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Can the temperate forage herb plantain (*Plantago lanceolata* L.) decrease nitrous oxide emissions from grassland on peat soils?

Pijlman J.[1], Mani D.T.C.[2], Van Groenigen J.W.[2], Erisman J.W.[1] and Van Eekeren N.[1]
[1]*Louis Bolk Institute, Bunnik, the Netherlands;* [2]*Soil Biology Group, Wageningen University, Wageningen, the Netherlands*

Abstract

Dairy grasslands on peat soils are prone to nitrous oxide (N_2O) losses as a result of relatively high soil organic matter contents, high potential N mineralization rates and shallow groundwater levels. The use of the temperate forage herb ribwort plantain (*Plantago lanceolata* L.) (RP) has been suggested as a means to reduce these emissions via the release of secondary compounds with biological nitrification inhibition (BNI) capacity. Here we report a study on the effect of varying shares of plantain (100%RP, 66%RP, 33%RP and 0%RP) sown in a mixture with perennial ryegrass (*Lolium perenne* L.) on N_2O fluxes in a dairy grassland on peat soil. Actual estimated plantain herbage shares during the measurement period were 68, 42, 22 and 0% for the treatments 100%RP, 66%RP, 33%RP and 0%RP, respectively. After calcium ammonium nitrate fertilisation, N_2O emissions were up to 26% lower (P=0.038) in the treatment 100%RP compared with the other treatments. Multiple linear regression analyses revealed a significant decrease of cumulative N_2O emissions at an increasing plantain herbage share (P=0.023). Our results suggest that plantain can reduce N_2O emissions in nutrient-rich conditions such as dairy grasslands on peat soils.

Keywords: nitrous oxide, nitrification, nitrogen, ribwort plantain, peat, grassland

Introduction

Dairy grasslands on peat soils are prone to high N_2O emissions due to the high soil organic matter content, high potential mineralization rates and shallow groundwater levels (Koops *et al.,* 1996). Biological nitrification inhibition (BNI) could be a potential means for reducing nitrification and therefore N_2O emissions. Plantain, a temperate forage herb, has been shown to release compounds with BNI capacity; allelochemicals that are released from the roots with an inhibiting effect on nitrifying organisms (Dietz *et al.,* 2013). Several studies performed on sand, silt loam and peat soils have reported that plantain decreases (potential) nitrification and N_2O emissions from the soil (Carlton *et al.*, 2019; Dietz *et al.,* 2013; Pijlman *et al.*, 2019; Simon *et al.,* 2019). However, studies on the effect of plantain on mineral N cycling in dairy grasslands on peat soils are lacking. Therefore, we measured N_2O emissions in a previously established field experiment at KTC Zegveld (the Netherlands). We hypothesised that N_2O emissions decreased with increasing shares of plantain grown in mixture with perennial ryegrass.

Materials and methods

In May 2017, twenty-four plots of 2.5×10.0 m were sown with perennial ryegrass and varying shares of ribwort plantain (100%RP, 66%RP, 33%RP and 0%RP) in a complete randomised block design with six blocks. For more details see Pijlman *et al.* (2019). In August 2019, three PVC rings (radius 10 cm, height 13 cm) per plot were inserted 10 cm into the soil at spots with a representative estimated plantain herbage share corresponding to the respective treatment. Plantain herbage share was visually estimated every other week by a standard protocol, using photographs taken from a top-down angle. Soil N_2O fluxes were measured two to three times per week during a period of 73 days, starting 5 August 2019. Build-up of N_2O concentration in the rings was measured using a photo-acoustic multi-gas monitor (Innova 1312, Innova AirTech Instruments, Ballerup, Denmark) after rings were sealed with 4.4 l polyethylene caps for a minimum of 30 min. N_2O fluxes were corrected for background air concentrations, determined

every sixth measurement. Results were averaged per plot after which the cumulative soil N_2O fluxes were calculated, assuming a linear change in flux between measurements days. At days 2 and 37, calcium ammonium nitrate (CAN: 50% NH_4^+ and 50% NO_3^-) was applied to provide 50 kg N ha^{-1}. Herbage was harvested 14 days prior to the first measurement and again on day 18. At each N_2O flux measurement day, soil temperature was measured at 10 cm depth at approximately 13:00 pm and soil samples (0-30 cm) were taken for analyses of soil moisture content (drying at 105 °C for 24 hours). Data of precipitation and the average day temperatures were retrieved from weather stations Zegveld and De Bilt (KNMI, the Netherlands), respectively. Before analyses, cumulative N_2O-N flux data were log-transformed after raising values to ≥1 using a constant, in order to obtain a range of positive log-transformed values. Analysis of covariance (ANCOVA) was used to analyse for significant differences between N_2O fluxes of treatments. Additionally, a multiple linear regression analysis was done for the prediction of the soil N_2O-N flux by the estimated herbage share of plantain, in which data from 0%RP were excluded from the analysis. Block was used as covariate in both analyses.

