# Mechanisms of drought response in summer forage brassicas

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**Abstract**
Soil moisture deficit is a common yield constraint for many forage brassica crops in New Zealand. However, there is little information on the physiological mechanisms underlying the response to water stress. Rape *(Brassica napus* spp. *Biennis*) and bulb turnip *(Brassica rapa* spp. *rapifera; syn. B. campestris*) crops were field grown and excluded from rainfall by a mobile rain-out shelter at Lincoln, Canterbury, New Zealand. Four irrigation treatments were applied to fully replace evapotranspiration. These ranged from irrigation each week to a single application at the mid-point of the growth cycle. Final yield decreased with increased water deficit, from about 12 t/ha for the fully irrigated crops to about 5 t/ha for the most severe drought treatments for both species. Leaf expansion was limited by increased water deficit for both species causing a maximum reduction in total accumulated radiation intercepted ($R_{acc}$) of 13% for rape and 16% for turnip crops. Water deficit also decreased radiation use efficiency (RUE) from 1.76 g DM/ MJ PAR for the fully irrigated rape crops to 0.99 for the treatments with the highest water deficits. RUEs for the turnip crops were 2.20 g DM/ MJ PAR and 1.21 for the same treatments, respectively. The relative decline of about 44% in RUE for both crops was greater than for radiation interception and the subsequent $R_{acc}$ across the treatments. These results highlight the importance of timing of water stress in relation to canopy development for brassica crops.

**Key words:** *Brassica napus* spp. *Biennis*, *Brassica rapa* spp. *rapifera; syn. B. campestris*, accumulated radiation, extinction coefficient, phyllochron, feed quality.

**Introduction**
Summer forage brassica crops form an integral component of cattle and sheep feed rations in the drier east coast of New Zealand (Chakwizira et al. 2010) and in Tasmania and southern Victoria (Rowe & Neilsen 2010), Australia. These regions are characterised by dry summers, which lead to low pasture growth rates and a decline in feed quality. Summer forage brassica crops such as rape *(Brassica napus spp. Biennis*), bulb turnips (*Brassica rapa spp. rapifera; syn. B. campestris*) and leaf turnips (e.g. Pasja; *Brassica rapa; syn. B. campestris*) are frequently used to fill this feed gap.

Irrigation of these crops has the potential to increase dry matter (DM) yields (Jacobs et al. 2004; Fletcher et al. 2010) and maintain nutritive value (Rowe & Neilsen 2011). However, our understanding of the crop level mechanisms underlying the brassica crop response to water availability is limited. This study determines the effects of water supply on accumulated radiation intercepted ($R_{acc}$) and radiation use efficiency (RUE) for forage rape and bulb turnip crops.

**Materials and Methods**
Two adjacent experiments were conducted in a mobile rain-out shelter (Martin et al. 1990) at The New Zealand Institute for Plant & Food Research Limited, Lincoln (43.83°S, 171.72°E), New Zealand.

A detailed description of the experiments has been published previously (Fletcher et al. 2010). Briefly, each experiment consisted of one of two crops (either 'Titan' rape or 'Barkant' turnips), each subjected to four irrigation-frequency treatments. The crops received irrigation to fully replenish cumulative evapotranspiration (ET) since the last irrigation event. Irrigation frequency treatments were: replenish ET through irrigation (i) each week, (ii) every 2 out of 3 weeks, (iii) every 2 weeks and (iv) a single irrigation event at the mid-point of the growth cycle. Both crops were sown on 19 November 2008 and the final harvest was on 10 February 2009. Irrigation treatments were introduced 4 weeks after sowing. From this point onwards the rain-out shelter excluded all rain from the plots. DM yield and leaf area were determined from destructive sampling five times throughout crop growth. In order to calculate cumulative light interception, equation 1 (Monsi & Saeki 2005) was used along with measured leaf area index (LAI) and an assumed extinction coefficient (k) of 0.90 (Chakwizira et al. 2011).

