INCREASED WHEAT YIELDS AND IMPROVED QUALITY FROM THE APPLICATION OF NITROGEN FERTILISER

Termination report to the Grains Research and Development Corporation on Field Trials undertaken in the Donald, Warracknabeal and Birchip areas in the period 1990-1992

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Background

The cropping system in the Wimmera region of Victoria has changed dramatically over the last 15 years. The area under medic pastures has fallen away, and long fallows are less frequently employed for moisture conservation and mineralisation of nitrogen. At the same time the cropping mix has shifted away from an emphasis on wheat on fallow, to continuous cropping systems based on large areas under grain legumes (field peas, chickpeas and faba beans) and lesser areas under oilseeds (principally canola). Over the last 15 years it has become clearer that grain legumes crops are unable to provide sufficient nitrogen, through nitrogen fixed in excess of that removed in harvested grain, to maintain the nitrogen fertility of the more intensive cropping systems. The productivity of the intensive cropping systems has therefore become increasingly dependent on fertiliser nitrogen inputs.

Fertiliser trials conducted during the late 1960's and 1970's in the Wimmera demonstrated that responses to nitrogen were notoriously variable, but that there were many opportunities for profitable use of nitrogen fertiliser. The series of trials reported here were conducted to determine which soil tests and tissue tests could be used to increase the likelihood of tissue tests could be used to increase the likelihood of profitable responses from the application of nitrogen to wheat.

Methods

1. Sites and Treatments

A total of fifteen field trials were conducted in the Wimmera and southern Mallee over three seasons 1990-1992. Growing season rainfall (April - October) varied from that equivalent to driest 10% of years in 1990 (viz. 150 - 200 mm) to that equivalent to the best five percent of seasons (viz. 450 mm) in 1992. Sites were chosen to represent a range of soil fertility and pasture histories. For the most part sites were chosen to minimise the effect of cereal root disease (cereal cyst nematode and take-all), but there were two sites which showed symptoms of these diseases.

At each site ten nitrogen fertiliser treatments were applied by pre-drilling urea and by top-dressing ammonium nitrate. Ammonium nitrate was used to avoid the complication of possible volatilisation losses from urea. However volatilisation losses from top-dressed urea during winter in the Wimmera were subsequently found to be small and no greater than those from ammonium nitrate.

Four rates of nitrogen (0, 25, 50, 100 kg N/ha) were applied at each site. These were applied either as pre-drilled and topdressed, or topdressed applications. All plots had triple superphosphate sown with the seed to provide 13 kg P/ha. These treatments were applied in a randomised block design with three replicates. Wheat (cv Rosella or Meering) was sown at 60 kg/ha in the last week of May in each year. Plot size was 3.5 x 120 m, and the central 1.25 m of each plot was harvested with a small auto plot header to determine grain yields.

2. *Measurements*

a. Site Characterisation

Each site was sampled at six points to a depth of 60 cm and the cores were split into 0 - 10 cm and 10 - 60 cm segments. A comprehensive set of analyses were conducted on the surface (0 - 10 cm) samples and these included organic carbon content and nitrate nitrogen. The nitrate nitrogen content of the subsoil (10 - 60 cm) was also determined. The neutron probe was employed to estimate plant available water held in the soil profile.

b. Sap Nitrate

At all sites samples (20 - 30 plants) were removed from all plots on two occasions (4 - 5 leaf and mid-tillering) to determine sap nitrate levels in basal stems. We derived the sap nitrate level at 70 days after sowing (5 - 6 leaf stage) by interpolating between these two sampling dates. The Nitraquick Test Kit (distributed by Aghitec, Woodside, S.A.) was used to determine sap nitrate levels. This kit employs Merckoquant Nitrate Test Strips and a hand held reflectometer to measure intensity of colour development. The standard technique for extracting sap involves grinding basal stems with a mortar and pestle and using a garlic crusher to remove a few millilitres of sap from the sample. This sap is then diluted twenty-fold before using the Merckoquant strips. An alternative (fast) method was developed to extract sap using a vitamiser (Braun KM32 liquidiser attachment, speed 2 for 90 seconds) to extract directly from 10 g of fresh basal stems placed in 200 ml of water until maximum colour development of the Merckoquant strips (speed 2 for 90 seconds).

c. Yield

Yields were determined by direct heading with a small plot autoheader which harvested the central 1.25 m of each plot.