Results and discussion

Average soil and air temperatures during the experiment were 17.2±1.9 and 15.5±3.2 °C, respectively, and cumulative precipitation was 239 mm (Figure 1). In the treatments with plantain, the estimated herbage share was lower than intended (22-68%) (Table 1). The gravimetric soil moisture content was highest for 100%RP (450 mg g^{-1}), followed by 0%RP, 33%RP and 66%RP (421-432 mg g^{-1}, Table 1). Cumulative N_2O emissions were up to 26% lower (P=0.038) at 100%RP, compared with the other treatments (Table 1, Figure 2). Multiple linear regression analyses only using data from treatments with plantain showed a significant decrease of cumulative N_2O emissions (P=0.023, r^2=0.865, n=18) at an increasing plantain herbage share.

The current study confirmed the hypothesis that the presence of plantain can lead to lower N_2O emissions from grassland on peat soils. Interestingly, the soil moisture content was the highest for 100%RP while N_2O emissions were the lowest. Soil denitrification has been shown to positively correlate with soil

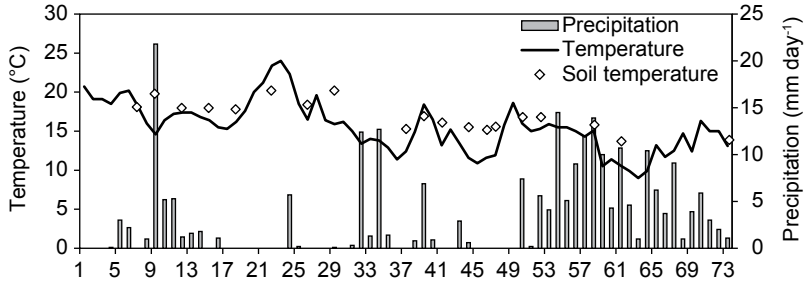

Figure 1. Average day temperature, soil temperature at 10 cm depth and daily precipitation, measured from 5 August 2019 to 16 October 2019.

Table 1. Estimated herbage share of plantain within rings, soil moisture content and cumulative N_2O-N emission per treatment.[1,2]

Treatment	Estimated plantain share (%) ± SD	Soil moisture (mg g^{-1}) ± SD	Cumulative N_2O-N emission (g m^{-2}) ± SE
0%RP	0±0	432±35	1.29[a]±0.22
33%RP	22±17	427±35	1.26[a]±0.22
66%RP	42±11	421±42	1.24[a]±0.23
100%RP	68±10	450±49	0.95[b]±0.16

[1] Values showing the same letter are not significantly different (P<0.05).

[2] RP = ribwort plantain; SD = standard deviation; SE = standard error.

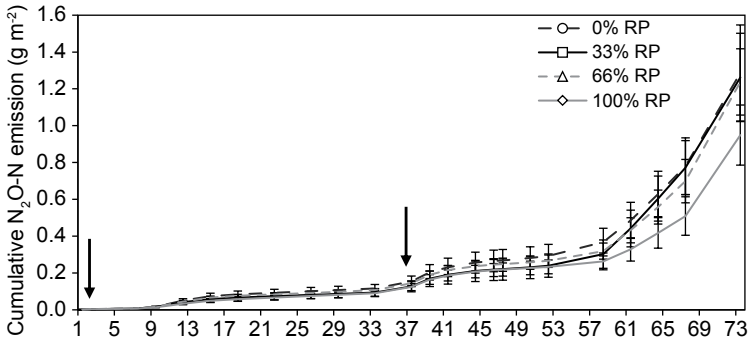

Figure 2. Cumulative N_2O-N emission per treatment, measured from 5 August 2019 to 16 October 2019. Arrows indicate calcium ammonium nitrate applications of 50 kg N ha^{-1}.

humidity (Koops *et al.*, 1996). Therefore, we expected higher N_2O emissions at higher soil humidity, for the observed soil moisture contents. This suggests other factors reduced soil N_2O emissions in the current experiment. This is in line with the suggested effect of compounds with BNI potential that are released by plantain. Previous research at the same location showed no difference in herbage N uptake between treatments, and suggested that the presence rather than the herbage share of plantain was key in decreasing N_2O emissions (Pijlman *et al.,* 2019). Current findings, after a more extended period of measurements than Pijlman *et al.* (2019) (73 vs 23 days), suggest that N_2O emissions negatively correlate with the herbage share of plantain. The observed negative correlation with the share of plantain is in accordance with research on a loamy soil (Simon *et al.*, 2019).

Conclusions

N_2O emissions after CAN fertilisation were significantly lower at increasing plantain herbage shares, when plantain was grown in a mixture with perennial ryegrass in a dairy grassland on peat soil. The use of the temperate forage herb plantain could be a means to reduce N_2O emissions from nutrient rich soils of temperate grasslands.

Acknowledgements

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