Balanced phosphorus fertilization on grassland in a mixed grazing and mowing system: a 13-year field experiment

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Abstract

In the Netherlands the legal phosphorus (P) application standard is decreasing from the year 2006 to 2013, to balanced P fertilization (input equals output). The long term effect of balanced P fertilization on grassland is estimated by simulations, not in experiments. In a field experiment from 1997 to 2009 the development in time of dry matter (DM) yield and P content of grass at balanced P fertilization is compared with positive P surpluses at two N levels on four permanent grassland sites (sand1 and sand2, clay and peat). The plots were grazed and mown. Three P surpluses (0, 10 and 20 kg P ha^{-1} yr^{-1}) and two N surpluses (180 and 300 kg N ha^{-1} yr^{-1}) were applied. The mean DM yield at balanced P fertilization was lower than at 20 kg P ha^{-1} yr^{-1} surplus, 690 kg DM ha^{-1} yr^{-1} on sand and 526 kg DM ha^{-1} yr^{-1} on peat. On clay the difference was reversed. The average P content of the grass at a surplus of 20 kg P ha^{-1} was 0.3 g P kg^{-1} DM higher than at balanced P fertilization. At all locations, except on clay, the P content of grass from balanced P fertilization declined to values below the Dutch standard for grass in dairy cattle rations with silage maize.

Keywords: grassland, grazing, phosphorus, balanced fertilization, dry matter yield, P content

Introduction

In the Netherlands farmers are obliged to decrease fertilization, due to the Nitrate Directive of the European Union. From 2006, the nitrogen (N) and phosphorus (P) fertilization is limited. The legal P application standard is decreasing to 2013, to balanced P fertilization (input equals output). Simulations of the long-term effect of balanced P fertilization on grassland in the Netherlands showed that a positive soil surface P balance of 10–20 kg P ha^{-1} yr^{-1} is necessary to maintain soil fertility and, as a consequence, the production level of grassland (Oenema and Van Dijk, 1994). This is, however, not measured in experiments. To examine the effect of balanced P fertilization, a field experiment was started in 1997. The objectives were development in time of soil fertility, dry matter yield (DMY) and grass composition at balanced P fertilization, compared with positive P surpluses and the interaction with N level, grazed and fertilized with cattle manure and mineral fertilizer. This paper presents the results of DMY and P content of grass from 1997 to 2009 (13 years).

Materials and methods

The field experiment was carried out on four permanent grassland sites in the Netherlands: sand (sand1 and sand2), young marine clay, and peat soil. At the start (autumn 1996) the P soil fertility was, according to Dutch standards, sufficient for all four locations. In the 0–5 cm layer, organic matter was 5% on sand1 and sand2, 8% on clay and 52% on peat; pH_{KCl} was 5.6 on sand1 and sand2, 7.7 on clay, 5.0 on peat ("good" according to Dutch standards).
At each location six plots were randomly assigned to a combination of P and N surpluses, without replicates. Fertilization levels were aimed to supply surpluses of 0, 10 and 20 kg P ha^{-1} yr^{-1} (P0, P10 and P20) and 180 and 300 kg N ha^{-1} yr^{-1} (N180 and N300). Cattle slurry

and mineral P fertilizer were applied in early spring and before the fourth cut, and mineral N fertilizer was applied throughout the whole season. The P10 and P20 surpluses were to be achieved by applying superphosphate or triple-superphosphate. The first and fourth cuts were taken for silage, and the other cuts were grazed by (non-lactating) heifers. Each plot was split into a part to adapt the animal excreta to the mineral composition of the grass and a part to measure and sample. Assessments of DMY and N and P content were determined when grazing or cutting took place. The surpluses were calculated as fertilization minus output in silage cuts and in weight increase of heifers. Grazed and excreted nutrients were considered to be an internal cycle.
The annual DMY and grass P content were statistically analysed with the Restricted Maximum Likelihood (ReML) technique (Harville, 1977), using Genstat. ReML fits a random and a systematic part of a model to the data. The random part contains factors that are not controllable. The systematic part contains factors that can be controlled (like treatments). Non-significant interactions ($P > 0.05$) were deleted from the model. The analysis determined significant effects ($P \leq 0.05$) and inclusions of variables in the model quantified the effects. All equations were linear. In order to determine if there was an indication of curvature, year number^2 was tested. The value of year number in the starting year was 1. Sand1 was included in the analysis until 2001 due to a change to organic fertilization on this location.

Results and discussion

The N surpluses were much lower and P surpluses slightly lower than planned (Table 1). The lower N surplus proved to be close to the application standard for total N on grassland. The ReML analysis for DMY and P content showed that in the random part year.location had a significant contribution, implying different year effects per location.

