Recovery of 15N urea fertiliser applied to wheat under different management strategies, in the High Rainfall Zone of south western Victoria

Rob Harris[1], Roger Armstrong[2] and Ash Wallace[2]

[1]Vic Dept. of Economic Development, Jobs, Transport and Resources, Hamilton VIC 3300, rob.harris@ecodev.vic.gov.au,
[2]Vic Dept. of Economic Development, Jobs, Transport and Resources, Horsham VIC 3400.

Abstract
The fate of ^{15}N labelled urea applied to wheat cv. Bolac was studied at Hamilton (2012) and Tarrington (2013) on brown chromosol soils in the High Rainfall Zone of south western Victoria. Wheat was fertilised with ^{15}N labelled urea solution, equivalent to 100 kg N/ha, either deep banded 10 cm below the seed at sowing or topdressed with or without the nitrification inhibitor DMPP (3,4-*Dimethylpyrazole phosphate or* ENTEC®) at the first node growth stage. At physiological maturity, the recovery of ^{15}N in straw, grain and soil (40 to 60 cm depth) was assessed. At both sites, topdressing N resulted in significantly ($P<0.001$) greater recovery of applied N than deep banding. However, topdressing with DMPP did not significantly improve crop recovery of ^{15}N urea compared with untreated urea. Across both sites, between 76 and 84 % of the applied ^{15}N was recovered in the plant and soil at maturity when topdressed at first node, compared with 7 to 23 % when ^{15}N was deep banded. The poor recovery of deep banded ^{15}N appeared to result from winter waterlogging triggering gaseous or drainage losses before wheat reached peak growth and demand for N in spring. Despite, the poor recovery of deep banded ^{15}N, wheat grain yields were statistically the same as those topdressed with ^{15}N; the former treatment compensating for low fertiliser recovery by sourcing more N from the soil. Both sites had high concentrations of soil organic C (>3.1 %) and the potential for large rates of mineralisation.

Key words
Wheat, nitrogen, nitrification inhibitor, 3,4-dimethylpyrazole phosphate, urea, nitrogen recovery

Introduction
Nitrogen (N) fertiliser now constitutes the single largest variable cost for most grain growers, and so maximising N fertiliser uptake and avoiding wastage, is essential for increasing grower returns and reducing losses into the surrounding environment. In the High Rainfall Zone (HRZ) of south west Victoria, potential yield for wheat (*Triticum aestivum*) is around 10 t/ha, and high rates of N fertiliser may be required to meet expected crop demand arising from the high yield potential. However, recent research has highlighted large losses of N as nitrous oxide (N_2O) into the atmosphere (Harris *et al*. 2013) from soils in the region, which are prone to waterlogging, making it more difficult to judge the appropriate N fertiliser management. Cropping soils in the region are characterised by strong textual changes between the topsoil and subsoil, and in combination with a winter dominant rainfall pattern, can experience prolonged periods of transient winter waterlogging (MacEwan *et al*. 1992).

Anderson *et al*. (1992) suggested that early sown, well fertilised, dense vigorous crops growing on textual contrast soils prone to waterlogging were an important strategy for achieving high yielding crops. However, peak demand for N occurs during the stem extension phase of crop growth (Angus 2001) in late winter to early spring, and N supply during this period might encourage greater crop recovery of applied N. Another potential strategy for improving N fertiliser recovery in waterlogged soil, might be through the use of nitrification inhibitors such as *DMPP coated to conventional urea* (ENTEC®). Nitrification inhibitors are designed to delay the oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) (Zerulla *et al*. 2001) thus keeping N in a form less prone to escape (Pfab *et al*. 2012) and potentially greater retention for crop uptake. In this paper we study the fate of ^{15}N labelled urea, either deep banded 10 cm below the seed at sowing or topdressed with or without DMPP at the commencement of stem extension, to determine the appropriate method for maximising wheat N uptake and minimising losses under waterlogged conditions.

Methods
Two replicated field experiments were conducted; one at Hamilton (142°07'E 37°82'S) in 2012 and another at Tarrington (142°10'E 37°79'S) in 2013, in south west Victoria on Ferric-Eutrophic Brown Chromosol

soil. The Hamilton experiment was conducted on 1.35 m wide raised beds, while the Tarrington experiment on a conventionally flat site with a slight slope (between 1 and 2% grade). Both experiments comprised a completely randomised block design with four treatments replicated five times. Treatments included a 0N experimental control, and three other treatments where ^{15}N labelled urea (100 kg N/ha) was either deep banded at a depth of 10 cm below the intended seeding depth the day before planting (DB100N@Z00), topdressed at the first node (Z31) growth stage (TD100N@Z31); or treated with DMPP and also topdressed at Z31 (DMPP100N@Z31). Treatments were imposed to microplots comprising two rows of wheat planted 15 cm apart within rectangular metal boxes (30 cm wide by 53 cm long) with open bottoms and tops, inserted to a depth of 20 cm into the soil, at the beginning of the growing season. ^{15}N-enriched (10 % a.e.) urea solution was pipetted at 10 mL or 1.590 g per microplot to the fertilised treatments; with DMPP (1% w/w) mixed thoroughly with the ^{15}N-enriched solution before applying the DMPP100N@Z31 treatment. Microplots were installed in the 0N treatment to quantify the natural enrichment of ^{15}N in the crop and soil. All treatments received a basal application of 15 kg of P/ha at sowing when wheat cv. Bolac was sown on 31 May 2012 at the Hamilton site, and 9 May 2013 at the Tarrington site. Fertiliser was topdressed on 10 September 2012 and 19 August 2013 at the respective Hamilton and Tarrington sites.

