Sowing date effects on timing of growth stages, yield and oil content of potential biodiesel crops

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Abstract

Oilseed rape (*Brassica napus)* is the major temperate crop producing biodiesel. Management of nitrogen applications and monitoring of pests and diseases in oilseed crops overseas relies heavily on correct identification of crop growth stages. In New Zealand, other crops besides oilseed rape are being trialled for biodiesel production including brown mustard *(Brassica juncea)* and camelina or false flax *(Camelina sativa*), which also belongs to the Crucifereae family. Together with yield evaluation this study was designed to investigate whether growth stages for oilseed rape were similar to these other potential biodiesel crops. The times from emergence to stem elongation, 50% flowering and final harvest were recorded in the 2010-11 season across four sowings dates on three species in a trial at Lincoln University near Christchurch, New Zealand. All species took different periods of time to reach the four growth stages measured. The time to reach a certain growth stage varied considerably more in the two autumn sowings, but much less in the spring sowings for all species. Oilseed rape out yielded the other crop species at all sowings in seed yield and oil content, but took longer to reach full maturity. Oilseed rape yielded an average of 2.4 t seed/ha with 42% oil content. Brown mustard and camelina yielded an average just over 1 t seed/ha, with 30 and 35% oil content respectively.

***Additional keywords**:* Oilseed rape, *Brassica napus*, brown mustard, *Brassica juncea,* camelina, *Camelina sativa*

Introduction

New Zealand (NZ) uses 83% more diesel than petrol. 57% of diesel in NZ is used for transport, postal and warehousing (Statistics New Zealand, 2010). Biodiesel is a substitute or additive to diesel that is considered sustainable and renewable (Energy, Efficiency and Conservation Authority, 2012). Oilseed rape (*Brassica napus* L.) [OSR] is one of the main sources used to produce biodiesel (Ministry of Economic Development, 2011). In a previous NZ paper OSR growth on marginal land was evaluated due to the concern of growing fuel crops on fertile soil that is used to produce food (McKenzie *et al.*, 2011). Oilseed rape can be sown on fertile soils as a break crop to reduce diseases caused by growing continuous cereals (Daly and Martin, 1988).

There are alternative oilseed crops available for biodiesel which have had limited evaluation under NZ conditions. Brown mustard (*Brassica juncea* (L.) Czern.) [BM] has a seed rich in oil (>30%) and has been reported to have a low input requirement and be useful in the production of biodiesel (Pavlista *et al.*, 2011). Another oilseed crop considered to be an alternative for the production of biodiesel is camelina or false flax (*Camelina sativa* (L.) Crantz) [CS] (Frohlich and Rice, 2005). CS has the ability to grow on marginal soils and has a short maturity length when compared with OSR (Berti *et al.*, 2011).

The phenological stages of plant growth are used to determine fertiliser application timings (HGCA, 2009). They can also be used to determine crop adaptability to different environments and for crop breeding programmes (Martinelli and Galasso, 2011).

Later sowing date can reduce OSR yields (Taylor and Smith, 1992; Hocking and Stapper, 2001). Delaying sowing date in OSR reduces the time between sowing and flowering and hence reduces biomass at flowering which can consequently reduce yields (Farre *et al.*, 2002). The ideal OSR sowing date in Canterbury is mid-February to April for winter types (Biodiesel NZ, 2009). However, early sowings may experience drought while the risk of frost damage increases if sowing is delayed in autumn. Sowing date is dependent on climate but is designed to ensure adequate moisture at sowing and sufficient crop cover prior to winter. Spring sown crops are recommended to be sown between September and October (Biodiesel NZ, 2007) before water becomes a limiting factor.

This paper describes the on-going evaluation of biodiesel crops at Lincoln University and examines the development and yields of three oilseed crops, sown on four different dates.

Materials and Methods

The trial was carried out in Iversen Field (43° 38' 55" S, 172° 27' 59" E) at Lincoln University, Canterbury, on an irrigated Wakanui silt loam soil. A split plot trial design with four replicates was established, with sowing dates as main plots and plant species as subplots. Subplots were 4.2 m x 10 m. Sowing dates (SD) were 19 March, 19 April, 23 September and 15 October 2010. The cultivars used for OSR were 'Bravour' (for the two autumn sowing dates) and 'Ability' (for the two spring sowing dates); 'Centennial' for BM and Accession no 4164 were used for CS. Both OSR cultivars are open pollinated types. Seeding rates were 5 kg/ha for autumn and 4 kg/ha for spring sown OSR, 4 kg/ha for BM and 6 kg/ha for CS. Species were sown using an Oyjord cone seeder, with sowing depth approximately 1-1.5 cm.

