Phosphorus fertilisation enhances biomass yield as well as nitrogen yield and herbage nutritional status in a long-term grassland experiment

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Abstract

We investigated effects of phosphorus (P) fertilisation on yield and forage nutrient content measured for 28 years in a long-term grassland experiment. Mountainous grassland plots were set up at constant nitrogen (N) fertilisation of 25 kg ha^{-1} yr^{-1} and at two levels of P: no P (P0) and 31 kg P ha^{-1} yr^{-1} (P31). Potassium was applied in non-limiting amounts. Here, we report biomass yield, N yield, and the nutritional status of herbage from the first cut per year, on average across years. Biomass yield was 3.74 and 4.38 Mg ha^{-1} yr^{-1} at P0 and P31, respectively, indicating a yield loss of 15% due to the lack of P (P<0.001). Despite this yield difference, N content did not differ between P treatments and was 18.2 g N kg^{-1} DM on average. As a result, N yield was significantly enhanced by adequate P supply (P<0.001), and was 66.5 and 79.2 kg ha^{-1} yr^{-1} at P0 and P31, respectively. The phosphorus nutrition index (PNI) indicated P limited growth at P0 (PNI=0.6), while it confirmed adequate P supply at P31 (PNI=1.1). We conclude that adequate P fertilisation not only enhanced biomass yield but also allowed plants to exploit N sources better, leading to more N yield for a given amount of soil N.

Keywords: long-term grassland experiment, P fertilisation, phosphorus nutrition index, N yield, nitrogen nutrition index, nutrient limitation

Introduction

Adequate nutrient supply is essential for plant growth. While grasslands are generally nitrogen (N) limited, phosphorus (P) limitation can also lead to strong yield losses (Fay *et al.*, 2015). Interestingly, adequate supply of one nutrient can also stimulate the uptake of another nutrient. For example, it has been demonstrated that increased availability of N in the soil can also enhance uptake of other soil resources such as P (Hoekstra *et al.*, 2015; Husse *et al.*, 2017). While interactions between N availability and other soil resources (including water) have been studied repeatedly (e.g. Farrior *et al.*, 2013), the relation between P supply and the uptake of N is less clear. It must be assumed that increased fertilisation of P at constant rates of N leads to an enhanced N limitation relative to P (Güsewell, 2004). Under such conditions, plants might increase their root biomass to exploit soil N resources better, leading to an indirect positive effect on N yield. Here, we evaluated how increased P fertilisation affected biomass yield and the P nutrition status of herbage in a long-term grassland experiment, and how P fertilisation indirectly affected N yield and the N nutrition status.

Materials and methods

A grassland fertilisation experiment was established in 1990 in the Swiss mountains at 1,200 m a.s.l., and was measured for 28 years. Prior to experimentation, the species-rich, permanent grassland was used for hay production for decades. It contained more than 30 plant species per 10 m^2 and was dominated by *Trisetum flavescens* (L.) PB. and *Dactylis glomerata* L. Sixteen plots of 10 m^2 were set up, and a P treatment was established in that one half of the plots were not fertilised with P (P0) while the other half were fertilised with 31 kg P ha^{-1} yr^{-1} (P31) as triple superphosphate. All plots received N fertiliser (NH_4NO_3) at a rate of 25 kg N ha^{-1} yr^{-1}, while potassium was applied in non-limiting amounts. Plots were arranged in a randomized complete block design. They were generally mown three times per year and biomass yield per plot was sampled. Dry matter (DM; after drying biomass to constant weight) was analysed for its total P and N content, which allowed calculating N yield by multiplying DM with its N content. To determine the nutritional status of plant biomass, the phosphorus nutrition index (PNI) was calculated following Duru and Ducrocq (1997):

$$PNI = P\% / 0.15 + 0.065 \times N\%)$$

with P% and N% being the measured P and N content in bulk DM. In addition, the nitrogen nutrition index (NNI) was calculated following Lemaire and Gastal (1997):

$$NNI = N\% / 4.8 \times DM^{-0.32}$$

An index value ≥1 indicates adequate or surplus provision of the respective nutrient, a value <0.8 indicates that plant growth is limited. Here, we analysed biomass yield, P and N content, N yield, and the PNI and NNI as affected by P fertilisation. All presented data are from the first harvest of the year, which was taken at the beginning of June and made up 56% of the annual biomass yield. For analyses, all data were averaged across the 28 years. Differences between the P treatments were analysed with *t* tests.

