Soil nitrogen: can pasture yields be increased by capitalising on seasonal trends in mineralisation and immobilisation?

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Abstract
Decomposition of organic nitrogen (N) into inorganic N is known as mineralisation. This process and its converse, immobilisation, may occur simultaneously and continuously under the controls of soil temperature, moisture, texture and organic N content. As plants utilise inorganic nitrogen as the primary source of N, the rate of net mineralisation (i.e., the difference between gross mineralisation and gross immobilisation) may be a determinant of subsequent pasture growth. Here we examine how the timing of inorganic N fertilisation influences net N mineralisation and pasture growth. We simulated the long-term effects of adding urea fertiliser in August, when pasture growth was near its peak, or in December, when pasture growth was often lowest; the latter treatment being designed to test whether N would be immobilised and released from soil organic matter in the following growing season(s). Pastures were cut on a monthly basis with litter returned to the soil. Application of 100 kg N/ha in December resulted in 7-14 kg N/ha.year greater net mineralisation within and across all years in the simulation relative to N fertiliser applied in August. These trends were consistent in both the vertosol and chromosol soils, suggesting that time of year of fertilisation had a significant and sustained influence on subsequent net N mineralisation. N fertilisation in August partially relieved N stress and stimulated growth (growth rates in August were on average 4 kg DM/ha higher than in December), but also resulted in lower net N mineralisation relative to fertiliser applied in December. We found that greater N utilisation of pastures in the August-fertilisation treatment in concert with litter of higher N concentration resulted in lower potential for immobilisation compared with the December-fertilisation treatment.

Key Words
Mineralisation, immobilisation, nitrogen, soil organic matter, pasture nutrition, dynamic model

Introduction
Nitrogen mineralisation is the process by which organic N is converted into plant-available forms (Crohn, 2004). N mineralisation rates are governed by soil temperature, organic N content, digestibility of plant litter inputs, soil moisture and clay content. As a corollary, mineralisation generally follows seasonal trends dictated by climate. The converse of mineralisation, immobilisation, occurs when inorganic N is consumed by soil microbes and assimilated into organic material, during which process CO_2 is respired and the C/N ratio of the soil is reduced. In general, mineralisation and immobilisation are continuous processes such that fluxes of inorganic N to and from organic N may be simultaneous.

There are few reports of the interplay between N fertiliser, mineralisation and pasture growth, particularly with respect to seasonal variation. Here, our aim was to simulate the effect of different seasonal timing of inorganic N fertilisation on long-term mineralisation and pasture growth. In southern Australia, August/September traditionally represents the most active period of pasture growth, so addition of N at this time would be expected to be rapidly used by growing plants. In contrast, rainfed pastures are generally dormant in December due to lack of soil moisture, thus application of N during this month would not be expected to benefit plants to the extent that it would if applied in August. Depending on seasonal conditions and soil C/N ratios, it is likely that a greater fraction of N applied in December would be immobilised compared with that applied in August, this later potentially being mineralised in the subsequent year.

Methods
Effects of N fertilisation at different times of the year were studied using DairyMod v5.8.2 (Johnson, 2016). The model was used to explore interacting effects of N fertilisation on mineralisation and pasture growth, in two different soils at Hamilton, Australia (37.7° S, 142.02° E). Decile 5 rainfall at Hamilton from 1983 to 2019 was 611 mm (decile 1 = 587 mm, decile 9 rainfall = 730 mm), with 70% of rainfall falling between April and

October. Mean daily temperatures at Hamilton are 18°C in summer and 8°C in winter. We examined net mineralisation in chromosol and vertosol soils (Isbell, 2002); these soils being commonly found in the region and having contrasting clay and soil organic matter content. Biophysical parameters used in the modelling were adapted from the HC-HW soils presented in Meyer et al. (2015). Soil organic matter to 30 cm, plant available water capacity and clay content were respectively set to 88 t C/ha, 57 mm and 25% for the chromosol and 108 t C/ha, 61 mm and 40% for the vertosol. The site modelled represented a rainfed pasture comprised primarily by perennial ryegrass (*Lolium perenne*), phalaris (*Phalaris aquatica*) and subterranean clover (*Trifolium subterraneum*) with respective root depths of 40 cm, 120 cm and 50 cm (Meyer et al., 2015). Pastures were cut rather than grazed to facilitate interpretation of changes in N mineralisation as a consequence of inorganic N fertilisation. Cutting was performed at the end of each month to a residual of 1 t DM/ha with litter returned to pasture. Daily climate data used in the model were sourced from SILO (https://www.longpaddock.qld.gov.au/silo-legacy/). Model initialisation was conducted from 1 Jan 1901 to 31 Dec 1997 with no addition of N. This management approach was conducted to create soil profiles with equilibrated mineral N and organic matter to help discern pasture and mineralisation responses to fertiliser N application during the experimental period. System states at the end of the initialisation period including biomass, mineral N, soil water content and organic matter were used as the initial conditions for subsequent experimental analyses. The simulation in the experimental period was ran continuously from 1 Jan 1998 to 31 Dec 2018, with 100 kg N/ha as urea applied once per year, either on 1 August or 1 December. This rate of N application is likely higher than regional best management practice but was applied here to help elucidate mineralisation trends resulting from fertiliser application. Both initialisation and experimental simulations were conducted using two loops for model equilibration.

