Wheat and canola water requirements and the effect of spring irrigation on crop yields in the Central Murray Valley

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Abstract

Grain yield and water use data were obtained from field irrigation experiments in the Central Murray Valley. Mid-season crop factors ($K_{c\ mid}$) were found from this data to be 1.2 and 1.15 for the wheat and canola respectively. Yield (Y) and applied water (W_A) production functions were derived for flood irrigated wheat and canola crops growing on red-brown earth soils in the southern Murray-Darling Basin:

Y_{canola} = -3.40 + 2.59?10^{-2}.W_A – 2.44?10^{-5}.$W_A{}^2$ (R^2 = 0.92)
Y_{wheat} = -2.25 + 2.30?10^{-2}.W_A – 1.25?10^{-5}.$W_A{}^2$ (R^2 = 0.94).

This data was used to determine profit maximising irrigation strategies for these crops.

Key Words

canola, wheat, production function, deficit irrigation, crop factor

Introduction

The current focus to improve water use efficiency in Australia's irrigation industries is generally interpreted as encouragement for a shift to higher value commodities or to more capital intensive irrigation systems. Such a shift would require irrigation farmers in the NSW Central Murray Valley (CMV) to increase the level of capital invested in their farms without any guarantee of improved reliability in their water supply, and they would have to raise this capital using their current (relatively) low value enterprise mix. Few farmers are willing to accept this risk, particularly as their soils are generally unsuited to higher value horticultural crops and/or pressure application systems. The dilemma they face is how to remain profitable as water becomes increasingly scarce and costly, without needing to raise large amounts of capital and exposing themselves to greater economic risk for an uncertain outcome.

This study examined the potential of deficit irrigation strategies for improving farm profitability for the dominant water user group (i.e. rice growers) in the NSW CMV. The study aimed to determine:

- the relative responses of wheat and canola to a range of spring irrigation frequencies
- local crop factors (K_c) and the shape of a generalised K_c curve for wheat and canola
- crop production functions for flood irrigated canola and wheat in the CMV to indicate the profit maximising irrigation strategy when water is limited

Methods

Field experiments were conducted in 1998 and 1999 at Deniliquin, NSW to compare the effects of 4 spring irrigation treatments on wheat var. Janz and canola var. Oscar. All plots were irrigated prior to sowing and the 4 spring irrigation strategies were: no spring irrigation (I_0); one spring irrigation (I_1); irrigation at an evaporation minus rainfall (*E-R*) deficit of 90 mm (I_{Def}); and full irrigation at an *E-R* deficit of 60 mm (I_{Full}).

One site was used in 1998 and 2 sites in 1999. Both sites were in border check, flood irrigation bays on red-brown earth soils (Stace, *et al.* 1968). Site 1 was a *Subnatric Calcic Red Sodosol* (Isbell 1996), known locally as a Birganbigil Loam (Smith 1945). It had only fair internal drainage and was classified suitable for growing rice. Site 2 was a *Brown Chromosol* (Isbell 1996), known locally as a Cobram Loam (Smith 1945). It was lighter textured, with a slightly deeper A horizon, a fine sandy clay B2 horizon and a higher proportion of coarse sand at all depths. It had good internal drainage and was classified unsuitable for growing rice because of excessive deep percolation.

Agronomic measurements were made to assess treatment effects on crop growth and yield. Hydrological data was collected in 1998 and used to calculate crop water use (0-1 m) according to the water balance equation:

$$ET_c = (P + I_a + CR) - (\Delta S + RO + DP)$$

ET_c = crop evapotranspiration; P = rainfall; I_a = depth of irrigation water; CR = capillary rise; ΔS = change in profile soil water content; RO = runoff; and DP = deep percolation. Potential crop evapotranspiration (ET_o) was determined from Deniliquin class A pan data (E_{pan}) according to

$ET_o = 0.88$? $(E_{pan})^{0.91}$ ($R^2 = 0.98$, $P < 0.001$, $n = 1721$).

Results

Relative responses to spring irrigation

The total depth of water applied to each plot was calculated ($W_A = I_a + R - \Delta S - RO$). W_A varied from 300 to 600 mm and, in response, Y varied from 4.8 to 7.3 t/ha in the wheat and from 2.9 to 3.6 t/ha in the canola. Regression analysis showed there was a strong linear relationship between grain yield (Y) and W_A within each crop type ($R^2 = 0.97$; se obs. = 0.3; $P < 0.001$). Y increased by 9 and 3 kg/ha/mm of W_A in the wheat and canola respectively. *Septoria* reduced wheat yields by an estimated 0.75-1 t/ha in the I_{Full} treatment in 1998.

