Optimizing Nitrogen for Wheat Growing on Hostile Subsoils

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Nitrogen application to areas of wheat paddocks with high subsoil salinity, alkalinity, and/or boron (B) often gives low nutrient use efficiency and poor returns. These areas can be identified within a variable landscape using electromagnetic induction surveys. Paddock zones can be identified and then N managed according to the degree of constraint imposed by the hostile subsoils.

In the south-eastern Australian grain belt, there are large areas with subsoils that have high levels of salinity, sodicity, and alkalinity. These chemical imbalances result in subsoil compaction, toxic levels of B, and poor water availability due to salt. A survey of some of these paddocks showed that the subsoil limitations often – but not always – occur together **(Table 1)**. The constrained root growth that results prevents crops from using stored subsoil moisture and nutrients. In particular, crop response to N fertilizer on these soils is un-reliable even in years of good rainfall, giving low nutrient use efficiency and poor returns to growers.

Table 1. Results of a survey of 36 paddocks in the southern Mallee and Wimmera, showing levels of B, sodicity (% of CEC), and salinity (electrical conductivity in 1:5 soil:water) in the top 60 cm of soil and some critical thresholds for those values.

Soil limitation and damage threshold	% of Paddocks
Boron (>8 mg/kg) in total	67
Sodicity (>15% ESP) in total	67
Salinity (>2 mS/cm) in total	67
Boron (>8 mg/kg) and sodicity (>15% ESP)	56
Boron (>8 mg/kg) and salinity (>2 mS/cm)	47
Sodicity (>15% ESP) and salinity (>2 mS/cm)	36

Table 2. Response of wheat yield to N delivery (40 kg N/ha) on soils with subsoil limitations (10 sites) and soils with no subsoil limitations (4 sites) between 1999 and 2004 in north-western Victoria.

Sites	Grain yield, t/ha			
	Nil	Presowing[1]	MRB[2]	Split[3]
All Sites	2.94 a	3.11 ab	3.52 c	3.30 b
Subsoil limited	2.80 a	2.92 a	3.45 b	3.17 ab
No subsoil limits	3.27 a	3.58 b	3.64 b	3.62 b

[1]Presowing N drilled approximately 2 weeks prior to sowing on 22 cm row spacing.
[2]Mid-row banding (MRB) between alternate sets of plant rows on 44 cm spacing.
[3]Split application, with half applied in MRB at sowing and half broad-cast at stem elongation.
Yields with the same letter in the same row are not significantly (p < 0.05) different from each other.

Figure 1 shows the locations of a series of field experiments between 2000 and 2004 in north-western Victoria. The region has an average growing season rainfall of 392 mm, which varies from 104 to 596 mm. We evaluated a range of N management options for wheat at each experiment. Our

**Abbreviations: N = nitrogen; ESP = exchangeable sodium percentage.
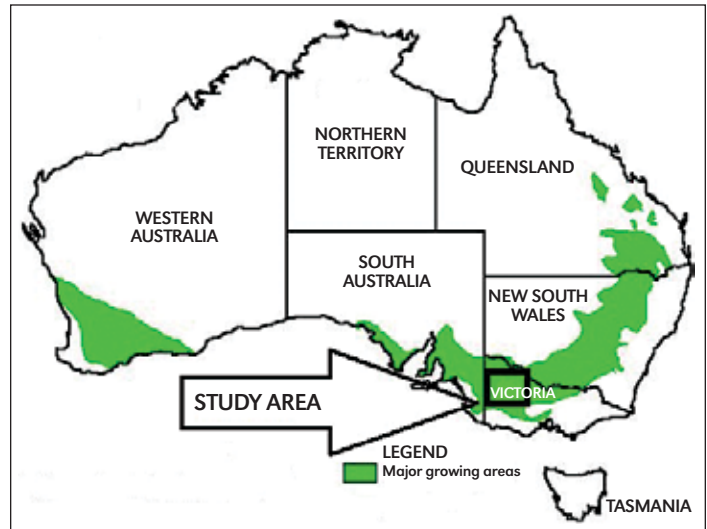Note: USD 1 is approximately equal to 1.14 Australian dollars (AUD).**

Figure 1. Location of replicated experiments and paddock scale N strips in north-western Victoria, Australia.

