Side-band injection of acidified cattle slurry as starter P-fertilization for maize seedlings

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Abstract

Accumulation of phosphorus (P) in agricultural soils has caused increasing environmental concerns. Maize cropped for fodder implies return of animal manures rich in nutrients. In addition, starter fertilization with mineral P is used in cold conditions for maize cropping. It was hypothesized that the use of the additional mineral P could be excluded by increased availability of the P applied by animal manures. In a growth chamber experiment we investigated the effect of acidified slurry on the growth and nutrient uptake in maize seedlings. In special designed pot the slurries and mineral reference treatments were banded next to the seed row. Plants were harvested on nine dates with 4-6 days interval and an exponential growth function was fitted to the recordings. The P-uptake from acidified cattle slurry was clearly increased compared to raw slurry, and comparable to the mineral P-reference treatment. The effect of untreated raw slurry was similar to the mineral reference without P.

Introduction

In Danish farming practice maize is typically fertilized with animal manure in rates, which fully covers the crop requirements for phosphorus (P). On top of that, mineral P fertilizer is side-banded next to the seeds at sowing to overcome P deficiency at early growth stages. Maize is typically grown in the same field in consecutive years, which cause an unintended accumulation of P in soils. This raise at least two concerns: 1) the agricultural use of the limited global P reserves that puts emphasis on the need for reducing the use of mineral P fertilizers in agriculture, and 2) the environmental impact of P losses from agriculture, e.g. expressed in the third *Action plan for the aquatic environment* passed by the Danish parliament, which stipulates a 50% reduction of the national P-surplus in 2015. Our aim was to examine the opportunities for replacing mineral starter P fertilization by side-band placement of cattle slurry as P source for maize seedlings.

Material and Methods

Growth chamber experiment

A pot experiment with maize seedlings was carried out using in total 270 pots with five treatments, nine sampling dates and two replicates completely randomised within each of three growth chambers with temperature regimes of 7, 10 and 13°C (increasing by +0.1°C/day, oscillating ±4°C during 24h for a day/night of 16/8h), respectively. The temperature regimes simulated temperatures in April-May corresponding to the sowing time of maize under Danish conditions.

The pots were 27×14×20 cm (L×W×H) which gave the opportunity to simulate side-banding of nutrients next to a crop row (Figure 1). They were filled with a coarse sand soil (corresponding to 7.8 kg dry soil) characterized by pH=4.4 and Olsen-P=65 mg kg^{-1}. The application rate for all five treatments (Table 1) was 0.75 g P pr. running meter nutrient band corresponding to an application rate of 10 kg P ha^{-1} for a maize crop sown at 75 cm inter-row distance. The actual slurry application rate (Table 2) was calculated based on preliminary P analysis. The pots were surface irrigated and any surplus was drained through holes at the bottom of the pots. Soil water status was recorded daily by using tensiometers and weighing of selected pots to avoid water shortage.

Two replicates (pots) of each treatment and growth chamber combination were harvested at each sampling date during a 6-9 week period of growth adjusted to the growth within each temperature regime (Table 3). Dry matter yield and uptake of N, P and potassium (K) were determined. In addition, plant height, growth stage, P deficiency symptoms, and root proliferation in relation to the fertilizer band were also recorded.