Table 1. Treatments and results of P fertilization experiment on grassland (1997–2009)

N-surplus planned kg ha^{-1}	P-surplus planned kg ha^{-1}	Nfertilization kg ha^{-1}	Pfertilization kg ha^{-1}	DM yield kg ha^{-1}	N content g kg^{-1}	P content g kg^{-1}	Total N yield kg ha^{-1}	Total P yield kg ha^{-1}	N-surplus, actual kg ha^{-1}	P-surplus, actual kg ha^{-1}
180	Mean	238	33	10816	28.3	3.7	307	39.4	125	8.6
300	Mean	370	35	12250	30.6	3.6	374	43.5	234	8.8
Mean	0	304	24	11340	29.5	3.4	335	39.0	182	0.2
Mean	10	304	34	11518	29.3	3.6	337	41.7	180	8.6
Mean	20	304	44	11740	29.6	3.7	348	43.7	177	17.3

* sand1 results taken until 2001.

For DMY in the systematic part the interaction location.soil type was significant, implying that the level of DMY on the two sand locations was different (Table 2, eq. 1).

Table 2. REML estimates for factors affecting DM yield (1000 kg DM ha^{-1}) and P content in grass (g P kg^{-1} DM)

	DM yield			P content	
Location	constant	ß1 (P fert)	ß2 (N fert)	Constant	ß1 (P fert)
Sand1	10.387	0.0345	0.002959	3.571	0.006662
Sand2	8.399	0.0345	0.002959	3.571	0.006662
Clay	6.505	–0.0134	0.01719	4.436	–0.00076
Peat	8.531	0.0263	0.005981	3.538	0.005708

The factors N- and P-fertilization, location and the interactions between soil type and N and P fertilization were significant. The response of DMY to N- and P-fertilization was different between soil types, not between sand1 and sand2. Year number[2] was not significant. According to the model the difference in DMY between P0 and P20 was 690 kg DM ha^{-1} on sand, 526 kg DM ha^{-1} on peat, and – 268 kg DM ha^{-1} on clay (Table 2, eq. 1). There was no significant trend in time in this difference as the interaction of P-fertilization. year number was not significant. The negative effect of P-fertilization on clay was thought to be out of line with other results. It is a consequence of a deviated plot. The lower DMY at a lower P-surplus resulted in a significant ($P \leq 0.05$; analysis not shown) lower N-yield (Table 1) and therefore a higher N-surplus.

$$\text{DM yield} = \text{constant}_{location} + \text{P-fertilization}*\text{ß1}_{soil\ type} + \text{N-fertilization}*\text{ß2}_{soil\ type} + \text{year number}*-0.1296 + \text{year number}*\text{N total fertilization}*0.00066 + \varepsilon_{year+year.location} \quad \text{(Equation 1)}$$

The ReML analysis for P-content of the grass showed that in the systematic part N- and P-fertilization, soil type, year number, P-fertilization.soil type and P-fertilization.year number were significant (Table 2, eq. 2). The two sandy soils showed no significant difference. P-content responded negatively to N-fertilization, probably by dilution as both N levels were harvested at the same time. P-content responded positively to P-fertilization except initially on clay but after two years the response was also positive. The trend over time was the same (significant and negative) for all locations and treatments. It was becoming less negative at a higher P-fertilization. A zero trend would be reached with a P-fertilization outside the experimental treatments. The net trend for P-content in the experiment was negative.

$$\text{P content of grass} = \text{constant}_{soil\ type} + \text{P-fertilization}*\text{ß1}_{soil\ type} + \text{N-fertilization}*-0.00101 + \text{year number}*-0.07534 + \text{P-fertilization}*\text{year number}*0.0004134 + \varepsilon_{year+year.soil\ type} \quad \text{(Equation 2)}$$

In the Netherlands the standard for P-content in dairy cattle rations is 3.5 g P kg^{-1} DM and 3.3 g P kg^{-1} DM for grass in rations including silage maize (derived from Valk, 2003) which is common in the Netherlands. At all locations, except clay, grass from P0 declined to values below this standard during the experiment.

Conclusions

The mean difference between 13 years of balanced P fertilization and a surplus of 20 kg P ha^{-1} yr^{-1} was 625–750 kg DM ha^{-1} yr^{-1} on sand and 530 kg DM ha^{-1} yr^{-1} on peat. There was a negative effect on clay of P surplus, but this was thought to be out of line with other results obtained at the same site. The average P content of the grass at a surplus of 20 kg P ha^{-1} was 0.3 g P kg^{-1} DM higher than at a surplus of 0 kg P ha^{-1}. The N surplus had a significant negative effect on P content, probably by dilution as both N levels were harvested at the same time. At all locations, except clay, grass from balanced P fertilization declined to values below the standard for grass in dairy cattle rations with silage maize.

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