Growth, development and seed yield of autumn forage rape in response to sowing date and sowing rate

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Abstract

Minimal local data on the effects of sowing date and sowing rate on forage rape seed production in New Zealand has meant that current production practices are based on general overseas data for oilseed rape (OSR) rather than for forage rape seed. Oil seed rape is bred to produce high seed yields, whereas forage rape is bred to produce vegetative dry matter and therefore their seed production characteristics may differ. In a field experiment, we examined the effects of four sowing dates (February, March, April and May) and three sowing rates on the growth, development and seed yield of forage rape crops at Lincoln, Canterbury. Best seed yield was from March and April sowing. Delaying the sowing date beyond February increased seed yield from a mean of 2.3 t ha^{-1} to 3.3 t ha^{-1} for the March and April sowings and also increased the mean number of seed pods from 17 to 19. Delaying sowing to May caused poor emergence, because of wet and cold conditions. However, total dry matter (DM) yield decreased with delayed sowing. This was reduced from approximately 20 t DM ha^{-1} for the February and March sown crops to approximately 17 t DM ha^{-1} for the April sown crops. Sowing date had no effect on pod density or thousand seed weight (TSW). Sowing rate had no effect on all yield components except the number of pod per m^2. This decreased from approximately 5000 for the 2 and 4 kg ha^{-1} sowing rate to 3700 for the 6 kg ha^{-1} sowing rate. Increased sowing rate resulted in reduced percentage establishment from 74% for the 2 kg ha^{-1} sowing rate to 51% and 65% for the 4 kg ha^{-1} and 6 kg ha^{-1} sowing rates, respectively. It is recommended that farmers sow forage rape seed crops in March to optimise seed yield. Soil conditions also encourage better emergence in March sowing. A sowing rate of 4 kg ha^{-1} was recommended as it ensured optimum establishment at reasonable seed costs.

Additional keywords: *Brassica napus*, harvest index, lodging, plant establishment, plant density, production guidelines, yield components

Introduction

Seed production of forage brassicas is an industry worth of around $10 million (Johnson and Gallacher, 2008) and occupies approximately 1700 ha in New Zealand. This industry is primarily based in Canterbury and is a highly profitable alternative crop for arable farmers. Typically, forage rape (*Brassica napus* L.) is grown as an alternative feed in animal production systems (Trethewey, 2009). When grown for seed, detailed investigations on the growth and reproductive development are required to determine best management practices. Current production guidelines are mostly derived from European and Australian research on oilseed rape (OSR). This data contributes to our understanding of forage rape seed production but for two reasons the scope to which the data can be extrapolated to forage rape seed crops is limited. Firstly, OSR has been bred to produce high seed yields, whereas forage rape is bred to produce vegetative dry matter and possibly at the expense of seed yield. Secondly, differing climatic and soil conditions in New Zealand may cause differing responses. In particular, sowing date and sowing rate effects on forage rape seed yield in New Zealand have not been defined.

Good establishment is critical to achieve economic seed yields from forage rape crops. Optimum sowing time and sowing rates are critical for forage rape establishment and subsequent growth and development because there are known links between plant population, biomass development and seed yield (Scarisbrick *et al.*, 1982). The base temperature (T_b; temperature below which growth ceases) for forage rape is 0°C (Nanda *et al.*, 1995). Late autumn sown rape crops are exposed to low soil temperatures resulting in stand losses due to seed rotting (Vigil *et al.*, 1997). Knowledge of the accumulated thermal time (Tt; accumulated heat available for crop growth) and T_b required for initial emergence can be used to determine the latest sowing dates for autumn sowing. Experiments in the United Kingdom (UK) and Australia have shown differing responses of seed yield to sowing date. High seed yields have been achieved with delayed sowing in the UK (Jenkins and Leitch, 1986; Leach *et al.*, 1999), whereas in Australia, early sowing resulted in higher seed yields regardless of location and variety (Walton *et al.*, 1999). In Australia no seed yield differences were found for crops sown in April and May (Taylor and Smith, 1992), but yields declined with delayed sowing beyond May.

