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Response of silage maize to placement of cattle slurry

J.J. SCHRÖDER*, L. TEN HOLTE AND G. BROUWER

DLO-Research Institute for Agrobiology and Soil Fertility (AB-DLO), PO Box 129,
NL-9750 AC Haren, The Netherlands
* Corresponding author (fax: 31-317-423110, email: j.j.schroder@ab.dlo.nl)

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Abstract

Placement of nitrogen (N) or phosphorus (P) fertilizers can improve the efficiency of fertilizer use, reduce the input needed for maximum production, and better balance the nutrient put in with fertilizers and removed with crop products. From this perspective, the effect of the placement of cattle slurry on the dry matter (DM) yield of silage maize was studied in five experiments on sandy soils in 1993 and 1994.

Slurry was injected in spring at a rate of 30 m^3 ha^{-1} in slots 25 cm apart ('standard injection') or in slots 75 cm apart ('banded injection'). Subsequently, maize was planted at a row spacing of 75 cm parallel to the slots, either at random lateral positions in the 'standard injection' treatment or 10 cm next to the injection slots of the 'banded injection' treatment. All treatments, including a control without slurry, were combined with 0 and 20–31 kg ha^{-1} subsurface banded P starter fertilizer.

DM yields of silage maize were on average reduced by 8% when conventionally injected slurry ('standard injected') was not supplemented with a P-starter. However, the yield reduction was limited to 2% when slurry was banded ('banded injection').

Observations on the distribution of soil mineral N and roots in two of the experiments indicated that during the first 5–7 weeks after planting, nutrients were predominantly supplied by the soil volume close to the plant row. This may explain the positive response of maize to placement which was strongest and significant on P-responsive sites, indicating that placement mainly improved the availability of slurry P. Improvements in the availability of slurry N may have played a secondary role.

Our results suggest that slurry placement can minimize the risk of yield loss associated with reduced fertilizer inputs and contribute to a better nutrient balance between fertilizer inputs and removal in crop products.

Keywords: cattle slurry, maize, nitrogen, phosphorus, placement, root distribution

Introduction

Placement of fertilizers reduces the risks of microbial immobilisation of nitrogen (N) and phosphorus (P), physico-chemical fixation of P and, in case of ammonium, early nitrification into leachable nitrate (Wetselaar *et al.*, 1972), as compared to the broadcast application of fertilizers. When fertilizers are placed close to the root system, placement can further promote a timely interception of nutrients by crops. Maize crops are commonly grown at row spacings of 70–80 cm and can respond markedly to fertilizer placement, probably due to the initially incomplete exploitation of the soil by their roots (De Willigen & Van Noordwijk, 1987; Barber & Kovar, 1991; Schröder *et al.*, 1996). The first records of a positive response to the placement of P date from the 1950's (De Wit, 1953; Prummel, 1957). More recently, a positive response to the placement of N was reported (Eckert, 1987; Touchton, 1988; Maidl, 1990; Maddux *et al.*, 1991). Such a positive response is most likely at low levels of soil fertility (Jokela, 1992) and when low soil temperatures reduce mineralization (Addiscott, 1983), root extension rate and root functioning (Ketcheson, 1968; Mackay & Barber, 1984; Engels & Marschner, 1990). Low soil temperatures occur frequently in spring in Northwest Europe. Hence, most maize growers have their planters equipped with extra coulters enabling them to apply subsurface banded mineral NP-starters and reduce the risk of temporary deficiencies.

In The Netherlands, maize is mainly grown on dairy farms. External inputs of N and P on these farms should be reduced for environmental reasons (Korevaar & Den Boer, 1990). Recently, legislation has been proposed in The Netherlands, putting a levy on the difference between nutrient inputs on a farm and the nutrients taken off through products (Anonymous, 1995). Consequently, the nutrient demand of crops is to be covered with the on-farm produced manure rather than with purchased fertilizers. This requires application techniques for manure which enable a timely availability of nutrients to maize. Sawyer *et al.* (1991) observed a negative relationship between the yield of maize and the lateral distance between the plant rows and the slurry injection slot. Yields were depressed by 8% when maize was planted in between the slots instead of next to the slots. They attributed the effects to the availability of slurry N and considered their results to be an illustration of todays imperfect injection systems. On the other hand the results can be seen as an indication of placement benefits and suggest that slurry placement may be a method to substitute for the commonly used mineral NP-starters. From this perspective we studied the effect of slurry placement on maize yields and investigated whether effects, if any, are due to an enhanced availability of P or N.

