Water use efficiency of dryland canola

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ABSTRACT

The French and Shultz approach which relates seasonal rainfall to potential yield in wheat has yet to be applied to dryland canola. Using experimental plot yields and simulation we have devised an improved method for estimating water-limited potential yield for canola that retains the ease of use of the French and Shultz approach, and can be used by farmers and advisors to diagnose yield constraints in dryland environments. The approach appears to be robust across a range of rainfall locations for southern NSW and awaits further extrapolation to Mediterranean and summer-dominant rainfall environments in the Australian wheat belt. In the equi-seasonal rainfall environment of southern NSW we found it is important to account for stored soil water at sowing when computing seasonal water supply, and to a lesser extent soil water remaining at harvest. The new approach has been used to benchmark commercial canola paddocks in NSW in the 2003 and 2004 seasons and has shown promise as a rapid tool for estimating yield potential.

Additional keywords: Rainfall, evapotranspiration, APSIM, available soil water, sowing date

INTRODUCTION

The French and Schultz (1984) approach of relating seasonal rainfall to yield potential has been applied extensively to wheat in temperate areas of the Australian wheat belt. Apart from the limited studies of Cocks et al. (2001) and Hocking et al. (1997), there has been no comprehensive assessment of the relationship between water supply and grain yield of canola in Australia, with an attempt to derive a potential yield-water use relationship similar to that derived for wheat by French and Schultz (1984). A number of authors have pointed out the limitations of the French and Schultz (F&S) approach (eg Connor and Loomis 1991): that it takes no account of the timing of rainfall in relation to crop development, it assumes that runoff and deep drainage losses are negligible, it ignores the contribution that stored soil water may make to crop water use, and assumes that all rainfall received during the season contributes to yield. Despite these limitations, the F&S approach remains popular because farmers can readily calculate it without relying on more complex methods such as the use of simulation models.

The main aim of this paper was to derive relationships between potential yield and water supply for canola using a large dataset of well-managed dryland canola crops from southern NSW that were kept free of weeds, pests and diseases. Long-term simulations with historical climate data were then used to test the generality of the relationships derived from the experimental sites for a wider range of seasons and locations. We sought to derive a refinement to the F&S approach by considering the contribution of stored water at sowing towards crop water supply, and by discounting soil water remaining at harvest – both of which likely in the equi-seasonal environments of southern NSW. To retain the utility of the F&S approach while improving estimates of seasonal water supply for farmers and advisors, simple rules-of-thumb were developed from rainfall data to account for stored water at sowing and water remaining at harvest.

METHODS

Relationships were derived between grain yield of 42 crops (Robertson and Kirkegaard 2005) and various measures of seasonal water supply: April to October rainfall (French and Schultz 1984), rainfall between sowing and crop harvest (hereafter termed in-crop rainfall), in-crop rainfall plus available stored soil water at sowing, in-crop rainfall plus available stored soil water at sowing minus simulated available soil water remaining at harvest (termed here “seasonal
water supply”). While measured data for rainfall and available stored soil water at sowing were available for each of the crops, other data (available soil water remaining at harvest, in-crop evapotranspiration, and transpiration) were not and these were estimated using the Agricultural Production Systems Simulator (APSIM). Confidence in using simulation to estimate water balance components was predicated on an ability to simulate a wide range of crop yields in the dataset, as well as soil water accumulation over the summer fallow (i.e. from the harvest of the previous crop), and in a few cases, available soil water remaining at harvest.

Crops were all grown in southern NSW between 1991 and 2003, under a diverse range of growing conditions and ranged in yield from 499 to 5440 kg/ha (mean = 2572 kg/ha). Sowing dates ranged from mid April to mid June. Cultivars were a mix of conventional and triazine-tolerant (TT) types. The crops were managed to minimise the incidence of weeds, pests, diseases, lodging and nutrient limitations. Crop and soil measurements at all sites included soil water at sowing, established plant density, dates of flowering and physiological maturity, and bordered quadrat cuts at maturity for biomass and grain yield. APSIM-Canola was able to simulate the 42 datasets with a RMSD of 483 kg/ha. There was no apparent bias and low yields (<1000 kg/ha) were simulated as accurately as high (>5000 kg/ha) yields. The $R^2$ value for the linear regression between observed and simulated was 86%. Model performance on this dataset is comparable with previous tests for APSIM-Canola (eg. Robertson and Holland 2004).

