Cereal response to N fertiliser in relation to subsoil limitations

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Abstract

Much of the dryland cereals in southern Australia grow in semi-arid regions where the subsoils are highly alkaline and contain high levels of salinity, sodicity and boron. The severity of the limitations that these impose on crops varies across the landscape, both between and within paddocks. The levels of salinity, boron and sodicity are positively correlated and tend to increase with depth in the soil, typically reaching levels that confine the roots of cereal crops to the top 40-90 cm. Areas with the shallowest rooting zones have limited amounts of available soil water, leading to low cereal yields and poor responses to N fertiliser. A possible strategy to maximise yield is to concentrate N fertiliser on the parts of the landscape with the least subsoil limitations. To test this hypothesis, we applied ~10m-wide strips of urea along the length (~1km) of eight cereal paddocks. The yield response to N were measured and related to apparent electrical conductivity (EC_a), measured by electromagnetic induction (EM) surveys. In five of the paddocks the average yield response to N decreased with increasing EC_a, falling from 20 kg grain /kg N where EC_a was zero, to no response where EC_a =136 mS m^{-1}. Of the other paddocks, responses in one were masked by frost damage, in another by soil-water depletion on soils of low EC_a by previous high-yielding crops, and in the last by large N responses by barley on a paddock with low EC_a. The results offer a strategy to increase cereal yield by concentrating N on the most responsive parts of the landscape identified by EM surveys.

Media summary

Subsoils that contain high concentrations of salt and boron limit wheat growth. Electromagnetic induction mapping can help define zones of paddocks most likely to respond to N fertiliser.

Key words

wheat, subsoil, salinity, sodicity, boron, electromagnetic induction, EM38; nitrogen fertiliser

Introduction

The semi-arid cropping land of southern Australia includes more than 20 million hectares of alkaline soils with sodic subsoils containing high concentrations of boron and salt (Cartwright et al., 1984; Rengasamy 2002). The levels of pH, sodicity, boron and salt generally increase with depth in the soil and also vary across the landscape, with the highest levels sufficient to limit cereal yield (Nuttall et al. 2003). The levels of sodicity, boron and salt at a given soil layer are positively correlated, so the combination can be considered as a general subsoil limitation to growth (Walker et al. 2002).

The combined effect of the vertical and horizontal variation in these properties is that the depth of soil with no apparent limitations is variable. In general the roots of mature crops are confined to this benign layer, which varies in depth from about 40 to 90 cm. In subsoils with no apparent chemical limitations, cereal roots typically extend to 90-120 cm, while in subsoils with no physical or chemical restrictions, such as deep sands, cereal roots can reach deeper than 150 cm. It is not evident that deeper roots are always desirable because deep soil layers may not necessarily contain available nutrients and water. Water and nutrients leached into hostile layers are unavailable to the crop.

In regions of southern Australia with hostile subsoils, cereal yields are static or increasing slowly and grain protein levels are low. In contrast, yields and grain proteins are increasing in regions with benign subsoils. The difference is partly due to the inputs of N fertiliser, which are increasing rapidly in regions with benign subsoils but are static or increasing slowly in regions with problem subsoils (Angus 2001). Previous research showed that the low use of N was justified because crop responses to applied N in these regions were generally poor (H. van Rees pers. comm.). Our research has investigated ways to obtain larger N responses by cereals growing on these soils. One theme addresses delayed N uptake by crops, for example by topdressing or applying N fertiliser in mid-row bands at sowing, so as to reduce early growth and conserve water and nutrients for grain growth (Walker et al 2002). The other theme of our research, reported here, is to identify parts of the landscape on which crops give the largest yield responses to applied N (Pedler et al 2003). This research aims to test whether N-responsive zones in paddocks can be defined economically using electromagnetic induction.

Materials and methods

From 2001 to 2003 eight experiments were conducted in a ~200 km loop in the Mallee and Wimmera regions of Victoria (Table 1). The paddocks were selected on the basis of high variability in expected yield and a range of soil types representative of the region (Rowan and Downes 1963). Each experiment consisted of a strip of urea, about 10 m wide, applied along the length of a paddock and aligned to cross small ridges and hollows. Soils were cored before sowing at ~100 m intervals along the strips and the soil layers analysed for water, mineral N, electrical conductivity (EC), sodicity and boron. On one paddock where the farmer intended a blanket application of N, the strip was a minus-N. Yield was measured with a plot harvester in an area of 1.5 m ? 10-20 m close to the site of each soil sample. The comparison of the yields in and out of the strip provided the estimate of N response. In addition, we measured spatial distribution of apparent EC (EC_a) by electromagnetic induction using an EM38 instrument with a vertical dipole (Geonics, Mississauga, Ontario, Canada). The project was conducted in collaboration with farmers who applied the urea.