The effect of sowing rate is site-specific as plant establishment and final plant population vary with soil and climatic conditions. There are conflicting reports on the effect of sowing rate on OSR seed yield. Yields increased with plant densities up to 50-60 plants m^{-2} (Leach *et al.*, 1999) and decreased at plant densities over 150 plants m^{-2}. However, most studies have shown no effect of plant density on seed yield (Mendham *et al.*, 1981b; Scarisbrick *et al.*, 1982; Taylor and Smith, 1992). The lack of response to plant density has been attributed to the ability of rape plants to compensate for the low density by increasing the number of pod m^{-2} and/or seeds per pod. Crops are susceptible to lodging and increased disease incidence with no yield benefit if sown at more than 150 plants m^{-2}. High plant densities may also lead to fewer pod-bearing branches, low dry matter (DM) and fewer fertile pods per plant. Sowing rates for OSR in Europe are set to achieve between 80–150 plants m^{-2} before winter and 60–80 plants m^{-2} at the beginning of spring (Rathke *et al.*, 2006). Plant density for autumn sown OSR of 50–80 plants m^{-2} (Hodgson, 1978; Mendham *et al.*, 1981b) can be achieved by sowing 3-4 kg ha^{-1} of seed. These results demonstrate the importance of appropriate sowing dates and sowing rates for forage rape seed crops. These are likely to be site specific and no quantitative data exist for forage rape seed crops in New Zealand. This paper reports the results of an experiment designed to find the optimum sowing date and sowing rate for forage rape grown for seed production in Canterbury.

Materials and Methods

The experiment was carried out at The New Zealand Institute for Plant & Food Research Limited, Lincoln, New Zealand (43°39´S, 172°28´E), on a Templeton silt loam.

The trial was a split plot randomised complete block design with three replicates. Four sowing dates (25 February, 26 March, 23 April and 20 May 2009) were the main plots and three sowing rates (2, 4 and 6 kg ha^{-1}) were the sub-plots. The forage rape cultivar used was Greenland.

The site had been in perennial ryegrass (*Lolium perenne* L.) for the previous two years. A soil test to 150 mm depth showed adequate fertility (Table 1) except for nitrogen (N) and sulphur (S). Soil preparation consisted of conventional cultivation after deep ploughing. Seed was drilled using a nine-row Öyjord cone drill in 15-cm rows with seed placement at 20-mm depth. Plots were three drills widths (4.05 m) by 12 m long. The outer passes (9 rows each) were used for sequential dry matter harvests and canopy development (leaf development and light interception) and the central drill rows for the final seed harvest.

Table 1: Average soil Quick test (MAF units unless stated otherwise) results for the site and the optimum nutrient requirements (McLaren and Cameron, 1996).

	pH	Olsen P (µg ml^{-1})	K	Ca	Mg	Na	S	Available N (kg ha^{-1})
Results[1]	6.3	26	15	11	14	8	7	62
Optimum	5.8–6.0	20–25	5–7	4–10	8–10	N/A	10–12	200

[1]Average values for the 36 plots.

Irrigation, N and weed and pest control were applied to ensure no constraints to growth throughout the season. All treatments received 200 kg ha^{-1} diammonium phosphate (DAP; 18:20:0:2) and 1.5 kg ha^{-1} boron at sowing. All plots were sprayed with 1.7 l ha^{-1} of Treflan (active ingredient 480 g l^{-1} trifluralin EC) in 200 litres of water for weed control just before sowing. Fertiliser and herbicide were maxi-tilled into the top 5 cm of the soil profile. For the February and March sown crops, 1 l ha^{-1} of Diazinon 800EC in 200 litres of water ha^{-1} was applied a day after sowing to guard against insects, especially springtails. Lorsban (1 l ha^{-1}) in 200 litres of water $hectare^{-1}$ was applied to the April and May sown crops. Additional nitrogen was applied as urea to the February and March sown crops at 60 and 70 kg N ha^{-1} on 12 August and 15 September, respectively. The April sown crops received the same amount of fertiliser in split applications on 26 August and 12 October. All crops received a fungicide, Folicur® SC (active ingredient 430 g l^{-1} tebuconazole) at 400 ml ha^{-1} in 200 litres of water $hectare^{-1}$ at the end of September.

