Nitrapyrin with nitrogen can improve yield or quality of wheat, grass pasture, canola or sugarcane in Australia

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Abstract
Nitrapyrin has been used extensively in the USA to stabilise applied nitrogen particularly for maize production. In 2012 nitrapyrin (product name eNtrench™ Nitrogen Stabiliser) was approved by National Industrial Chemicals Notification and Asessment Scheme (NICNAS) for use in crops including wheat, sorghum, maize, sweet corn and cotton in Australia. It is the only product that has undergone this type of review for approval for use in Australia.

This paper reports on field research trials to determine whether nitrapyrin use improved yield or quality in crops or ryegrass in Australia. Research to date has shown the the potential value of nitrapyrin to improve nitrogen use efficiency and to mitigate nitrous oxide emissions. This paper will focus on field research trials to demonstrate improved nitrogen use efficiency.

Key Words
Nitrapyrin, eNtrench™, crops, yield, quality

Introduction
Nitrapyrin has been used widely in the USA and other countries to stabilize applied nitrogen, and so to improve nitrogen use efficiency. In Australia, nitrapyrin was approved for use in crops in 2012. Research work has been undertaken to determine whether it could improve yield or quality in crops, when applied with nitrogen (N).

Dalal et al. (2003) reported atmospheric nitrous oxide (N_2O) concentration had increased 16% since 1750 and losses from agriculture varied from 0.02-1.4% of applied N in irrigated rice, and up to 15.4% in irrigated sugar cane in the first four days after application. Chen et al. (2010) showed that both 3, 4- dimethylpyrazole phosphate (DMPP) and 2-chloro-6-(trichloromethyl) pyridine (nitrapyrin) could be used to reduce the amount and rate of nitrification of ammonium from N sources and so N_2O emissions in incubation studies on a Vertosol soil from southern Australia that was treated with urea and at a range of temperatures (5-25^oC) and moisture regimes (40 or 60% water filled pore space).

Wolt (2004) reported from a meta-analysis of the agronomic and environmental effectiveness of nitrapyrin treated urea applied to corn in the Midwestern USA, that crop yield increased 7%, N retention increased 28%, N leaching decreased by 16% and reduced N_2O emissions by 51%, compared to N alone. Qiao *et al.* (2015) also reported from a summary of 62 nitrification inhibitor (NI) field studies, that the chemical inhibition of nitrification resulted in an average 20% increase in ammonia (NH_3) emission, reduced dissolved inorganic N leaching by 48%, reduced N_2O emission by 44% and reduced nitrogen oxide (NO) emission by 24%, which resulted in a 16.5% reduction in total N release to the environment, compared to N alone. Nitrification inhibition increased plant N recovery by an average of 58%, grain recovery 9%, straw 15%, vegetable 5% and pasture 14%.

This paper will report on research work in wheat, canola, ryegrass and sugarcane that compared the yield and quality or N recovery between N alone and N applied with nitrapyrin.

Methods
Wheat – yield and protein – Lake Bolac, Victoria
In 2015 at Lake Bolac, Victoria a trial was conducted to determine the effect on yield (t/ha) or protein (%) of addition of nitrapyrin to applied N (either UAN 32-0-0 or urea 46-0-0), at either planting or the noding (stem elongation) stage of wheat. Prior to planting soil samples were taken at 0-60cm to determine pre-existing N levels. Target N rates were determined using the CSIRO N budget web tool method Baldock (2003). Nitrogen plus/minus nitrapyrin was applied using a motorbike mounted sprayer, or applied as urea by hand spreading. The N rate used was selected to meet 100% or 75% of target yield, which allowed for comparison

of effect of nitrapyrin at two N rates. Wheat was assessed for vigour, normalised difference vegetative index (NDVI) score, yield, protein and test weight at harvest. Spring 2015 was very dry for Lake Bolac. Treatments were replicated four times.

Wheat – soil N – Westmere, Victoria
In 2015 at Westmere, Victoria a trial was conducted to determine the effect of addition of nitrapyrin to applied N on yield, protein and soil N (ammonium (NH_4) and nitrate (NO_3)). Nitrogen was applied as urea, deep banded at sowing, followed by topdressing at GS22 stage of wheat (second tiller). Soils were sampled prior to planting and target N rates were calculated for 75% (TY75) and 100% (TY100) of target yield (5.8 t/ha) based on the water limited yield potential. Soil samples were taken at 2, 4 and 8 weeks after treatment to measure for NO_3 and NH_4 levels in the soil by depths of 0-10, 10-30 and 30-60cm. The site was located on field pea stubble, so there were high levels of mineralisable N over the duration of the trial. There was little rain in October at the site. Treatments were replicated four times.