Farmers are interested in the yield response per megalitre (ML) of irrigation water. To assess this, the yield response to water applied in spring (i.e. $W_S = I + R - RO$) was determined for each crop. Step-wise multiple linear regression showed there was a strong correlation between Y and W_S within each crop type ($R^2 = 0.97$; se obs. = 0.25; $P < 0.001$), with yields increasing by 4.6 and 1.9 kg/ha/mm of W_S for the wheat and canola respectively. The response of canola yield to W_S was not significantly different from zero (t = 0.73).

Local crop factors and K_c curves

Crop factors (K_c) were determined for consecutive 7 to 10 day periods for the crops grown in 1998:

$$K_c = \frac{ET_c}{ET_o}$$

This data was used to derive K_c curves for each crop (Figure 1), with growth stage lengths defined by Allen, *et al.* (1998). Neither the wheat nor the canola were water stressed between 20th Aug and 8th Sept and a zero flux plane existed at 100 cm. Therefore, ΔS (0–1.0 m) during this period reflected maximum crop water use in the mid-season stage and $K_{c\ mid}$ was estimated to be 1.2 and 1.15 for the wheat and canola respectively.

Production functions for flood irrigated wheat and canola

Quadratic yield (Y) and applied water (W_A) production functions were obtained for flood irrigated wheat and canola crops growing on red-brown earth soils in the southern Murray-Darling Basin (MDB) using data from this and other experiments (Figure 2). The production functions were determined to have the form:

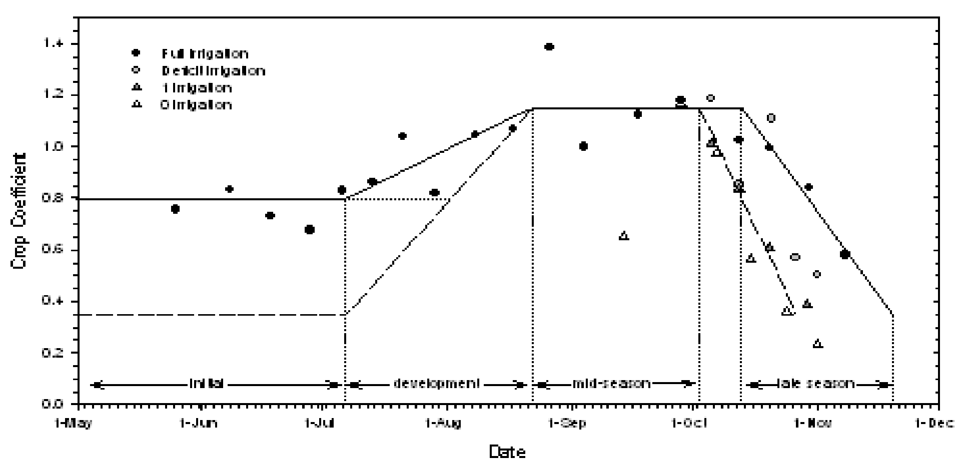
$Y_{canola} = -3.40 + 2.59?10^{-2}.W_A - 2.44?10^{-5}.W_A^2$ ($R^2 = 0.92$)
$Y_{wheat} = -2.25 + 2.30?10^{-2}.W_A - 1.25?10^{-5}.W_A^2$ ($R^2 = 0.94$).

The potential transpiration efficiency for grain (T_e) of canola and wheat crops in the southern MDB was estimated from this data to be 15 and 20 kg/ha/mm respectively. Direct soil evaporation (i.e. x-axis intercept) was estimated to be 130 and 110 mm for canola and wheat respectively (Figure 2).