In addition to testing APSIM-Canola for grain yield, we also tested its ability to simulate available soil water at the start of the season from summer fallow rainfall. A total of 20 observations, ranging from 0 to 205 mm (pre-season rainfall ranged from 0 to 461 mm) taken within 2 weeks of sowing, were available for testing. Despite a number of assumptions being made about the summer fallow (initial soil water, weed-free, stubble cover) simulated starting soil water agreed well with observed and 89% of the variation was explained by the simulation.

In 10 crops, available soil water remaining at the end of the season, ranging from 4 to 150 mm, was measured and used to test simulations for late-season water use. Simulation explained 83% of variation.

Long-term simulations with historical climate data were then used to test the generality of the relationships derived from the experimental sites for a wider range of seasons and locations. Outputs from the runs were used to examine the effects of seasonal variability and location on the relationship between (1) potential yield and seasonal water supply, (2) summer fallow rainfall and stored soil water at sowing, (3) rainfall between anthesis and crop maturity (hereafter termed post-anthesis rainfall) and available soil water at harvest, (4) between WUE (grain yield divided by seasonal water supply minus 120 mm) and sowing date. Simulations were run using daily climate data from 1904 and 2003 from locations lying on a similar latitude in southern NSW (and hence similar distribution of winter vs. summer rainfall) from Narrandera (430 mm annual rainfall) to Yass (660 mm).

**RESULTS AND DISCUSSION**

An increasing proportion of the variance in the grain yield of the 42 canola crops could be explained as the water supply predictor became more accurately defined: from April to October rainfall (48%), to in-crop rainfall (30%), in-crop rainfall plus available soil water at sowing (56%), and in-crop rainfall plus available soil water at sowing minus available soil water at harvest (which we have called “seasonal water supply”) (68%). The largest incremental improvement in predictive power was achieved by accounting for available soil water at sowing ($R^2$ increasing from 0.30 to 0.56), with a further but smaller improvement by accounting for available soil water remaining at harvest (0.56 to 0.68). This indicated that a F&S approach could be improved upon by accounting for stored soil water at sowing and discounting for soil water remaining at harvest.

The linear regression between grain yield and seasonal water supply gave a slope (WUE) of 11 kg/ha.mm and intercept of 117 mm (Fig. 1a). Long-term simulations implied a median line of 12 kg/ha.mm for conventional and 11 kg/ha.mm for TT cultivars (Fig 1b). The difference between the cultivar types is consistent with their known differences in radiation use efficiency and transpiration efficiency of biomass production (Robertson et al. 2003).
In both the 42 experimental crops (Fig 1a) and the long-term simulations (Fig 1b), nearly all of the crops could be encompassed by boundary lines that had slopes of 15 and 8 kg/ha.mm above an intercept of 120 mm. The upper envelope of 15 kg/ha.mm represents crop response to those seasonal conditions where water is used the most efficiently due to its timing in relation to crop demand and minimal unproductive losses of water (deep drainage, runoff and soil evaporation). Importantly, crops which fall below this line were not limited by poor management or biotic constraints but rather could not make the most efficient use of the water available due to less favourable timing of rainfall and an increase in the unproductive loss of water. It is erroneous to assume that crops falling below the upper WUE frontier are poorly managed because all of the crops in this study were managed to water-limited potential, and there was good correspondence between observed and simulated yield.

We also found a trend with lower WUE in late sown crops, in both the experimental data and simulations. Of the 42 experimental crops, the middle 60% had a WUE between 8.5 and 14.5 kg/ha.mm, while the bottom 20% varied down to 3.8 kg/ha.mm and the top 20% varied up to 18.3 kg/ha.mm. There was a trend for the bottom 20% of crops to be sown later, have lower soil water at sowing, lower grain yield, and harvest index, and use less ET as transpiration compared to the middle 60% of crops, which in turn were lower than the top 20%. Long-term simulation for Narrandera, the most water-limited location, indicated that there was a trend for later sown crops to have lower water use efficiency than earlier sown crops, confirming the trend found in the experimental data. WUE declined by an average of one-third between sowings in early April to early July. A less efficient relationship between water supply and growth for later sowing is consistent with the concept that vapour pressure deficit rises with later sowing and hence more water is transpired for a given amount of biomass produced. Moreover, later sowings would be expected to have more occurrences of terminal water deficit and hence lower harvest index. This effect would add to that of vapour pressure deficit and result in a lower conversion of water supply to grain yield. We believe that accounting for sowing date effects on WUE would also improve F&S estimates of potential yield.

