The effects of salinity, sodicity and soluble boron on wheat yields in the Victorian southern Mallee.

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Abstract

Soil salinity, sodicity and high extractable boron are believed to reduce grain yields of cereals on alkaline soils of south-eastern Australia; however, little quantitative information is available. We investigated the relationship between wheat growth and soil conditions in the Victorian southern Mallee, using natural variation in the field. Wheat yields in the survey ranged from 1.3 to 6.1 Mg/ha. Low yields were attributed to pre-anthesis water stress. Descriptive models for crop yield, which used ridge regression, accounted for 54% of variation in grain yield. Rainfall, plant available water in the shallow subsoil (0.10-0.40 m), nitrate in the topsoil and salinity and sodicity in the 0.60-1.00 m layer were the main factors correlated with wheat yield. Edaphic constraints in the 0.60-1.00 m layer may be reflected in a lack of water extraction by crop roots. The analyses suggested that subsoils need to have an EC_e<8 dS/m and ESP<19% for crops to make use of water deep in the profile. Levels of B appeared to have little correlation with root growth, water extraction or yield on the alkaline soils considered.

Introduction

Water supply is the major factor influencing dryland crop production in semi-arid environments, particularly during the post-anthesis phase (3). Because growing season rainfall is often unreliable in these regions, crops rely on soil water stored deeper in the profile for sustained supply. Well-developed root systems within the subsoil are required to access this soil water (9). Within the Victorian Mallee, variable rooting depth and water extraction by cereal crops have been commonly attributed to high levels of salts, exchangeable sodium and boron (3,8), but high correlation between these physicochemical properties can confound interpretation (6). In the present study, the relationship between a range of environmental/edaphic variables and wheat yield in the Victorian southern Mallee was examined. We aimed to (i) define the factors which most effectively explain variation in crop yield and (ii) separate the effects of physicochemical constraints on wheat production.

Methods

Experimental sites

The study covered a 3600 km^2 area in the Birchip district (35?58'67"S, 142?54'58"E) of Victoria, Australia, where dryland cropping is dominated by rotations containing cereals. The environment is semi-arid with an average annual rainfall of 376 mm, of which ca 65% falls between April and October inclusive. Average monthly temperatures are lowest in July (min. 3.6?, max. 13.7?) and highest in January (min. 14.0?, max. 30.7?).

Sampling and analysis

Details of sampling methods and analysis for soil physicochemical characteristics, crop, nitrogen nutrition, soil water and rainfall are given else where (6,7). Briefly, soil samples were taken using a 50 mm diameter probe on a hydraulic sampling rig. Five depths were examined at 10 survey points at each of 15 sites, in 0-0.10, 0.10-0.20, 0.20-0.40, 0.40-0.60 and 0.60-1.00 m increments (n=750). The attributes measured, which were relevant to this study, were clay content ($P_{2\mu m}$), pH in $CaCl_2$ ($pH_{1:5}$), salinity (EC_e), sodicity (ESP), equivalent cation exchange capacity (ECEC), soluble boron (B), soil nitrate at sowing (NO_3-N), available soil water at sowing (θ), rainfall during a four-week period centred on anthesis and wheat (Triticum aestivum) yield. Crop water-use (ET), calculated as the difference between soil water at sowing and maturity to one metre plus growing season rainfall, was used to calculate crop water-use efficiency.

Statistical analysis

Ridge regression techniques (2) were used to define wheat yield in terms of an optimised variable subset (p). The initial set of independent variables was large (q = 31) and there was the need to reduce this to maintain parsimony and overcome collinearity. Probabilities of exceedence curves were used to assess the effects of split ranges of physicochemical constraints, (based on median values) on wheat yield.

Results and Discussion

Soil characterization

The dominant soils were Calcic Calcarosols in the southern Mallee and a Grey Vertosol at the one site in the Wimmera (2). On average these soils become saline (EC_e > 4.0 dS/m) (4) in the 0.20-0.40 m layer, sodic (ESP > 6%) (5) in the 0.10-0.20 m layer and had potentially phytotoxic levels of boron (B > 15 mg/kg) (1) at 0.20-0.40 m (Table 1).

Table 1. Mean values of soil parameters over 15 sites in the southern Mallee and Wimmera. Standard deviation in parentheses.

