



A slow release brown coal-urea fertiliser reduced gaseous N loss from soil and increased silver beet yield and N uptake

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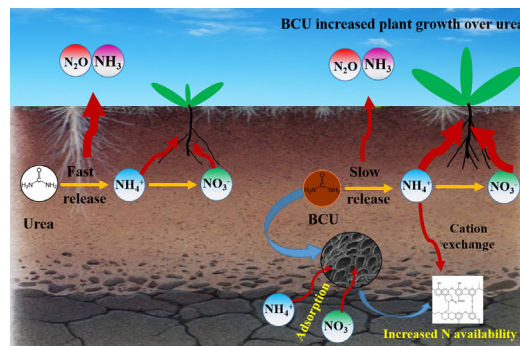
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HIGHLIGHTS

- Brown coal-urea fertiliser (BCU) reduced gaseous N-losses (N_2O and NH_3) from soil compared to urea.
- BCU increased fertiliser N availability to crop plants over a longer period of time than conventional urea.
- BCU enhanced biomass yield and N uptake by silver beet over urea.
- The benefits of combining urea with a humic acid rich brown coal have been demonstrated.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 27 May 2018

Received in revised form 9 August 2018

Accepted 10 August 2018

Available online 14 August 2018

Editor: Charlotte Poschenrieder

Keywords:

Brown coal

Urea

Slow release fertiliser

Biomass yield

Fertiliser N use efficiency

Humic acid

ABSTRACT

Increasing crop yield and fertiliser nitrogen (N)-use efficiency is important for productive agricultural systems with a reduced environmental footprint. The aim of this study was to assess the effect of slow release brown coal-urea (BCU) fertiliser on the gaseous N losses, biomass yield and N uptake by silver beet (*Beta vulgaris* L.) compared to commercial urea. Two soils were amended with urea, BCU 1 (22% N) or BCU 2 (17% N) as N-fertiliser at the rate of 50 or 100 kg N ha⁻¹. Five gas sampling periods were undertaken to measure the loss of N as N_2O and NH_3 . After 10 weeks, biomass, N concentration, and N uptake of silver beet, and mineral and mineralisable N of post-harvest soil were measured. BCU substantially increased fertiliser N availability and uptake by silver beet, reduced N_2O emission by 29% and NH_3 emission by 36% compared to urea alone, irrespective of soil type. Compared to urea, BCU blends increased biomass yield by 27% and 23% in a Tenosol and Dermosol soil, respectively. In addition, application of BCU fertiliser substantially enhanced the potentially mineralisable N and organic carbon content of soil. These results provide evidence that granulation of urea with brown coal (BC) can increase silver beet N-use efficiency and yield in different soil types, and more work is now required to validate this technology for other crops.

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1. Introduction

Nitrogen (N) is one of the key nutrients for leafy vegetable production. An optimum supply of N can accelerate plant growth and enhance crop production, while excessive and inappropriate application of N

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fertilisers can accumulate nitrate in the edible parts which could be detrimental for human health (Collins and McCoy, 1997). Consequently, N is one of the most challenging elements to manage in the soil-plant system to ensure adequate N supply through fertilisation, while minimising losses and avoiding over application. Urea is the dominant source of N input in many crop production systems world-wide because of its high N content (46%). Unfortunately, the efficiency of urea fertiliser use is very poor and recovery of N in soil-plant systems seldom exceeds 50% of applied N (Raun et al., 2002). The low use efficiency of urea is associated with losses by leaching, denitrification and volatilisation (Fageria and Baligar, 2005). This lost N represents both an economic inefficiency and an environmental burden, as off-site N transport in water pollutes both surface and groundwater, whilst N₂O and NH₃ contributes to greenhouse gas accumulation in the atmosphere.

Excess application of chemical fertilisers and intensive agriculture, particularly tillage has reduced soil organic matter (SOM) over time in many agricultural systems (Chen et al., 2008). The widespread loss of SOM has consequently impacted on soil fertility and crop productivity, via reductions to soil water-holding capacity; decreased nutrient availability and cycling; and a reduced capacity to buffer changes in pH, salinity and other chemical stressors (Accoe et al., 2004). Soils depleted in organic carbon (C) often have a decreased N retention capacity, hence retaining applied fertiliser N in the plant-soil system becomes increasingly difficult (Richards et al., 1993). Furthermore, the C sequestration potential of a soil is intricately linked with the sequestration of other nutrients, especially N (Dong et al., 2009). Therefore, improving fertiliser N use efficiency and increasing soil organic carbon (SOC) is an essential goal on a global scale to provide food security, maintain soil health and minimise adverse effects on the environment.

Granulation of organic material with synthetic N fertiliser to meet crop requirements may have several benefits over the application of organic material or synthetic fertiliser as a sole N source. Organo-mineral blending can delay the loss of N from the soil-plant system by reducing leaching (Richards et al., 1993) or N₂O emissions (Rose et al., 2016), potentially maintaining N availability throughout the plant growing cycle. For example, Sikora and Enkiri (2001) blended ammonium nitrate with a biosolid compost and found that the blended product significantly increased yield and N uptake by fescue. In another study, Antille et al. (2014) found that the application of biosolid derived organo-mineral blends increased the biomass yield of ryegrass and organic matter content of soil, compared to commercial inorganic fertilisers.