Measurements

The number of emerged seedlings on either side of a 1.1-m rule (2 rows) was determined from a marked area from 5 days after sowing. This was done every 2-3 days until plant numbers remained constant within the marked area. Emergence was defined by unfolding of the two cotyledons (Morrison and McVetty, 1991)

Pod damage by birds occurred in mid-November, especially for the February sowing. All the plots intended for final seed harvest were covered with netting from November 2009 to January 2010. Measurements of seed yield were taken from each plot at the end of physiological maturity (PM) by hand harvesting a single 2 m^2 quadrat from each plot. The date of harvest was determined on the basis of accumulated Tt of approximately 715°Cd (Berry and Spink, 2006) from 50% flowering to PM and by visual assessment of seed maturation which occurred on 12 January 2010 for sowing date 1 and 20 January 2010 for sowing dates 2 and 3. Components of yield such as plant density (calculated from number of plants harvested per plot), pods per m^2, seeds per pod and TSW were determined on all plots at the final harvest. Seed moisture content was determined using a DICKEY-john Grain Analysis Computer (model GAC®500XT). The number of damaged pods $plot^{-1}$ was also determined at final harvest. Sequential dry matter measurements were taken from each plot by harvesting a single 0.5 m^2 quadrat (five central rows) to ground level. Early harvests were at fortnightly intervals up to early November and monthly thereafter.

A representative five-plant sub-sample was retained for measurements of leaf area, fresh and dry weight of the leaf and stem components. The DM samples were dried in a forced air oven at 80°C to constant weight. Leaf area was determined on five plant sub-samples using a leaf area meter (LiCor model LI-3100) and corrected to total leaf area per quadrat and leaf area index (LAI).

Percentage light transmission through the canopy was measured twice for the first sowing before winter and once for both the first and second sowing after winter with a Decagon Sunfleck Ceptometer (Model SF-80). Measurements of intercepted light ceased when the critical LAI (LAI_{crit}; LAI when 95% of the incoming radiation was being intercepted; Brougham, 1960) was attained.

Ten plants per plot were selected and marked for developmental observations. Plants were observed for the different growth stages (GS) as described by Bayer Crop Science (Anonymous, 2007) every 6-10 days; from 18 September to 16 November.

Data Analysis

Crop emergence, canopy development, DM yields and yield components were analysed by analysis of variance (ANOVA). Significant interactions and main effects were separated using Fisher's protected least significant difference (LSD) tests (α=0.05). Main effects of sowing date and sowing rate were reported as significant when $P<0.10$.

Meteorological conditions

The total rainfall for the experimental period was 533 mm with Penman potential evaporation of 867 mm. The total deficit of 334 mm was alleviated with 55 mm of irrigation. The highest daily maximum temperature recorded was 31.2°C on 2 January 2010 and lowest daily minimum temperature of -4.6°C was recorded on 14 July 2009. The highest daily rainfall (30.2 mm) was recorded on 6 May 2009. There were 81 ground frosts during the trial period.

Results

Poor emergence was attributed to the wet and cold conditions with 184 mm of rainfall and mean temperature 6.5°C in May and early June causing the final sowing date to be abandoned. Therefore data from only the first three sowing dates are presented here.

Plant establishment

Although plant density was increased (P<0.001) by sowing rate (Table 2) at both establishment and final harvest, the percentage establishment decreased with increased sowing rate and delayed sowing. Fewer plants had established by May in late sown compared with early sown plots. Mean establishment for the February sown crops was 81% compared with 60% for the March sowing and 49% for the April sowing. Mean establishment of the 2 kg ha^{-1} sowing rate was 74% compared with 51% for the 4 kg ha^{-1} and 65% for the 6 kg ha^{-1} sowing rates. This difference was maintained until final harvest when plant numbers equated to 78%, 59% and 35% of the drilled seeds for the 2, 4 and 6 kg ha^{-1} sowing rates, respectively.

Emergence was rapid for the February sowing with 50% of the plants appearing in 6-8 days (data not shown), while the later sown crops took longer (14-17 days) to attain 50% emerge and were more variable.

Plant density increased with sowing rate, with an optimum at 4 kg ha^{-1} at both sampling dates (Tables 2 and 3). Sowing date did not affect plant density for both sampling dates. Table 3 also shows that no plants were lost during winter.

Table 2: Plant numbers per m^2 and percentage establishment of forage rape seed measured at establishment and final harvest when sown at different dates and sowing rates at Lincoln in 2009.

