Subsoil constraints have little impact on crop growth in the Wimmera and Mallee during dry seasonal conditions.

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Abstract

Many alkaline soils used for dryland cropping in south-eastern Australia have high levels of salinity, sodicity, soluble boron and chloride in the subsoil. Previous studies conducted during the 1990's showed that these subsoil constraints significantly restricted root growth and water extraction at depths greater than 60 to 80 cm and therefore grain yields. A series of extremely dry seasons, however, reduced the accumulation of soil water within the potential rooting zone. A survey of crops within 15 growers paddocks over 4 consecutive years (2003-2006) in the Wimmera and Mallee (Vic.) and Eyre Peninsula (SA) regions found that plant available soil water at sowing in the 10-60 cm layer ($\theta_{avail10\text{-}60}$) was less than 10 mm for 44% (*n* = 440) of all the crops assessed and growing season rainfall generally failed to significantly increase this amount during the season. For three crop types, low available soil water ($\theta_{avail10\text{-}60}$ < 10 mm) existed for 68% of lentil crops grown and in contrast, 5% of canola crops and 43% of wheat crops. Limited available soil water at sowing caused crops to be increasingly reliant on growing season rainfall distribution and exposed them to greater risk of failure. We suggest that physicochemical constraints in the deep subsoil (> 60 cm) are less likely to affect crop growth when there is limited plant available water.

Key words

wheat, canola, lentil, water deficit

Introduction

For rain-fed crops grown on highly alkaline soils in south-eastern Australia, growth is potentially limited by factors such as water supply and nutrition (Incerti and O'Leary 1990). Low and unreliable rainfall makes stored soil moisture important in buffering dry periods, especially during grain fill. Both agronomic management (Ridge 1986; O'Leary 1994) and subsoil properties influence the amount and availability of stored soil water to a crop. Subsoil properties which can limit water extraction include salinity, sodicity, chloride and high levels of extractable boron, which tend to be co-correlated, spatially variable and at high levels in alkaline soils (Cartwright *et al.* 1986; Sadras *et al.* 2002; Nuttall *et al.* 2003). Over the last decade, however, extremely dry seasonal conditions have created substantial soil water deficits as continuous cropping and a trend not to fallow has progressively drawn down plant available water (PAW). Consequently the extent to which physicochemical properties in the subsoil impact on crop growth may be limited. Alternatively agronomic management such as rotation, trash management and weed control are likely to play an increasingly important role in budgeting soil water during dry seasonal conditions. This study examines the relationship between various abiotic variables and a range of rain-fed crops including canola, lentil and wheat and identifies important factors driving crop yield variation under low water conditions.

Materials and Methods

The study covered the neutral-alkaline soils of the dryland cropping belt of north-western Victoria and the Eyre Peninsula region of South Australia. The soils are predominantly Calcarosol and Sodosol profiles (Nuttall *et al.* 2003). Fifteen farmer-sown paddocks were selected (13 sites within Victoria and two sites in South Australia) where commercial rain-fed crops were assessed over four consecutive years. In each paddock 10 geo-referenced points were monitored and at each point a range of crop parameters and soil variables were measured. The soil profile at each monitoring point was segmented into seven depths (0-

10, 10-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm.) and the soil analysed for clay content ($P_{2?m}$), bulk density (ρ_b), $pH_{1:5}(CaCl_2)$, carbonate (CO_3^{2-}), salinity (EC_e), sodicity (ESP), effective cation exchange capacity (ECEC), soluble boron (B), and nitrate-nitrogen ((NO_3-N) sowing only). Soil water content was measured at sowing, anthesis and grain maturity, for the same depth intervals and converted to volumetric water content by adjusting for bulk density. Plant available water (Θ_a) was calculated by subtracting the lower storage limit (-1500 kPa laboratory derived) from the total soil water. Plant growth was monitored used quadrats and rooting depth assessed by core-break method. Rainfall and temperature were continuously logged at each paddock. On average the soils examined had high clay subsoils, were alkaline and saline (> 4 dS/m) at 40 cm. (Fig 1).

Results and discussion

Water supply

For the three crops (canola, lentil and wheat) mean (standard deviation in parentheses) plant available soil water to 120 cm at sowing was 92 mm (55), 3 mm (48) and 39 mm (55) respectively (Table 1). The frequency distribution across all monitoring points by seasons is shown in Fig 1. For canola crops, water was concentrated in the 10-60 cm layer (47 mm) and restricted soil water at sowing ($\theta_{avail10-60}$ < 10 mm) occurred for only 5% of crops. All followed either long fallow, pulse or a previous failed crop, which accounts for the high stored soil water at sowing (Fig 2). Where canola followed fallow/failed crop average available water was 103 mm compared to 65 mm following a legume. In contrast, 68% of lentil crops had less than 10 mm of available water at sowing in the 10-60 cm layer and all followed a previous cereal crop. For wheat crops available water was distributed evenly down the profile where 43% of crop had $\theta_{avail10-60}$ < 10 mm at sowing.