Soil samples to 15 cm depth were taken prior to cultivation for soil fertility analysis. Results showed the site was low in phosphorous and sulphur (Table 1). Lime at 4 t/ha was applied prior to the first sowing (19 March). Superphosphate at 175 kg/ha was applied in August and October to all plots. Spring N (100 kg N/ha) was applied to the March and April sowings in September when the growth stage was between stem elongation and full flower. The September and October sowings received N in October at 50% emergence and sowing respectively.

Weeds were initially controlled with Glyphosate 360 at 3 l/ha (a.i. 360 g/l glyphosate) plus 100 ml/100 l of Accelerate (a.i. polyether modified polysiloxane) before cultivation. The site was rotary hoed, Cambridge rolled and cultivated before

Treflan at 3 l/ha (a.i. 480 g/l trifluralin) was incorporated into the soil in March for the autumn sowings. Prior to sowing in September the final two sow dates were dutch harrowed and Cambridge rolled before Treflan at 3 l/ha was incorporated.

Table 1: Soil test (0-15cm) results from Iversen Field, Lincoln University. Soil samples were analysed using MAF Quicktest procedures. Bracketed numbers are optimum levels for autumn sown OSR establishment (Biodiesel New Zealand, 2009).

pH	Olsen P	SO_4-S	K	Ca	Mg	Na
H_20	(mg/l)	(mg/kg)	---------------------MAF units---------------------			
5.7 (5.8-6.3)	9 (20-30)	5 (>10)	9	9	23	10

Measurol® at 1 kg/ha (a.i.750 g/kg methiocarb) was applied after emergence for the March, April and September sowings to deter birds. Insects were controlled as required with Attack® at 1 l/ha (a.i. 25 g/l permethrin plus 475 g/l pirimiphos-methyl) until four beehives were introduced on site in November to ensure pollination, after which Prohive™ at 250 g/200 l (500 g/kg pirimicarb) was used for insect control. Proline® at 800 ml/ha (a.i. 250 g/litre prothioconazole) in July and again in September to autumn sown plots after *Rhizoctonia solani* was identified. The maximum recommended rate was used rather than two applications at 400 ml/ha because of the difficulty in spraying the crop under bird netting. Ridomil Gold MZ WG® at 2 kg/ha (a.i. 40 g/kg metalaxyl-M plus 640 g/kg mancozeb) was applied to the March, April and September sowings after white blister (*Albugo candida*) was identified and Rovral Gold® at 67 g/100 l (a.i. 750 g/kg iprodione and 336 g/litre liquid hydrocarbon) was applied in October for *Sclerotinia* control.

Time domain reflectometry (TDR) rods to 20 cm depth were placed in replicates one and four. Brown (2004) found field capacity in 0-0.2 m soil on an adjacent site with a similar soil was approximately 33%, therefore the irrigation trigger point was at 50% plant available water (22.5%). The trial was irrigated with an Ocmis travelling irrigator.

Seedling emergence was counted from 5 × 1 m drill rows per plot until emergence records were considered constant. Growth stage measurements were taken every 5-13 days from September to February. The trial was covered in bird netting in November to reduce seed loss and to determine potential seed yield. One net covered each replicate.

Final harvest occurred when the majority of the plants were at full maturity. At final harvest an area of 2 m^2 was used to determine seed yield. Plant samples at final harvest were cut by hand and hung to dry in a warm room for at least 3 weeks before processing them for seed. Final harvest samples were threshed using a Kurt Pelz thresher and hand cleaned.

Oil was extracted mechanically using a cylinder hole screen press operating at a throughput of 20-35 g/minute with a choke size of 4 mm and operating temperature of 80°C. Sample size extracted was 250 to 300 g. Seed moisture content was determined at the time of extraction. Seed moisture was calculated using the constant temperature oven method (ISTA, 2008). All seed yield data presented has been adjusted to a seed moisture content of 0%.