We have also recently demonstrated that granulation of urea with brown coal (BC) increased N availability in soil compared with urea alone by reducing N losses (Rose et al., 2016; Saha et al., 2017). A major factor in the increased N retention was attributed to the high humic acid content of the BC, where hydrolysed urea-N is retained as ammonium on the acid exchange sites in the coal. In addition, physical adsorption of urea onto the porous surface of BC has been shown to occur (Saha et al., 2017). Therefore, there are strong reasons to hypothesise that granulation of urea with BC could improve N uptake and biomass of crop plants compared to conventional urea. In this study, we present the results of a glasshouse experiment investigating N losses, N use efficiency and growth of silver beet in soil treated with brown coal-urea (BCU) fertiliser blends, compared with urea. Silver beet is a plant which has a significant N demand (75 to 140 kg N ha⁻¹) (Ali and Ali, 2011) and is a model for leafy vegetable crops grown worldwide. The study was conducted in two different soil types to evaluate the effect of soil type on the N fertiliser behaviour and plant response.

2. Materials and methods

2.1. Soil collection and characterisation

Two soils were used in this study sourced from grazed pastures in southern Australia. The Dermosol (Isbell, 2002) was collected from

Stony Creek of south-eastern Victoria and the Tenosol (Isbell, 2002) was collected from the Wimmera region of north-western Victoria. Both soils were collected from the 0–15 cm soil layer. Following collection, the soils were air-dried and sieved to <2 mm. Subsamples (200 g) of each soil were then analysed for a range of key physicochemical properties (Table 1).

2.2. Plant growth experiment

Plastic pots (25 cm depth and 16 cm diameter) were filled with 7.9 kg of the Dermosol and 8.2 kg of the Tenosol to match with the bulk densities for the two soils of the fields they were collected from, which were 1.3 g cm⁻³ and 1.4 g cm⁻³, respectively. The experiment was laid out following a completely randomised design with five replicates. Each soil was treated with three N fertilisers (urea, BCU 1 and BCU 2) (Table 2) at two different N-fertiliser rates of 50 and 100 kg N ha⁻¹. Two additional treatments were also included: a control comprising the soils only and a granulated raw BC added at a rate equivalent to the BCU 2 treatment, to allow for any effect of the added organic carbon alone. In addition, P (single superphosphate) and K (potassium sulphate) were added at a rate of 40 and 60 kg ha⁻¹, respectively. All the fertilisers were mixed with the topsoil (0–5 cm) in the granular form. The pots were then left to equilibrate at field capacity for 3 days before the sowing of seeds. To each pot, 5 seeds of silver beet (Fordhook Giant) were sown to 2 mm below the soil surface. Soil moisture was maintained at field capacity by regular addition of deionised water as required based on the weight difference, usually every 2 days. No leaching was observed during the experimental period. After germination, only one plant was allowed to grow in each pot.

2.3. Gas sampling, plant harvesting and soil analysis

Five N₂O gas sampling periods at days 7, 14, 21, 28 and 35, and five NH₃ gas samples at days 1, 3, 6, 10 and 14 after fertiliser addition were undertaken to measure the loss of N as N₂O and NH₃ emissions. Five N₂O and NH₃ gas samplings were done at the early growth stage because the losses of N via these pathways are at a maximum during these time periods. The N₂O gas flux was calculated according to the method and equations detailed by Van Zwieten et al. (2010). Ammonia emissions were measured using polyurethane foam absorbers (Cabezas et al., 1999) and flux was calculated using the equation of Singh et al. (2009). The details of ammonia volatilisation and N₂O gas determination can be found in the Supporting Information (SI). Leaf samples were collected from the third leaf from the top at 45 days after fertiliser addition to determine chlorophyll content. Leaf chlorophyll was extracted using 80% aqueous acetone and measured following the method of Arnon (1949).

Plants were destructively harvested at 10 weeks after seed sowing. The plants and soil were carefully removed from the pots. The soil was

Table 1
Physical and chemical properties of soils used in this study.

Property	Tenosol	Dermosol
USDA soil order	Entisol	Alfisol
Texture	Sandy loam	Loam
pH (soil:water = 1:5)	7.23	5.46
Total carbon (%)	0.77	1.19
Total nitrogen (%)	0.13	0.17
^a Ammonium nitrogen (mg kg ⁻¹)	6.1	3.7
^a Nitrate nitrogen (mg kg ⁻¹)	2.2	2.6
Available phosphorus (Colwell) (mg kg ⁻¹)	10	31
^a Calcium (mg kg ⁻¹)	915	260
^a Magnesium (mg kg ⁻¹)	89	71
^a Potassium (mg kg ⁻¹)	92	52
^a Sulphate sulphur (mg kg ⁻¹)	2.7	3.7
^a Iron (mg kg ⁻¹)	44	122

^a Indicates the soluble form of the nutrients.

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