In the second part of this study, we sought rules to calculate the contribution of stored water at sowing towards crop water supply, and to discounting soil water remaining at harvest both of which likely in southern NSW where rainfall is equally distributed through the year. The measurements (Fig. 2a) and long-term simulations (Fig. 2b) highlighted that starting soil water in this environment can vary from an empty to a full profile, depending upon the timing and amount of summer rainfall. For a given total of fallow rainfall there was a wide range of storage.
efficiencies. Nonetheless trend lines fitted to the long-term simulated data indicate that a rule of thumb could be used to estimate stored soil water based on a total fallow rainfall. Above a threshold value of 80 mm between 40 and 60% of rainfall, depending upon location, was stored at sowing time. The measured data (Fig. 2a) did not indicate an intercept value, however as it was based on a limited number of seasons the long-term simulations are likely to give a more reliable estimate of an intercept value. It must also be emphasised that both the measured data and simulations concerned situations where summer water storage would be maximised due to stubble cover and the absence of weeds. When the management of the summer fallow does not meet these assumptions then storage of available soil water will be less than that reported here.

Figure 2: (a) Observed (■) and simulated (□) starting available soil water versus summer fallow rainfall; fitted line is $y = 0.47x + 3$, $R^2 = 0.71$, n=22. (b) Long-term (1904-2003) simulated relationship between available soil water at sowing and summer fallow rainfall for Narrandera. Each point is one of 100 simulated seasons. Trend line fitted to the data by eye has a slope of 0.4 mm/mm at Narrandera, between values of fallow rainfall of 80 and 400 mm.

Figure 3. (a) Observed (■) and simulated (□) finishing available soil water versus post-anthesis rainfall, fitted line is $y = 0.50x - 27$, $R^2 = 0.77$, n=42. (b) Long-term (1904-2003) simulated relationship between available soil water at harvest and post-anthesis rainfall for Narrandera. Each point is one of 100 simulated seasons. Envelope lines plotted have slopes of 0.2, 0.5 and 1 mm/mm above a value of 50 mm post-anthesis rainfall.

Rainfall near harvest may not be used by crops. Analysis of simulated soil water at harvest for the 42 datasets suggested that it could be predicted reasonably reliably from total post-anthesis rainfall (Fig 3). While long-term simulations (Fig 3b) and the measured datasets (Fig 3a)
confirmed that negligible water would be stored if post-anthesis rainfall was less than ca. 50 mm, considerable scatter existed in the relationship between soil water and rainfall for totals > 50 mm. There was a tendency for wetter sites (e.g., Yass) to store rainfall more efficiently than drier sites (e.g., Narranadera) in seasons with rainfall totals >50 mm.

Failing to account for both water stored at sowing and water remaining at harvest will result in a poorer ability to predict yield when using totals of seasonal rainfall, and as a result, yield limitations may be incorrectly ascribed to poor management when inefficient water use due to rainfall distribution was the primary cause.

Summarising these simplified rules-of-thumb, an improved prediction of grain yield of canola in relation to seasonal water supply is as follows:

\[
WUE = \frac{\text{Yield}}{\text{Seasonal Water Supply [SWS]}}
\]

(Equivalent median 11 kg/ha.mm for TT cultivars; range 8 – 14 depending on timing of rainfall and sowing date. WUE can be reduced by 10% for each month’s delay in sowing between early April and early July).

where,

\[
\text{SWS} = \text{[in-crop rain]} + \text{[soil water at sowing]} - \text{[soil water at harvest]} - [120]
\]

where

\(\text{in-crop rain} < 450 \text{ mm}\)

\(\text{soil water at sowing} = [\text{Fallow rainfall - 80}] \times 0.5^*\)

(*vary from 0.4 – 0.6 depending on timing and amount of rainfall). This assumes a weed-free fallow with stubble cover.

\(\text{and}\)

\(\text{soil water at harvest} = [\text{Post flowering rainfall - 50}] \times 0.5^*\)

(*vary from 0.5-1.0 at wetter locations and 0.2-0.5 at drier locations)

CONCLUSION

For the purposes of practical application by farmers and advisors, water-limited potential yield can be calculated as a function of seasonal water supply minus 120 mm up to a limit of 450 mm, beyond which potential yield is not limited by water. Seasonal water supply can be computed as in-crop rainfall plus available soil water at sowing minus soil water at harvest. Available soil water at sowing can be estimated from summer fallow rainfall above a threshold of 80 mm, while water remaining at harvest can be estimated from post-anthesis rainfall above a threshold of 50 mm.

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REFERENCES