Table 1. Paddocks with experimental strips of N fertiliser applied to cereals

Site and year		Strip Length (km)	Sample number	April-Nov rain (mm)	Crop species	N applied (kg/ha)	Yields (t ha^{-1})	Method and time of N application
Jil Jil	2001	1.6	30	204	Wheat	40	1.8-5.1	Drilled before sowing
Jil Jil	2003	1.6	10	216	Wheat	40	0.5-2.8	Topdressed at DC15
Gooroc	2003	1.6	10	262	Wheat	50	0.9-2.1	Topdressed at DC30
Birchip	2003	0.8	9	213	Barley	24	3.5-5.2	Drilled before sowing
Gama	2003	0.8	10	181	Wheat	40	0.6-1.7	Topdressed at DC15

Kellalac	2003	1.2	9	255	Barley	20	0.9-3.0	Drilled before sowing
Goruya	2002	1.0	6	109	Wheat	50	0.4-0.8	Topdressed at DC30
Goruya	2003	1.0	6	216	Barley	50	2.2-4.2	Topdressed at DC30

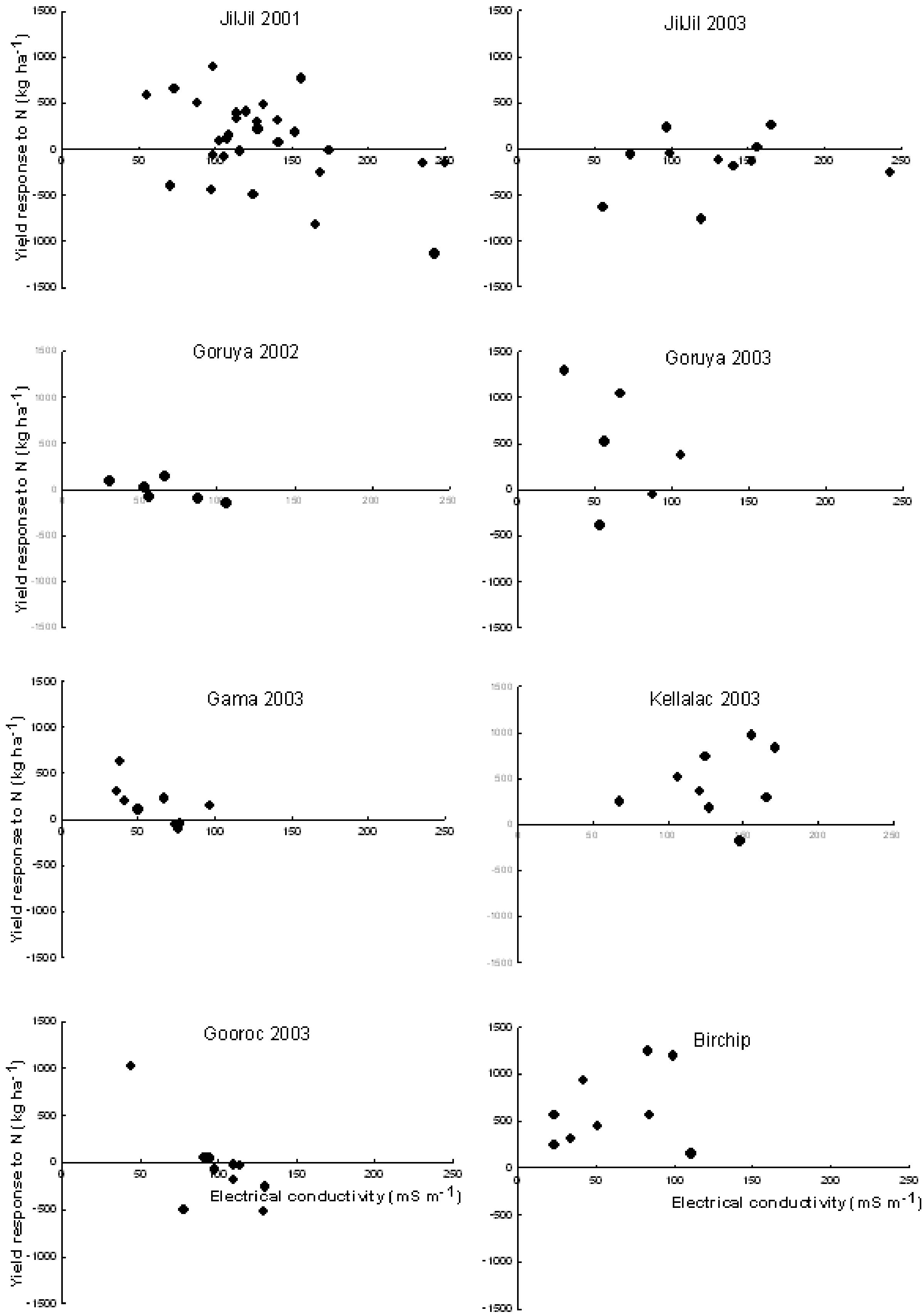
Results and discussion

The results varied greatly between the sites, from relatively high yields and large N responses at Jil Jil in 2001, to small yields and small responses during the 2002 drought at Goruya (Fig. 1). The negative yield responses to applied N in parts of the paddocks with high EC_a represent haying-off, where insufficient soil water was available for grain filling (Angus 2001). Of the eight paddocks, five showed large yield responses in areas of low EC_a and decreasing responses at higher values of EC_a. Data for these paddocks were combined in a linear model (Eq. 1) relating EC_a to the marginal yield response to applied N