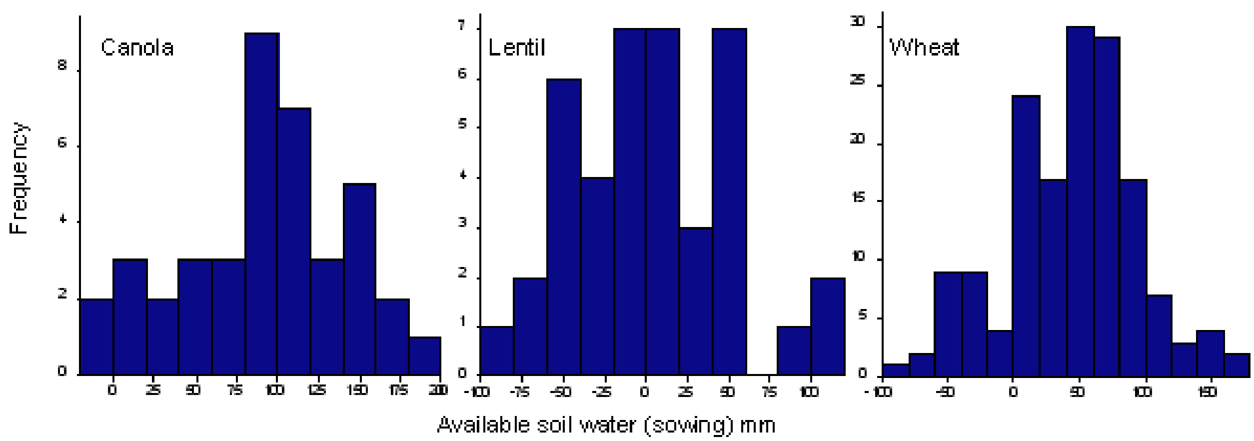

Figure 1. Distribution of available soil water (mm) within the soil layer 0-120 cm at sowing for canola, lentil and wheat crops.

Growing season rainfall (GSR) for sites where lentil crops were monitored were 223 mm (2003), 188mm (2004) and 203 mm & 229 mm (2005). For canola crops GSR across sites ranged from 141 mm to 195 mm in 2003 and 76 mm in 2006. For wheat crops, GSR across the 17 sites monitored, was on average 211 mm for 5 sites in 2003, 167 mm for 6 sites in 2004, 239 for 2 sites in 2005 and 81 mm for 4 sites in 2006. Average rainfall around crop anthesis, for wheat was 50 mm (n = 6) in 2003, 5 mm (n = 6) in 2004, 48 mm (n = 2) in 2005 and 0.5 mm (n = 4) in 2006.

Table 1. Available soil water (mm), by soil layers to 120 cm, for paddocks grown to wheat, canola and lentil crops and mean soil properties pooled across all sites. $P_{2?m}$, clay content (%), $pH_{(CaCl2)}$; EC_e, salinity (dS/m).

Standard deviation in parentheses.

Crop	Available soil water at sowing (mm) Wheat	Canola	Lentil	P_{2mm}(%)	$pH_{(CaCl_2)}$	EC_e(dS/m)
Soil layer (cm)						
0-10	5.9 (4.5)	8.3 (3.9)	0.6 (11.1)	32 (12)	7.0 (0.8)	2.1 (1.4)
10-20	5.8 (7.7)	11.0 (5.7)	5.3 (7.2)	39 (11)	7.6 (0.6)	2.0 (1.4)
20-40	7.3 (13.9)	20.3 (11.9)	1.7 (9.6)	43 (9)	8.0 (0.5)	2.8 (2.1)
40-60	6.5 (12.7)	16.1 (12.4)	-3.2 (10.4)	44 (9)	8.3 (0.5)	4.2 (2.9)
60-80	6.6 (14.1)	12.8 (11.9)	-1.5 (13.3)	45 (9)	8.4 (0.4)	5.2 (3.3)
80-100	5.4(13.1)	10.5 (14.4)	-0.5 (11.0)	45 (9)	8.4 (0.6)	5.8 (3.3)
100-120	6.7 (13.5)	12.8 (16.7)	0.7 (9.4)	46 (9)	8.4 (0.6)	6.3 (3.1)
0-120	**39 (55)**	**92 (49)**	**3 (48)**			

