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Long-term effects of nutrients on productivity and species-richness of grasslands: the Ossekampen Grassland Experiment

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Summary

The Ossekampen Grassland Experiment was established in 1958 on a species-rich old pasture on heavy clay soil near Wageningen, the Netherlands, to track productivity and plant species shifts under long-term application of inorganic fertilizers. Fertilizers were applied annually as a single nutrient: N, P, K or Ca, or in combinations: PK, NPK and PK+N.

Nutrient application had a strong effect on productivity and species-richness. Adding single nutrients had no positive effect on dry matter production compared to the unfertilized treatment. Combined application of P and K increased dry matter production by more than 1 t ha^{-1} and NPK by about 3 t ha^{-1}. Liming had a positive effect on species-richness, presented as the total number of species found in 50 samples whereas N application resulted in a serious reduction in species numbers. Species-richness in all plots initially declined but started to recover after about 25 years of continued fertilization (Pierik *et al.*, 2011), clearly demonstrating the added value of long-term experiments.

Key words: Species-rich grasslands, N, P, K fertilizers, productivity, long-term experiment, botanical composition

Introduction

In the years after the Second World War agriculture in the Netherlands showed tremendous and rapid changes. Drainage, reseeding, fertilization, mechanization, and new methods of fodder conservation resulted in an increase in grassland productivity but also in a tremendous loss of biodiversity within grassland communities. Semi-natural grasslands were improved and re-sown with highly productive varieties. Dutch grassland scientists - Prof ML ‘t Hart and Prof DM de Vries - were aware of the rapid decrease in diversity of semi-natural grassland and took the initiative to establish an experiment, following the example of the ‘Park Grass Experiment’ at Rothamsted, UK (Silvertown *et al.*, 2006), to conserve a part of these semi-natural grasslands and to study the impact of a grazing regime in combination with a limited fertilization level and a haymaking regime in combination with higher fertilizer applications on these grasslands. The fertilizers were applied as a single element or in combination.

Materials and Methods

The Ossekampen Grassland Experiment was established in 1958 on a species-rich old pasture on heavy clay soil near Wageningen, the Netherlands, to track productivity and plant species shifts under long-term application of inorganic fertilizers (Elberse *et al.*, 1983). This paper will focus only on the results of the haymaking treatments, not on the grazed plots. Fertilizers are applied yearly as a single element: N (ammonium nitrate), P (superphosphate), K (potassium nitrate) or Ca (lime marl) or in a combination of nutrients PK, NPK (N applied in spring and summer) and PK+N (N only applied after first cut). Fertilization levels are adjusted, depending on crop nutrient uptake, with the aim of keeping the nutrient status of the fertilized treatments at a medium/high level. In addition to the fertilized plots the experiment includes an unfertilized control treatment. Plots (each 40 m^2) are replicated twice.

Productivity is measured annually by cutting a strip of 20 m^2; two cuts are taken annually at the end of June or beginning of July and again in October on every plot. After the first cut the grass dries for a few days on the plots before being removed. In autumn the grass is removed immediately after cutting. Fresh grass samples are analyzed for dry matter content (DM) and N, P and K concentration. Botanical composition has been analyzed annually or biannually and since 2005 triennially. Fifty samples of 25 cm^2 were taken by clipping from each plot at regular intervals along three parallel lines. Species-richness is derived from the total number of species found in the 50 samples. Soil fertility was previously analyzed at irregular intervals but has been measured triennially since 1985.

Results

Dry matter production varies strongly between years (Fig. 1). Different fertilizer applications result in great differences in DM productivity and nutrient uptake by the crop (Table 1). Application of single N, P or K fertilization gives no increase in DM production compared to the unfertilized control treatment but results in a higher crop uptake of the element on the specific plots. Liming alone has no effect on DM production but stimulates P uptake by the crop on the limed plots.

The combination of P and K fertilization gives significantly higher DM yields and results in a higher crop uptake of N, P and K as well. Applying N in combination with P and K leads to an extra increase in DM production as well as in N, P and K uptake. Splitting N application into two doses makes no difference to yield compared with N application in one dose after the first cut.

Liming has a positive effect on species diversity (Table 1). In 2014, pH in the top-soil layer (0–5 cm) on the limed plots was more than two units higher then on the unfertilized plots (6.3 *vs* 4.1). Many years of N application, on the other hand, resulted in a serious decrease in species numbers and some decrease in pH (3.6, 4.0 and 3.8 for treatments N, NPK and PK+N).