Data analysis

All results were analysed by analysis of variance (ANOVA) using GenStat (version 14, VSN International Ltd, UK). Mean separation was through the use of Fishers protected least significant difference (LSD). Replicate two in both spring sowings were abandoned because of wind damage to bird netting, reducing statistical analysis to three replicates in all treatments.

Results

Climate

The mean air temperature during the 2010-11 season was warmer in 9 out of the 12 months (0.2-2.0°C), with the exception being July (-0.1°C), October (-0.2°C) and January (-0.3°C) compared with the long term means (LTM) (Table 2). The LTM annual rainfall for this location is 647 mm/year, however during the 2010-11 season the total was 846 mm. In the months of May, June and August 2010 the rainfall was at least 63 mm more per month than the monthly LTM. Another significant weather event occurred on 21 December 2010 when hot gale force winds were experienced. This caused considerable damage to the bird nets, which subsequently allowed birds onto the crop, resulting in some seed loss and the abandonment of one replicate.

Table 2: Mean monthly air temperatures and monthly rainfall at Lincoln, Canterbury during the 2010-11 growing season. Bracketed numbers are from the Long term (1971-2010) mean monthly air temperatures and monthly rainfall at Lincoln, Canterbury (NIWA, 2011).

Month	Air temperature (°C)	Rainfall (mm)
March 2010	15.7 (15.0)	31.8 (51.3)
April 2010	13.6 (12.2)	31.8 (52.8)
May 2010	10.2 (9.3)	200.6 (60.0)
June 2010	6.8 (6.6)	138.8 (55.8)
July 2010	6.0 (6.1)	48.6 (69.1)
August 2010	8.4 (7.5)	131.4 (68.0)
September 2010	10.4 (9.6)	42.6 (38.6)
October 2010	11.2 (11.4)	26.4 (56.4)
November 2010	14.7 (13.3)	61.4 (48.5)
December 2010	17.3 (15.3)	49.4 (54.0)
January 2011	16.4 (16.7)	42.6 (46.1)
February 2011	17.1 (16.6)	40.2 (46.1)
Annual	12.3 (11.6)	845.6 (646.7)

Plant population

There was no interaction between sowing date and species at emergence (Table 3). The mean plant population across sowing dates at emergence for OSR, BM and CS were 100, 139 and 300 plants/m^2 respectively. There were no significant losses in plant population between emergence and final harvest for the OSR. However, BM and CS had an average loss of 40 and 148 plants/m^2 respectively or 29% and 49% stand loss. In both BM and CS the majority of the stand loss occurred in the two autumn sowings. Specific winter and spring type OSR cultivars were used, preventing such significant winter losses for this species.

Growth stage

The time to reach stem elongation (SE), 50% flowering (F) and final harvest (H) varied considerably between species and also between the two autumn and two spring sowings. Autumn sown CS took 72 days to reach stem elongation, compared with an average of 124 and 138 days for BM and OSR respectively (Table 4). In contrast, autumn sown CS took on average 93 days to grow from stem elongation to 50% flowering compared with 78 days for BM and 45 days for OSR. Similarly, between 50% flowering and harvest, CS took 86 days, compared with 49 days for BM and 72 days for OSR. OSR took 268 days and 241 days (March and April sowings respectively) to go from emergence to harvest while both BM and CS matured slightly earlier (9 days) for these sowing dates.

The spring sowings behaved differently. Overall all species took less than half the time to get from emergence to 50% flowering compared with the autumn sowings. BM and CS took up to 15 days less from 50% flowering to final harvest compared with OSR. Oilseed rape took 127 days and 112 days to go from emergence to harvest (September and October sowings respectively). BM and CS were much quicker, being harvestable 20-29 days earlier than OSR.

Table 3: Plant population at establishment (plants/m^2). Bracketed numbers are plant population at final harvest.

