Economic Development,
Jobs, Transport
and Resources

Summary Report:

Reducing on-farm nitrous oxide emissions through improved nitrogen use efficiency in grains*

June 2017

*An Action on the Ground Research Trial and Demonstration Project

AGRICULTURE VICTORIA

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SUMMARY OVERVIEW

The '*Reducing on-farm nitrous oxide (N_2O) emissions through improved nitrogen use efficiency in grains'* project provided direct evidence that significant amounts of the nitrogen (N) applied as fertiliser (and potentially also mineralised soil N) remains unaccounted for and is, presumably, irretrievably lost from the cropping system; representing both a significant cost to growers, as well as having a negative impact on the environment.

This research indicates that the best strategies to reduce both fertiliser costs and N_2O emissions in these systems are through:

1. Increased crop utilisation of soil N ('soaking up' excessive N)
2. Reducing fertiliser inputs, via better predictions of current soil N status using deep soil sampling prior to sowing.

Growers and their advisers can predict the likely amount of In Crop Mineralisation (ICM) prior to sowing using simple and rapid soil tests and adjust fertiliser N rates accordingly. Two soil tests (Hot KCl and Solvita) showed promise as predictors of ICM, both of which performed better than some of the current '*rules of thumb*' used by advisers across the regions.

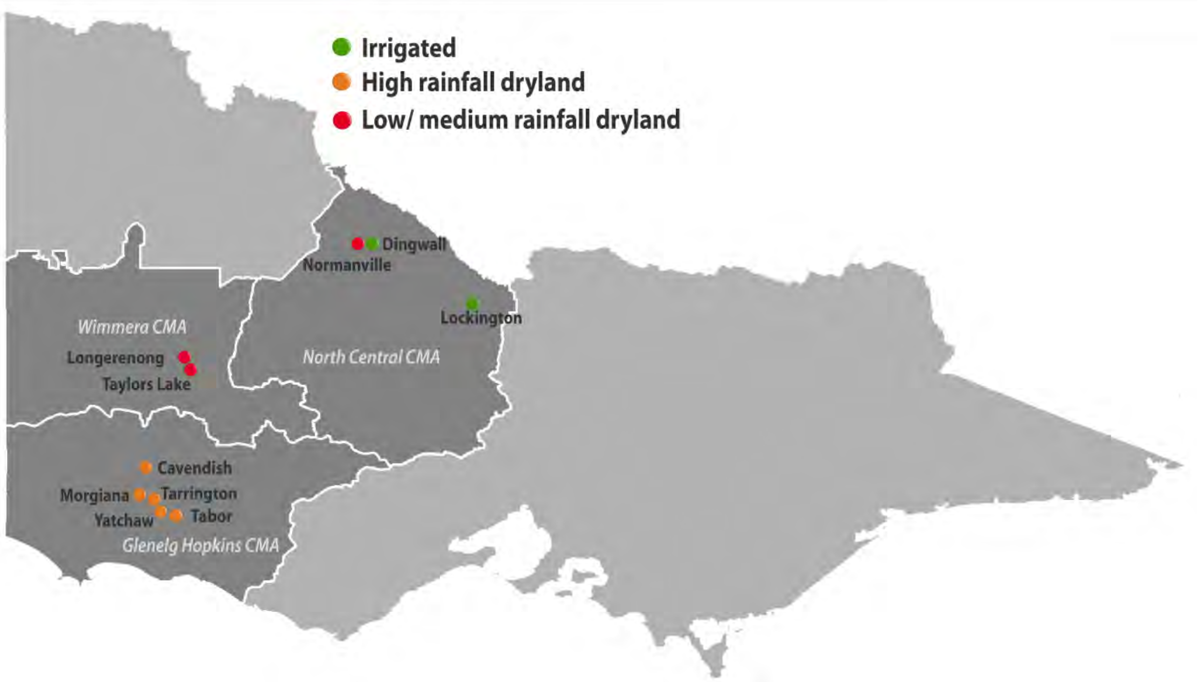

Figure 1. Trial sites located across the North Central, Wimmera and Glenelg Hopkins CMA regions of Victoria

INTRODUCTION

Grain growers are keen to reduce their production costs and increase productivity, while reducing environmental impacts. Nitrogen (N) fertiliser constitutes one of the single largest variable cost inputs for grain production in Australia, therefore even relatively small improvements in N use efficiency (NUE) can potentially result in significant financial benefits for grain growers.

