Crop architecture and light interception in forage rape (*Brassica napus* L.) grown for seed

J.A.K. Trethewey
AgResearch Lincoln, Private Bag 4749, Christchurch, New Zealand

Abstract

In New Zealand, forage rape is typically grown as an alternative feed in animal production systems. Detailed investigations on the growth and reproductive development of forage rape grown for seed are limited. Maximum light interception by photosynthetic tissues throughout a canopy is important for achieving optimum seed yields. Factors such as water availability and crop management can influence plant growth and, as a consequence, light interception. Changes in crop architecture and light penetration during reproductive development in forage rape grown with and without irrigation were investigated. Trials were established in grower fields at two locations with forage rape cv. Greenland. Crops were monitored from early flower head emergence (growth stage 54) through to harvest. Photosynthetically active radiation was measured regularly at four different heights throughout the canopy. Individual plants were also investigated further for various reproductive characteristics. The irrigated crop was 70 cm taller and had more secondary racemes than the non-irrigated crop. Light penetration at different levels varied considerably, with the non-irrigated crop allowing more light to penetrate into the various canopy levels. However, better light penetration did not give higher seed yield as the seed yield of the non-irrigated crop (455 kg ha^{-1}) was only 22% that of the irrigated crop; (2025 kg ha^{-1}). Results are discussed in terms of crop architecture, light penetration through the canopy and water stress and their effect of on these on seed yield.

Additional keywords: irrigation, photosynthetically active radiation, seed yield, canopy architecture

Introduction

In New Zealand, forage rape (*Brassica napus* L.) is typically grown for green feed to fill gaps in the feed supply of pasture-based animal production systems. Consequently, detailed investigations on the growth and reproductive development of forage rape, grown for seed, are limited. Seed yield potential is determined by the ability of a plant to produce biomass and the partitioning of biomass in the plant to seed. Biomass accumulation depends on crop architecture and the ability of the canopy to intercept photosynthetically active radiation (PAR) (Sinclair and Muchow, 1999). In some brassicas, including forage rape, as biomass accumulation continues to maturity, crop architecture and the amount of PAR intercepted by the crop are important for optimum seed yield (Rose *et al*., 2007).

Water is vital for many plant physiological processes including photosynthesis (Lawlor and Tezara, 2009). Water stress can alter the proportion of dry matter (DM) partitioned among organs (Taylor *et al*., 1991) and can reduce seed sink size (Anderson *et al*., 1996). Water stress at flowering has negatively influences seed pod formation resulting in lower seed yields (Johnston *et al*., 2002). Further, the timing of water stress may have more of an effect on seed yield than the intensity of the stress (Korte *et al*., 1983). The aim of this research was to investigate changes in crop architecture and light interception in forage rape grown for seed with, and without. irrigation.

Materials and Methods

Plant material

Trials were positioned in established crops of forage rape (cv. Greenland) at two locations in Canterbury, New Zealand.

Location one (Long Beach, Ashburton) at 20 m above sea level was irrigated with a total water application, including rain, of 170 mm. The soil type was a Lowcliffe silt loam.

Location 2 (Methven) at 280 m above sea level was non-irrigated (dryland) but received 15 of rain. The soil type was a Lyndhurst silt loam. The dryland site was exposed to strong Northwest winds during seed fill. Both crops received approximately 200 kg ha^{-1} of nitrogen in spring.

Sampling

At both locations 15 individual plants were tagged on 17 October 2008 when single flower buds on the main inflorescence were visible but still closed (growth stage 54) (Bayer CropScience, 2008). Crops monitored regularly through to harvest (7 January 2009). PAR was measured at four different canopy heights (75% of canopy height, mid-canopy, 25% of canopy height, canopy base) using a Decagon AccuPAR LP-80 linear PAR Ceptometer. Individual plant heights and the number of secondary racemes were also recorded.