Results & Discussion

N fertilisation in December increased N mineralisation within (Figure 1) and across (Figure 2) all years in the simulation relative to N fertiliser applied in August. These trends were consistent in vertosol and chromosol soils, resulting in 7-14 kg N/ha.year greater mineralisation, suggesting that time of year of fertilisation had a significant and sustained influence on subsequent N mineralisation. We suggest that N mineralisation in the vertosol was greater than that in the chromosol due to the greater soil organic matter content of the former soil, notwithstanding the negative influence of higher clay content on mineralisation in the vertosol.

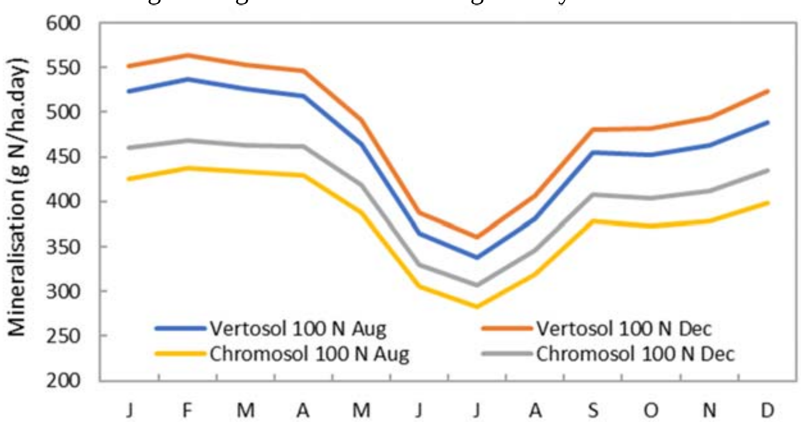

Figure 1. Average daily nitrogen mineralisation in vertosol and chromosol soils at Hamilton, Victoria, for treatments that applied 100 kg N/ha on either 1 August or 1 December each year. Values shown are averaged over the simulation duration (1998-2018).

Seasonally, N mineralisation was lowest in winter (June-August) and greatest in late summer/early autumn (February-March, Figure 1). These results are comparable to those of Yokobe et al. (2018), who suggested that one of the main drivers of seasonal patterns of mineralisation and immobilisation were changes in plant C inputs via leaf litter and root exudate. In this study, we returned cut material to the pasture, so an effect of leaf litter on mineralisation is plausible. On average over the 20-year simulation, the August fertilisation treatments had greater litter deposition than the December fertilisation treatments between August and January the following year, and during this period the N concentration in dead tissue of the August treatments were also higher than those of the December treatments. In DairyMod, N is remobilised from dying leaves, thus litter would have a higher C/N ratio than the plant and thus immobilise N as it becomes part of the soil organic matter. Pastures fertilised in August had higher growth rates than those fertilised in December (Figure 3). The August fertilisation timing was selected because this time of year typically precedes the spring growth flush when demand for N becomes greatest. Fertilisation in August thus alleviated much of the N stress limiting growth in August and September. In contrast, N fertilisation in December had little effect on pasture growth due to soil moisture limitation (Figure 4), and the

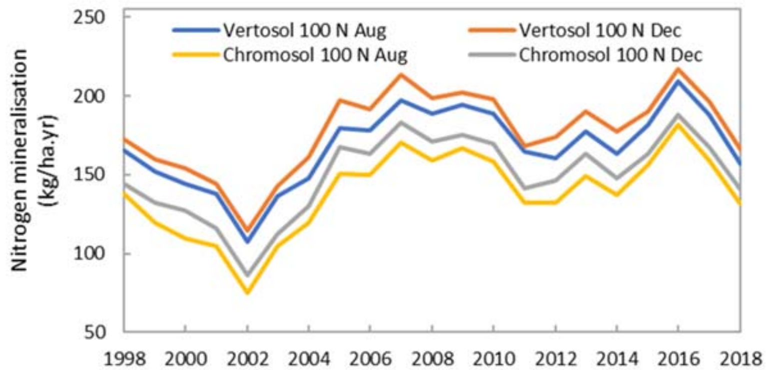

Figure 2. Total annual nitrogen mineralisation in vertosol and chromosol soils at Hamilton, Victoria, for treatments that applied 100 kg N/ha on either 1 August or 1 December each year. Values shown are averaged over the simulation duration (1998-2018).

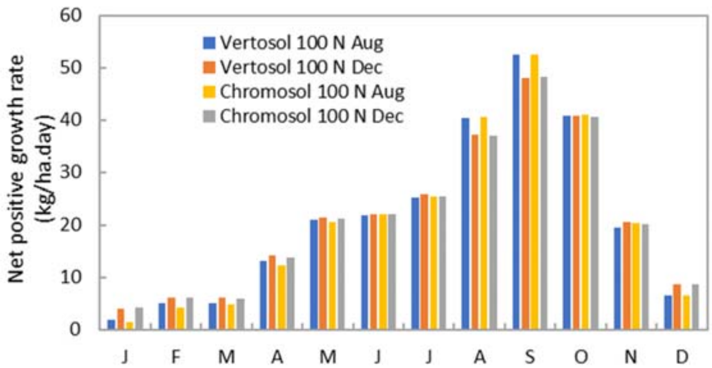

Figure 3. Net positive growth rates of pastures subjected to 100 kg N/ha applied on either 1 August or 1 December each year in vertosol and chromosol soils at Hamilton. Values shown are averaged over the simulation duration (1998-2018).