Time	Sowing rate (kg ha^{-1})	No. of seeds drilled (TSW = 3.34 g)	Sowing Date 25 February	 26 March	 23 April
Emergence (4 WAS)[1]	2	60	60 (100)[2]	42 (70)	32 (53)
	4	120	78 (65)	67 (56)	38 (32)
	6	180	143 (79)	97 (54)	111 (62)
$LSD_{(\alpha=0.05)}$				60	
Significance[3]			*	NS	*
Final harvest[4]	2		36 (60)	54 (90)	51 (85)
	4		69 (58)	101 (84)	41 (34)
	6		61 (34)	72 (40)	56 (31)
$LSD_{(\alpha=0.05)}$				33	
Significance			*	*	NS

[1]Weeks after sowing.
[2]Numbers in parenthesis are percentage establishment of seed sown.
[3]Levels of significance are *P<0.05, ** P<0.01, *** P<0.001 and NS=not significant.
[4]See Table 4 for actual final harvest dates.

Total dry matter

As was expected, total DM increased (P<0.001) with time until the final harvest in January 2010 (Figure 1). The DM accumulation differed (P<0.001) with time of sowing (Figure 1). Total DM yield decreased with delayed sowing (P<0.09) from approximately 20 t DM ha^{-1} for the February and March sown crops to approximately 17 t DM ha^{-1} for the April sown crops. The early sown crops maintained their advantage until December, after which there was no difference between the February and March sown crops.

Table 3: Plant numbers per m^2 of forage rape seed measured early winter and spring when sown at different sowing rates at Lincoln in 2009.

Seed rate (kg ha^{-1})	Number of plants per m^2	
	19 June	1 September
2	51	50
4	95	108
6	113	117
LSD$_{(\alpha=0.05)}$	33	
Significance	*	*

Levels of significance are *P<0.05, ** P<0.01, *** P<0.001 and NS=not significant.

However, DM accumulation was slow in autumn through to the end of September 2009. Substantial increases in DM occurred, for all sowing dates, during October. However, the DM production was always lower with delayed sowing, but there were no differences (P<0.810) between the March and April sowings until the final harvest. The DM accumulation for the first sowing decreased in early November (Arrow (a); Figure 1) which coincided with the crops attaining 50% flowering (GS = 65; Table 5). However, late sown crops did not show a loss of DM at 50% flowering (Figure 1, arrow (b)).

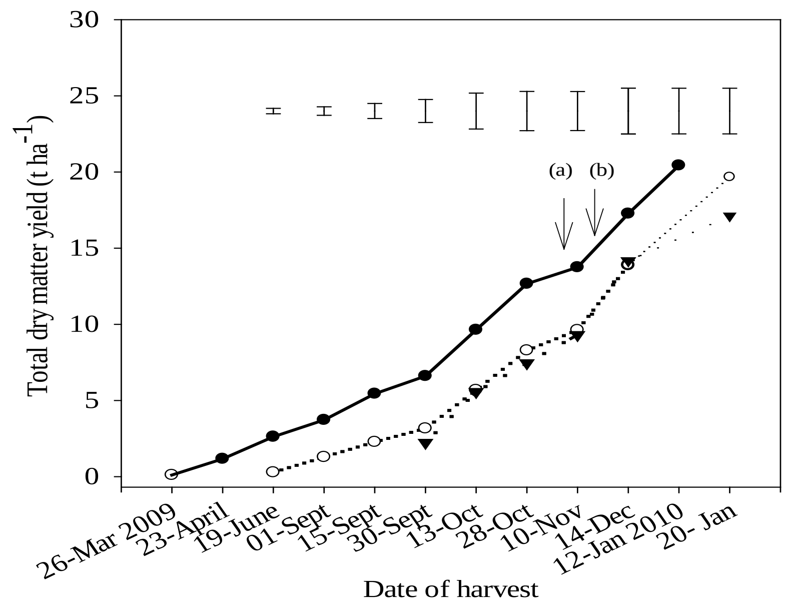

Figure 1: Total dry matter (DM) accumulation of forage rape crops sown at different dates; 25 February (-●-), 26 March (-○-) and 23 April (-▶-) at Lincoln in 2009-10. Bars represent the least significant differences (LSD$_{(0.05)}$). Arrows indicate 50% flowering; (a) February and (b) March and April sowing dates.