At harvest (approximately 40% seed moisture content) tagged plants were divided into 12 different seed fractions (Figure 1). Based on pod position, primary racemes were divided into upper, middle and lower fractions (Fractions 1 to 3). Based on the position of secondary racemes, secondary racemes were also divided into upper, middle and lower fractions. Individual racemes within the fractions were further divided into upper, middle and lower fractions. Each seed fraction was hand threshed, sieved and cleaned on a small scale Westrup air-screen cleaner. Dry matter was assessed by taking the weight of plants both before and after drying at 80 °C for 18 h.

Tin foil trays (207 cm^2) were placed at soil level underneath the crops on 27 December 2009 before windrowing to assess the amount of seed loss. GenStat (Version 10) was used for statistical analysis using a general ANOVA model for a direct comparison between irrigated and dryland Greenland forage rape and the difference between harvest components. Individual and combined measurements were designated as treatments and replicates and individual plants designated as blocks.

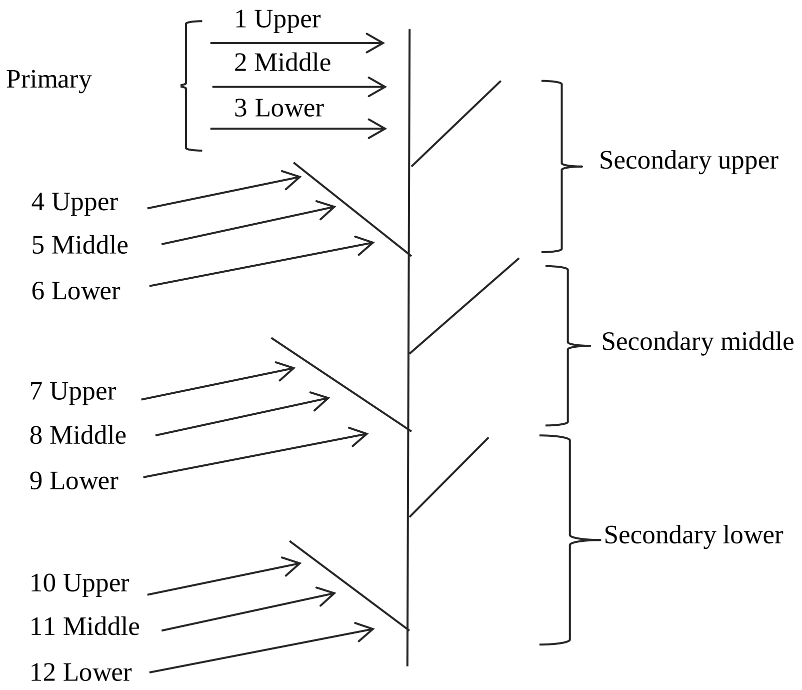

Figure 1: Dissection of tagged plants for seed yield analysis. The total number of secondary racemes was divided into upper, middle and upper fractions. Individual racemes within fractions were further divided into upper, middle and lower fractions.

Results

Plant height and biomass

At the beginning of the trial crop heights were similar between the irrigated and dryland sites. There was no significant difference until one week after flowering (Figure 2). Compared with the dryland crop, flowering in the irrigated crop was delayed by approximately four days. Associated with flowering and pod (silique) formation, for both irrigated and dryland crops, there was a decline in the rate at which crop height increased. In the irrigated crop this decline coincided with flowering and pod formation and lasted approximately three days. The average daily increase in crop height fell by 38% at flowering and 57% at pod formation. In the dryland crop, this decline was delayed until four days after flowering and pod formation (Figure 2) with the average daily increase in crop height declining by 68% at flowering and 73% at pod formation. From pod formation to harvest the irrigated and dryland crops increased in height by 37% and 21% respectively.