Crop growth

Canola yields ranged 0.4 to 2.4 t/ha with a mean of 1.3 t/ha (n = 40). Water extraction by canola crops occurred to at least 120 cm. Harvest index (HI) across all canola crops averaged 0.21 (0.05). Evapo-transpiration ranged between 97 and 386 mm and water-use efficiency from 2.5 to 9.4 kg/ha.mm with a mean of 6 kg/ha.mm. Lentil grain yields ranged from 0.4 to 2.5 t/ha with a mean of 1.5 t/ha (n = 40) and HI averaged 0.37 (0.06). Water extraction was restricted to the top 40 cm of profile although rooting depth ranged from 40 to 80 cm across sites. The apparent disparity between rooting depth and water extraction may indicate subsoil constraints was limiting root function by lentil crops rather than growth. Evapo-transpiration was between 188 and 317 mm and water-use efficiency from 2.4 to 8.4 kg/ha.mm with a mean of 6 kg/ha.mm. For wheat crops assessed (n = 170), the rotation sequence of previous crop was spread relatively evenly across legume (29%), oilseed (24%), fallow (18%) cereal (12%) phases and unknown (18%). Wheat yields ranged from 0 to 4.7 t/ha with a mean of 1.5 t/ha and HI averaged 0.26 (0.10) across all wheat crops. Soil water extraction occurred to at least 80 cm. Evapo-transpiration ranged between 52 and 485 mm and water-use efficiency from 0 to 19 kg/ha.mm with a mean of 6.4 kg/ha.mm.

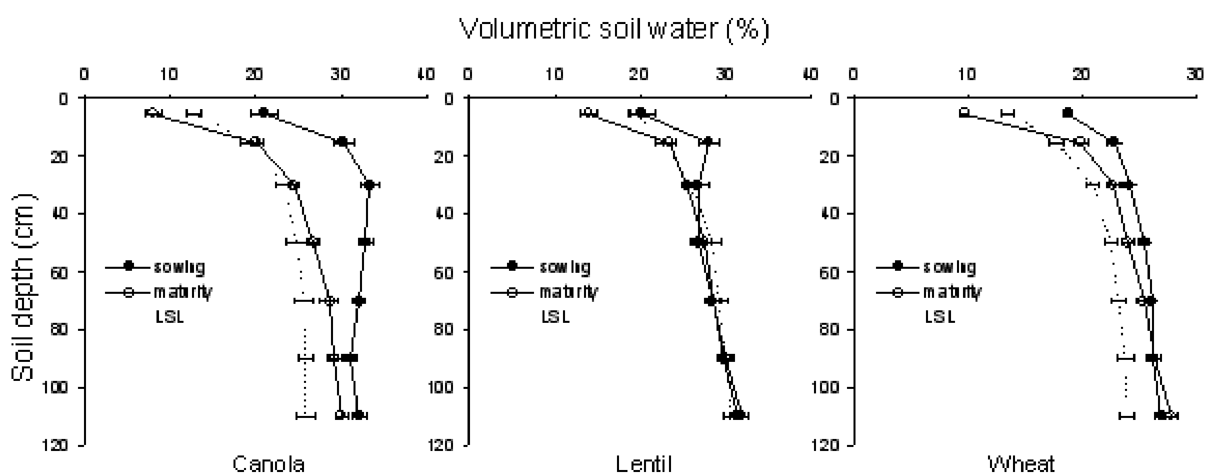

Figure 2. Shift in mean soil water from sowing to maturity, in comparison to the lower storage limit (-1500 kPa) (LSL) for canola, lentil and wheat crops. Error bars represent standard error of means.

Yield and it relationship with abiotic/edaphic factors

For canola crops, growing season rainfall (GSR) accounted for 41% of variation in yield (Table 2). Available moisture in the subsoil at sowing was also an important factor in explaining crop yield where pooled deeper subsoil layers (60-120 cm), explained 43% of crop yield variation. Available soil water in the shallow subsoil layers (10-60 cm) explained 20% variation in crop yield. There was no apparent effect of soil physicochemical properties on yield, despite water being present in the subsoil at sowing. For lentil crops GSR accounted for 72% of variation in lentil yield (Table 2). Rainfall around anthesis was also a sensitive indicator of grain yield variation. Salinity (EC_e) in the shallow subsoil (10-40 cm) was negatively correlated with lentil growth, accounting for 29% of the yield variation. For example the probability of getting a 1.2-1.5 t/ha lentil yield was 80% when salinity (EC_e) was less than 2.2 dS/m in the 10-40 cm layer, but only 15% when salinity was greater than 2.2 dS/m in this layer (Fig 3).

Table 2. Estimates of linear regressions between canola, lentil and wheat yield (t/ha) and soil and water variables. *P* <0.001 unless stated. Values in parenthesis denote standard errors.