Sowing Date	Oilseed Rape	Brown Mustard	Camelina
19 March 2010	66 (78)	118 (69)	246 (30)
19 April 2010	93 (95)	163 (68)	341 (74)
23 September 2010	131 (117)	146 (141)	323 (281)
15 October 2010	109 (91)	130 (117)	290 (223)
Mean	100 (95)	139 (99)	300 (152)
P-value (Interaction)		0.156 (<0.001)	
P-value (Sowing date)		0.013 (<0.001)	
P-value (Species)		<0.001 (<0.001)	
LSD within SD		43 (37)	
LSD all other comparisons		46 (45)	

Table 4: Number of days between 50% emergence (E), stem elongation (SE), 50% flowering (F) and final harvest (H) for OSR. Numbers in italics are differences between BM or CS and OSR. Negative numbers indicate fewer days than OSR.

Sowing date	Harvest date	Species	E - SE	SE - F	F - H	E - H
19 March 2010	23 December 2010	OSR	148	48	72	268
	14 December 2010	BM	*-22*	*36*	*-23*	*-9*
	14 December 2010	CS	*-76*	*55*	*12*	*-9*
19 April 2010	23 December 2010	OSR	127	42	72	241
	23 December 2010	BM	*-6*	*30*	*-24*	*0*
	23 December 2010	CS	*-55*	*40*	*15*	*0*
23 September 2010	08 February 2011	OSR	41	24	62	127
	19 January 2011	BM	*-9*	*0*	*-11*	*-20*
	10 January 2011	CS	*-9*	*-6*	*-14*	*-29*
15 October 2010	15 January 2011	OSR	22	35	55	112
	25 January 2011	BM	*0*	*-6*	*-15*	*-21*
	25 January 2011	CS	*0*	*-19*	*-2*	*-21*

Seed yield

Seed yield ranged from 664 to 2939 kg/ha for March sown CS and OSR respectively (Table 5). March sown OSR produced significantly higher seed yield than any other treatment. OSR seed yields for April and September sowings were also high at 2406 and 2325 kg/ha respectively. Both BM and CS were more variable across sowing dates, but did show a similar trend in seed yield, where April and September sowings producing significantly more seed than the March sowing. Yields for October sowing were intermediate. OSR seed yields for March, April and September sowing dates were significantly higher than all BM or CS yields recorded.

Oil content

OSR had higher oil content (42% on average) compared with the BM (30%) and CS (35%). Oil content of all three species generally decreased with later sowing times (Table 6).

Table 5: The effect of sowing date on seed yield (kg/ha), on a dry-weight basis, for three oilseed crops sown in Canterbury.

Sowing Date	Oilseed Rape	Brown Mustard	Camelina
19 March 2010	2939	773	664
19 April 2010	2406	1443	1162
23 September 2010	2325	1335	1412
15 October 2010	1786	1010	869
Mean	2364	1140	1027
P-value (Interaction)		0.002	
P-value (Sowing date)		0.042	
P-value (Species)		<0.001	
LSD within SD		470	
LSD all other comparisons		471	

Table 6: The effect of sowing date on expressed oil content (%) for three oilseed crops sown in Canterbury.

Sowing Date	Oilseed Rape	Brown Mustard	Camelina
19 March 2010	42.9	30.5	37.6
19 April 2010	45.1	33.1	37.6
23 September 2010	41.4	27.5	32.9
15 October 2010	39.2	27.3	32.8
Mean	42.2	29.6	35.2

Discussion

This trial used winter and spring OSR cultivars provided to the local farmers by Biodiesel NZ. 'Bravour' was supplied for autumn sowings and 'Ability' for spring sowings. There was no information on whether the CS and BM cultivars used were winter or spring types. The CS was bred for Western Australian conditions and the BM was sourced from a NZ food company. This may have put the CS and BM at a disadvantage to OSR, but further research will be required to characterise the suitability, vernalisation and photoperiod requirements of these two species.

Oilseed rape cultivars have a wide range of flowering responses to photoperiod and/or vernalisation responses (Myers *et al.*, 1982), which have an effect of timing of growth stages. 'Bravour' has a higher photoperiod and/or vernalisation requirement than 'Ability' that prevents it bolting until the end of winter. All OSR cultivars respond to photoperiod and vernalisation (Robertson *et al.*, 2002), but it can be difficult to determine the exact requirements for individual cultivars to switch to reproductive growth as, in many cultivars, photoperiod and vernalisation are interchangeable (Myers *et al.*, 1982).