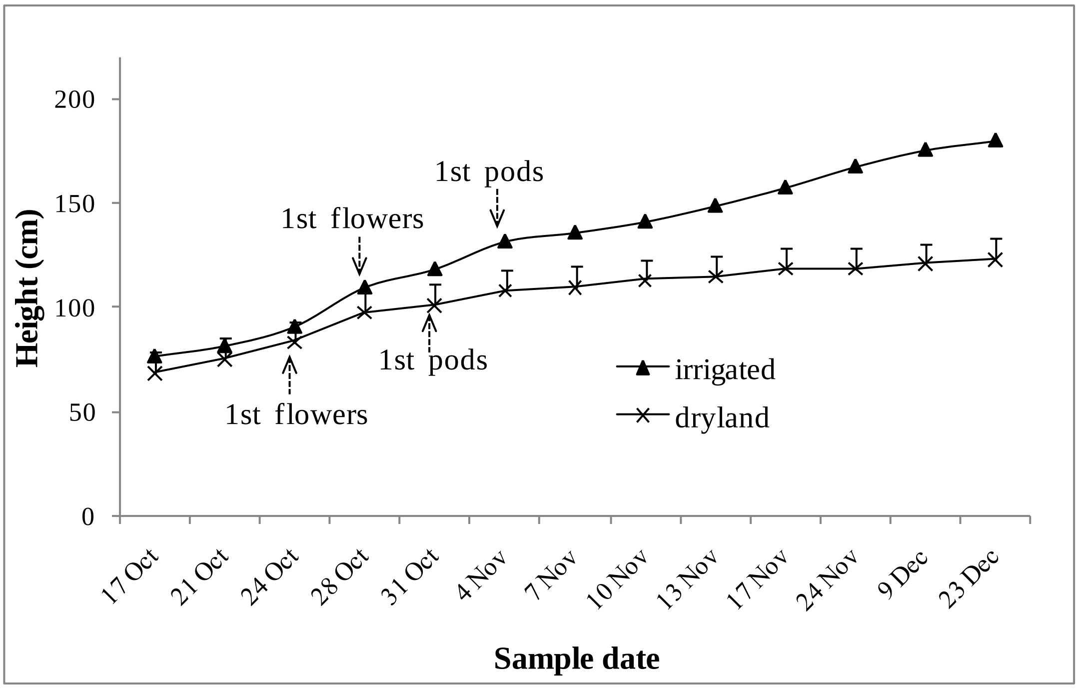

Figure 2: Average height of irrigated and dryland crops from early flower emergence through to harvest. First flowers and first pods are indicated. Bars = 5% LSD.

There was a significant difference in average plant biomass. Irrigated plants had 3.5 times more biomass than plants from the dryland site (data not shown). The dry weight % of plants at both the irrigated and dryland site were similar at 27% and 29%, respectively.

Secondary racemes

The dryland site had significantly more plants m^{-2} (55) than the irrigated site (37) (Figure 3a). However, the number of secondary racemes plant^{-1} was lower at the dryland site (Figure 3b). These results combined, emphasize differences in crop architecture between the irrigated site (fewer larger plants with more secondary racemes) and the dryland site (smaller plants with fewer secondary racemes). Although both sites had different crop architectures the total number of secondary racemes per unit area was similar (Figure 3c).

Light interception

Differences in crop architecture between the two sites resulted in differences in light interception at different levels in the canopy. At the start of the experiment the % PAR (% relative to the canopy top), measured at 75% crop height, was similar for both the irrigated (74%) and dryland (78%) sites (Figure 4). In the irrigated crop this increased to 90% at the start of flowering with a subsequent decrease to 77% at the start of pod formation (Figure 4a). During pod development and seed fill through to harvest the amount of PAR at 75% crop height steadily declined to 10%.