Table 4: Seed yield (SY; t ha^{-1}), total dry matter (TDM; t ha^{-1}) and harvest index (HI) of autumn sown forage rape sown at different dates and sowing rates at Lincoln in 2009-10.

Sowing Date (SD)	Sowing rate (SR; kg ha^{-1})	Yield component		
		TDM	SY (9% moisture)	HI
25 February	2	22.25	2.30	0.10
	4	22.04	2.80	0.13
	6	16.37	1.89	0.12
$LSD_{(\alpha=0.05)}$		2.69	0.89	0.05
Significance[1]		*	*	NS
26 March	2	18.84	3.22	0.17
	4	24.14	3.05	0.13
	6	16.33	3.55	0.22
$LSD_{(\alpha=0.05)}$		2.69	0.89	0.05
Significance		*	NS	*
23 April	2	17.55	3.37	0.20
	4	15.12	3.33	0.22
	6	18.68	3.37	0.18
$LSD_{(\alpha=0.05)}$		2.69	0.89	0.05
Significance		*	NS	NS
$LSD_{SD\ (\alpha=0.05)}$		2.69	0.89	0.05
Significance		*	*	*
$LSD_{SD*SR\ (\alpha=0.05)}$		5.49	1.53	0.84
Significance		NS	NS	NS

[1]Levels of significance are *P<0.05, ** P<0.01, *** P<0.001 and NS=not significant.

Table 5: Growth stages (GS)[1] of autumn sown forage rape sown at different dates and sowing rates at Lincoln in 2009.

Date	Sowing rate (kg ha^{-1})	Growth Stage at Sowing Date Indicated		
		25 February	26 March	23 April
7 October	2	53	50	45
	4	51	44	45
	6	49	47	48
$LSD_{(\alpha=0.05)}$			5	
Significance[a]		NS	NS	NS
10 November	2	65	64	64
	4	65	63	64
	6	64	63	63
$LSD_{(\alpha=0.05)}$			4	
Significance		NS	NS	NS

[1]GS 0-11 = Germination; 12-20 = Leaf development; 20-29 = Side shoot formation; 30-49 = Stem elongation (rosette stage); 50-59 = Stem elongation, flower buds present; 60-69 = Flowering; 70-79 = Fruit development; 80-100 = Ripening.

At the beginning of winter, February sown crops had accumulated 2.62 t DM ha^{-1} compared with 0.28 t DM ha^{-1} for the March sown crops (Figure 1). Both leaf area (Figure 2) and dry matter production were significantly reduced by delayed sowing. The low leaf area for the late sown crops meant they attained full cover later than the February sown crops (Table 6).

Total DM response to sowing rate was inconsistent (Table 4). Total DM decreased with increasing sowing rate for the February sowing (P<0.08). However, it was highest for the March sowing and lowest for the April sowing dates at 4 kg ha^{-1} sowing rate, but similar for the 2 and 6 kg ha^{-1} sowing rates at each of the later sowing dates. There was a correlation with plant population (Table 2). This resulted in lower (P<0.008) harvest indices (HI) at the February sowing compared with the later sowings (Table 4) as seed yield was lowest in the February sowing date. Increased sowing rate caused no difference in HI for the February and April sowing, but the 6 kg ha^{-1} sowing rate had a higher HI than the two lower rates.