$R/R_o = 1\text{-}\exp^{(-k*LAI)}$ ------------ Equation 1.

where the fraction of radiation intercepted ($R/R_o$) was derived from k and LAI. Attainment of full canopy cover was based on crops reaching the critical LAI ($LAI_{crit}$: the LAI at which the crop will be intercepting 95% of the incoming PAR) of 3.6 (Chakwizira et al. 2009; Chakwizira et al. 2011).

All statistical analyses were performed using Genstat version 12.2 (VSN International Ltd) and SigmaPlot 10.0. The RUE was taken as the ratio between crops DM ($g/m^2$) against accumulated intercepted radiation ($R_{acc}$; $MJ/m^2$) for each treatment.

**Results**

Yield decreased ($P \leq 0.02$) with increasing water deficit, from about 11–12 t/ha for the fully irrigated crops to about 5 t/ha for the treatments with the highest water deficits for both species (Table 1). The partially irrigated treatments produced an intermediate yield of between 6 and 9 t/ha.

Table 1: Total dry matter yield (TDM), total accumulated radiation ($R_{acc}$) and the radiation use efficiency (RUE) for forage rape and turnip crops grown under different irrigation treatments, at Lincoln in the 2008–09 season.

| Crop | Irrigation treatment | TDM ($g/m^2$) | $R_{acc}$ ($MJ/m^2$) | RUE (g/ MJ PAR) |
|---|---|---|---|---|
| Rape | Full | 1070.00 | 609.40 | 1.76 |
| | Every 2 out of 3 weeks | 686.00 | 574.30 | 1.20 |
| | Every second week | 815.00 | 572.30 | 1.42 |
| | Once at mid-point of growth cycle | 524.00 | 529.10 | 0.99 |
| | $LSD_{0.05}$ (6 df) | 288.10 | 29.40 | 0.53 |
| | Significance level ($P \leq$) | 0.018 | 0.003 | 0.037 |
| Turnips | Full | 1188.90 | 540.70 | 2.20 |
| | Every 2 out of 3 weeks | 677.30 | 529.20 | 1.28 |
| | Every second week | 793.40 | 466.40 | 1.70 |
| | Once at mid-point of growth cycle | 550.60 | 456.60 | 1.21 |
| | $LSD_{0.05}$ (6 df) | 135.20 | 68.30 | 0.26 |
| | Significance level ($P \leq$) | 0.001 | 0.05 | 0.001 |

Total $R_{acc}$ also decreased ($P \leq 0.05$) with increased water deficit (Table 1) from 609.4 $MJ/m^2$ for the fully irrigated rape crops and 540.7 for turnip crops, to 529.1 and 456.6 $MJ/m^2$ for the rape and turnip crops irrigated once at the mid-point of the growth cycle, respectively. RUE was lowest ($P \leq 0.05$) for the most severe water deficit treatments, at 0.99 g DM/ MJ PAR for rape and 1.21 for turnip crops, compared with 1.76 g DM/ MJ PAR and 2.20 for the fully irrigated crops, respectively.

*Canopy development*

Both LAI (Figure 1) and the subsequent radiation intercepted (RI) increased with time after sowing but differed with irrigation intensity. At 20 days after introduction of treatments, the crops under the most severe water deficit and those irrigated once every second week had the lowest LAI, hence least RI.

The attainment of the $LAI_{crit}$ was determined by the level of moisture stress experienced by the crops (Figure 1). Crops under the most severe moisture deficit failed to attain full canopy cover. However, rape crops under full irrigation and those irrigated every 2 out of 3 weeks reached full canopy cover at about 48 days after sowing (DAS), 10 days earlier than those irrigated once every second week. For turnips, only the crops receiving full irrigation and those irrigated once every second week attained full cover. Turnip crops irrigated every 2 out of 3 weeks failed to close their canopies. For both crops the canopies for the most severe water deficit and those partially irrigated started opening up about 58 DAS.