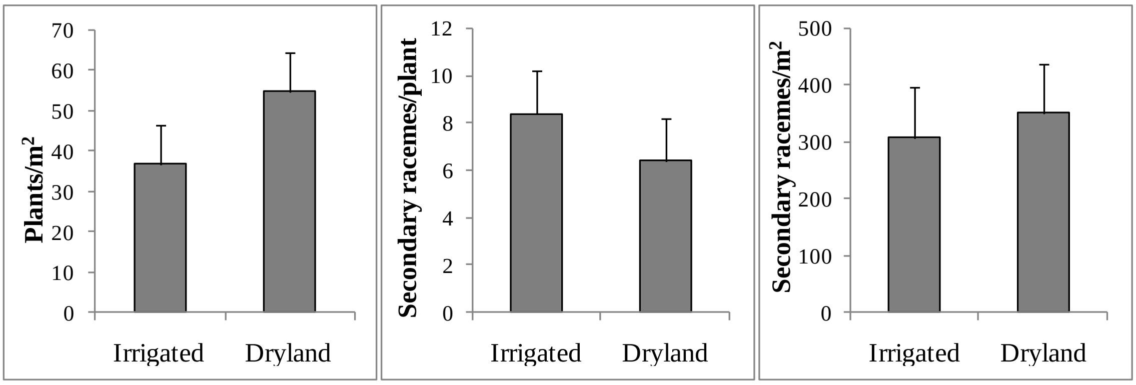

Figure 3: Number of plants (a), secondary racemes plant^{-1} (b) and total number of secondary racemes for irrigated and dryland crops. Bars = 5% LSD.

By comparison, at 75% crop height, in the dryland crop there was little change from early flower development through to the start of pod formation (Figure 4b). During pod development through to harvest % PAR only decreased from 78% to 69%.

At 50% crop height the initial amount of PAR (% relative to the canopy) was substantially lower for the irrigated crop (12%) compared with the dryland crop (36%) (Figure 4). In the irrigated crop this increased to 42% at the start of flowering with a decrease to 23% at the start of pod development with a continued decrease to 3% at harvest (Figure 4a). By comparison, in the dryland crop, there was a decrease from early flowering (36%) to the start of pod formation (22%). However, during pod development and seed fill through to harvest the % PAR increased to 31% (Figure 4b).

In the irrigated crop at 25% crop height and at the base of the canopy (0% crop height) % PAR was initially 9% and 4%, respectively. Both of these decreased to 1% by the start of flowering and remained low until harvest (Figure 4a). In the dryland crop at 25% crop height and at the base of the canopy, % PAR was initially 20% and 8%, respectively. These decreased to 4% and 2% respectively, by the start of pod formation. However, these values increased during pod development and seed fill and continued to increase to 25% and 20%, respectively, at harvest (Figure 4b).

Flower and pod number

At both sites the number of flowers and pods on primary racemes were similar (Table 1). However, there were large differences in the number of pods secondary raceme^{-1} between the two sites with over five times as many pods secondary raceme^{-1} on irrigated plants.