d. Grain Nitrogen

Samples were taken from the grain harvested from each plot and analysed by Kjeldahl procedure for nitrogen content. Grain protein levels were estimated by multiplying grain nitrogen content by 5.7. All estimates were on an 'as harvested' basis.

e. Intensive Monitoring at Two Sites Each Year

Three treatments (0, 50 and 100 kg N/ha) were monitored intensively at two sites each year. In addition to the measurements outlined above, these three treatments were sampled for dry matter production (2 quadrats/plot, each 0.7 m2) on four occasions during the season. The dry matter was partitioned into stems, leaves and heads and the nitrogen content of stems, leaves and heads were determined by Kjeldahl analyses at each sampling time.

In addition changes in soil water content under each of the three treatments were monitored by installing two neutron probe access tubes in each plot, and these were read at each sampling time to establish changes in soil water content.

Results

1. Site Characteristics

The nitrate N (0 - 60 cm) at sowing varied from 21 to 140 kg/ha, and organic carbon contents (0 - 10 cm) ranged from 0.5% to 1.2% (Table 1). The soil N supply at each site was calculated by adding the nitrogen expected to be mineralised from the soil during the growing season, to the nitrate N measured at sowing. The nitrogen mineralised was estimated using the approach of Myers (1984), and was based on the assumption that the C:N ratio in surface samples was 8. Our formula, derived from that o f Myers, was:

N mineralised = 0.155 x Organic C (%) x GSR

where Organic C is the organic carbon content of the 0 - 10 cm layer, and GSR is the growing season rainfall at the site. Hence the N supply (kg N/ha, 0 - 60 cm) calculated for each site varied from 49 to 223 kg N/ha (Table 1).

2. Nitrogen Uptake in the Absence of Applied Nitrogen

Over the six intensively monitored sites, an average of 45% (range 24 - 56%) of the crop's N uptake was recovered in the harvested grain (Table 2). This recovery figure was applied to all 15 sites to calculate the apparent uptake of nitrogen by the crop (viz. N harvested/0.45). There was a close correspondence between the apparent uptake of N by the crop and calculated soil N supply (Table 1), with the calculated soil N supply explaining 76% of the apparent crop uptake in the absence of applied nitrogen.

3. The Impact of Soil and Applied Nitrogen on Sap Nitrate

Applied nitrogen was assumed to be 80% efficient in augmenting the soil N supply (Myers, 1984). Hence the total soil N supply was the sum of the inherent soil N supply and 80% of the applied N. Sap nitrate (Fast, 70 days(reflected the total soil N supply according to the equation:

$$\text{Sap Nitrate (ppm)} = \underset{(229)}{1704} + \underset{(1.7)}{11.8}\,(\text{Total Soil N Supply kg/ha}) \qquad R^2 = 0.45,\ n = 60$$

However, sap nitrate values appeared to be higher in drier seasons, and hence the explanatory power of the equation could be slightly improved by including water supply (viz. growing season rainfall plus available soil water) according to the equation:

$$\text{Sap Nitrate (ppm)} = \underset{(597)}{2957} + \underset{(2.0)}{14.4}\,(\text{Total Soil N Supply kg/ha}) - \underset{(37.2)}{84.3}\,(\text{Water Supply mm}) \qquad R^2 = 0.48,\ n =\text{-}\ 60$$

It is evident from both equations that each kilogram increase in total soil N supply increases sap nitrate values (Fast, 70 days) by 12 to 14 ppm.

4. The Relationship between the Fast and Standard Methods for Determining Sap Nitrate

The relationship between the fast and standard methods was best summarised by the regression equation:

$$\text{Fast Sap Nitrate (ppm)} = 632 + 1.15\,(\text{Standard Sap Nitrate}) \qquad R^2 = 0.55,\ n = 61$$

For practical purposes, the standard sap nitrate value was 800 - 1000 ppm below that determined by the fast method.