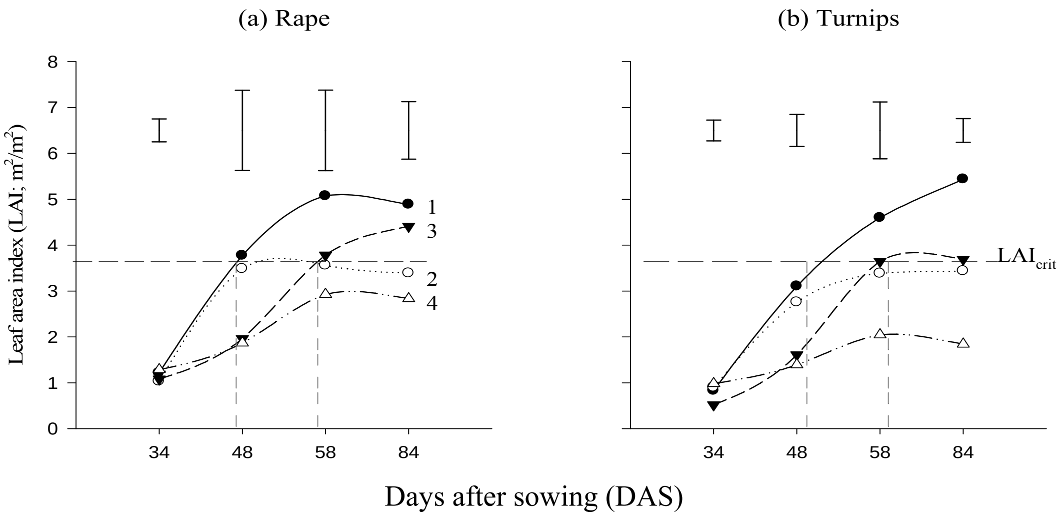


Figure 1: Leaf area index over the growing period for: (a) forage rape and (b) bulb turnip crops grown under four irrigation treatments (1–4) at Lincoln, New Zealand in 2008–09 season (See Table 1 for treatment details). The horizontal dashed lines indicate the critical LAI ($LAI_{crit}$), of 3.6. Bars represent the least significant differences ($LSD_{0.05}$; 6 df)

**Discussion and conclusions**

Total DM yields of 5–12 t/ha reported here are consistent with reports in the literature (Neilsen et al. 2000; Rowe & Neilsen 2010) for summer brassica crops grown under different moisture deficits. The DM yield differences between the fully irrigated crops and those receiving the least water (Table 1) were 51 and 54% for forage rape and turnips, respectively. These differences can be explained by effects on $R_{acc}$ and RUE. The $R_{acc}$ by the crops under the most severe moisture deficit was about 85% of the fully irrigated crops for both species, while RUE was about 44%. It is therefore concluded that most of the differences in DM yield were due to a reduction in RUE with the increased level of drought intensity. This could be interpreted as a reduced level of productivity in response to the timing of moisture stress causing a delay in canopy development. Since the treatments were introduced 4 weeks after sowing, leaves had already appeared and mostly expanded. The effect on leaf senescence happened at the end of the growing period, and therefore was not the main driver of DM yield production. Our results are similar to those in the literature for sweet corn (Stone et al. 2001) which showed that DM accumulation was reduced by water deficit, through reduction in RUE, more than $R_{acc}$. This was attributed to the fact that leaf area of sweet corn approaches a maximum when both irradiance and photoperiod are near maximum, which means that LAI declines when incident radiation is also declining (similar to forage brassica; Figure 1). As a consequence, leaf senescence had a diminishing impact on RI, and the effects of drought on RUE became more important than the effects on RI, for most treatments.

The treatment differences in the canopy closure response (Figure 1) may be due to differences in phyllochron or leaf size per unit leaf (Fletcher et al. 2012) under the different moisture stress situations. These authors have reported that the key difference among forage brassicas was their rate of canopy development, principally due to differences in leaf appearance. This is supported by differences in maximum LAI in the current experiments. The consistently lower LAI and opening up of the canopy for turnip crops under severe moisture deficit (Figure 1) may be an indication of the differences in water extraction depth of the two crops as reported by Fletcher et al. (2010) and hence severity of stress. These differences in canopy development resulted in variable RI and hence $R_{acc}$ (Table 1).

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