Oats – hay yield – Halbury, South Australia
In 2015 at Halbury, South Australia a trial was conducted to determine the effect on hay yield, of addition of nitrapyrin to applied N at planting. Soil N was measured prior to planting and desired yield was estimated using the CSIRO method mentioned above. Treatments applied were diammonium phosphate (18-46-0, DAP), DAP followed by urea, or DAP followed by urea plus nitrapyrin. Treatments were applied at planting and incorporated by sowing and subsequent rain, for post-planting treatments. Biomass cuts were taken when the crop would have been cut for hay. The site was unreplicated, but 12 subsamples per plot were taken to give average yields.

Canola – yield, protein and oil content – Kojonup, Western Australia
In 2015 at Kojonup, Western Australia a trial was conducted to determine the effect of nitrapyrin use in the typical agronomic N use pattern on yield, protein and oil. Three N applications were made – first at planting, then at rosette (4-8 leaf) and finally at green bud. Two N regimes were applied - full rate regime (TY100%) and 75% regime (TY75%). Nitrapyrin was either applied at planting or rosette stage at 0.5kg/ha. Canola was monitored for crop effect, harvest yield (t/ha), protein and oil (%). Treatments were replicated four times.

Ryegrass – biomass – Kangaroo Island, South Australia
In 2014 at Kingscote, Kangaroo Island a trial was conducted to determine the effect of nitrapyrin on ryegrass production, when used with urea. The trial site was planted on 7th June with 25kg/ha of ryegrass, cv. Vortex. Nitrapyrin (0.5kg/ha) was applied either at planting or tillering. Urea at 100kg/ha was applied at tillering. Rain (13mm) occurred within seven days and the site had high rainfall for the remainder of the trial. Treatments were replicated four times.

Sugarcane – yield and sugar – Ingham, Queensland
In the 2013/14 cane growing season, a trial was conducted at Ingham to determine the effect of nitrapyrin on cane yield (t/ha) and sugar (ccs). Three fields on one farm were treated with grower standard practice N regime, with and without nitrapyrin at 0.5kg/ha, where N was applied to the cane stool via stool splitter. The three fields were then monitored throughout the growing season and cane yield and sugar content was taken at normal harvest time. This work was not replicated, but was done in 3 separate fields on the one farm with field scale equipment and cane harvest.

Results

Wheat – yield and protein – Lake Bolac, Victoria
Table 1 shows results for a yield, protein and test weight. In the very dry spring of 2015, wheat yield was similar among N treatments, but protein was increased where nitrapyrin was added and highest where urea was applied with nitrapyrin.

Table 1. Effect of nitrapyrin on wheat yield and protein, Lake Bolac, Victoria.

Treatment (product/ha)	Timing	Yield (t/ha)	Protein (%)	Test Wt. (kg/hL)
Untreated		2.83	7.1	79.6
UAN 30L fb* UAN 20L	Planting Noding	2.95	7.9	78.8

UAN 30L + nitrapyrin 0.5kg fb UAN 20L	Planting Noding	3.0	8.1	78.7
UAN 40L fb UAN 25L	Planting Noding	3.06	7.9	79.4
UAN 45L + nitrapyrin 0.5kg fb UAN 25L	Planting Noding	3.01	8.2	78.1
Urea 40kg + Nitrapyrin 0.5kg fb Urea 25kg	Plant Noding	3.09	8.7	78.9
LSD (P=0.05)		0.09	0.61	3.67

fb* **-** indicates followed by in treatments. (UAN 32-0-0, urea 46-0-0).

Wheat – soil N – Westmere, Victoria

Table 2 shows results for NO_3 and NH_4 measured by depth at eight weeks after treatment. There was more NO_3 and NH_4 in the 10-30cm profile depth where nitrapyrin was added to the urea application compared to either untreated or urea treatments.

Table 2. Soil distribution and average amount of NO_3 or NH_4 (kg/ha) at 8 weeks after application at planting, Westmere, Victoria (± SE).

N Treatment	NO_3	NO_3	NO_3	NH_4	NH_4	NH_4
	0-10cm	10-30cm	30-60cm	0-10cm	10-30cm	30-60cm
TY75	16 (± 1.5)	66 (± 11.2)	66 (± 0.5)	9 (± 1)	17 (± 2.7)	5 (± 0.5)
TY75 + nitrapyrin	16 (± 0.7)	88 (± 3.8)	75 (± 4.6)	12 (± 1.2)	27 (± 4)	6 (± 0.6)
Untreated	15 (± 0.5)	72 (± 0.3)	64 (± 8.3)	6 (± 0.2)	13 (± 0.1)	7 (± 0.5)

Oats – biomass yield – Halbury, South Australia

Table 3 shows results for oat biomass after addition of nitrapyrin to N regime of DAP +/- urea. Numerically higher oat biomass was produced where nitrapyrin was added.