Soil layer (m)		0-0.10	0.10-0.20	0.20-0.40	0.40-0.60	0.60-1.00
$P_{2μm}$	%	33.7 (8.7)	40.8 (7.7)	43.9 (7.1)	45.4 (5.9)	45.9 (5.1)
$pH_{1:5}$		7.5 (0.6)	8.0 (0.4)	8.4 (0.3)	8.6 (0.3)	8.6 (0.2)
EC_e	dS/m	2.0 (1.1)	2.4 (1.2)	4.1 (2.3)	6.3 (4.0)	8.4 (4.3)
ESP	%	3.1 (1.7)	6.3 (4.3)	10.9 (6.1)	15.4 (6.3)	19.1 (6.5)
ECEC	$cmol_c$/kg	23.0 (9.1)	27.5 (7.9)	31.9 (5.9)	33.2 (5.7)	32.4 (5.4)
B	mg/kg	2.4 (1.1)	5.5 (5.1)	13.3 (10.7)	21.1 (12.5)	24.7 (9.8)
θ	mm	-3.7 (4.4)	5.1 (0.4)	11.3 (10.1)	10.4 (9.0)	23.2 (13.9)
NO_3-N	kgN/ha	27.1 (12.2)	19.5 (11.2)	15.0 (10.5)	6.9 (7.7)	8.9 (7.2)

Grain production ranged from 1.3 to 6.1 Mg/ha with a mean of 3.1 (s.d. 1.0) Mg/ha across all observations (n =150). For cv. Frame crops, water-use efficiency (WUE) ranged between 6.0 and 15.8 kg/ha/mm with a mean of 12.0 (s.d. 3.5) kg/ha/mm. This high value was achieved at one site where crops consistently withdrew water to at least one metre. Here abiotic or environmental stresses were not apparent. For one site where cv. Silverstar was inadvertently grown the average WUE was 18.1 kg/ha/mm. For all crops, grain protein ranged from 8 to 17% with a mean of 12 (s.d. 2.0) %. There was a moderate negative correlation between grain yield and protein (r = -0.57).

The ridge procedure was applied to the original variable set (*q* = 31) to identify a subset of variables with stable and large coefficients (Table 2). In contrast with methods such as stepwise regression, the effects of collinearity do not confound this technique. Six variables: rainfall, available soil water in the 0.10-0.20 and 0.20-0.40m layer at sowing, nitrate in the topsoil and ESP and EC_e in the 0.60-1.00 m layer explained 54.1% of the variance in grain yield. For edaphic constraints, ESP had greater impact on grain yield than EC_e. Soil B held no strong relationship to variation in grain yield. It follows that salinity and sodicity are effective surrogates for estimating the likelihood of water extraction in the 0.60-1.00 m layer.

Given the significance of edaphic constraints in the deep subsoil on wheat production, the frequency distribution of yield data was considered in terms of the physicochemical factors (ESP, EC_e and B) in the 0.60-1.00 m layer (Fig. 1). Crop yields were divided in three ways based on the median values of ESP (19%), EC_e (8 dS/m) and B (24 mg/kg). Only data where soil water was not limiting (θ >15mm) in this layer were used. The range of each constraint followed a normal distribution. Greater median yields, (3.5-4.0 Mg/ha) were observed on soils where ESP<19% compared with sites where ESP>19% (2.0-2.5 Mg/ha). For high ESP sites, crops did not exceed 4.5 Mg/ha. This compared with the low ESP soils, where yields reached 6.0 Mg/ha. The affect of subsoil sodicity was most apparent for yields in the range 3.0-3.5 Mg/ha where chances of exceedence were 12 and 60% for high and low sodicity respectively. In comparison, split populations of salinity and boron levels had less pronounced effect on yield compared with ESP. The exception was for crops >4.5 Mg/ha for which exceedence patterns for salinity and sodicity were equivalent.

Table 2. Six variable model where variables were selected using the ridge procedure with grain yield as the response variate. Mean variance inflation factor (VIF) is also defined. Coefficients are all significant at (P=0.01).

OLS ($k = 0$) Variable	Coefficient std	*s.e.*	original	*s.e.*	*t*-test
Constant			2236	406	5.51
Water supply					
Rainfall**	0.22	0.06	32.6	9.2	3.57
θ 0.10-0.20 m	0.26	0.07	51.1	14.5	3.53
θ 0.20-0.40 m	0.17	0.07	16.9	7.3	2.33
Nutrition					
NO_3-N 0-0.10 m	0.20	0.06	16.8	5.0	3.39
Edaphic					
EC_e 0.60-1.00 m	-0.16	0.07	-37.5	15.7	-2.38
ESP 0.60-1.00 m	-0.30	0.06	-48.0	9.5	-5.03
			$R^2 = 0.541$	Mean VIF = 1.37	