Crop	Independent variable	Intercept	Slope	% Variance accounted
Canola (n = 40)	Growing season rainfall (mm)[A]	-	0.0087 (0.0005)	41
	θ_a 10 – 60 cm (mm)	0.733 (0.191)	0.0078 (0.0014)	20[B]
	θ_a 60 – 120 cm (mm)	0.905 (0.099)	0.0210 (0.0039)	43
Lentil (n = 40)	Growing season rainfall (mm)[A]	-5.074 (0.653)	0.0310 (0.0031)	72
	Rainfall ca. anthesis (mm)	0.511 (0.114)	0.0202 (0.0021)	69
	EC_e 10 - 40 cm (dS/m)	2.286 (0.215)	-0.3426 (0.0831)	29
Wheat (n = 170)	Growing season rainfall (mm)[A]	-	0.0092 (0.0005)	29
	Rainfall ca. anthesis (mm)	0.569 (0.082)	0.0417 (0.0025)	62
	θ_a 10 - 20 cm (mm)	0.963 (0.098)	0.0809 (0.0101)	30
	θ_a 20 - 40 cm (mm)	1.078 (0.088)	0.0495 (0.0058)	33
	θ_a 40 - 60 cm (mm)	1.224 (0.010)	0.0306 (0.0068)	11

[A] April - November inclusive
[B] $P = 0.003$

In assessing the impact of shallow subsoil salinity on water extraction by lentil crops, water use in the 10-40 cm layers were divided based on the median values of EC_e (2.2 dS/m) and only sites where available soil water existed in the 10-40 cm layer were used. Salinity (EC_e (10-40 cm)) explained 41% of variation in crop water use. Greater water extraction (median 8 to 24 mm) was observed on soil where $EC_e < 2.2$ dS/m compared with sites where $EC_e > 2.2$ dS/m (median -8 to 8 mm). Water extraction never exceeded 40 mm on high salinity (>2.2 dS/m) sites in contrast to the low salinity soils where water extraction reached 63 mm.

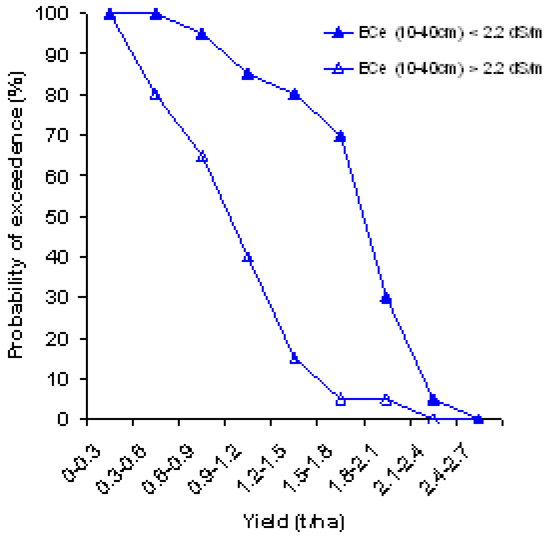

Figure 3. Probability of exceedence curves for lentil crops given subsoil salinity (EC_e) in the 10-40 cm layer

For wheat crops, growing season rainfall (GSR) accounted for 29 % of variation in grain yield (Table 2). Of greater importance, however, was the amount of rainfall occurring around anthesis, as rainfall two weeks either side of anthesis explained 64 % of variation in grain yield. Available subsoil moisture at sowing was also an important factor in explaining crop yield where that stored in the soil layers 10-20 and 20-40 cm explained 30 and 33 % of the variation in wheat yield, respectively. No other edaphic factors measured, including potential physicochemical constraints in the subsoil, helped explain variation in wheat growth. Evidently over multiple years with large differences in growing season rainfall and distribution, subsoil moisture has the dominant effect on crop yield compared with variation in other abiotic factors. Overall canola and wheat crops were sensitive to the amount of stored soil water, however insensitive to potential physicochemical constraints. The apparent water remaining in the profiles at maturity for these crops may be related to the determinant nature of these crops where time constraints prevent thorough water extraction from the bulk soil.

Conclusions

Assessment of farmer sown canola, lentil and wheat crops over 4 years (2003 to 2006) suggest that besides growing season rainfall, the amount of stored soil water was important in explaining variation in crop yield of canola and wheat. Available water at sowing was influenced by crop rotation. Canola crops generally followed a long fallow or previously failed crops, thus creating an opportunity for soil water accruement. Conversely lentil crops were generally sown after a cereal, where little carryover soil water existed. As a result lentil crops were exposed to greater risk, (more reliant on growing season rainfall), despite potentially greater price returns for lentil grain. Subsoil (10-40cm) salinity (EC_e), where EC_e > 2.2 dS/m also reduced crop water extraction and lentil yield. Potential soil physicochemical constraints such as boron toxicity, salinity sodicity or chloride, appeared to have little impact on grain yields of wheat and canola during the dry seasonal conditions.

Acknowledgements

This experimentation was co-funded by the Grains Research and Development Corporation through the project ‘Improving the profitability of cropping on hostile subsoils’ (DAV00049). Thanks also to R Perris, G Price and M Baker for technical support.

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