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Maize yields benefit from injected manure positioned in bands

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ABSTRACT

The use of positioned mineral fertilizer phosphorus (P) starters reduces the risk of yield penalties in maize production. However, it also increases the soil P surplus and attendant risk of P losses to the environment, in particular on farms with ample supplies of livestock manures. We examined whether routine applications of starter P can be refrained from if manure is injected in subsurface bands close to the anticipated position of the maize rows as an alternative to the conventional even injection at random lateral positions relative to the rows.

Fourteen field experiments were executed on sandy soils in The Netherlands. In these experiments comparisons were made of the nitrogen (N) and P-concentrations in shoots and of dry matter (DM), N and P-yields over time, between evenly injected liquid manure (with and without starter P) and band-injected liquid manure.

Silage yields of DM, N and P generally responded positively ($P < 0.05$) to starter P applied at a rate of 9–31 kg per hectare where manure had been applied at rates of circa 120 kg N and circa 20 kg P per hectare, but less so when the manure was band-injected. This positive response to P was not reflected in the concentration of P in shoots. Positioning of manure via band-injection without extra starter P resulted in silage maize dry matter yields that were similar to yields after even injection combined with a P-starter. Band-injection improved the recovery of the N and P ($P < 0.05$) supplied by the manure and reduced the soil surpluses of N and P. Planting maize close to bands where liquid manure had been injected, thus increased silage yields and contributed to a better balance between the inputs and outputs of plant nutrients.

1. Introduction

The low solubility of phosphorus (P) limits its concentration in soil water. Hence, plants cannot always acquire sufficient P by the transpiration-driven mass flow or by diffusion toward the root surface. P-demand of annual crops must thus also be met by the constant proliferation of roots into as yet unexplored sections of the soil profile (Syers et al., 2008). Annual row crops such as maize (*Zea mays* L.) may thus acquire insufficient P, resulting in retarded growth and the typical purpling of leaves (Plénet et al., 2000). P-uptake requirements of maize per unit time are small during the first weeks after emergence, but uptake requirements per unit root length are relatively great (Smit et al., 2010; Schröder et al., 2011). P-deficiency can be prominent, particularly under dry or cool conditions. Drought increases the tortuosity of the path along which P has to move from the bulk soil to the root surface, whereas low temperatures reduce the root length per unit dry matter (DM) invested in roots (Mackay and Barber 1984; Engels and Marschner, 1990). Cool weather also prevents maize roots from growing into deeper layers (Kuchenbuch and Barber, 1988; Tardieu and Pellerin, 1991). These factors explain why the crop is relatively responsive to P-applications.

Maize growers are keen on avoiding P-deficiency and the use of mineral P-starter fertilizer is therefore often a routine. The efficacy of mineral P-fertilizers is generally enhanced by applying them in combination with planting as that practice allows positioning of P close to the seeds from where the first roots appear (De Wit, 1953; De Willigen and Van Noordwijk, 1987; Lu and Miller, 1993). The use of mineral fertilizer P is, however, questionable on farms where manure is available in amounts that sufficiently meet the P-uptake capacity of crops. This applies particularly to intensive livestock farms where silage maize is often one of the dominant crops. The use of mineral P-starter fertilizer contributes in that case to further depleting finite rock P-reserves (Rosemarin et al., 2011) and

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Table 1
Characteristics of experimental sites and crop husbandry.

Experiment	Year	Location		Soil[a]				Dates			Maize	
		Council	Coordinates North, East	Type	pH	OM	Pw	Manuring	Planting	Harvest	Variety	Plant density per ha
1	1993	Wageningen	52°58″,5°40″	Haplic podzol	5.4	36	32	15/4	16/4	23/9	Mandigo	107000
2	1993	Wageningen	52°58″,5°40″	Haplic podzol	5.4	36	32	26/5	27/5	25/10	Mandigo	110000
3	1994	Wageningen	52°58″,5°40″	Haplic podzol	4.8	26	52	19/4	21/4	5/9	Mandigo	108000
4	1994	Wageningen	52°58″,5°40″	Haplic podzol	4.8	26	52	1/6	1/6	10/10	Mandigo	112000
5	1993	Hengelo	52°03″,6°18″	Haplic podzol	5.4	50	33	26/4	27/4	24/9	Melody	107000
6	1994	Hengelo	52°03″,6°18″	Haplic podzol	5.4	47	30	2/5	3/5	12/10	Anjou09	91000
7	1995	Hengelo	52°03″,6°18″	Haplic podzol	5.4	47	30	26/5	27/5	25/9	Moreno	82000
8	1999	Cranendonck	51°23″,5°60″	Haplic podzol	5.4	47	32	12/5	12/5	22/9	Accent	102000
9	1999	Heino	52°50″,6°08″	Haplic podzol	5.9	44	25	18/5	18/5	1/10	Accent	102000
10	2000	Cranendonck	51°23″,5°60″	Haplic podzol	4.8	44	33	9/5	9/5	5/10	Accent	102000
11	2000	Heino	52°50″,6°08″	Haplic podzol	6.0	44	33	9/5	9/5	18/10	Accent	102000
12	2010	Vredepeel	51°53″,5°98″	Histic fluvisol	5.5	44	81	28/4	6/5	22/10	Torres	90000
13	2011	Vredepeel	51°53″,5°98″	Histic fluvisol	5.2	38	93	21/4	2/5	11/10	Torres	95000
14	2012	Vredepeel	51°53″,5°98″	Histic fluvisol	5.2	47	55	12/4	22/4	16/10	Torres	95000