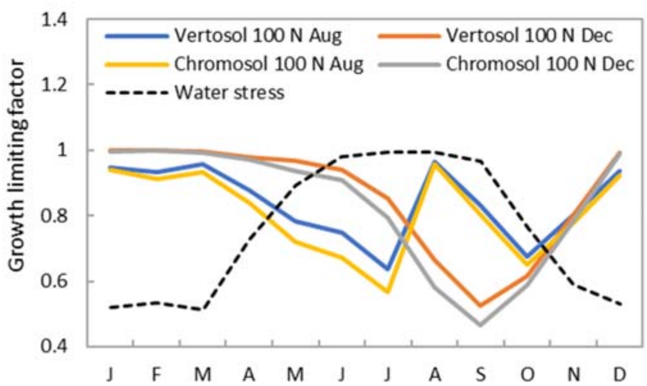

Figure 4. Effect of N and water stress on growth in vertosol and chromosol soils for treatments that applied 100 kg N/ha on either 1 August or 1 December. Average water stress over the four treatments is shown as the dashed line. All values were computed as averages over the simulation duration. A GLF of 1.0 represents no stress.

treatment showed greater growth limitation during late winter/early spring (August/September; Figure 4). These results show that N applied in August only briefly entered the NH_4^+ pool before being used by plants, as shown via elevated growth rates (Figure 3). In contrast, a lower fraction of the N applied in December was used by pasture. Our hypothesis was that some of the N applied in December would have been immobilised via assimilation into soil organic matter and microbial biomass, and that on a fractional basis, more of the N applied in December cf. that in August would have been immobilised. Our results indicate this hypothesis may be true; N applied in August was used by pasture, thus less N remained for immobilisation. Litter from this treatment had a higher N concentration than that of the December treatment (data not shown), further reducing the potential for immobilisation. In contrast, N applied in December was not utilised by pasture to the extent it was in the August treatment and litter from this treatment had lower N concentration than the August treatment (data not shown), thereby increasing the potential for immobilisation. It should also be noted that DairyMod outputs net rather than gross mineralisation, the former being the sum of gross mineralisation and gross immobilisation, the latter being total N mineralised over the simulation duration. Although the timing of fertilisation influenced seasonal growth rates, there was little effect of fertilisation timing on pasture yields over the long-term (Figure 5). There was no difference between mean annual pasture yields of treatments or soil types; mean biomass of both treatments was 7.8 t DM/ha over the 20-year simulation (1.6 t DM/ha standard deviation). Figures 2 and 5 indicate that climatic variation had a much greater influence on net N mineralisation and dry matter production, cf. the influence of N treatment. This could be caused by several successive cycles of remineralisation of immobilised N, uptake by plants, mineralisation from fresh litter and organic matter, immobilisation etc.

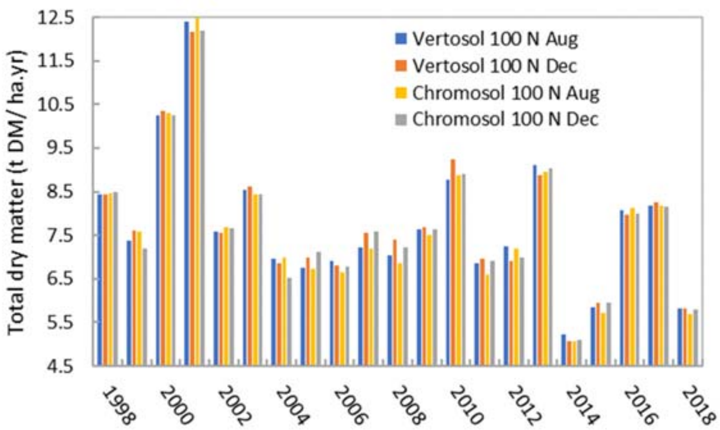

Figure 5. Total annual dry matter production in vertosol and chromosol soils at Hamilton, Victoria, for treatments that applied 100 kg N/ha on either 1 August or 1 December each year.

Conclusions

Timing of N fertilisation had implications for the magnitude of net N mineralisation in both vertosol and chromosol soils. Applying N in August, slightly before the pasture growth peak, resulted in greater plant N uptake and less mineralisation compared with fertilisation at the start of summer (December). Although August N fertilisation alleviated pasture N stress and incremented growth rates in August and September, such effects on annual dry matter accumulation over the long-term were not significant. Greater N usage of pastures in the August-fertilisation treatment in concert with litter of higher N concentration resulted in lower potential for immobilisation compared with the December-fertilisation treatment (and vice versa).

Acknowledgements

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