$$\Delta Y/\Delta N = 20.1 - 0.147\ EC_a \qquad \text{(Eqn.1)}$$

(?3.8) (?0.0334)

When site was included with EC_a in a general linear model, $R^2 = 0.38$ and SE_{obs} = 12 kg grain/kg N. There was no interaction between EC_a and site. The three exceptions to the trend for decreasing $\Delta Y/\Delta N$ with EC_a were in 2003 at Kellalac, Jil Jil, and Birchip. The barley crop at Kellalac was frosted at flowering and yields were mostly 1-2 t ha^{-1} when water-limited potential yield was >4 t ha^{-1}. In the Kellalac paddock one site was close to a large dam where higher yields (>3 t ha^{-1}) may have been due to the thermal buffering of the water.. The wheat crop at Jil Jil in 2003 was located on areas examined in 2001. The reason for the different responses in the two years was that sites that had yielded well in 2001 yielded poorly in 2003. Examination of the initial soil water in 2003 showed that these sites were very dry, apparently because of water extraction by the high-yielding 2001 crop and no recharge during the 2002 drought. This result reflected the ‘mirror imaging’ commonly found in yield maps of the same paddock in successive years. At Birchip the barley crop responded well to applied N along the entire strip, probably because of the greater salt tolerance of barley and the generally low levels of EC_a.



JilJil 2001
JilJil 2003
Goruya 2002
Goruya 2003
Gama 2003
Kellalac 2003
Gooroc 2003
Birchip
Yield response to N (kg ha-1)
Electrical conductivity (mS m-1)

Fig. 1. Relationship between wheat yield response to N fertiliser and the apparent electrical conductivity measured by EM38 along strips of urea, ~1km in length on paddocks in the Mallee and Wimmera regions of Victoria.

We used equation (1) to predict the sites in the eight paddocks where crops would respond profitably to applied N. To the extent that these paddocks and sites are representative of the region this approach estimates the N-responsive proportion of this landscape. The definition of profit was when gross returns from additional grain exceeded double the cost of the applied N, at 2003 prices and costs. Probability was estimated from the number of sites that gave responses greater than this threshold and the standard error

of the response. The probability of profit at a particular site from a blanket N application was 21%, but when N was confined to the 28% of sites with EC_a <75 mS m^{-1}, the probability of profit rose to 65% (Table 2).

Table 2. Probability of profit from N fertiliser (Gross returns > 2 ? fertiliser costs) applied to all sites represented in Fig. 1, or only to sites with less than defined levels of apparent electrical conductivity.

Rule for N application	<50 mS m^{-1}	<75 mS m^{-1}	<100 mS m^{-1}	All
Probability of profit (%)	72%	65%	57%	21%
Land area represented (%)	11%	28%	48%	100%

Additional rules considering variables besides EC_a and yield are likely to improve the probability of profit. For example, including grain-protein responses to N may justify N application to sites where yield responses alone were marginally unprofitable. Equally, avoiding N application to otherwise favourable areas may be justified where the soil had been de-watered by high-yielding crops in the previous year and which had received little rain to recharge the profile. A two-stage decision-making process may be justified, where N is applied before sowing N only to zones of low EC_a, and top-dressed on zones of higher EC_a in a wetter than average year (Walker et al. 2002).

The increased probability of profit from concentrating N fertiliser appears to refute the null hypothesis of precision agriculture, that “the optimal risk aversion strategy is uniform management.” (Whelan and McBratney 2000). A further requirement for site-specific N application is that zones are sufficiently well defined and of sufficient size to warrant zone management. Examination of EM maps of paddocks in this region suggests that discrete zones of at least tens of hectares can be defined (data not shown). The one-off cost of an EM survey is about $5/ha, and based on the data here, annual net returns from zoned application of, say, 20 kg N/ha on 30% of the land would be about $5/ha. This is not a bonanza and alone may not justify the costs of investing time and money in precision agriculture throughout the region. However it is sufficiently encouraging to justify research to improve rules for variable application and to promote concentration of N fertiliser on responsive parts of paddocks with highly variable subsoil limitations.

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