Before experimentation, five deep soil cores (internal diameter 42 mm) were randomly collected from each replicate of the Hamilton and Tarrington sites. Cores were divided into 10 cm increments to 40 cm depth, and thereafter in 20 cm increments. Four of the five cores collected were combined for each layer within each replicate. Samples were then oven dried at 40°C for 48 h and passed through a 2 mm sieve in preparation for chemical analysis. The remaining core collected from each replicate was weighed and oven dried at 105^{o}C for 48 h and weighed again to determine bulk density.

At physiological maturity plants from within each microplot were cut at ground level and dried at 60^{o}C until constant weight reached, then threshed to separate grain from straw, and subsampled for analysis. Following harvest the entire 0-10 and 10-20 cm soil layers were excavated, and 6 cores (internal diameter 42 mm) randomly taken by hydraulic auger from the 20-40 cm layer at both sites, and the 40-60 cm layer at the Tarrington site, within each microplot. Cores were combined for each layer within each microplot. All soil samples were weighed, then a subsample retained weighed and dried at 105^{o}C until a constant weight was reached before being reweighed to determine soil water content. Another subsample from each layer was dried at 40^{o}C until constant weight reached for analysis. Plant and soil subsamples were finely ground to <100 µm in preparation for subsequent analysis. Plant and soil samples were analysed for total N and ^{15}N enrichment by a continuous flow mass spectrometer. The percentage of N derived from fertiliser was determined by dividing the atom% ^{15}N excess of total N in the plant, by the atom% ^{15}N excess of N in the fertiliser. The percentage recovery of ^{15}N fertiliser in the crop and soil were calculated using the formulas of Hauck and Bremner (1976). Treatment differences were tested using analysis of variance (ANOVA).

Results

Before imposing treatments there was 297 and 116 kg of soil NO_3^- /ha stored in the top 100 cm of the soil profile at the respective Hamilton and Tarrington sites. At the Hamilton site, 90% of the NO_3^- was stored in the top 40 cm of the profile compared with 48% at the Tarrington site (Figure 1a). At both sites soil organic carbon (C) concentrations declined with depth (Figure 1b).

Deep banding of ^{15}N labelled urea at sowing (DB100N@Z00) resulted in significantly (P<0.001) lower amounts of N fertiliser recovery compared with topdressing at Z31, at both the Hamilton and Tarrington sites (Figure 2). Adding DMPP did not significantly improve ^{15}N urea recovery in the crop, when topdressed at Z31, at both sites (Figure 2). Total recovery of N fertiliser in the soil at plant maturity was also significantly (P<0.001) lower under the DB100N@Z00 treatment in comparison with the topdressed treatments, with only 4.3 and 10.5% of the N initially applied recovered at the respective Hamilton and Tarrington sites. The differences were confined to the 0-20 cm soil layers at the Hamilton site and the 0-10 cm layer at the Tarrington site. The very low recovery of ^{15}N labelled urea in the DB100N@Z00 treatment resulted in significantly (P<0.001) higher losses of applied N, compared with the topdressed treatments, with 93.1 % of the N fertiliser unaccounted for in the soil and crop at the Hamilton site, and 77.1 % unaccounted for at the Tarrington site. Fertiliser management did not alter either crop biomass nor grain yield at either sites (data not shown), with wheat yielding 16,660 (±959) kg DM/ha and 6,735 (±552) kg/ha of grain at Hamilton and 12,882 (±580) kg DM/ha and 6,052 (±275) kg/ha of grain at the Tarrington site, averaged across all treatments.

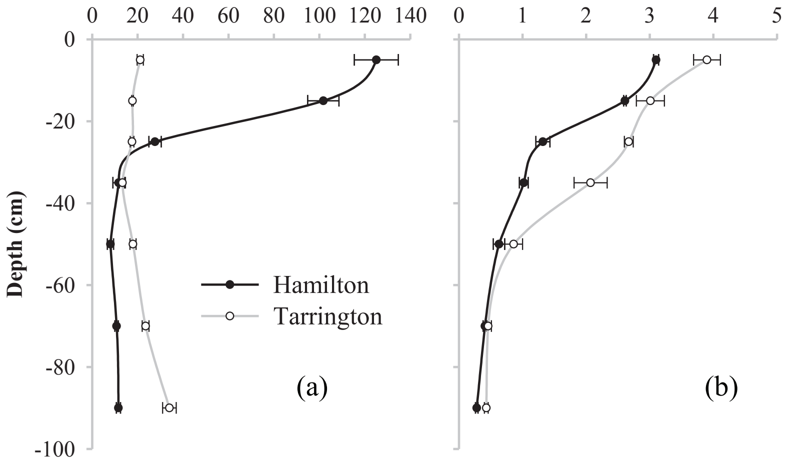

Fig 1. Distribution of soil NO_3^- (kg/ha) to 100 cm depth in autumn, before seeding at Hamilton (a) and Tarrington (b) in south west Victoria. Bars ±SE (n=5).