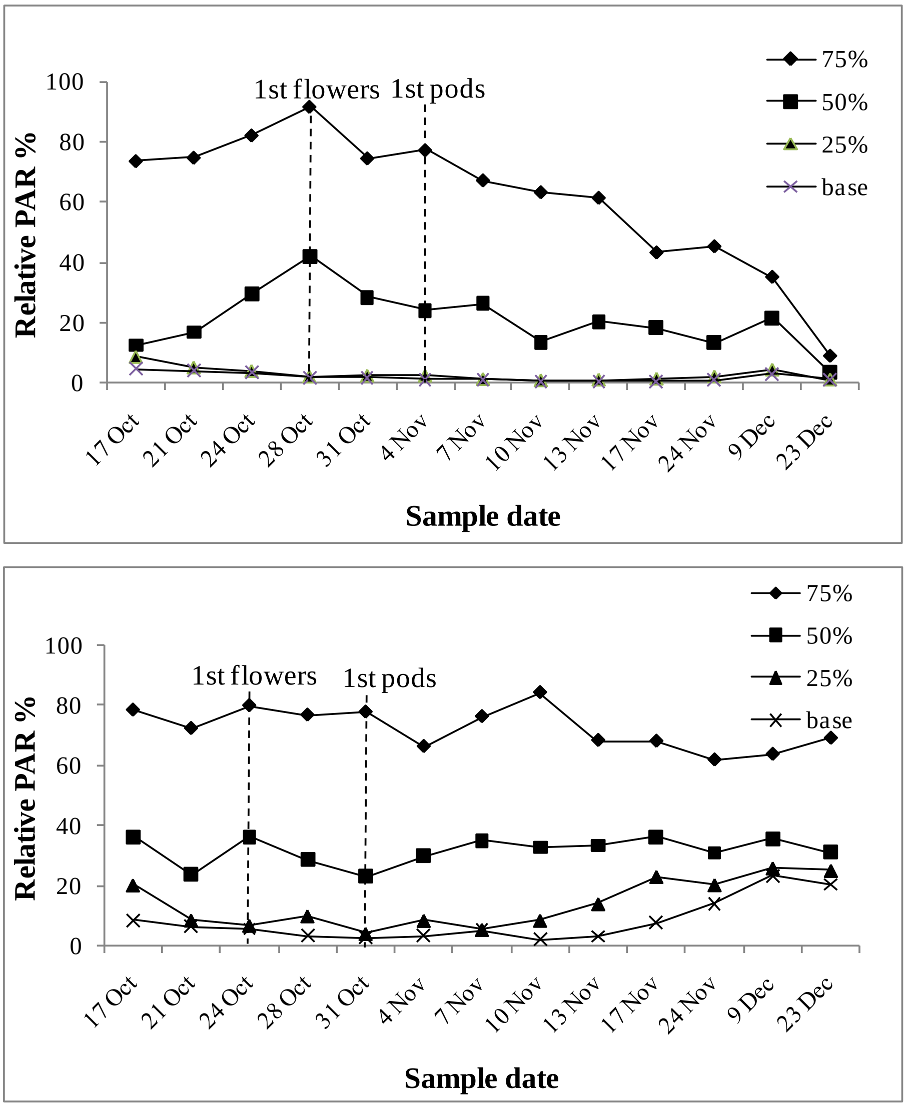

Figure 4: Photosynthetically active radiation (PAR) at different levels throughout the canopy of irrigated (a) and dryland (b) crops from early flower emergence through to harvest. First flowers and first pods are indicated.

Table 1: Number of pods raceme^{-1} for irrigated and dryland sites.

Site	Pods 1^{o} raceme^{-1}	Pods 2^{o} raceme^{-1}	Pods from 1^{o} raceme (%)
Irrigated	55	36	12
Dryland	61	7	60
LSD (5%)	13	15.6	13
Pr > F	0.246	0.006	<0.001

This resulted in 60% of the total number of pods plant^{-1} coming from the primary raceme at the dryland site compared with only 12% at the irrigated site. There was a strong linear relationship between pod density and DM (R^2 = 0.89) (Figure 5).

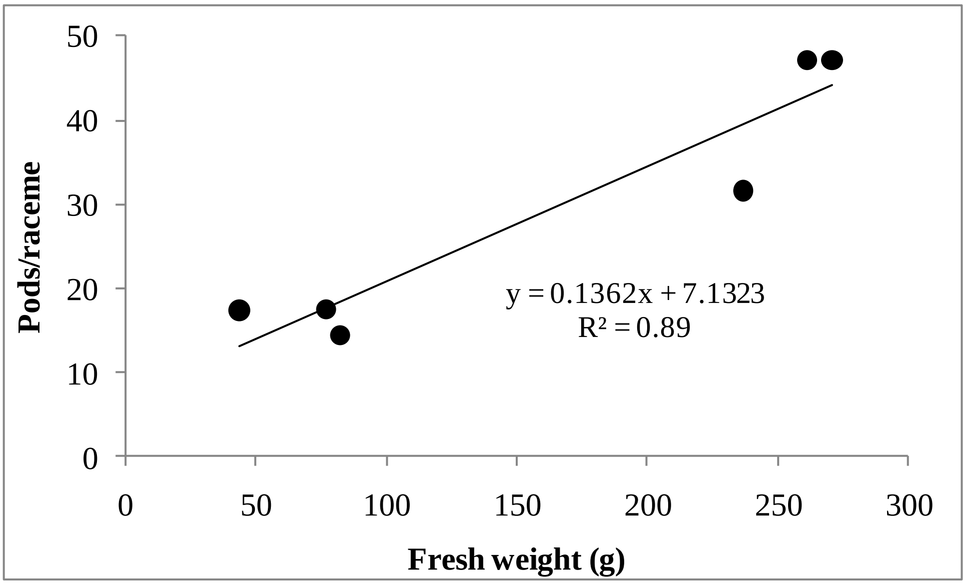

Figure 5: Relationship between the number of pods per secondary raceme and biomass.