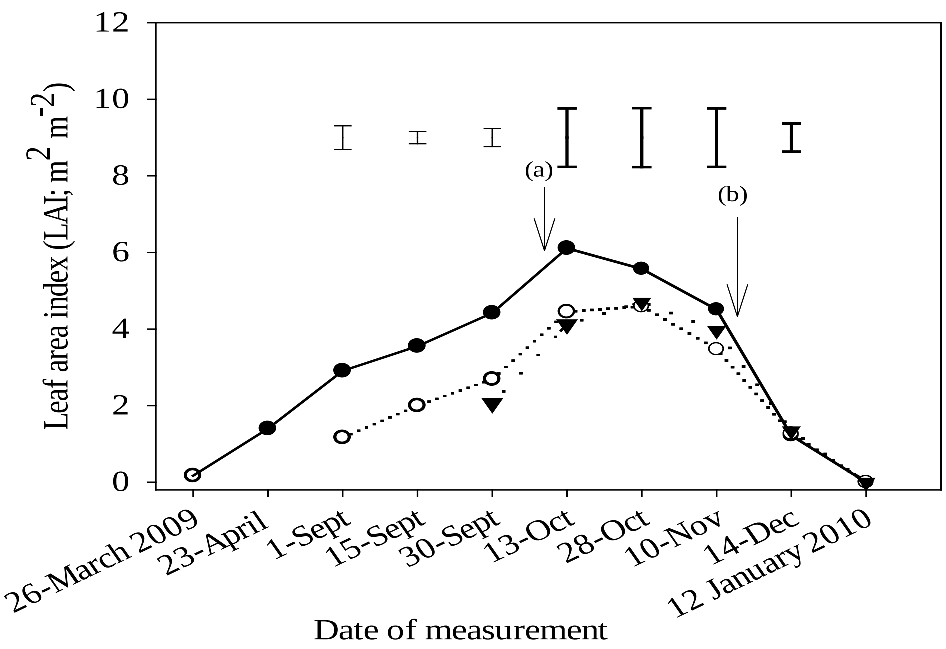

Figure 2: Leaf area index (LAI) of forage rape sown at different sowing dates, 25 February (-●-), 26 March (-○-) and 23 April (-►-) at Lincoln in 2009. Bars represent the least significant differences (LSD $_{P<0.05}$). Arrows indicates crop growth stages (a) flower buds present for all sowing dates, though at different stages of development and (b) when all crops were at full flowering (50% of flowers on main raceme open).

Table 6: Light interception (%) of forage rape grown at three sowing dates and three sowing rates at Lincoln in 2009.

Factors		Light interception (%) at sampling dates indicated				
Sowing date (SD)	Sowing rate (SR; kg ha^{-1})	3 April	22 April	8 September	15 October	3 November
25 February	2	93	98	94	99	99
	4	94	99	94	99	99
	6	96	99	92	99	99
26 March	2	-[2]	-	94	97	97
	4	-	-	96	99	98
	6	-	-	98	99	99
23 April	2	-	-	-	87	96
	4	-	-	-	84	97
	6	-	-	-	93	97
LSD[1] $_{SD}$				4.64	5.30	1.23
Significance[3]				NS	***	***
LSD_{SR}		2.04	0.76	5.68	5.30	1.23
Significance		*	*	NS	NS	NS
LSD_{SD*SR}				8.04	9.18	2.13
Significance				NS	NS	NS

[1] LSD at α=0.05.

[2]No sampling done as crop was either too small or not yet sown.

[3]Levels of significance are *P<0.05, ** P<0.01, *** P<0.001 and NS=not significant.

Seed yield and yield components

Delaying sowing date increased (P<0.045) seed yield (Table 4) from a mean of 2.3 t ha^{-1} for the February sowing to approximately 3.3 t ha^{-1} for the March and April sowings. Sowing rate did not affect seed yield for late sown crops.

Sowing rate had no effect on the number of seeds per pod, TSW or the proportion of damaged pods at the final harvest (Table 7).

However, the number of pods m^{-2} at maturity decreased (P<0.036) with increasing sowing rate for the February and March sown crops. It was unaffected at the April sowing. The mean pod density was lowest for the 6 kg ha^{-1} sowing rate, at 3700 pods m^{-2} compared with 4710 pods m^{-2} for the 2 kg ha^{-1} and 5679 pods m^{-2} for the 4 kg ha^{-1} sowing rates (Table 7). Sowing date had no effect on pod density.

Table 7: Number of seeds per pod, pod per m^2, thousand seed weight (TSW) and percentage (%) of damaged pods of autumn sown forage rape sown at different dates and sowing rates at Lincoln in 2009.