[a] pH refers to pH-KCl, OM to organic matter (g kg^{-1}) Pw to mg P_2O_5 $litre^{-1}$ soil after extraction (Sissingh, 1971) in upper 0.25 m soil layer.

also increases the P soil surplus (Neeteson et al., 2006). This surplus can eventually increase P-emissions to the detriment of the aquatic environment (Correll, 1998; Kronvang et al., 2007). However, maize growers are reluctant to refrain from P-starters. The P-fertilizer replacement value of manures generally averages at least 60% in the first season after its application (Oenema et al., 2012). Farmers yet fear that manure P is insufficiently available to young maize plants as it takes many weeks before the soil between two adjacent maize rows (commonly 0.7–0.8 m apart) is fully larded with roots (Schröder et al., 1996, 1997). The insufficient initial availability of nutrients also explains why maize responds positively to positioned nitrogen (N), despite the high mobility of N (Sawyer et al., 1991; Van Dijk and Brouwer, 1998). Positive effects of NP-starters are hence not necessarily the result of an improved availability of P only.

During the last two decades we carried out fourteen field experiments in which we compared the yield response of maize to a conventional 'even' application of manure and a 'row' application, to determine whether a more precise lateral positioning of manure could be an alternative to mineral fertilizer starters. Results from the first five experiments have been partly published before (Schröder et al., 1997). We consider it worthwhile to present the results of all fourteen experiments in combination, considering that a much more judicious use of P is required (Cordell et al., 2009).

2. Materials and methods

2.1. Experimental set up and husbandry

The response of whole crop silage maize (*Z. mays* L.) to liquid manure applications that were either evenly injected (EI) in bands at circa 0.2 m distance or injected in narrow bands (BI) close to the intended position of the maize rows (row distance 0.75 m in both cases), was tested in fourteen experiments on sandy soils (Haplic podzols and Histic (peaty) fluvisols (FAO, 2006)), less than 10% of the particles <50 μm in The Netherlands. Information on locations, soil characteristics, and crop husbandry is presented in Table 1. The soil P-status, reflected in water-extractable P ('Pw', Sissingh, 1971), was qualified as 'sufficient' (Pw 21–30) at three locations, as 'high' (Pw > 60) at two locations, and had an intermediate status at the other locations (www.bemestingsadvies.nl). The preceding crop was silage maize, except for experiment 6 (sugar beets) and experiments 12–14 (potatoes). All experiments had at least three treatments in common: a control where manure and mineral P-starter fertilizer were withheld (M0P0), an EI manure application at an intermediate rate without P-starter (EIM2P0) and a BI manure

Table 2
Macro nutrients (N, P, K) applied with manure (kg ha^{-1}) in treatments M1, M2 and M3.

Experiment	N			P			K		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
1		122			21			129	
2		118			20			112	
3		131			21			134	
4		138			21			151	
5		97			13			124	
6		147			17			158	
7		109			14			137	
8	74	148	246	13	26	44	89	177	295
9	54	109	181	8	17	28	72	144	241
10	59	118	196	9	17	28	64	127	212
11	48	96	161	7	13	22	90	179	299
12		83	145		31	55		104	182
13	62	144		10	23		53	125	
14	60	141		9	21		53	125	

application at an identical rate (BIM2P0). Experiments 8–14 also included one or two more treatments of the same manures at lower (M1) and/or higher (M3) rates (Table 2), and experiments 1–4, 5–7 and 8–11 also included mineral (N)P-fertilizer starter treatments (denoted as P1 treatments, as opposed to P0) at rates of (0) 31, (0) 22 and (20) 9 kg (N)P per hectare, respectively. These starter fertilizer treatments were combined with at least one of the manure treatments. The starters (triple super phosphate '0–46-0' in experiments 1–7, ammonium-enriched Di-Ammonium Phosphate '20–20-0' in experiments 8–11) were applied in combination with planting and positioned at a depth of circa 0.05 m below and 0.05 m next to the seeds whilst avoiding sides where BI manure had been positioned.

As for the M treatments, pig slurry was used in experiment 12 and cattle slurry in all other experiments. The slurry contained on average 86 (range: 61–115) g DM, 4.0 (3.1–4.9) g total N, 2.1 (1.7–2.6) g ammonium-N, 0.7 (0.4–1.6) g P, and 4.6 (4.3–7.2) g potassium (K) per kg fresh material. The amounts of applied N, P and K in the form of manure are listed in Table 2. The soil fertility status of some experiments required additional dressings of mineral fertilizer K in order to rule out K-effects of manure (www.bemestingsadvies.nl). Amounts of applied fertilizer K (muriate of potash) amounted to 200–250 kg K per hectare in experiments 1–4, 0–320 (increasing from M3 to M0) kg K per hectare in experiments 8–11, and 0–75 kg K per hectare in experiments 5–7 and 12–14. In experiments 8–11 magnesium (Mg) fertilizer supplementation was considered necessary at incremental rates of 0–65 (increasing from M3 to M0) kg Mg per hectare.