Discussion

Following English & Raja's (1996) method, revenue and cost functions were used to determine W_A when (1) yields are maximised (W_m), (2) when profits are maximised if land is limiting (W_l) and (3) when profits are maximised if water is limiting (W_w). It was assumed that: crop price equals the long term average ($180/t for wheat and $350/t for canola); crops receive median growing season rainfall (250 mm); crops are pre-irrigated in autumn (100-150 mm); and spring irrigations apply 60 to 75 mm. The results showed that:

- irrigating to maximise yield is not a profit maximising strategy. The fact that yields at W_l are not much lower than at W_m indicates that water is cheap ($41.90/ML; NSW DPI 2008) compared to crop price.
- the profit maximising strategy when land is limiting is to irrigate wheat with 4.9 ML/ha to achieve 8 t/ha (i.e. max net return/ha; Yaron & Bresler 1983). However, if water is plentiful, CMV farmers will irrigate rice rather than wheat as rice has a net return of $1,500 to $2,000/ha (NSW DPI 2008) compared to optimal net returns of $700/ha and $620/ha for wheat and canola respectively estimated using he production function analysis.
- the profit maximising strategy when water is limiting is to maximise average net returns per ML (Yaron & Bresler 1983) and this is achieved by spreading available supplies over the largest feasible area by pre-irrigating canola in autumn and, if necessary, irrigating once in spring.



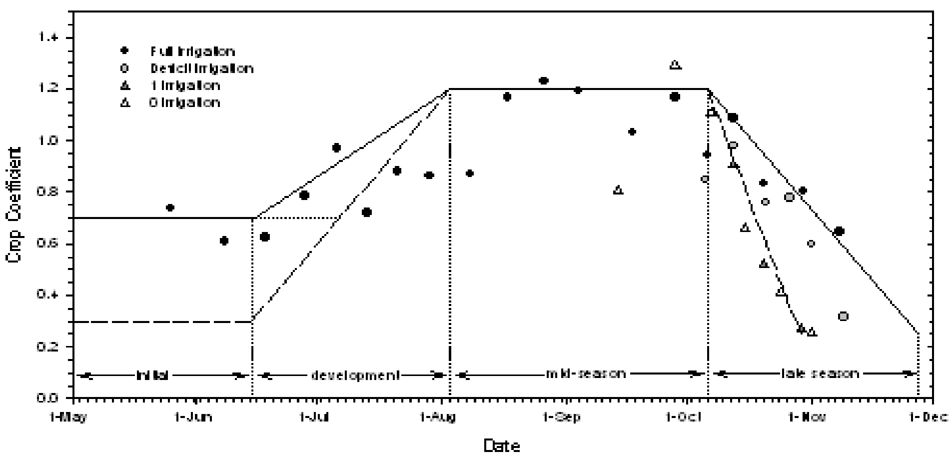


Figure 1. Average K_c of consecutive 7-10 day periods (●) for the canola (top) and wheat (bottom) at Site1 in 1998. The solid line (—) shows the K_c curve for the I_{Full} treatment, with growth stages lengths determined according to Allen *et al's* (1998) criteria and crop observations. The dashed line (– –) shows $K_{c\ ini}$ from Allen *et al.* (1989) which is unadjusted for wetting frequency and ET_o and then $K_{c\ end}$ showing the effect of deficit irrigation.