Results and discussion

On average across years, biomass yield was 3.74 and 4.38 Mg ha^{-1} yr^{-1} at P0 and P31, respectively, indicating a yield loss of 15% due to the lack of P ($P<0.001$, Figure 1A). Absence of P fertilisation strongly reduced the P content in plant biomass, P contents being 1.5 (P0) and 3.0 g P kg^{-1} DM (P31) ($P<0.001$, Figure 1B). Concordantly, the PNI clearly indicated P limited growth at P0, while it confirmed adequate P supply at P31 (Figure 1C).

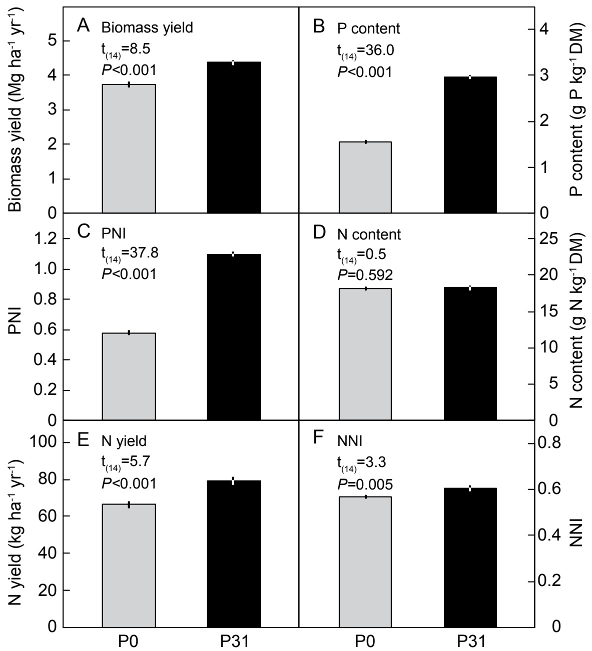

Figure 1. Effects of P fertilisation (P0: no P, P31: 31 kg P ha^{-1} yr^{-1}) on biomass yield (A), P content (B), the phosphorus nutrition index (PNI) (C), N content (D), N yield (E), and the nitrogen nutrition index (NNI) (F) in a long-term grassland experiment. Data were averaged across 28 years. The inference refers to the difference between the P treatments.

Despite the difference in biomass yield, the N content did not differ between P treatments and was 18.2 g N kg^{-1} DM on average (P=0.592, Figure 1D). As a result, N yield was significantly enhanced by 19% at increased P fertilisation (P<0.001), and was 66.5 and 79.2 kg ha^{-1} yr^{-1} at P0 and P31, respectively (Figure 1E). This means that N yield per unit of applied N, i.e. N efficiency, was higher at P31 than at P0. Evaluating the NNI showed that all communities grew N limited (Figure 1F). The NNI was fairly similar at P0 (0.57) and P31 (0.60), yet slightly enhanced at P31 (P=0.005). A recent study by Perotti *et al.* (2020) indicates that the relatively high proportions of forbs in the communities did not cause the NNI to be underestimated. We argue that increased P availability allowed plants to grow better, which enhanced their relative demand for other nutrients such as N. In addition, plants may have produced more roots under adequate P supply in the long-term, allowing the plant community to better exploit soil and/or fertiliser N resources and thereby reduce N deficiency relative to P. A combination of both factors might have caused increased N yields at P31. Notably, the P fertilisation effect on N yield was not related to legume proportion. On average across both treatments, the proportion of grass, legume, and forb species was 55, 10 and 35%, respectively, without substantial difference between treatments.

Conclusions

Alleviating P limitation can modify the exploitation on N resources in the soil. P fertilisation not only enhanced biomass yield but also allowed the grassland community to take up more N in the long-term, leading to a higher N yield for a given amount of N fertilisation.

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