Sowing Date (SD)	Sowing rate (SR; kg ha^{-1})	Yield component			
		Seeds pod^{-1}	Pods m^{-2}	TSW (9% moisture)	Damaged pods (%)
25 February	2	15.37	6441	2.96	40
	4	18.45	6320	2.97	38
	6	17.88	3766	3.02	54
$LSD_{(\alpha=0.05)}$		1.90	1455	0.20	12
Significance[1]		*	*	NS	*
26 March	2	19.35	3934	2.89	11
	4	19.99	6236	2.89	10
	6	17.55	3522	3.02	11
$LSD_{(\alpha=0.05)}$		1.90	1455	0.20	12
Significance		NS	*	NS	NS
23 April	2	19.59	3755	2.99	9
	4	20.63	4481	3.17	6
	6	18.85	3834	2.96	2
$LSD_{(\alpha=0.05)}$		1.90	1455	0.20	12
Significance		NS	NS	NS	NS
$LSD_{SD\ (\alpha=0.05)}$		1.90	1455	0.20	12
Significance		*	NS	NS	***
$LSD_{SD*SR\ (\alpha=0.05)}$		3.12	2520	0.33	22
Significance		NS	NS	NS	NS

[1]Levels of significance are *P<0.05, ** P<0.01, *** P<0.001 and NS=not significant.

Sowing date also did not affect TSW. However, delaying sowing later than February resulted in an increased (P<0.029) number of seeds pod^{-1} from 17 to approximately 19 at final harvest. There were no significant differences in the number of seeds pod^{-1} between the March and April sown crops.

The number of pods $plant^{-1}$ (Tables 2 and 7) at the final harvest decreased with increasing sowing rate across all sowing dates. There was also a decrease in pods $plant^{-1}$ as sowing was delayed for both the 2 kg ha^{-1} sowing rate treatment. Numbers of pods $plant^{-1}$ over the sowing dates was not consistent at the 4 kg ha^{-1} sowing rate. At final harvest, a mean of approximately 44% of the pods from the February sowing had been damaged by birds (Table 7) compared with 11% for March and 6% for April sown crops.

Canopy development

At all sowing rates, crops produced flower buds in the first week of October for the February sown crops (Table 5). The March and April sown crops reached the same stage one week and two weeks later, respectively. Sowing rate had no effect on time to 50% flower. February sown crops attained 50% flower 10 days earlier (P<0.011) than both the March and April sown crops.

Leaf area and light interception

Leaf area developed rapidly in late autumn for the February sown crops (Figure 2) which attained full cover (> 95%; Table 6) by the end of April. However, light interception for the late sown crops was below 95% (Table 6) in mid-spring. The late sown crops produced small leaf areas and had not attained full cover at the last sampling before winter. Leaf area index (LAI) and light interception for these late sown crops were measured from early spring as they were too small before then. Peak LAI declined with delayed sowing after February but there were no differences between the March and April sown crops. All crops reached full canopy cover by the end of October (Figure 2; Table 6). The LAI measured for the February sown crops increased ($P<0.03$) with sowing rate before winter, but sowing rate had no effect on LAI for all sowing dates after winter.

Rapid leaf area expansion occurred in all sowing dates from early spring (Figure 2); reaching peak LAI in October. Later sowing resulted in delayed leaf area development in spring with a lower peak (Figure 2) for both the March and April sown crops. For example, the February and March sown crops were at full canopy cover by mid-October (Table 6) and the April sown crops attained full cover about two weeks later. Figure 1 (arrow a) shows that the onset of flowering and pod set restricted vegetative development for the February sown crops. The LAI declined rapidly after reaching the peak (Figure 2) to almost zero at the final harvest.

Table 6 also shows that increasing the sowing rate, at all sowing dates, gave increased radiation interception in mid-autumn for the February sown crops and early to mid-spring for the later sown crops. High light interception explains the continued growth (Figure 1) after full flowering by the late sown crops. It also explains the growth patterns in spring for the late sown crops.

Discussion

The present study demonstrated that delaying sowing from February to March or April resulted in increased seed yield. The low February seed yield could be attributed to the 44% pod damage by birds compared with 11% and 6% for the March and April sown crops, respectively. Most of the seed from later sowings was saved from bird damage through netting. There was also visual evidence that most of the damaged pods were from the primary raceme, which may have affected seed numbers pod^{-1} in this experiment.