Two key strategies for improving NUE are to:

1. Better predict how much N the soil can supply to the crop (with the difference between crop demand and soil supply made up by applying fertilisers)
2. Improve the utilisation of N fertiliser by the crop.

Previous Australian studies (De Antoni Migliorati *et al*. 2016, Schwenke *et al.* 2015), including those undertaken in the High Rainfall Zone (HRZ) of south-west Victoria (Harris *et al.* 2016) have linked high rates of N fertiliser application with increased nitrous oxide (N_2O) emissions. These emissions not only represent a financial loss in N investment, however as N_2O is a greenhouse gas 300 times more powerful than carbon dioxide, they are an important contributor to climate change. Some of the highest N_2O emissions in Australian agricultural systems occur in the medium and high rainfall (and potentially irrigated) cropping systems of Victoria. These N_2O emission rates usually result from large background levels of soil N and carbon (C) during periods of temporary water logging.

Current Best Management Practice (BMP) recommendations for N management in grain production tend to vary little across the wide diversity of soil types, cropping systems and environments (especially rainfall) that constitute the Victorian grains industry. Concerned that the residual soil N may not supply sufficient N to meet crop demand, growers often apply high rates of N fertiliser to cover this difference. However, there is little evidence that this N fertiliser is efficiently used (or often even beneficial). It results in both reduced grower profitability (through wasted investment in fertiliser) and increased N_2O emissions (resulting from poor utilisation of this N by the crop).

In-crop nitrogen mineralisation, (ICM) where nitrate and ammonium is produced from organic N in the soil, can be a significant source of N in cropping systems, especially those centred on acid soils of southern New South Wales (Angus et al 1998). These New South Wales systems often have a high frequency of legume pastures in the rotation resulting in high background soil N and C contents. However, little is known about the relative importance of ICM on alkaline soils and in modern continuous cropping systems that dominate Victoria and South Australia; soils and systems which either rely solely on N fertiliser or pulse crops to meet their N requirements. Current crop N utilisation coefficients (the proportion of the soil: fertiliser N used by a crop) in Decision Support Systems (DSS) rarely account for these regional differences, which can be significant.

Project Aims

This *Action on the Ground (AotG)* project aims to:

1. Maximise adoption of project learnings by trialling N fertilisers at rates and timing of application that are agronomically relevant and representative of the local industry practice
2. Increase farmer's profitability and reduce environmental impact of Victorian cropping systems through improved NUE.
3. Enable grain growers in the medium and high rainfall zone (HRZ) of Victoria (and irrigation districts) to improve their current DSS for managing N, by:
    a. Accounting for ICM
    b. Developing appropriate crop N utilisation coefficients.

METHODOLOGY

With the cooperation of seven farming families, Agriculture Victoria research scientists, working in partnership with Glenelg Hopkins, Goulburn Broken and Wimmera Catchment Management Authorities, established nine trial sites within low, medium, high rainfall and irrigated cropping zones across Victoria (Figure 1).

Field experimentation was undertaken between 2014 and 2016. Data collected at each site included:

1. Soil characterisation – both pre and post-harvest to a depth of 1.2 metres
2. Measurement of soil based N_2O emissions and monitoring changes in soil water and mineral N at key times during the growing season
3. Recovery of N, applied as urea fertiliser, by the crop as well as residual N in the soil – post harvest
4. Crop measurements including establishment, biomass at flowering, grain yield at maturity, N uptake and grain quality indicators.