Robertson *et al*. (2002) found that, in a number of OSR cultivars, most of the variability in OSR crop development was in the vegetative stage. In this study autumn sown OSR took nearly 20 weeks to go from 50% emergence to stem elongation compared with 17 weeks from stem elongation to harvest. Spring sown OSR took less than five weeks from 50% emergence to stem elongation and 13 weeks from stem elongation to harvest

Robertson *et al*. (2002) concluded that BM acts like an early flowering OSR crop. However, in this study, autumn sown BM was only up to two weeks faster than OSR to stem elongation, compared with CS, which was nine weeks faster than OSR. However BM and CS were slower to go from the start of stem elongation to 50% flowering, indicative of the more indeterminate nature of these two crops, which have not been intensively bred for determinacy like OSR.

Despite the large variability in timings to intermediate growth stages, autumn sowings of all three species reached harvest maturity at around the same time. However, this may have been partly due to the gale damage to nets and posts, which meant that some plots were harvested earlier than full maturity to avoid bird losses.

BM and CS in the spring sowings reached harvest maturity 20 to 29 days earlier than OSR, mainly because of the shorter time to grow from stem elongation to harvest. The duration of the measured growth stages between the two spring sowing dates was quite variable both across and between species. This could have been a result of the December high temperatures and NW gales accelerating the development of both spring sowings. These results agree with McKenzie *et al.* (2011) and Pavlista *et al*. (2011) who found CS matured faster than BM and OSR, when sown in the spring.

Seed yield was consistently higher in OSR (2.4 t/ha) than BM (1.1 t/ha) and CS (1.0 t/ha) over the four sowing dates (Table 5), reflecting results similar to those of Pavlista *et al*. (2011). The seed yield for autumn sown BM and CS was variable, possibly due to white blister (*Albugo candida*) found on the BM and *Rhizoctonia solani* on the CS. Table 3 shows a reduction in plant population for both species, which was probably a combined effect of the fungus diseases and premature bolting. For CS, there were a high number of plants that bolted prematurely in the first sowing; plant mortality was observed from June onwards. In a trial 10 km away in the same season, CS sown a week earlier than this trial all bolted and died in early winter (McKenzie *et al.*, 2011). In contrast to previous trials (McKenzie *et al.*, 2011) the CS was observed to have some seed loss through bird damage. However, the loss appeared to be less than OSR and BM.

The autumn sown OSR yields were similar to other autumn sown OSR around Canterbury (Foundation for Arable Research, 2011). Despite a higher OSR population in the April sowing (Table 3), the March sown OSR still yielded 500 kg/ha more seed. Leach *et al*. (1999) noted OSR sown at low plant population densities is able to compensate by producing bigger leaves, more branches and more pods.

The effects of duration of post flowering growth in OSR and BM have been quantified by Si and Walton (2004). The reduced time from 50% flowering to final harvest in BM compared with OSR and also in spring sowings compared with autumn sowings will reduce their yield potential.

These results show that seed oil content in OSR was higher than BM and CS (Table 6). Pavlista *et al.*, (2011) and McKenzie *et al.*(2011) also found the oil content in OSR to be higher than BM and CS. Pavlista *et al.* (2011) concluded this would be expected since OSR has had more genetic improvement than BM and CS. There may be other CS and BM cultivars with higher oil contents. However, they were not available. Oil content was stable across sowing dates for OSR but tended to decrease in BM and CS, which is in contrast to Pavlista *et al*. (2011). The reason for this is unclear, however the results presented here are not replicated so should be used as a guide only.

Conclusions

This trial has demonstrated that autumn sown BM and CS are susceptible to fungus diseases; therefore adequate fungus control at an early plant growth stage is required. The growth stages used for OSR can be adapted for BM and CS and allow an adequate comparison of growth rates between species. The growth rates of OSR, BM and CS over the 2010-11 season show that BM and CS can mature faster than OSR. However, due to warmer temperatures experienced in the 2010-11 season further research is required. BM had no advantages over OSR when grown in Canterbury across a wide range of sowing dates. This agrees with McKenzie *et al*. (2011). CS also showed no seed yield or oil yield advantages over OSR. However, a variety needing a strong vernalisation or photoperiod response may yield considerably more than the cultivar used under autumn sown conditions in this trial.

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A more detailed photographic description of the growth stages of potential biodiesel crops is available from the senior author on request.

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