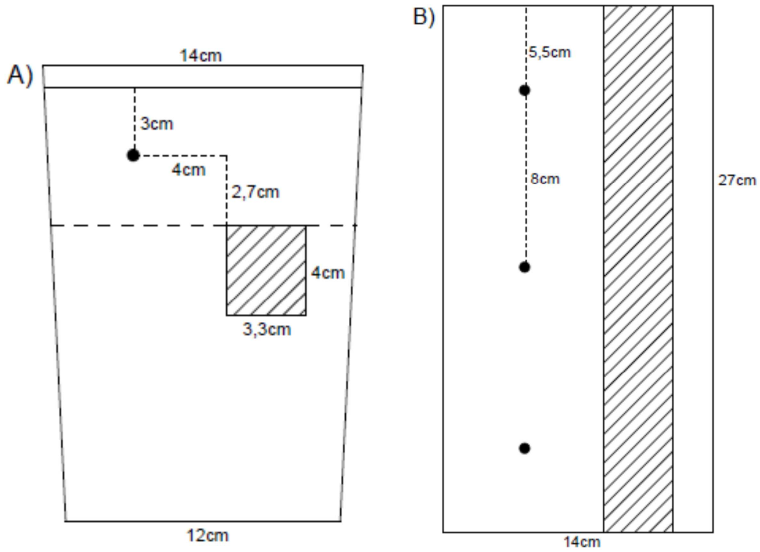

Figure 1. Placement of seeds and manure/fertilizer in relation to each other within the pots. A) Pot viewed from the end, and B) viewed from the top. The dots represent seeds and the cross-hatched area the manure volume of treatment 1 and 3. The horizontal and vertical distance of 4 and 2.7 cm, respectively, from the seeds to manure/fertilizer was fixed for all treatments (see text). The soil below the dotted line in figure A was filled into the pots (1.3 g/cm^3) and the shape of the space for manure in treatment 1-3 was formed by removing the soil using specialized designed tools to obtain the desired volume for the slurry. The position of manure/fertilizer was intermediately marked before immediately and gently filling of the soil above the dotted line (approx. 1.1 g/cm^3). Finally the seeds were sown relative to the manure/fertilizer using the intermediate marks. All pots were placed in a greenhouse until emergence of the maize seedlings and then moved to the growth chambers.

Table 1. Description of the five treatments.

Treatment	Description
1	Raw cattle slurry
2	Acidified cattle slurry
3	Mixture of raw cattle slurry in half rate spiked with mineral P (NaH_2PO_4)
4	Mineral nitrogen (N) – reference treatment without P (solution of $(NH_4)_2SO_4$)
5	Mineral NP – reference treatment with P (solution of $(NH_4)_2SO_4$ and NaH_2PO_4)

Table 2. Characteristics and rate of the slurries.

Treatment/slurry	Slurry rate [g/pot]	Total-P [g/kg]	Water extractable P [% of total P]	Total-N [g/kg]	pH
1 – Raw slurry	362	0.53	60	3.2	7
2 – Acidified slurry	362	0.52	77	3.3	5.5
3 – Mixture of raw slurry and mineral P	181	1.1	55	3.1	7

Table 3. Number of fully unfolded leaves recorded for >60% of the plants within the three temperature regimes. In some cases the two most dominating numbers of unfolded leaves are given.

Temperature regime	Day number from emergence of maize seedlings												
	6	10	15	21	26	31	35	40	45	49	54	59	63
7°C					2	3	3	3	¾	4	4/5	5	5
10°C		1	2	3	3	3/4	4	5	5	6			
13°C	1	2	3	3	4	5	5	6	7				

Modelling
An exponential function:

$$y = a \times \exp[b_i \times T_{sum} \times 10^{-3} + c_i \times (T_{sum})^2 \times 10^{-6}],$$

where index *i* denotes treatment 1-5 and T_{sum} the accumulated temperatures based on the daily average temperature above the base temperature of 5°C was applied to describe the growth of dry matter yield and N, P and K uptake. The parameter *a* was common for the five treatments, whereas parameter *b* and *c* were estimated for the individual treatments. The parameters and standard errors (s.e.) were estimated using the procedure NLMIXED in SAS (SAS Institute Inc., Cary, NC).

Results and discussion
The plants were 50-70 cm tall at the last sampling date for the temperature regime of 13 °C, but the temperature regime of 7 °C was too cold for maize growth, particularly during the first six weeks where the plants had yellow leaves.