In order to provide a good representation of grain production systems in south east Australia, the trial sites selected represented a diverse range of:

* Soil types (Vertosols, Calcarosols, Sodosols and Chromosols)
* Rainfall (average annual from 325mm to nearly 700mm)
* Background soil fertility (varying N and C concentrations)
* Management systems.

All agronomic management, with the exception of in-season N fertiliser application, was undertaken by the grower. Data from these experiments were used to specifically:

1. Assess how soil based N_2O emissions in commercial cropping systems are influenced by soil type, background N and C content, environment (rainfall and temperature) and N fertiliser application
2. Determine the utilisation and recovery in the soil: plant system of N fertiliser applied to these crops using ^{15}N mass balance approach in order to develop crop utilisation coefficients
3. Assess the importance of ICM to crop N supply
4. Evaluate different methodologies to allow growers to more readily predict the amount of ICM.

Agriculture Victoria Research Scientist, Ash Wallace.

Trial Design and Fertiliser Treatments

Initial soil testing determined that at 0-10 cm depth, concentrations of both soil total N, and total and organic C, were highest in the HRZ sites (organic C was three to 6.5 per cent) and lowest (less than two per cent) in the low rainfall Mallee and medium rainfall Wimmera regions. Soil N and C concentrations at the two irrigated cropping sites, were also relatively low (organic C ranged from 0.09 to 0.31 per cent and total N from 0.97 to 2.42 per cent).

A simple N rate response trial was established at each site using a randomised complete block design with plot sizes of approximately $18m^2$. Three N treatments were applied at each of the nine sites, (representing 29 N fertiliser rate experiments) based on industry standard practice relevant to each region and the seasonal conditions. Sites received a small rate of N fertiliser across all plots at sowing (0-20 kg N/ha), typically in the form of Mono-Ammonium Phosphate (MAP) or Di-Ammonium Phosphate (DAP) depending on farmer management. Treatments included two rates of N fertiliser applied during the growing season plus a control which received no N during the season.

Nitrogen rates and timing were determined by the farmer's normal practice for the broader paddock and applied as hand spread, top-dressed urea granules (46 per cent N). Where the farmers rate of application was considered modest (for expected yield potential), the higher experimental rate was set as twice the farmer rate. Where the farmer rate was high, the second experimental rate was set as half the farmer rate.

Fertiliser application (top-dressed by hand) was generally made in anticipation of a rainfall event occurring within the following two to three days, during the vegetative or stem elongation growth stages, although in higher yielding situations (especially the HRZ and irrigated sites), follow up applications were made in some seasons.

RESULTS

The experimental period was characterised by extremes in rainfall, ranging from low (decile 1-2) Growing Season Rainfall (GSR) at many sites in 2014 and 2015 to extremely wet (decile 10) annual and GSR at most sites in 2016. The wide range of seasonal conditions recorded during the life of the project was similarly matched by large differences in soils and key variables affecting N management. This range of seasonal conditions, combined with the inherent variation across the nine experimental sites examined in the project, provided a strong basis to examine the full diversity of grain production systems in Victoria.

N recovery

A key feature of the crop data was the general lack of response to N fertiliser application (Table 1). Using ^{15}N tracer procedures to differentiate between N derived from fertiliser and large background levels of soil N, the project found that the amount of fertiliser N used by the target crop ranged from less than five per cent to a maximum of 62 per cent of the N applied. Fertiliser N recovery was significantly related to the amount of water (GSR + irrigation) recorded in the growing season. Average recovery of fertiliser N by the crop was low, ranging from 42 per cent in irrigated, 32 per cent in low/medium rainfall, to 30 per cent in high rainfall systems. These values are considerably lower than the figure of 50 per cent (for crop utilisation coefficients) currently used as a *rule of thumb* by many in the industry when estimating N fertiliser requirements.

Of real concern to growers is the large losses of fertiliser N detected. Fertiliser N recovery in the crop, **plus** that remaining in the soil at maturity, averaged only 71 per cent; varying from 63 per cent in the HRZ to 76 per cent in the low/medium rainfall regions. On one occasion, total N recovery of only 60 per cent of the N fertiliser applied was recorded, i.e. 40 per cent of the N applied was irretrievably lost to the environment.