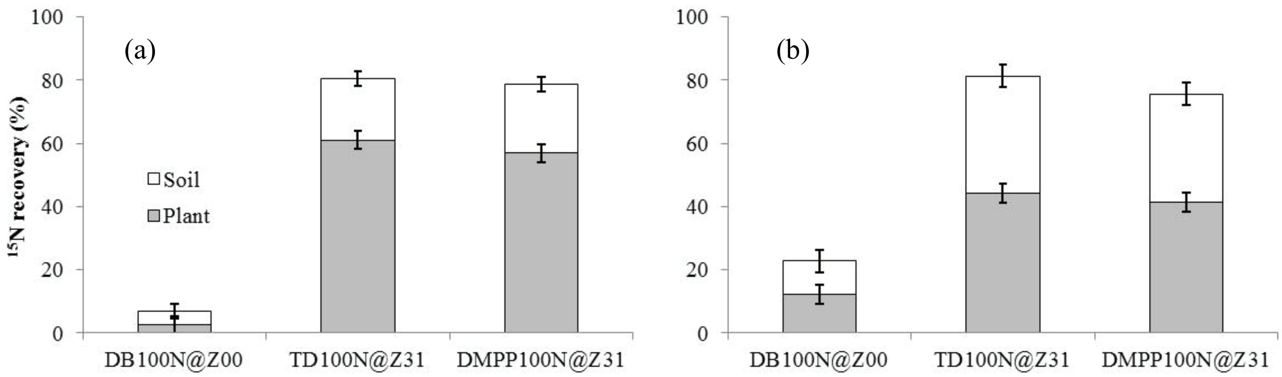

Fig 2. Percent ^{15}N urea recovery in the plant (grain and straw) and soil, for respective treatments at the Hamilton (a) and Tarrington (b) experimental sites. Bars are least significant difference (*P*<0.001).

Discussion

Deep banding high rates of ^{15}N labelled urea early in the growing season caused a temporal mismatch between supply and peak demand for N by the wheat, resulting in poor recovery of fertiliser by the crop and greater opportunities for loss of N from the soil: plant system. Crop recovery of topdressed urea applied in our studies were close to the range of 20 to 56% previously reported by other collective studies (Fillery and McInnes 1992). However, the crop recovery of deep banded urea at sowing was well below the 44 to 49% previously reported by Fillery and McInnes (1992) and Adjetey *et al*. (1999). Both sites in our study experienced above average winter rainfall leading to both surface and subsurface waterlogging and possible drainage losses. Furthermore, high concentrations of soil organic C in the top 40 cm of the profile at both sites (Figure 1b), may have provided desirable habitat for denitrifying microbial communities (Clark *et al*. 2012). Both sites were cultivated prior to sowing and research elsewhere has shown greater nitrous oxide emissions associated with deep N placement in recently cultivated soil, compared with shallow N placement under high soil moisture (Drury *et al*. 2006). While our data showed no evidence of leaching below 20cm, subsoil lateral flow along the top of the subsoil may have been another avenue for escape, especially at the Hamilton site where microplots were installed on raised beds, designed to drain water laterally.

Crop recovery of ^{15}N labelled urea was not enhanced by the use of DMPP, implying no increased retention of the applied N for crop uptake or improved yield over conventional urea. While other studies have shown a greater retention of NH_4^- in response to the application of DMPP (Weiske *et al*. 2001; Pfab *et al*. 2012), few have demonstrated improved plant N uptake and yield. Soares *et al*. (2012) reported the nitrification inhibitor dicyandiamide (DCD) coated to urea and applied to the soil surface, increased ammonia (NH_3) volatilisation by 5-16%, resulting from a longer retention period of elevated soil ammonium and soil pH concentrations, compared with urea. Although our study involved the use of DMPP, we speculate that perhaps higher NH_3 losses may have resulted in no greater net retention of N for crop uptake compared with urea, and therefore no improvement in yield over the use of conventional urea.

Wheat growing on top of the deep banded treatment at the Hamilton and Tarrington sites predominantly sourced N requirements from the soil. In addition to stored soil N at the beginning of the growing season (Figure 1a), it's also likely that a significant proportion of crop N uptake was sourced from in-crop N mineralisation (Angus *et al*. 2001), especially at the Tarrington site. Although mineralisation was not measured in our study, applying the Baldock (2003) model, accounting for high organic C concentrations at the Hamilton and Tarrington sites, we estimate that between 99 and 195 kg N/ha may have mineralised over the respective growing seasons. The high in-crop mineralisation potential at both sites, helps partly explain the lack of grain yield response to N application irrespective of N management strategy. Clearly, wheat growing in the deep banded treatment was able to compensate for the poor recovery of ^{15}N urea, by sourcing larger amounts of N from the soil over the growing season.

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