5. Effects on Grain Yield

Across all sites and treatments, yields mostly reflected water supply (viz. growing season rainfall plus available soil water less assumed evaporation of 110 mm), with this factor alone accounting for 80% of the variation in yields in the following regression equation:

$$\text{Yield (t/ha)} = \underset{(0.240)}{-0.645} + \underset{(0.00088)}{0.0136}\,(\text{Water Supply} - 110\text{ mm}) \qquad R^2 = 0.80,\ n = 60$$

The inclusion of an interaction term, incorporating total soil N supply and water supply, in the regression equation lifted its explanatory power from 80 to 85% as follows:

$$\begin{aligned} \text{Yield (t/ha)} = \; & -0.157 + 0.00825 \text{ (Water Supply - 110 mm)} \\ & (0.238) \quad (0.00145) \\ & + 0.000025 \text{ (Water Supply - 110) (N Supply)} \\ & (0.0000057) \qquad R^2 = 0.85, n = 60 \end{aligned}$$

Clearly this equation implies that the **apparent** water use efficiency increases with an increasing supply of nitrogen.

6. Effects on Grain Protein

Protein levels (Table 3) varied from a low of 6.4% (Donald, 1992) to a high of 19.6% (Birchip, 1991). Water supply alone (viz. growing season plus available soil water) accounted for 46% of this variation, but the inclusion of total soil N supply in the following regression equation lifted its explanatory power to 66%.

$$\begin{aligned} \text{Protein (\%)} = \; & 27.37 - 0.0278 \text{ (Water Supply mm)} \\ & (0.78) \quad (0.0026) \\ & + 0.0314 \text{ (Total N Supply kg/ha)} \qquad R^2 = 0.66, n = 60 \\ & (0.0053) \end{aligned}$$

7. Impact of Nitrogen Fertiliser on Water Use

Statistically significant ($P < 0.05$) differences in water use associated with nitrogen fertiliser application were only recorded at one (Raynes, Donald, 1992) of the six intensively monitored sites. This was the most responsive of all the sites studied with grain yields increasing from 3.3 t/ha to 6.2 t/ha with the application of 100 kg N/ha. This increase in grain yield was associated with a doubling in peak dry matter from 9200 kg/ha to 19200 kg/ha. However even this massive increase in growth resulted in a mere 62 mm increase in extraction of soil water, with total of water use rising from 430 mm to 492 mm. Hence this confirms that the application of nitrogen fertiliser principally increases the apparent water use efficiency (assuming a constant soil evaporation of 110 mm). In this case the apparent water use efficiency increased from 10.25 kg/mm in the absence of applied nitrogen to 16.3 kg/mm with 100 kg/ha of applied nitrogen.

8. Economic Rate of Nitrogen Fertiliser

Over the fifteen sites the potential yield (Table 1) was calculated by assuming a water use efficiency of 15 kg/ha/mm. The nitrogen required to grow this yield was calculated on the assumption of 1.7% grain N (9.5% protein) in the harvested grain and an N requirement to grow the crop of 2.2 times (1/0.45) the N removed in the harvest. The economic (profit maximising) rate of N fertiliser at each site was determined, and compared with the difference between the crop's N requirement to achieve its potential, and that available from soil reserves (calculated soil N supply, Table 1). There was reasonable agreement between the most economic rate of N, and that determined by difference between the N required, and the calculated soil N supply, and this is indicated in the following regression equation:

$$\text{Economic N Rate (kg N/ha)} = 1.04\ (\text{N required} - \text{Soil N Supply})$$
$$R^2 = 0.64,\ n = 15$$

CONCLUSIONS

These experiments provide a framework to allow growers in the Wimmera and southern Mallee to use soil tests for nitrate N, organic carbon, and soil water to determine firstly, their yield potential, and secondly, whether there is a need for nitrogen fertiliser to achieve that potential.

Clearly yield potentials can be adjusted with the unfolding of the season, and sap nitrate measurements at 10 weeks after seeding can be used, in conjunction with revised estimates of yield potential, to determine if there is a need for further applications of nitrogen fertiliser.

In addition to effects on yield, the data collected in these experiments enables growers to estimate their protein content, and the likely impact on grain protein of augmenting the soil N supply with fertiliser nitrogen.