Table 1: The amount (per cent) of fertiliser N recovered in the grain, straw, crop (grain + straw), in the soil and crop + soil at maturity in relationship to the amount of N fertiliser applied and growing season rainfall (GSR) + irrigation applied (mm) for (a) 2014, (b) 2015 and (c) 2016.

(a) 2014								
Farming system	**Site**	**N fertiliser applied (kg/ha)**	**GSR + Irrigation**	**Grain**	**Straw**	**Crop**	**Soil**	**Crop + Soil**
Low rainfall continuous cropping	**Normanville**	40	172	38.9	16.4	55.2	21.9	77.1
Medium rainfall continuous cropping	**Taylors Lake 1**	80	202	2.5	1.8	4.3	98.4	102.6
	Taylors Lake 2	80	202	3.0	1.2	4.3	57.9	62.2
	Longerenong T4	36.8	202	20.9	23.3	44.2	44.9	89.1
	Longerenong T6	36.8	202	26.9	16.0	43.0	45.0	88.0
High rainfall mixed farming	**Cavendish**	36.8 + 36.8	356	21.6	16.7	38.3	36.8	75.1
	Yatchaw	36.8 + 36.8	491	23.4	5.9	29.3	47.0	76.3
	SFS	50 + 50	366	31.8	10.9	42.8	51.3	94.1
Irrigated cropping	**Dingwall**	73.6	185 + 3.2 ML	28.0	7.3	35.4	17.1	52.5
	Lockington	82.8 + 82.8	172 +2.9ML	42.8	14.9	57.7	54.6	112.3
	1sd (P = 0.05)*			26.6^{+}	9.5	32.3	33.6	n.s.

(b) 2015								
Farming system	**Site**	**N fertiliser applied (kg/ha)**	**GSR + Irrigation**	**Grain**	**Straw**	**Crop**	**Soil**	**Crop + Soil**
Low rainfall continuous cropping	**Normanville**	40	150	9.6	6.0	15.6	69.1	84.7
Medium rainfall continuous cropping	**Taylors Lake 1**	80	130	0.3	11.5	11.8	56.8	68.6
	Taylors Lake 2	80	130	4.1	7.0	11.1	55.8	66.9
	Longerenong T4	36.8	142	2.9	11.4	14.7	59.3	74.0
	Longerenong T6	36.8	142	5.0	11.4	16.4	53.9	70.2
High rainfall mixed farming	**Cavendish**	57 + 57	275	8.9	13.7	22.6	39.9	62.5
	Yatchaw	73.6	393	21.0	3.1	24.1	55.5	79.6
	SFS	50	339	14.8	5.2	20.0	19.8	39.9
Irrigated cropping	**Dingwall**	78.2	171 +3.7ML	44.2	7.5	51.7	16.8	68.5
	Lockington	82.8	130 + 2.8ML	24.6	6.4	31.0	35.5	66.5
	1sd (P = 0.05)*			8.5	n.s.	9.2	18.0	14.5

(c) 2016								
Farming system	**Site**	**N fertiliser applied (kg/ha)**	**GSR + Irrigation**	**Grain**	**Straw**	**Crop**	**Soil**	**Crop + Soil**
Low rainfall continuous cropping	**Normanville**	45.5	301	38.1	8.9	47.1	25.9	72.9
Medium rainfall continuous cropping	**Taylors Lake 1**	45.5	377	41.3	19.1	60.4	22.1	82.4
	Taylors Lake 2	45.5	377	47.0	14.6	61.7	15.6	77.2
	Longerenong T4	46	373	34.0	14.1	48.0	15.3	63.3
	Longerenong T6	46	373	29.5	11.7	41.2	17.3	58.5
High rainfall mixed farming	**Cavendish**	46	631	27.2	10.7	37.9	16.6	54.4
	Yatchaw	91	633	22.8	6.1	28.8	17.5	46.3
	SFS	91	624	26.1	4.4	21.8	18.8	40.6
Irrigated cropping	**Dingwall**	91	340	27.1	5.0	32.1	24.0	56.0
	Lockington	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	1sd (P = 0.05)*			11.1	6.2	10.2	5.9	14.2