Seed yield

There was a large difference in the final dressed seed yield between the irrigated crop (2,025 kg ha^{-1}) and the dryland crop (455 kg ha^{-1}). Seed loss trays beneath the crops indicated that in the irrigated crop approximately 200 kg ha^{-1} of dressed seed was not recovered compared to 1,000 kg ha^{-1} of dressed seed in the dryland crop. The poor plant water status and the strong northwest winds, at Methven, during late seed fill and harvest accounted for much of the seed loss at the dryland site.

Compared with the irrigated site, the dryland site had a recovered seed yield of 22% (455 kg ha^{-1} versus 2,025 kg ha^{-1}). There was a seed shatter yield loss of 49% (1,000 kg ha^{-1} from 2,025 kg ha^{-1}) leaving a 28% seed loss which may be attributed to moisture stress.

At the irrigated site seed yield was mainly driven by the secondary racemes with over 85% of the seed coming from pods on the secondary racemes (Figure 6). Also, over 60% of the seed could be accounted for by the middle and lower secondary racemes.

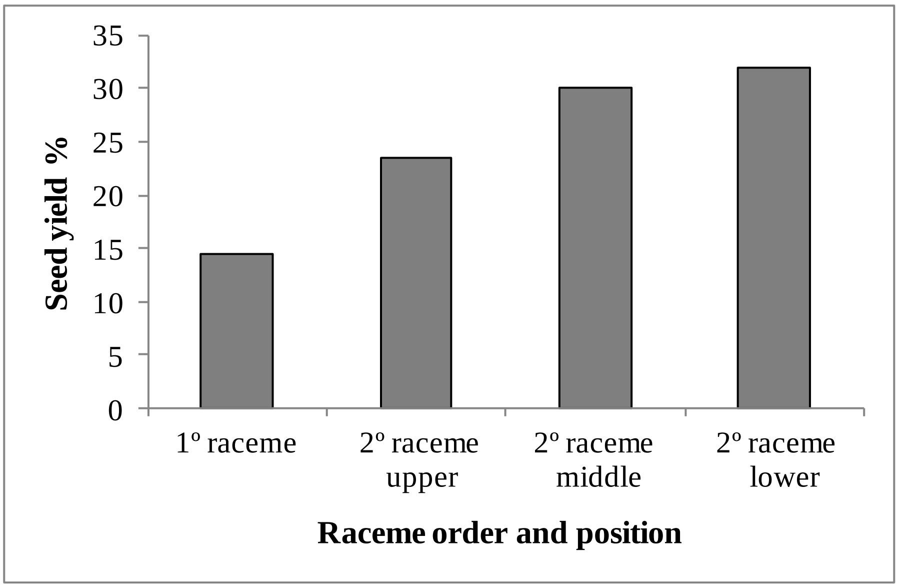

Figure 6: Seed yield (%) from primary and secondary racemes for the irrigated crop.

In the primary and upper secondary racemes seed yield decreased from the top of the raceme towards the base (Figure 7). In contrast, in the middle and lower secondary racemes, seed yield was highest in the middle of the raceme (Figure 7) with more seed from the lower part of the raceme compared with the primary and upper secondary racemes.