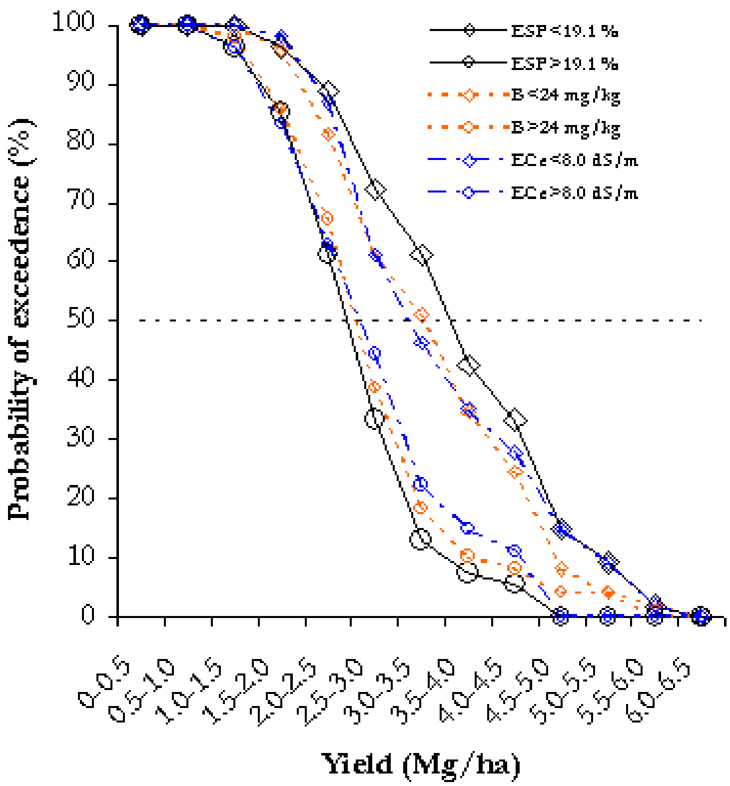

Figure 1. Probability of exceedence for wheat (*Triticum aestivum*) yield given subsoil (0.60-1.00 m) sodicity (ESP), salinity (ECe) and boron (B) where effects of levels either side of medians are compared. For all crops 15 mm of available water was present in this soil layer at sowing.

Difference in crop root density and water extraction based on physicochemical constraints in the 0.60-1.00 m layer were also considered (Table 3). For data split according to the median ESP, significant differences in root density and water extraction were observed across these subsets. This occurred similarly for high and low salinity subsets, but was not the case for boron. The lack of significance of B on cereal growth in this study contrasts with earlier work on barley (1). There was also strong correlation between B and ESP, which could complicate interpretation of the causal agent. For saline/sodic conditions subsoils can retain their structure thus poor root growth is likely to be osmotically related. The better agreement, however, between ESP and wheat yield may indicate final production is limited more by Na-toxicity.

Table 3. Wheat root growth and water extraction in a subsoil (0.60-1.00 m) as it relates to the ESP, EC_e and B in the layer. Data was split three ways according to the median values of ESP, EC_e and B in the original data set. Negative values represent water loss from this soil layer.

	Root density (g/m^3)	Water extraction (mm)	
		Sowing to Anthesis	Sowing to Maturity

	Mean (SE)	t-test	Mean (SE)	t-test	Mean (SE)	t-test
ESP < 19%	45 (5)	P<0.05	-8 (2)	P<0.05	-10 (2)	P<0.05
ESP > 19%	26 (4)		3 (2)		-3 (2)	
EC_e < 8 dS/m	49 (4)	P<0.05	-8 (2)	P<0.05	-13 (2)	P<0.05
EC_e > 8 dS/m	21 (4)		3 (2)		0 (2)	
B < 24 mg/kg	41 (5)	P=0.12	-4 (2)	P=0.53	-7 (3)	P=0.72
B > 24 mg/kg	31 (4)		-2 (2)		-6 (2)	

Conclusion

For wheat grown in a semi-arid environment of the Victorian southern Mallee, rainfall, available soil water at sowing in the shallow subsoil and topsoil nitrogen contributed significantly to the explanation of yield. High soil salinity and sodicity in the deeper subsoil were negatively related to yield, making them good surrogates for estimating likelihood of water extraction of available water in this layer. For crops to make use of water at depth in the profile, subsoils need to have an EC_e<8 dS/m and ESP<19%.

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