*Statistical significance; 1sd = one standard deviation, n.s. = not significant n.d. = not determined

In-Crop N Mineralisation

In general, in-crop N mineralisation, (ICM) isn't currently well accounted for in farming. In this study, ICM was found to be a potentially major source of N to crops (Table 2); constituting up to 63 per cent of crop N, which needs to be factored into estimates of soil N supply. Overall, net ICM (ignoring cases with negative values) provided the potential to supply an average of 75.6 per cent of crop N in low/medium rainfall sites (n=11), 40.1 per cent at HRZ sites (n=8) and 57 per cent on the irrigated sites (n=3). The relative importance of this N source to crop N uptake varied predominantly with the seasonal rainfall, rather than with soil type or region, highlighting the need for an accurate soil test procedure to predict supply. Although the potential contribution of ICM to crop N supply is significant, it needs to be considered in the context of the, often, large amounts of mineral N in the profile recorded at pre-sowing (which is derived from N mineralisation during the preceding fallow period).

This project found that, in many cases, sufficient soil N is present in the soil profile prior to sowing to meet most of the crops demand for N. By undertaking appropriate soil testing, grain growers would save the expense of applying N fertiliser that the crop simply did not require.

Losses of fertiliser N (and presumably background soil N) from the soil: crop system can be significant and represent a major financial loss (and potential environmental problem) to grain growers.

Table 2: Estimates of net In-Crop N Mineralisation (ICM) as measured by the crop and soil nitrate.
NOTE: All units are in kg N/ha. Values presented as averages. Soil nitrate data were used for calculations, ammonia was not included. Negative values for ICM indicate either unaccounted for N losses to the environment, e.g. via denitrification and/or experimental error.

Year	Location	Crop N kg/ha	Pre-sowing kg/ha	Post harvest kg/ha	Fertiliser kg/ha	ICM kg/ha	ICM as proportion of crop N (%)
2014	Taylor's Lake (1)	24.3	39	30.4	4	14	58
	Taylor's Lake (2)	27.5	86.7	35.6	4	-24.9	-
	Longerenong (T4)	79.6	75.7	23.6	8.7	26.6	33.4
	Longerenong (T6)	35.8	72.2	13.5	8.7	-28	-
	Yatchaw	84.5	152	70.7	10	1.8	2.1
	Cavendish	83.2	88.3	40.1	7.75	35.6	42.8
	SFS	98.8	229.4	105.9	10	-24.9	-
	Dingwall	164.2	329	229.6	10	71.2	
	Lockington	60.3	121	22.9	8	-39.7	-
	Normanville	78.1	152.1	56	4	-14.2	-
2015	Taylor's Lake (1)	16	44.2	59.5	0	32.9	205
	Taylor's Lake (2)	49.6	82.3	44.1	0	16.3	32.8
	Longerenong (T4)	48.8	79.1	50.8	8.7	16.7	34
	Longerenong (T6)	28.4	48.3	23.1	8.7	-2.7	-
	Tabor	145.1	96.7	54.1	10	106.9	73.8
	Cavendish	103.7	165.1	108.4	9.6	47.8	46.1
	SFS	93.8	162.3	127.8	8	60.7	64.7
	Dingwall	102.7	57	11.7	20.25	47.4	46.1
	Lockington	55.8	31.6	35.7	20	45.5	81.5
	Normanville	26.2	66	82.5	3.5	41.9	160
2016	Taylor's Lake (1)	111.6	105.5	53.1	4	66.4	59.5
	Taylor's Lake (2)	101.2	47.4	14.5	4	74.5	73.7
	Longerenong (T4)	106.2	54.7	16.1	8.7	69.5	66
	Longerenong (T6)	85	47.9	23.1	8.7	60	70.6
	Yatchaw	114.1	129.3	18.1	8.96	5.3	4.6
	Cavendish	116.2	165.8	95.8	9.6	48.2	41
	SFS	109.4	171.5	100.8	0	49.6	45.5
	Normanville	138.9	145.8	47.2	3	51.2	36.7
	Dingwall	27	36.1	26.8	7.5	12.8	47.4

Nitrous oxide ($N_2$0) emissions

Generally, there was no clear effect on emissions when N fertiliser was applied (top-dressed) at rates up to double that used by growers, especially in the low/medium rainfall environments.

