Phytoextraction of soil phosphorus by grass-clover as a synergy between agriculture and nature restoration

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Abstract

In the development of the Dutch National Ecological Network, arable land is converted to nature areas. This development is often hampered by high phosphorus (P) levels. Standard practices to decrease the amount of P are either top-soil removal or mowing of low yielding established grassland. Both methods have their disadvantages and there is a need for additional techniques. As an alternative, phytoextraction ('mining') of soil P has been proposed. We tested a phytoextraction by cropping an intensively mown grass-clover with potassium (K) fertilisation, which could potentially be used as cattle feed. A long-term field experiment was conducted, comparing soil P removal by grass-clover swards with, and without, K fertilization on a sandy soil. Our results show that grass-clover with K fertilization is an effective method that removed excess soil P at a relatively high rate (34 kg P ha^{-1} $year^{-1}$, significantly higher than without K fertilization, $P<0.05$). Therefore phytoextraction can be an important synergy between agricultural production and nature restoration.

Keywords: grass-clover, potassium fertilisation, phytoextraction phosphorous, nature

Introduction

In the Netherlands, an extensive network of green corridors, called National Ecological Network is being implemented. In this context, many hectares of arable land have been transferred to nature reservations. In most of these former agricultural soils, long-term applications of fertilisers and animal manure in the past, that have stopped after land acquisition by nature organizations, have led to an imbalance in the levels of soil nutrients: while these soils often have high levels of relatively immobile soil P, the more mobile nitrogen (N) and potassium (K) have often become suboptimal according to agricultural standards. Apart from problems with leaching and eutrophication of surface water, high soil P levels are a threat to certain types of species-rich plant communities. One of the methods to decrease soil P levels for nature restoration is topsoil removal, but this practice is often expensive and conflicts with objectives of soil conservation and conservation of historical heritage. Hence, there is an urgent need for a better strategy to remove excess P from former agricultural land in a way that ensures successful development of 'ecosystem target types', such as nutrient-poor, species-rich grasslands. We designed a method to test phytoextraction of P with grass-clover swards. Experiences in practice in various nature areas using grass-clover swards resulted in 'losing' the clover from the sward and very low dry matter (DM) yields after some years. We argued that legumes are weak competitors for K and hypothesized that (1) K limitation could be the cause of clover decline in grass-clover swards in nature areas, and that (2) with K fertilisation, grass-clover swards could be an effective method to reduce soil P levels to levels low enough to accommodate species-rich plant communities. We designed a field experiment with a duration of 7 years to test these hypotheses, with the aim to develop a new and cost-effective way to remove excess P from former agricultural soils, by phytoextraction of P with a grass-clover sward (Timmermans and Van Eekeren, 2016).

Materials and methods

In a field experiment, two treatments were compared: (1) no K fertiliser application, and (2) K fertiliser application at a rate of 398 kg K ha^{-1} per year. Our experiment was set up on a former arable field that is currently part of a nature conservation area. The field with the experiment had a noncalcareous sandy soil (Spodosol; Podzol, cover sands of pleistocene origin). Some soil characteristics were: 5.8% soil organic matter in the topsoil, pH-KCl of 4.3 and K-HCl 28.2 mg K kg^{-1}. The experimental plots were sown in 2002, and treatments and measurements continued until 2009. The experimental design was a randomized block design in 4 blocks, with 4 replicate plots (4×10 m) per treatment. All plots were sown with a mixture of 30 kg ha^{-1} perennial ryegrass (*Lolium perenne*) and 4 kg ha^{-1} white clover (*Trifolium repens*). At each harvest date, all plots were mown with a two wheel tractor (Eurosystems P55). Freshly mown material was weighed and a representative fresh sample of about 700 g was dried at 70 °C for 24 hours. A sub-sample of these dried samples was analysed for P and another sub-sample was dried at 105 °C for one hour additionally to determine DM content and calculate total DM yield. Soil samples from the 0-10 cm soil layer were taken each year in winter and analysed for total P and ammonium lactate extractable P (P-AL). Statistical analysis was performed using GenStat. Repeated measures ANOVA was used for comparing annual data across years and treatments.

Results

In the first two years of the experiment the total DM yield (clover plus grass) was similar between treatments, but significantly lower in the unfertilised plots from 2004 onwards, up until the end of the experiment in 2009 (Figure 1).