The estimates of the parameters *b* anc *c* for the individual treatments appears from Table 4 and the average standard errors from Table 5. In general, the estimates of *b* increase by temperature regime in contrast to the estimates of *c* that decrease and even became negative. The estimates obtained for the temperature regime of 13°C had the smallest standard errors and most significant differences between the treatments. When interpreting the esimates of *b* and *c* they have to be considered together because they are not independent. A large estimate of parameter *b* indicates a relatively steep increase throughout the monitoried period, but this increase is reduced to the greatest extent by the most negative values of parameter *c*. To support the interpretation of the estimates in Tabel 4 the estimated curves and recorded values were plotted in Figure 2.

Table 4. Estimates of the treatment individual parameters *b* and *c* in the applied model. The estimate for the common parameter *a* are indicated in average of the three temperature regimes for each response variable. Average standard errors of the parameters *b* and *c* are given in Table 5.

Response variable	Treatment	Estimates of parameters *b* and *c* by temperature regime					
		b ($\times 10^{-3}$)			c ($\times 10^{-6}$)		
		7°C	10°C	13°C	7°C	10°C	13°C
Dry matter	1	6.3	10.2	14.3	-.24	.43	-7.37
(a=.06)	2	5.3	11.0	13.8	2.60	-2.90	-4.29
	3	5.8	9.9	15.3	1.99	0.75	-9.16
	4	5.6	12.9	15.4	2.82	-10.17	-10.78
	5	5.7	11.9	15.8	2.31	-5.32	-9.31
N offtake	1	1.50	7.7	11.7	6.3	2.0	-4.7
(a=.004)	2	.72	7.9	11.5	9.9	2.1	-2.0
	3	1.59	7.4	13.5	6.1	2.9	-8.9
	4	2.00	10.5	12.8	6.0	-7.6	-8.4
	5	1.67	8.7	14.0	6.7	.5	-9.1
P offtake	1	1.18	3.67	6.7	3.2	4.0	1.0
(a=.6)	2	.74	2.82	6.4	5.7	9.9	4.6
	3	2.38	3.31	8.4	-.3	6.9	-1.8
	4	1.93	6.48	7.8	1.7	-5.4	-3.2
	5	1.58	5.61	10.5	3.1	1.5	-6.1
K offtake	1	7.9	14.6	17.6	-1.6	-5.3	-12.4
(a=1.5)	2	5.9	14.1	16.8	4.1	-2.7	-8.8
	3	6.5	13.7	19.4	3.7	-1.3	-16.4
	4	5.5	16.0	18.1	4.8	-11.4	-16.4
	5	5.7	15.6	19.8	4.4	-8.8	-20.0

Acidification affected the crop response at the highest temperature regime by increased plant dry matter and nutrient uptakes compared with raw cattle slurry. The mineral NP reference was superior to the other treatments in the first half of the experimental period but the effect of the NP reference was surpassed by the acidified slurry during the later part. Similar effects on P-uptake were obtained at the middle and lowest temperature regimes but less significant. Thus, the P-availability was increased by acidification, but increased P-concentration by adding mineral P to the raw slurry did not clearly increase the P-uptake (treatment 1 *vs.* 3). Generally, treatment effects on maize growth and P up-take could be ranked: acidified slurry (2) > mineral NP (5) > mixed slurry/mineral P (3) > raw slurry (1) > mineral N (4). The treatment effects on K-uptake differed from this order as the two mineral reference treatments were even with a clearly smaller response than for the slurry treatments rich in potassium.

Table 5. Average standard error of the estimates for parameter *b* and *c* in Table 4.