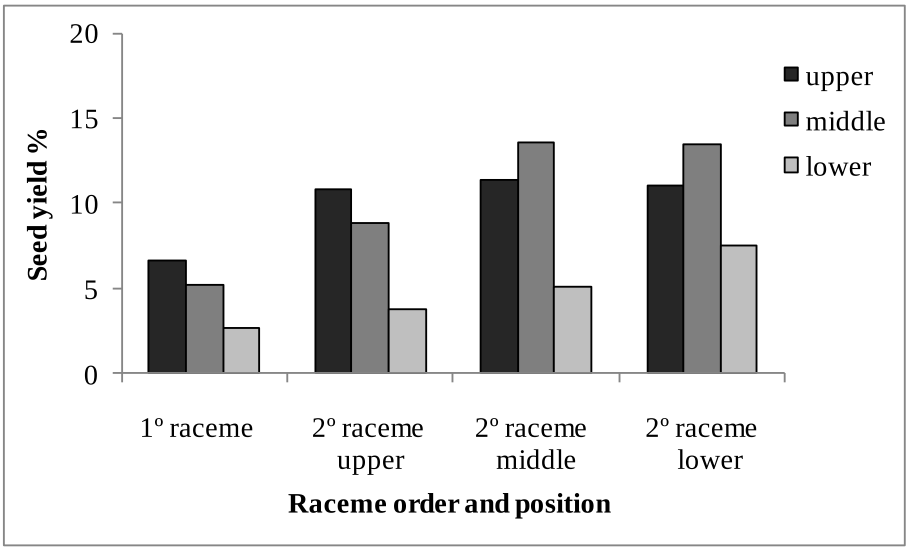

Figure 7: Seed yield (%) from different fractions of primary and secondary racemes for the irrigated crop.

Discussion

In New Zealand, forage rape is typically grown as an alternative feed in animal production systems. As a result detailed investigations on the growth and reproductive development of forage rape grown for seed are limited. This study, compared plants at an irrigated site, plants at a dryland site. The latter were shorter with less biomass, had fewer secondary racemes with fewer pods raceme^{-1}, intercepted less PAR throughout the canopy and had a lower seed yield. In a year with severe droughtat a dryland site there was a lower recovered seed yield and higher seed loss from shattering and moisture loss.

Crop architecture has a major influence on light penetration through the canopy. In this study the amount of PAR intercepted by the canopy differed between the irrigated and dryland sites. Plants at the irrigated site were larger with higher biomass and more secondary racemes. As a result the percentage of PAR intercepted by the canopy was higher than at the dryland site. However, during flowering much of the PAR is reflected by the floral canopy rather than being absorbed by the leaf canopy. In oil seed rape it has been estimated that between 7 and 22% of PAR reached the leaf canopy with the floral canopy absorbing 64% of PAR (Evans, 1984; Fray *et al*., 1996). In this study, from flowering to harvest, PAR interception did not change throughout the canopy in the dryland crop. In comparison, in the irrigated crop, floral canopy PAR absorption increased from 10% to 90% from flowering to harvest.

The dryland crop received only 15 mm of rain and although the soil moisture was not measured, the Lyndhurst soil is a shallower soil than the Lowcliffe soil at the irrigated site. Therefore, the soil water holding capacity at the dryland site should be lower compared with the irrigated site.

Water deficit can reduce seed yields and the stress response can depend on the crop developmental stage. Negative effects on seed yield have been observed with water stress during flowering and seed fill (Stoker and Carter, 1984; Nielsen, 1997). Johnston *et al*. (2002) also showed that, in canola, once minimum water use was achieved (approximately 130 mm) seed yield increased from 1,550 kg ha^{-1} by 7 kg ha^{-1} for every 1 mm of water. Minimum water use for Greenland forage rape, grown under New Zealand conditions, is unknown. However, the total amount of seed (recovered plus unrecovered) at the dryland site was 1,450 kg ha^{-1}, which is similar to the calculated seed yield using 130 mm water (1,550 kg ha^{-1}). Using the dryland site as the base measurement for water use, seed yield increased 3.7 kg ha^{-1} for every mm of water above 15 mm. However, seed shedding and seed abortion due to adverse growing conditions, such as low water availability and extreme weather, can severely reduce potential seed yields. In New Zealand, especially on dryland sites, early flowering cultivars of forage rape may be better suited for seed to take advantage of lower temperatures and increased water availability early in the season, although the risk of late spring frosts at flowering is also increased.

The irrigated crop produced larger plants, with more secondary racemes, during the yield establishment period (stem elongation through to and including flowering). Faraji *et al.* (2009) emphasized the contribution of photoassimilates to seed yield in canola showing that increased accumulated above ground DM resulted in increased seed yield. At the irrigated site the majority of the seed was from middle and lower secondary racemes. Pod density and seed density maybe fully determined at the end of flowering and Habekotté (1993) showed that actual pod density in canola was linearly related to cumulative DM production until the end of flowering. This is consistent with the strong linear relationship between pod density and DM observed in this study (Figure 5). During flowering, the irrigated plants intercepted more PAR and continued to produce more DM than plants at the dryland site.