Map adapted from USDA World Agricultural Outlook Board and Foreign Agricultural Service.

View of paddock at Warracknabeal with N application subplots across the landscape.

hypothesis was that N responses could be improved if available N was kept in the topsoil where roots could access it, but that the concentration should be prevented from becoming so high that excess vegetative growth would exhaust the normally limited soil water. To do this, a range of split applications, deep banding, mid-row banding, predrilling, and topdressing before sowing were evaluated. Across the 14 sites over 5 years, the application of 40 kg N/ha at sowing had no significant yield response on sites with subsoil limitations, but splitting and banding did give significant responses to N **(Table 2)**. On the sites without limitations, delivery method did not make a significant difference in grain yield.

So, these data support the hypothesis that slowing the rate of N release, either by splitting the application or placing it
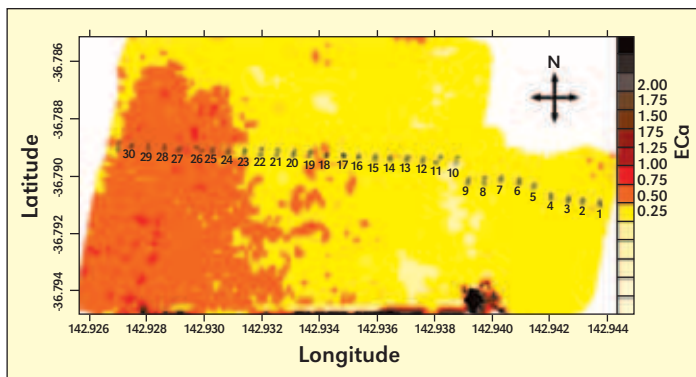
Figure 2. EM38 map, made in March, showing levels of apparent electro-conductivity, in mS/cm, measured in the horizontal dipole. Thirty paired sample sites are shown, within and beside the 10-m wide strip of urea, predrilled in May.

in bands, improved yields and nutrient use efficiency. This presents growers with an option to go to mid-row banding or to split N where soils have these limits. But here is the problem – subsoil limitations show high spatial variability and a uniform N application would supply too much N where the subsoils were a problem and possibly not enough N where the soils were not limited. So the key is to be able to easily and inexpensively find these areas within paddocks and manage those zones appropriately.

In 2001, a paddock north of Birchip was mapped for apparent electro-conductivity (ECa) using an EM38. The mapping was done in early March, to obtain the strongest ECa signals where the least subsoil moisture had been used by the previous crop. Poor use of subsoil moisture by a crop is a good indicator of hostile subsoil conditions. These hostile conditions frequently include salinity and sodicity, which give high ECa readings when the soil is moist. However, hostile subsoil conditions also include other possible problems such as B toxicity or soil compaction, which do not give high ECa readings. Using soil moisture remaining after harvest as the indicator of hostile subsoil therefore indicates a subsoil problem, but does not discriminate the possible causes. The EM38 map showed higher ECa in about a third of the paddock, where a highly variable gilgai flat stretched to the west **(Figure 2)**. Gilgai
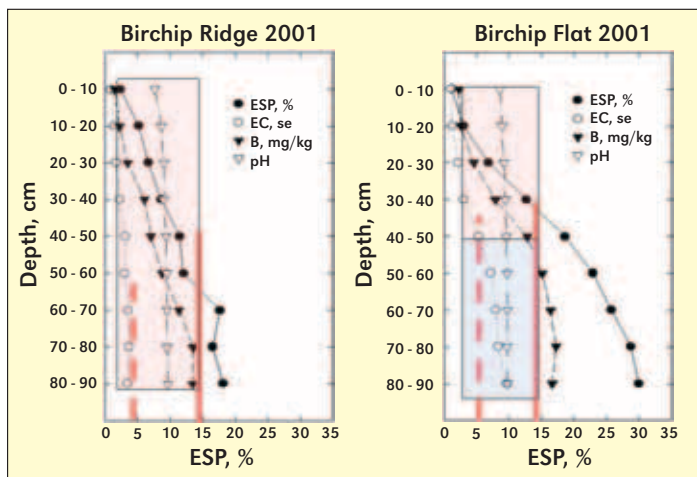

