffective competitor and at the 0.5x sowing rate there was a high level of weed biomass in the plots.

Radiation interception and leaf area index:

For all crops the light transmitted through the canopy declined with increased crop density. Higher densities (2.0 and 4.0x sowing rate) intercepted 95 % or more of the light, while lower densities intercepted less than 95 %. The results indicate that the amount of intercepted radiation increased with time. Crop type significantly differed in PAR interception throughout crop growth. At the early stages lupins had a greater effect than ryecorn and rape but at the later stages the opposite occurred where rape intercepted the highest PAR (397 MJ/m^2) at the 2.0x sowing rate for the early sown crops. At high plant populations, canopy closure occurred at about 70 DAS for lupins and rape and 80 DAS for ryecorn and maize at 2.0x sowing rate. This occurred at 40 DAS for lupins, rape and ryecorn and 75 DAS for maize at the 4.0x sowing rate. At the 0.5x sowing rate lupin, rape, beans and maize did not achieve canopy closure. Rape and maize also did not achieve canopy closure at the 1.0x sowing rate. Leaf area index for the late sown crops was highest in turnip even at the lower plant population densities, ranging from 1.0 – 6.0 (between 30-60 days from sowing) followed by beans and then maize (Fig. 3).

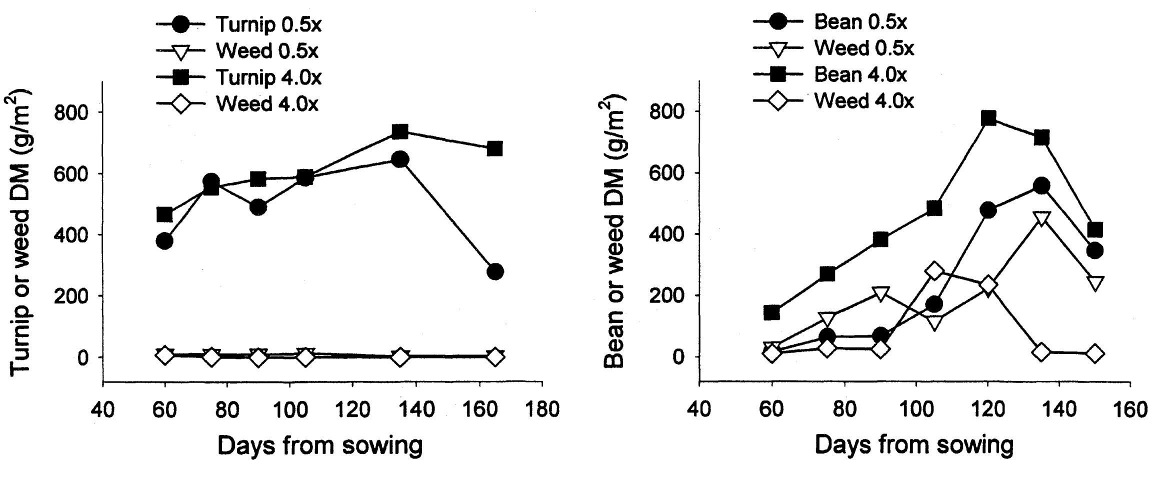

Figure 2. Turnip and weed, and bean and weed dry matter (DM) (g/m^2) at 0.5x and 4.0x the recommended crop sowing rate. Crops were sown in late September (turnip) and early November (bean) and data recorded at 2 week intervals from 60 DAS to final harvest.

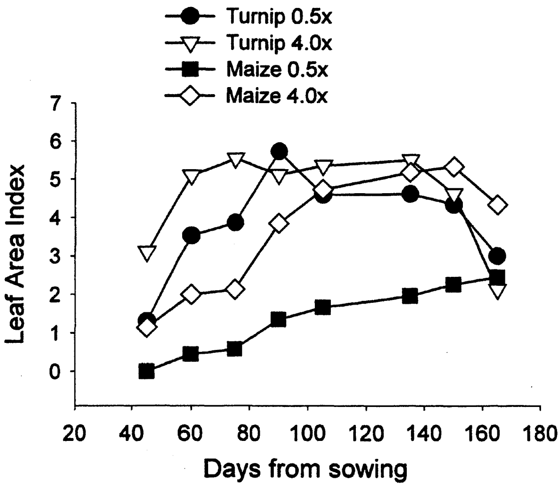

Figure 3. Changes in leaf area index over time at 0.5x and 4.0x the recommended sowing rate for turnips and maize.

Discussion

Initial growth of the maize and beans was greatly affected by low temperatures (Table 1). Lodging was extensive at the 4.0x sowing rate for lupins at 120 DAS and maize at 135 DAS caused by high winds and this contributed to reductions in the DM production. Herbert *et al.* (1978) showed that under irrigated conditions lupins had the potential to yield 20 t/ha of herbage DM at the recommended sowing rate.

The increased weed emergence in all crops in the first 6 weeks from sowing was directly related to increased light availability. With increased crop density, light availability to the understorey decreased, resulting in reduced weed growth. However, reduction in weed growth could also be due to a number of other factors, including competition, allelopathy or effects mediated by other organisms. Turnip leaves formed a dense canopy, suggesting that competition for light was responsible for some of the observed weed suppression. Forage rape leaves also formed a dense canopy but weeds were not efficiently suppressed. This suggests that rapid establishment of turnip ground cover could have been a factor contributing to their suppression of weed growth. After canopy closure from 60 DAS, weed DM decreased with increasing crop population. At higher crop populations there was presumably more interplant competition for light, water and other nutrients. The combination of competition for both water and light at these higher crop populations would therefore result in severe competition in the weeds and give lower weed DM production.

There was little or no shading effect of weeds on the crops except for the 0.5, 1.0 and 2.0x sowing rates of the beans, where weeds such as fathen, black nightshade, Californian thistle and hawksbeard shaded the crop in some instances from flowering to final harvest.

Turnips were highly effective in reducing weed biomass and this was probably due to the early higher LAI observed at all crop populations. This crop intercepted the most radiation at the 4.0x sowing rate, as unlike the other crops in the trial, it achieved canopy closure by 30 DAS. At the 1.0x sowing rate this occurred at 60 DAS. Collie and McKenzie (1997) reported canopy closure at 58 DAS for turnip at this density. McKenzie *et al.* (1989) found increases in lentil DM production and intercepted radiation as the crop population increased. This trend was similar for crops sown in this trial, with increased DM production at increased crop populations up to maximum DM production.

Conclusion

All crops used in this trial reduced weed DM production. Turnips were the most effective and nearly eliminated weeds at all populations. By contrast beans only significantly reduced weed yields at the 4.0x optimal sowing rate. Crop architecture and morphology had a significant effect on the level of weed suppression.

Increasing the crop plant population density generally gave improved levels of weed suppression.

Early establishment of crop ground cover reduced the chance of weed growth.

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