Conclusion

An irrigation effect on seed yield in forage rape was clearly observed. Reduced irrigation affected crop architecture, light interception, biomass and seed yield components. Early flowering cultivars which take advantage of lower temperatures and increased water availability during flowering and seed fill may improve forage rape seed production on dryland sites in New Zealand.

Acknowledgements

This research was funded by the Foundation for Research, Science and Technology (FRST) “Advanced seed production” contract number LINX0803. Thanks also to Aaron Lill (Long Beach) and Rodney Hyde (Methven) for provision of the trial sites.

References

Anderson, M.N., Heidman, T. and Plauborg, F. 1996. The effects of drought and nitrogen on light interception, growth and yield of winter oilseed rape. *Acta Agriculturae Scandinavica* 46: 55-67.

Bayer CropScience. 2008. Bayer Crop Science UK, Crop Centre, OSR Growth Stages. http://www.bayercropscience.co.uk

Evans, E.J. 1984. Pre-anthesis growth and its influence on seed yield in winter oilseed rape. pp. 81-90. *In*: Aspects of applied biology 6, 1984. Agronomy, physiology, plant breeding and crop protection of oilseed rape. Association of Applied Biologists, Wellesbourne.

Faraji, A., Latifi, N., Soltani, A. and Rad, A.H.S. 2009. Seed yield and water use efficiency of canola (*Brassica napus* L.) as affected by high temperature stress and supplemental irrigation. *Agricultural Water Management* 96: 132-140.

Fray, M.J., Evans, E.J., Lydiate, D.J. and Arthur, A.E. 1996. Physiological assessment of apetalous flowers and erectophile pods in oilseed rape (*Brassica napus*). *Journal of Agricultural Science* 127: 193-200.

Habekotté, Â.B. 1993. Quantitative analysis of pod formation, seed set and seed filling in winter oilseed rape (*Brassica napus* L.) under field conditions. *Field Crops Research* 35: 21-33.

Johnston, A.M., Tanaka, D.L., Miller, P.R., Brandt, S.A., Nielson, D.C., Laford, G.P. and Riveland, N.R. 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. *Agronomy Journal* 94: 231-240.

Korte, L., Specht, J.E., Williams, J.H., and Sorenson, R.C. 1983. Irrigation of soybean genotypes during reproductive ontogeny II. Yield component responses. *Crop Science* 23: 528-533.

Lawlor, D.W. and Tezara, W. 2009. Causes of decreased photosynthetic rate and metabolic capacity in water-deficient leaf cells: a critical evaluation of mechanisms and integration of processes. *Annals of Botany* 103: 561-579.

Nielsen, D.C. 1997. Water use and yield of canola under dryland conditions in the Central Great plains. *Journal of Production Agriculture* 10: 307-313.

Nuttal, W.F., Moulin, A.P. and Townley-Smith, L.J. 1992. Yield response of canola to nitrogen, phosphorus, precipitation and temperature. *Agronomy Journal* 84: 765-768.

Rose, T.J., Rengel, Z., Bowden, J. and Ma, Q. 2007. Differential accumulation of phosphorus and potassium by canola cultivars compared to wheat. *Journal of Soil Science and Plant Nutrition* 170: 404-411.

Sinclair, T.R. and Muchow, R.C. 1999. Radiation use efficiency. *Advances in Agronomy* 65: 215-265.

Stoker, R. and Carter, K.E. 1984. Effect of irrigation and nitrogen on yield and quality of oilseed rape. *New Zealand Journal of Experimental Agriculture* 12: 219-224.

Taylor, A.J., Smith, C.J. and Wilson, I.B. 1991. Effect of irrigation and nitrogen fertiliser on yield, oil content, nitrogen accumulation and water use of canola (*Brassica napus* L.). *Fertilizer Research* 29: 249-260.