Response variable	S.E. of parameters b and c by temperature regime					
	b ($\times10^{-3}$)			c ($\times10^{-6}$)		
	7°C	10°C	13°C	7°C	10°C	13°C
Dry matter	1.7	1.1	1.0	3.6	2.8	2.2
N-uptake	1.6	1.1	1.0	3.3	2.9	2.2
P-uptake	1.4	1.1	1.0	3.0	2.9	2.2
K-uptake	2.1	1.6	1.0	4.3	4.2	2.3

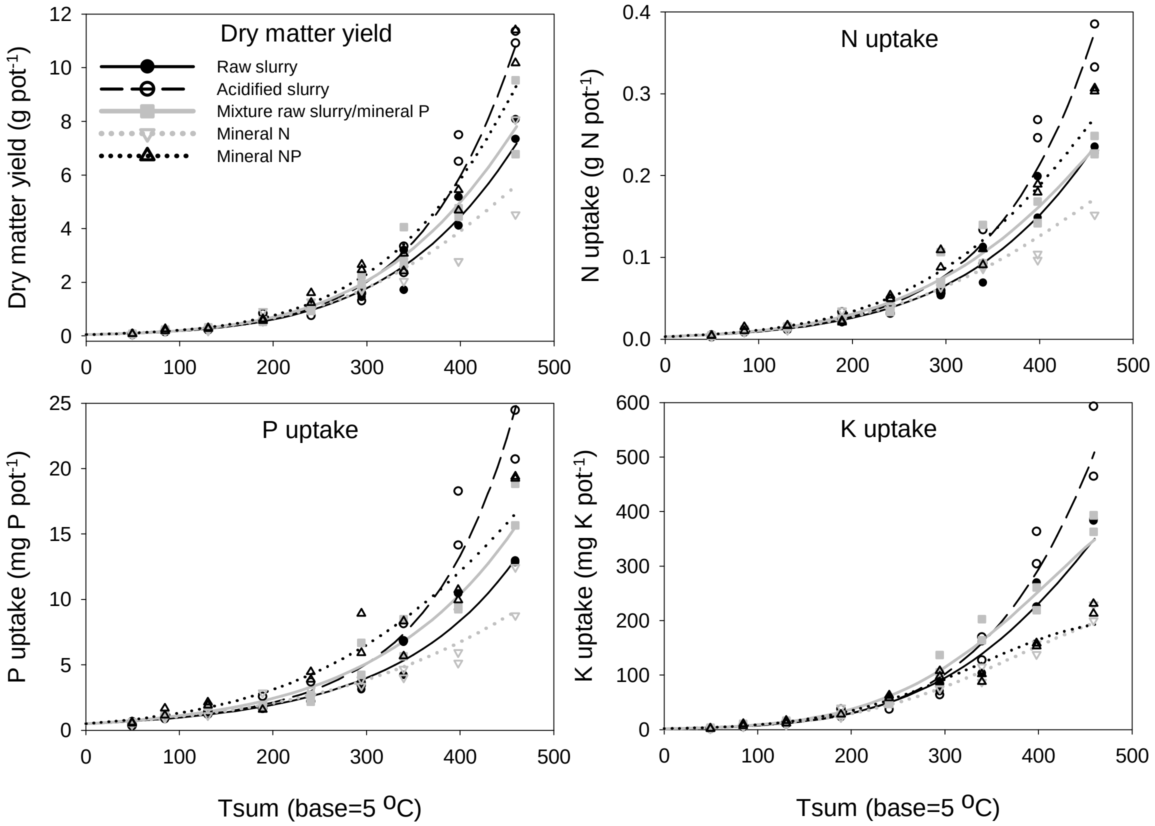

Figure 2. Recorded values and estimated curves using the estimated parameters in Table 4 for dry matter yield, N-, P- and K-uptake versus accumulated temperature using basis 5 °C for the temperature regime denoted 13 °C.

Conclusion and perspectives

Acidification of cattle slurry can increase P availability from the slurry to such a degree that acidified cattle slurry has a potential to substitute mineral P fertilizer as a starter fertilizer for maize. Although the results from this controlled experiment are promising, the effect of acidification on the availability of slurry P needs to be tested in other conditions before general conclusions may be drawn, both in relation to the opportunities to reduce the national P-surplus and with respect to advices in farming practise when growing maize. Furthermore, our results clearly show that the effects of starter fertilization has a very dynamic character implying that an experimental design with an intensive sampling strategy in conjunction with modelling have to be applied to interpret treatment effects.