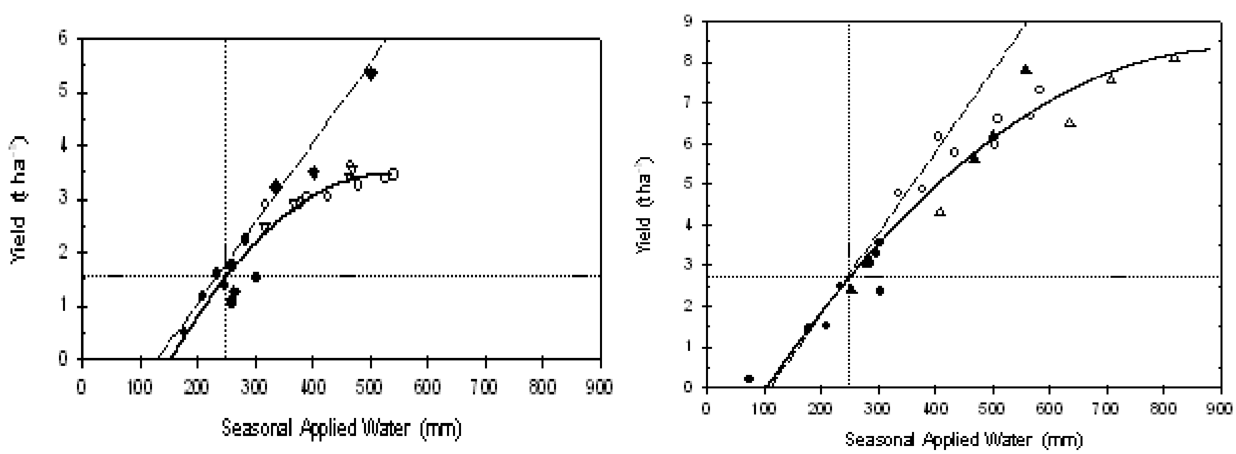


Figure 2. Grain yield (*Y*) as a function of seasonal applied water (W_A) for canola (left) and wheat (right) in the southern MDB. A regression line was fitted to the data from this experiment (○) as well as data from dryland crops at Deniliquin (●, Ian Lea, pers. comm.) and from canola experiments at Tatura (∇, Taylor *et al.* 1991) and from wheat experiments at Yanco (Δ, Cooper 1980) and Griffith (▲, Steiner *et al.* 1985). Vertical lines show median April-Oct rainfall at Deniliquin; horizontal lines show average district yields; dashed lines show transpiration efficiency (T_e) for grain. Tasmanian data (♦, Mendham *et al.* 1984) helped define canola T_e.

Phenological development in the wheat and canola was well predicted by the models of Stapper & Fischer (1990) and Robertson *et al.* (2002). This allowed crop stage lengths and thence K_c curves to be predicted for wheat and canola in the CMV for a range of sowing dates. Together with Deniliquin weather data (1960 to 2005), these were used in the single K_c model (Allen, *et al.* 1998) to estimate wheat and canola irrigation requirements. The model was run using two irrigation intervals based on: (1) a readily available water capacity (RAWC) of 55 mm; and (2) a RAWC of 75 mm. The model output showed that, in the CMV:

- canola requires one less irrigation on average than wheat if fully irrigated.
- wheat will nearly always experience at least one period of water stress in spring if not irrigated.
- spring irrigation of canola was not needed in 6% and 11% of years when RAWC was 55 and 75 mm respectively. This is attributed to a shorter mid-season stage and lower $K_{c\ mid}$.
- increasing RAWC from 55 to 75 mm reduced the median number of irrigations required in spring from 3 to 2 and reduced deep percolation, and hence W_A, by approximately 10 mm on average over all years.
- early sown crops require fewer spring irrigations than later sown crops.

The lack of response to spring irrigation by the canola is, in part, attributed to its indeterminate nature. This permitted leaf area and flowering to recover in I_0 and I_{Def} when rain fell during the vegetative and flowering stages. Such a recovery was not possible in the (determinate) wheat. It is postulated that the inability of the canola to achieve yields as high as Mendham *et al.* (1984) and Taylor *et al.* (1991) (i.e. 4-5 t/ha) is due to:

- high temperatures during pod/seed development. It is estimated that yields are reduced by 0.7 t/ha for every 1^{o}C that average daily mean temperature during pod/seed development exceeds 13^{o}C
- a root system which is less able to penetrate dense/massive clay sub-soils. This, combined with very low soil hydraulic conductivities and high evaporative demand in spring, leads to greater levels of crop water stress in canola compared to wheat when grown on soils similar to the Birganbigil loam.

Conclusion

With limited irrigation supplies in the cMV, the recommended profit maximising irrigation strategy for wheat is to pre-irrigate in autumn and apply 3-4 spring irrigations to attain a target yield of 6-7 t ha^{-1}. Applying more water to attain a higher yield is not recommended because of diminishing marginal returns. A single irrigation timed for flowering is not recommended as it does not ensure the greatest average return per ML and because there is a high risk of crop failure if spring rainfall is insufficient to support a large biomass. The profit maximising irrigation strategy for canola is to pre-irrigate and aim for a target yield of 3 t/ha by irrigating once in spring to ensure 1) good moisture until 3 weeks past full flower and 2) that biomass at flowering is maximised. Canola’s relative insensitivity to water stress during pod fill and grain ripening means that deficit irrigation can be practiced after flowering. When water is limiting, profits will be maximised if available supplies are allocated to canola. Its lower water requirement allows water to be spread over a larger area, maximising average net returns per ML. Its poor response to irrigation, however, makes this a risky strategy. To mitigate this risk, it is recommended to:

- sow early - to avoid high temperatures later in spring and to reduce the number of irrigations required.
- only irrigate canola on better soil types – hard soils restrict root growth and water supply to the crop and this combines with high evaporative demand and high temperatures in spring to limit yield potential.

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