Table 3. Effect of nitrapyrin on oaten hay biomass production, Halbury, South Australia

Treatment (product/ha)	Hay biomass (t/ha)
DAP 48kg/ha	6.09
DAP 48kg/ha + urea 58kg/ha	6.13
DAP 48kg/ha + urea 58kg/ha + nitrapyrin 0.5kg/ha	6.77
SD 0.75, CV 0.21	

(DAP 18-46-0, urea 46-0-0).

Canola – yield, protein and oil content – Kojonup, Western Australia

Table 4 shows results for canola yield (t/ha), oil (%) and protein (%), after three applications of N, applied in sequence of either urea or UAN, with or without nitrapyrin. The high N regime, with nitrapyrin applied at planting resulted in significantly more canola yield, than the corresponding N alone treatment. (There was no low N regime alone, to check the value of nitrapyrin addition).

Table 4. Effect of Nitrapyrin on canola yield, oil and protein, Kojonup, Western Australia.

Treatment (product/ha)	Timing	Yield (t/ha)	Protein (%)	Oil (%)
Untreated		1.33	19.9	45.4
Urea 36kg/ha fb* UAN 90L/ha fb UAN 70L/ha	Planting 4-8 leaf early bud	1.73	22.7	42
Urea 36kg/ha + nitrapyrin 0.5kg/ha fb UAN 90L/ha fb UAN 70L/ha	Planting 4-8 leaf early bud	1.87	22.6	42.3
Urea 36kg/ha fb UAN 90L/ha + nitrapyrin 0.5kg/ha fb UAN 70L/ha	Planting 4-8 leaf early bud	1.67	23.1	41.2
Urea 28kg/ha + nitrapyrin 0.5kg/ha fb UAN 69L/ha fb	Planting 4-8 leaf	1.67	22.6	41.8

UAN 55L/ha	early bud			
Urea 28kg/ha fb UAN 69L/ha + nitrapyrin 0.5kg/ha fb UAN 55L/ha	Planting 4-8 leaf early bud	1.61	22.3	42.3
LSD (p=0.05)		0.13	0.47	0.65

fb* - indicates followed by in treatments. (Urea 46-0-0, UAN 32-0-0).

Ryegrass – biomass – Kangaroo Island, South Australia

Table 5 shows the results of ryegrass production when nitrapyrin was added to urea applied at early tillering. Where nitrapyrin was added, higher ryegrass production occurred.

Table 5. Effect of nitrapyrin on ryegrass production, Kangaroo Island, South Australia.

Treatment (product/ha)	Nitrapyrin timing	Biomass (t/ha)
Urea 100kg/ha	-	11.15
Urea 100kg/ha + nitrapyrin 0.5kg/ha	Planting	12.47
Urea 100kg/ha + nitrapyrin 0.5kg/ha	Tillering	13.01
LSD (P=0.05)		0.07

(Urea 46-0-0).

Sugarcane – yield and sugar – Ingham, Queensland

Table 6 shows the results of cane production (t/ha) and sugar content (ccs) when nitrapyrin was added to applied N at planting. Nitrapyrin addition increased yield and maintained sugar content.

Table 6. Effect of Nitrapyrin on average cane yield and sugar production, Ingham, Queensland.

Treatment (product/ha)	Field name	Variety	Cane yield (t/ha)	Sugar (ccs)
CK 140s 650kg/ha	Orient 2-3	Q208	82.7	16.29
CK 140s 650kg/ha + nitrapyrin 0.5kg/ha	Orient 2-3	Q208	88.5	16.12
NitraKing S 575kg/ha	Orient 3-1	Q208	49.12	15.75
NitraKing S 575kg/ha + nitrapyrin 0.5kg/ha	Orient 3-1	Q208	53.57	15.26
NitraKing S 575kg/ha	Orient 3-2	MQ239	68.19	13.15
NitraKing S 575kg/ha + nitrapyrin 0.5kg/ha	Orient 3-2	MQ239	74.01	13.22

(CK 140s 32-2-17.5-3.8, NitraKing S 26.6-0-16-4.3). Treatments applied after harvest to cane stool.

Conclusion

Nitrapyrin used in trials in Australia has shown potential to increase nitrogen use efficiency. Further work is needed to confirm the preliminary findings across crop types, soils and geographies that are outlined in this paper.

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