The amount of P removed by grass-clover was significantly higher in the K fertilised treatment than in the unfertilised treatment (34 kg P ha^{-1} $year^{-1}$ compared to 26 kg P ha^{-1} $year^{-1}$ on average over the years). Compared to differences in DM yield, differences in P removal were somewhat smaller between treatments, because P content (g kg^{-1} DM) in the treatment without K fertilisation increased with decreasing biomass (P<0.001; R^2=0.18). Chemical analyses of soil samples from the experimental plots showed significant decreases in P-total and P-AL in both treatments over the years (Figure 2). Soil P levels were generally lower in K fertilised plots than in unfertilised plots, but this treatment effect was not significant (P=0.085 and P=0.107).

Discussion and conclusions

Our results indicate that our first hypothesis was correct: in plots without K fertilization, productivity of grass-clover was lower than in K fertilised plots. Our results also support the first part of our second hypothesis, i.e. that grass-clover combined with K fertilisation can be an effective method to reduce soil P levels in sandy soils: this treatment removed 34 kg P ha^{-1} $year^{-1}$ on average. Our results also provide

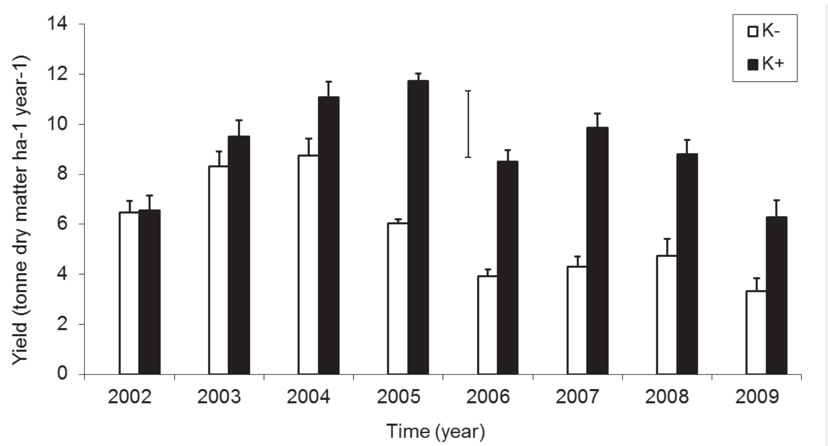

Figure 1. Average annual dry matter yield (t ha^{-1}) (P=0.004) in K fertilised plots and unfertilised plots, from 2002 to 2009. Error bars indicate standard error of the mean. The error bar at the top indicates the least significant difference (P<0.05) between the treatments.

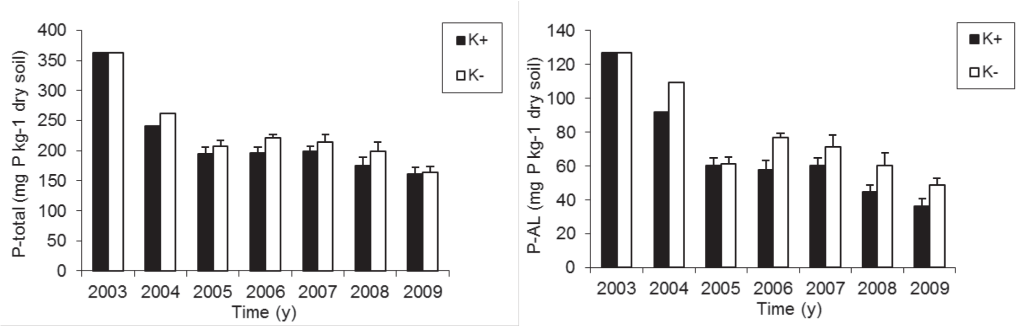

Figure 2. Average P-total (left) and P-AL (right) in the 0-10 cm soil layer of K fertilised plots and unfertilised plots.

evidence for the second part of this hypothesis: that this method could indeed remove enough P to arrive at a plant available P concentration low enough for species-rich grasslands. By the end of the experiment the average soil P level in the K fertilised treatment was comparable to soil P levels in nutrient-poor, species-rich grasslands in the region. We conclude that intensively harvested grass-clover fertilised with K is an effective alternative to topsoil removal to reduce excess P. Moreover, this method provides an elegant way to recycle P, i.e. to transfer excess soil P from new nature areas back into the agricultural system by cattle feed (Timmermans and Van Eekeren, 2016).

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