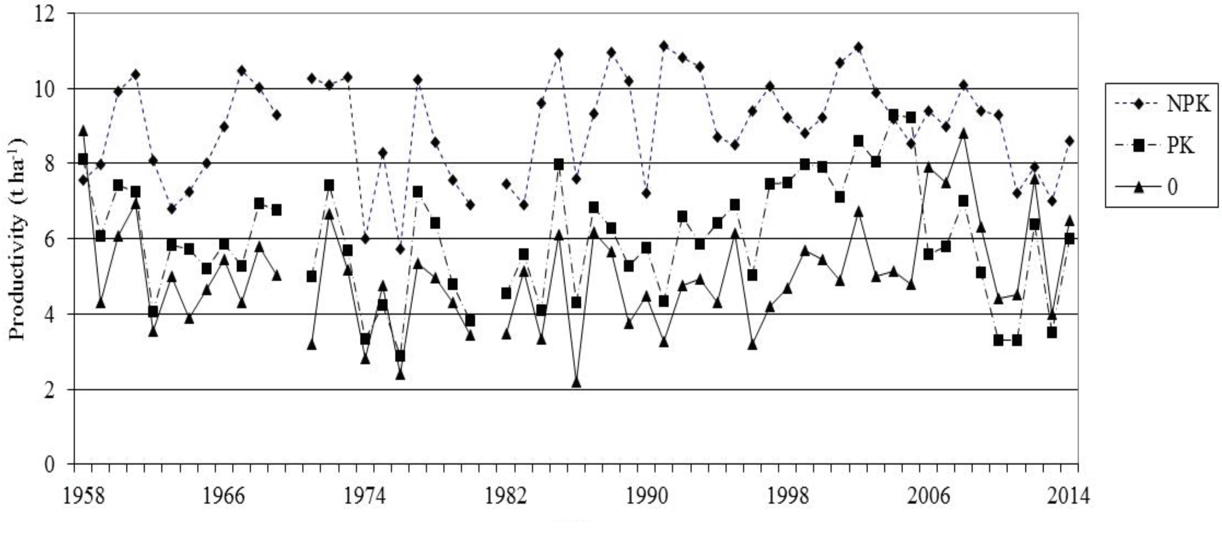

Fig. 1. Productivity (DM, t ha^{-1} yr^{-1}) on treatments NPK, PK and unfertilized.

Table 1. *Fertilizer application, average annual dry matter, N, P and K yields and species-richness in years 2005–2014*

Treatment	Fertilizer application (kg ha^{-1})				Productivity d.m. (t ha^{-1})		Yields in crop (kg ha^{-1})						Species richness (number of species per plot)	
	N	P	K	Ca			N		P		K			
0	0	0	0	0	5.0	a[3)]	77	a	6	a	52	a	32	cd
Ca	0	0	0	357	5.9	ab	87	ab	7	b	58	a	39	e
P	0	22	0	0	6.0	ab	87	ab	17	c	57	a	32	cd
K	0	0	108	0	5.4	a	80	a	6	ab	125	b	35	d
PK	0	22	166	0	6.7	b	92	ab	16	c	155	c	31	c
N	160[1)]	0	0	0	5.2	a	105	b	6	a	58	a	23	b
NPK	160[1)]	33	311	0	8.7	c	134	c	19	d	221	d	15	a
PK+N	160[2)]	33	311	0	9.3	c	136	c	20	d	242	d	18	a

[1)] 100 kg ha^{-1} N in April and 60 kg ha^{-1} N after first cut; [2)] 160 kg ha^{-1} N after first cut;
[3)] letters denote significant differences between treatments at *P*<0.

Discussion

Nutrient application had a strong effect on productivity and species-richness (Table 1). Adding single nutrients had no positive effect on DM production, once again demonstrating Liebig's law of the minimum which explains resource deficiencies and their interaction. When the years are grouped in periods of about 8 years, productivity is rather stable for the different treatments, except for the PK treatment. From 1998 to 2005 DM production on the PK treatment was more than two tonnes higher per ha than in other periods. In this period the weather conditions were probably favorable for legumes, resulting in a rather higher proportion of legumes and extra N fixation.

Pierik *et al.* (2011) showed that species-richness initially declined in all plots but started to recover after about 25 years of continued fertilization. This was also the case for the heavily fertilized NPK treatment. The decline was strongest in the NPK plots where it was associated with a strong divergence of plant species composition from the control treatment, reflecting a shift to a plant community adapted to nutrient-rich conditions (Pierik *et al.*, 2011).

At the Ossekampen Grassland Experiment different fertilization applications not only resulted in differences in plant productivity and plant species diversity but also in differences in soil biota communities (Van der Wal *et al*., 2009) and bacterial communities (Pan *et al.,* 2014). The diversity of nematodes, collembolans, mites and enchytraeids was increased by N, PK and NPK fertilization. Nematode and earthworm biomass increased by liming. Soil diversity might be driven more by plant productivity rather than by plant diversity (Van der Wal *et al.,* 2009). Pan *et al.* (2014) showed that several soil parameters, like the Al, As, Mg and Mn contents, differed within the N, P or K and the NPK treatments resulting in bacterial community composition shifts. Redundancy analysis of the soil parameters and the bacterial community profiles showed that Mg, total N, Cd and Al were linked to bacterial community variation. But, they found no fertilizer effects on microbial functional profiles, which suggests that on this site functional profiles are more resistant to environmental changes than bacterial community composition (Pan *et al*., 2014).

Conclusion

Nutrient application had a strong effect on productivity and species richness. Adding single nutrients had no positive effect on DM production compared to the unfertilized treatment. Combined application of P and K increased DM production by more than 1 t ha$^{-1.}$ In some years the differences are much greater due to extra N fixation by legumes. Application of NPK increased DM production by about 3 t ha^{-1} compared to the unfertilized treatment. Liming had a positive effect on species numbers whereas N application resulted in a serious decrease of these numbers.

On this site species-richness initially declined in all plots but started to recover after about 25 years of continued fertilization (Pierik *et al.*, 2011), clearly demonstrating the added value of long-term experiments.

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