Assuming there was no bird damage, the calculated seed yield would have been 3.3, 3.7 and 3.5 t ha^{-1} for the February, March and April sown crops, respectively. Although the increase in seed yield with delayed sowing in this study agrees with findings of Jenkins and Leitch (1986), it contradicts the results of most other work on oilseed rape (Scott *et al.*, 1973; Degenhardt and Kondra, 1981; Mendham *et al.*,, 1981a; Scarisbrick *et al.*, 1981). The difference in seed yield was attributed to increased number of seeds pod^{-1} with delayed sowing; mean of 17 for the February sowing compared with 19 for the later sowings. There was noticeable lodging of the February sown crops, particularly crops sown at 6 kg ha^{-1}, which may also have caused lower seed yields compared with the 2 and 4 kg ha^{-1} sowing rates. Jenkins and Leitch (1986) reported a more efficient light distribution within the upright canopies of the later sown crops. This led to increased pod photosynthesis and reduced abortion of pods and the resultant high seed yield.

The seed yields (2.3-3.3 t ha^{-1}) produced in this experiment are comparable with reports in literature (Mendham *et al.*, 1981b; Jenkins and Leitch, 1986; Leach *et al.*, 1994). They are also comparable with the 2 t ha^{-1} reported by Trethewey (2009) for an irrigated forage rape seed crop in Canterbury. The loss of DM in November for the February sowing was similar to findings of Jenkins and Leitch (1986) on oilseed rape. This was attributed to shading by flowers and reflection of radiation by petals at a time of increasing incident radiation. This resulted in loss of leaves and prevented further DM production. The loss of leaves was more pronounced when crops reached 50% flowering at growth stage 65 which was about 14 days after full canopy cover at the end of October. The lower HI for the February sowing was attributed to a combination of higher total DM and low seed yield, compared with the later sowing dates.

The large number of pods m^{-2} in the February sowing may have caused strong competition for assimilates thereby limiting the number of seeds produced. Conversely, the lower pod density in late sowings may have reduced competition among pods at full canopy cover giving maximum photosynthesis per unit area resulting in maximum potential growth. This would have enabled a large number of seeds pod^{-1} to be produced. This is similar to observations on oilseed rape (Mendham and Scott, 1975; Mendham *et al.*, 1981a; Jenkins and Leitch, 1986) that were attributed to the gradient of radiation within the profile and intense competition for assimilates between a large number of pods. Post-anthesis growth rates were higher in the late sown crops. This could have led to more assimilate supply to the pods for these crops at a time when the numbers of seeds was being determined and hence more seeds produced pod^{-1}. It is assumed (not measured) that at full flower, canopies would reflect more incident radiation as reported by Mendham *et al.* (1981a). If, through having fewer flowers per unit area, the late sowings reflect less incident radiation, then this could have increased assimilate production and supply to the pods at this time.

The increase in plant density with increased sowing rate was not associated with increased seed yield. The low population for the February sowing at 2 kg ha^{-1} was compensated for by more pods plant^{-1}. The current experiment demonstrated that seed rates of 4 and 6 kg ha^{-1} sown in February and March gave the recommended plant density of 60-80 after winter (Hodgson, 1978; Rathke *et al.*, 2006). However, this did not increase seed yield for the February sowing, thereby supporting findings of Mendham *et al.* (1981a) that adequate seed yield could be achieved over a wide range of plant densities (8-90 plants m^{-2}). Forage rape seed crops have the capacity to compensate for lower plant density by producing greater leaf area and more pods plant^{-1}. Neither the seeding date nor sowing rate affected the TSW. This agrees with previous work on oilseed rape by Degenhardt and Kondra (1981).

Plant establishment decreased with delayed sowing and the June sown crop failed to establish and was abandoned. The failure to establish was attributed to the relatively low temperatures with a mean of 6.5°C and excessive soil moisture in May. No plants were lost over winter period, in contrast to reports in the literature (Rathke *et al.*, 2006). This could be attributed to the comparatively mild winters experienced in New Zealand compared with Europe.

Future research will compare results from the present study with Agricultural Production Systems Simulator (APSIM; canola) to try and explain some of the conflicting results discussed in this paper, particularly as they relate to the effect of bird damage.

Conclusions

Farmers should sow forage rape seed in March as earlier sowing is often enforced by late-summer dryness or difficult seedbed preparation, resulting in lower yields. Early sowing can lead to enhanced plant growth in autumn. Delaying sowing beyond April led to poor emergence due to wet conditions and low temperatures.

The optimum seed rate was 4 kg ha^{-1}. Lower seed rates may lead to sub-optimal establishment (<60 plants m^{-2}) while higher rates are an added input cost with minimal yield benefit.

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