Figure 3. Soil chemical tests on two soil profiles… the ridge soils have an effective rooting depth of almost 1 m, while the soils on the flat have a rooting depth of about 0.5 m.
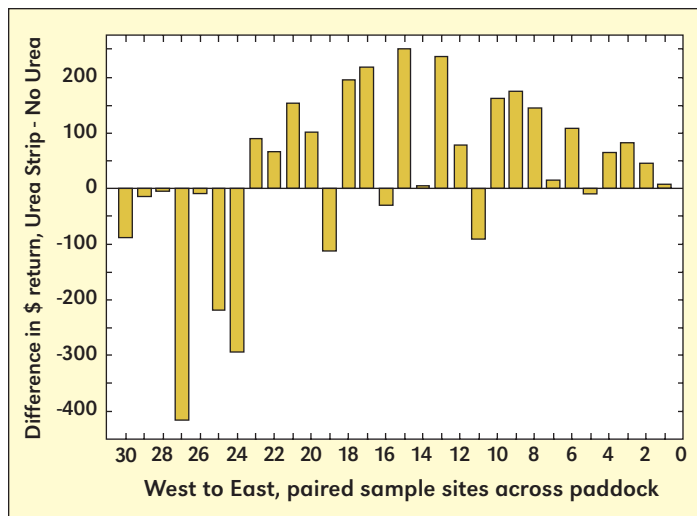

Figure 4. Differences in return (AUD) across a paddock, comparing application of 30 kg N/ha (Urea Strip) or none (No Urea). Return calculated using Australian Wheat Board (AWB) 'Golden Returns' matrix, with grain yield, protein, and screenings from 30 paired sample sites.

indicates undulating clay soils that shrink and swell with varying moisture. Sandier ridges had lower ECa, and presumably lower subsoil constraints to root growth **(Figure 3)**.

In May 2001, a 10-m wide strip of urea (30 kg N/ha) was predrilled the length of the paddock, prior to sowing H45 wheat in mid-June. In early August, 30 sites along the strip (at 50-m intervals) were sampled for soil characteristics. Soil cores were taken inside the urea strip, and in the adjacent crop where no urea had been pre-drilled. When the paddock was harvested in November, plots (10 m by 2 m) were harvested directly over those paired sample sites. Grain yield and protein content from the urea strip plots and the no-urea plots could thus be directly compared to soil characteristics at each site, and to ECa readings from the EM38 map **(Figure 2)**. Yield and protein responses to the pre-drilled urea changed with the paddock landscape, the soil characteristics, and ECa. Using yield, protein, and screenings for each plot, and the value of wheat produced, the return (AUD/ha) for each plot along the strip was calculated. The difference in return for applying urea (Urea Strip) or not (No Urea) show good agreement when the sample sites are lined up with the EM38 map **(Figure 4)**.

In the two-thirds of the paddock where the EM38 map from March showed an ECa of 0.25 mS/cm or less, it was either profitable or break-even to pre-drill urea. In the third of the paddock where the ECa was higher than 0.25 mS/cm, where the gilgai soils had high sodicity and high salinity, pre-drilling urea caused large yield and return reductions

Root growth and subsoil limitations at Warracknabeal site.

Hostile subsoils at Warracknabeal.

due to haying-off and small grain size.

In this paddock, the average wheat yield was 3.1 t/ha, with average protein of 10.5%. Using the map in **Figure 2**, if two zones were delineated by a line between sites 23 and 24 and the 'hostile' zone left without urea, the average yield for the whole paddock would have been 3.3 t/ha with a grain protein content of 11%. This resulted in an increase in return of nearly AUD 50/ha compared to the non-zoned paddock partly from reduced inputs and better grain quality on the areas with subsoil limitations. So it is thus possible to increase the average paddock yield and protein, with the same or even lower input costs.

Seven additional paddocks were mapped and strip-tested for N response over two more seasons. Using Australian classification (http://www.clw.csiro.au/aclep/asc_re_on_line/soilhome.htm), the paddocks were a mixture of vertosols (epicalcareous-endohypersodic, self-mulching, grey Vertosol), calcarasols (Epihypersodic, Pedal, Hypercalcic, Calcarasol), and sodosols (vertic and calcic, red Sodosol) typical of the region. Grain was harvested close to the site of each soil sample. The comparison of the yields in and out of the urea strip provided the estimate of N response.