Table 1. Trial site locations, soil characteristics, potential yield and calculated nitrogen supply

Site/Location	Nitrate N kg/ha 0-60 cm	Organic C % 0 - 10 cm	GSR mm	ASW mm	Potential Yield (t/ha)	N Supply Calc. (kg N/ha)
1990 sites						
Basset (Canola St.) Donald	21	0.9	200	40	1.95	49
Bell (Vetch St.) Warracknabeal	38	0.7	205	90	2.78	60
Martin (C'pea St.) Galaquil	41	1.0	150	85	1.88	64
Muller (Medic Past.) Bangerang	44	1.0	180	45	1.73	72
Barber (Pea St.) Birchip	30	0.8	150	40	1.20	49
1991 sites						
Campbell (Bean St.) Litchfield	26	0.6	275	90	3.83	52
Bell (Vetch St.) Warracknabeal	26	0.8	275	75	3.60	60
Martin Sth (Fallow) Galaquil	27	0.6	250	90	3.45	50
Martin Nth (C'pea St.) Galaquil	44	0.6	250	90	3.45	67
McClelland (Medic Past.) Birchip	71	1.0	225	70	2.78	106
1992 sites						
Raynes (C'pea St.) Donald	56	0.5	445	50	5.78	91
Hewitt (Fallow) Warracknabeal	84	1.0	445	75	6.15	153
Quick (Fallow) Brim	140	1.2	445	75	6.15	223
Marshman (Fallow) Lah	70	0.8	445	75	6.15	125
Postlethwaite (Canola St.) Donald	47	0.6	445	20	5.33	88

1. Nitrate N (kg/ha, 0 - 60 cm) derived from analyses for nitrate N in the 0 - 10 and 10 - 60 cm layers.
2. Organic Carbon (%) from analyses of 0 - 10 cm samples

3. GSR is growing season rainfall (millimetres) for May to November inclusive
4. ASW is the available soil water (millimetres) above the lower extractable limit observed for the soil type
5. Potential yield calculated (GSR + ASW - 110) x 15 kg/mm
6. N Supply estimated by addition of Nitrate N to that expected to be mineralised under growing crop (Myers, 1984).

Table 2. Peak Nitrogen Uptake and Recovery of N in the Grain at Intensively Monitored Sites

Year/Site	Treatment	Peak N Uptake (kg N/ha)	N in Grain (kg N/ha)	Recovery in Grain (%)
1990				
Basset	0 N	41	15	37
	50 N	37	15	41
	100 N	37	16	43
Bell	0 N	83	33	40
	50N	80	38	48
	100 N	87	37	43
1991				
Martin Nth	0 N	76	36	47
	50 N	113	54	48
	100 N	171	40	24
Bell	0 N	42	23	55
	50 N	114	40	35
	100 N	136	73	54
1992				
Raynes	0 N	80	37	46
	50 N	144	58	40
	100 N	158	79	50
Hewitt	0 N	207	100	48
	50 N	204	107	52
	100 N	218	121	56

Table 3. Responses in Grain Protein at the Trial Sites

Site/Location	Protein % with NO	Protein to 50 kg N	Response to 100 kg N	GSR plus ASW mm
1990 sites				
Basset (Canola St.) Donald	21	0.9	200	40
Bell (Vetch St.) Warracknabeal	38	0.7	205	90
Martin (C'pea St.) Galaquil	41	1.0	150	85
Muller (Medic Past.) Bangerang	44	1.0	180	45
Barber (Pea St.) Birchip	30	0.8	150	40
1991 sites				
Campbell (Bean St.) Litchfield	26	0.6	275	90
Bell (Vetch St.) Warracknabeal	26	0.8	275	75
Martin Sth (Fallow) Galaquil	27	0.6	250	90
Martin Nth (C'pea St.) Galaquil	44	0.6	250	90
McClelland (Medic Past.) Birchip	71	1.0	225	70
1992 sites				
Raynes (C'pea St.) Donald	56	0.5	445	50
Hewitt (Fallow) Warracknabeal	84	1.0	445	75
Quick (Fallow) Brim	140	1.2	445	75
Marshman (Fallow) Lah	70	0.8	445	75
Postlethwaite (Canola St.) Donald	47	0.6	445	20

1. Grain Protein (NO) in the absence of applied nitrogen
2. Response in Grain Protein to the application of 50 kg N/ha
3. Response in Grain Protein to the application of 100 kg N/ha
4. Sum of Growing Season Rainfall and Available Soil Water at sowing

Editor's Note: The BCDS would like to thank Peter for his tremendous work over the last decade. It was a great shock to all of us that Peter left Donald, to go to Toowoomba. Peter is now working with the Agricultural Production Systems Research Unit which is a joint venture between Queensland DPI and CSIRO. We wish Peter and his family all the best with this venture and hope that on completion of his work in Queensland, he will return to Victoria.

REMEMBER: BCDS Field Day - 14 September