Daily loss of N as N_2O varied significantly across sites and years with the highest values measured in irrigated and HRZ systems (Table 3). Irrigated cropping was particularly variable throughout the season with extremely high daily losses after irrigation followed by prolonged periods of low flux. These high N_2O emissions appear to result from poor drainage and occurred despite the low background soil N and C contents of these soils. High rainfall situations on the other hand tended towards lower peak losses, but were more consistently high compared with the Wimmera and Mallee.

Top-dressing N in the form of urea didn't always result in an increase in losses of N as N_2O compared with the unfertilised control. Across all years the strongest relationship between fertiliser addition and N_2O loss was in the irrigated situations and to a much lesser extent the Wimmera. In the HRZ, where soil N levels are higher, the addition of fertiliser N had limited effect on losses indicating that N was not limiting losses in this situation. In the Mallee, losses were low throughout and adding fertiliser made little difference.

Table 3: Peak and average N loss as N_2O across all years with and without fertiliser

	Peak N loss (g/ha/day)		Average N loss (g/ha/day)	
	No fertiliser	**+ N fertiliser**	**No fertiliser**	**+ N fertiliser**
Wimmera	29.6	51.7	0.76	1.4
Mallee*	11.2	5.6	0.7	0.6
High rainfall zone	186.5	132.1	8.1	7.3
Irrigated^	39.7	376.0	2.9	21.1

*Includes a site at Dingwall in 2016 which is normally irrigated, but was not irrigated due to seasonal conditions.
^Excludes data from Dingwall, 2014.

Wimmera:

Daily loss of N as N_2O in the Wimmera was generally low across all years and the relationship between topdressing urea and losses was limited (Table 4). The main exception to this was one of the Taylors Lake sites in 2015 where N_2O losses were significantly higher than those measured at most Wimmera sites over multiple years. In this case, peak losses were over 50g N/ha in a day, and emissions from the site were consistently higher than others in this region. Nonetheless, it appears that in most situations in the Wimmera, loss of N as N_2O is unlikely to be a major source of N loss to crops.

Table 4: Peak and average N loss as $N_2$0 across all years in the Wimmera with and without fertiliser

	Peak N loss (g/ha/day)		Average N loss (g/ha/day)	
	No fertiliser	**+ N fertiliser**	**No fertiliser**	**+ N fertiliser**
2014	29.6	3.2	0.96	0.04
2015	14.0	51.7	1.2	4.9
2016	7.7	8.7	0.5	0.6

North Central:

Daily loss of N as N_2O in North Central Victoria was highly dependent on whether or not the site was irrigated. Where irrigation was applied, peak and average losses were higher than any other region, in contrast dryland paddocks produced some of the lowest N_2O losses measured in Victoria. Interestingly, this also applied to a site at Dingwall which would normally be irrigated but wasn't in 2016 due to the wet seasonal conditions. Despite annual rainfall being one of the highest on record, peak N_2O losses were still small compared to those following irrigation in other years. Excluding data from Dingwall in 2014, the relationship between addition of fertiliser and N_2O was quite clear. Overall it appears that irrigated cropping has the ability to emit extremely high rates of N_2O over very short periods before falling away to background levels comparable with other situations. The challenge is that daily peaks can be of a similar magnitude or more, to annual totals from other environments.