The results varied from relatively high yields and large N responses during 2001, to small yields and small responses during the 2002 drought. The yield reductions to applied N in parts of the paddocks with high salinity were caused by haying-off, where there was insufficient soil water for grain filling. Of the eight paddocks, five showed large yield responses in areas of low salinity and decreasing responses as salinity levels rose and these data were combined to create an equation relating EM38 reading to the marginal yield response to applied N.

The N response equation was used to predict the zones in these paddocks where wheat would respond profitably to applied N. The definition of profit was when gross returns from additional grain exceeded double the cost of the applied N. A doubled cost was used to provide a 2:1 return on the N investment. The probability of profit at a particular site from a blanket N application was 21%. But when N was confined to the areas with salt concentrations less than 0.75 mS/cm, the probability of profit rose to 65% **(Table 2)**. Including grain-protein responses to N could justify N application to sites where yield responses alone were marginally unprofitable. Equally, avoiding N application to otherwise favorable areas could be justified where high-yielding crops have depleted the soil water reserves in the previous year and when little rain has occurred to recharge the profile.

The one-off cost of an EM survey is about AUD 5/ha. So, based on the information from the eight experimental paddocks, annual net returns from zoned application of, for example, 20 kg N/ha on 30% of the land would be about AUD 5/ha.

While this is not a high return and on its own might not

Author Charlie Walker discussing the management of subsoil limitations.

justify the costs of investing time and money in precision agriculture, it is sufficiently encouraging to justify research to improve rules for variable application and to promote concentration of N fertilizer on responsive parts of paddocks with highly variable subsoil limitations. BC

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Background Information Sources

Angus, J.F., R.M. Norton, J.F. Pedler, C.N. Walker. 2004. Cereal response to N fertiliser in relation to subsoil limitations, Proceedings for the 4th International Crop Science Congress, 26 September – 1 October 2004, Brisbane, Australia. Australian Society of Agronomy. http://www.cropscience.org.au/icsc2004/poster/2/5/1/1170_angusjf.htm

Armstrong, R.D. (Ed). 2009. Identifying, understanding and managing hostile subsoils for cropping. The Profitable Soils Group, 92 p.

Kaur, S., M. Nicolas, R. Ford, R. Norton, and P. Taylor. 2006. Selection of Brassica rapa genotypes for tolerance to boron toxicity. Plant Soil, 285, 115-123.

Kirkegaard, J.A., J.M. Lilley, G.N. Howe, and J.M. Graham. 2007. Impact of subsoil water use on wheat yield. Aust. J. Agric. Res. 58, 303-315.

Norton, R.M., J. Pedler, C.N. Walker, and J.F. Angus. 2003. Optimum management of N fertiliser for wheat growing on alkaline soils. Proceedings of the 11th Australian Agronomy Conference, 2-6 Feb. 2003, Geelong, Victoria, Australia. http://www.regional.org.au/au/asa/2003/p/5/norton.htm#TopOfPage

Nuttall, J.G., R.D. Armstrong, D.J. Connor. 2005. Early growth of wheat (Triticum aestivum cv. Frame, BT Schomburgk, and Schomburgk) is more sensitive to salinity than boron at levels encountered in alkaline soils of south-eastern Australia. Aust. J. Exp. Agric. 46, 1507-1514.

O'Leary, G., J. Peters, and D. Roget. 2006. A new standard for electromagnetic induction mapping of soils for the grains industry. Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006, Perth, Western Australia. Australian Society of Agronomy. http://www.regional.org.au/au/asa/2006/poster/soil/4586_oleary.htm

Pedler, J., M. Kentish, C. Walker, R. Norton, J. Ferrier, and J. Angus. 2003. Determining zones for yield response to N fertilizer in a paddock with subsoil limitations, using electromagnetic induction techniques. Proceeding of the 11th Australian Agronomy Conference, 2-6 Feb 2003, Geelong, Victoria. Australian Society of Agronomy. http://www.regional.org.au/au/asa/2003/c/15/pedler.htm#TopOfPage