Table 4: Peak and average N loss as N_20 across all years in the North Central with and without fertiliser

		Peak N loss (g/ha/day)		Average N loss (g/ha/day)	
		No fertiliser	**+ N fertiliser**	**No fertiliser**	**+ N fertiliser**
Irrigated	**2014^**	12.4	376.2	2.1	39.7
	2015	39.7	149.7	3.3	12.2
Dryland	**2014**	11.2	5.3	1.8	1.5
	2015	0.4	1.1	-0.1	0.3
	2016*	1.1	5.6	-0.1	0.5

*Includes a site at Dingwall in 2016, which is normally irrigated, but was not irrigated due to seasonal conditions.
^Excludes data from Dingwall, 2014.

South-West/Glenelg Hopkins:

Daily loss of N as N_2O in South-West Victoria was high compared to the Wimmera and Mallee. In 2015 and 2016, both peak and average N loss was higher where N was topdressed, however this was not the case in 2014. It is clear that soils in this region typically emit higher levels of N_2O than other regions even in the absence of fertiliser addition. This is likely related to a combination of factors including high levels of soil carbon and N as well as regular periods of waterlogging during the growing season. While N loss as N_2O is high compared to other regions, it is still unlikely that this loss would significantly affect crop yields. However, such high levels of N_2O loss is indicative of denitrification which can result in far more significant losses of N in the di-nitrogen form.

Table 4: Peak and average N loss as N_20 across all years in the South-West with and without fertiliser

	Peak N loss (g/ha/day)		Average N loss (g/ha/day)	
	No fertiliser	**+ N fertiliser**	**No fertiliser**	**+ N fertiliser**
2014	186.5	31.2	18.9	5.2
2015	13.3	17.5	1.9	3.3
2016	108.3	132.1	6.6	9.4

Deep soil testing

One of the aims of this project was to identify a rapid, reliable and cost effective soil assessment procedure that could estimate potential soil N mineralisation. Ideally, samples would be collected from the topsoil in the autumn period prior to sowing, to coincide with deep soil sampling of the profile to estimate soil mineral N present, which remains a key best management practice recommendation for all grain production systems throughout Australia.

Four soil testing methods were trialed; two anaerobic soil incubation procedures considered 'standard' soil sampling procedure by researchers were used as 'benchmark' soil test procedures for comparison with the Hot KCl extraction and the Solvita soil tests. Throughout this study, Hot KCl showed stronger correlations with Crop N and ICM than the other soils tests, except for the Solvita test, which also performed well. The strength of the correlations improved when the 10-20cm depths were included, instead of just the topsoil (0-10cm). The Hot KCl method was also well correlated with the other soil test indices. The results of this study suggest that Hot KCl may be a valuable method for predicting ICM and may warrant further investigation on a wider range of Australian soils.

The Solvita test strongly related with both the other soil indices examined, as well as ICM and Crop N. Nevertheless, the actual values obtained from the Solvita tests show much higher values of N than what is actually expected to be supplied by the soil in these cropping systems, and are unrealistically high relative to all of the other measures. However, the

Solvita test takes only 24 hours to complete and is relatively simple (just requiring an input of NaOH). It may therefore be a promising alternative for Australian grain producers to predict ICM, when it has been properly calibrated to suit Australian cropping soils.

The Myers '*rule of thumb'* prediction is a simple method for predicting ICM that only requires estimates of growing season rainfall and soil organic C concentration. This method is widely used by advisors in southern Australia because it is quick and simple and requires very little data input. This study found the Myers '*rule of thumb*' to be well correlated with all of the soil tests examined in this study, and also correlated well with ICM and Crop N. However, while the Myers '*rule of thumb*' may be well correlated with field based measures of ICM, these calculations were done retrospectively i.e. after the GSR was recorded, limiting its practical use by growers and advisors as a predictive management tool. At present, there is no accurate means of predicting GSR, although continuing improvements in seasonal forecasting may overcome this constraint.

MORE INFORMATION

More information about this project, including detailed research results, will be available at the nitrous oxide hub: http://agriculture.vic.gov.au/agriculture/weather-and-climate/understanding-carbon-and-emissions

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