Materials and methods

Experimental setup and crop husbandry

Five experiments referred to as Experiments I-V, were carried out on sandy soils in 1993 (Experiment I-III) and 1994 (Experiments IV-V). Experiment I took place in Hengelo (52.00° N, 6.20° E). Experiments II and III were located in Wageningen (52.00° N, 5.45° E) and were executed on the same site, as were Experiments IV and V. Maize was planted on April 27, April 16 and April 21 in the Experiments I, II and IV, respectively. Planting in Experiments III and V was postponed to May 27 and June 1, respectively, to evaluate interactions between slurry placement methods and soil temperatures. Soils had fairly similar HCl-extractable K (NEN 6442 procedure)

Table 1. Soil characteristics (0–30 cm).

Year	Site	Planting date	Experiment	Extractable		Mineral N*	Organic matter
				P	K		
				(mg l^{-1})	(mg g^{-1})	(kg ha^{-1})	(kg kg^{-1})
1993	Hengelo	early	I	14	0.06	15	0.050
	Wageningen	early	II	14	0.08	42	0.036
		late	III	14	0.08	71	0.036
1994	Wageningen	early	IV	23	0.06	22	0.026
		late	V	23	0.06	36	0.026

* NO_3–N and NH_4-N in the 0–60 cm layer of control plot at planting.

and organic matter (NEN 5754 procedure) contents but differed in their water extractable P (Sissingh, 1971) contents. Soil mineral N contents at the onset of the experiments varied among the sites, showing a relative increase of the N content as the season progressed (cf. II and III, IV and V; Table 1).

Two slurry placement methods ('standard injection' and 'banded injection') and a control without slurry were included in each experiment. Cattle slurry was injected at a depth of 10–15 cm and a slot spacing of 25 cm ('standard injection') or 75 cm ('banded injection') after mould board ploughing. Within 2 days after injection, maize (*Zea mays* L., cv. Melody in Experiment I, cv. Mandigo in Experiments II-V) was planted at a row spacing of 75 cm parallel to the injection slots, either randomly with respect to slots 25 cm apart ('standard injection') or 10 cm next to slots 75 cm apart ('banded injection'). These treatments were combined with 0 and 31 (0 and 20 in Experiment I) kg ha^{-1} subsurface banded P-starter fertilizer (triple super phosphate), applied at planting to evaluate interactions between slurry placement methods and the availability of P from sources other than slurry. In the banded slurry treatment P-starter was applied on the opposite side of the maize row.

Slurry was applied at a rate of 30 m^3 ha^{-1} in all five experiments. The nutrient input with the slurry is listed in Table 2. The experiments in Wageningen also included standard and banded slurry treatments at a rate of 60 m^3 ha^{-1} combined with 31 kg ha^{-1} starter-P.

A supplementary broadcast mineral fertilizer dressing of 225 kg ha^{-1} K was applied to all treatments of Experiments II, III, IV and V. In 1994 (Experiments IV and V) 45 kg ha^{-1} P was applied as an overall dressing to all treatments in the preceeding

Table 2. Nutrient input with 30 m^3 ha^{-1} cattle slurry (kg ha^{-1}).

Year	Experiment	N	NH_4-N	P	K
1993	I	97	47	13	124
	II	122	64	20	129
	III	118	63	20	112
1994	IV	131	62	21	134
	V	138	78	21	151

winter to find out whether placement effects would also occur in the presence of abundant P.

All experiments had a randomized complete block design with 3 blocks in Experiments I, IV and V and 4 blocks in Experiments II and III. Within the blocks, 3 slurry treatments (0 m^3 ha^{-1}, 30 m^3 ha^{-1} 'standard injection', 30 m^3 ha^{-1} 'banded injection' × 2 starter P treatments (with and without)) were included. In Wageningen 2 additional slurry treatments (60 m^3 ha^{-1} 'standard injection' with P-starter, 60 m^3 ha^{-1} 'banded injection' with P-starter) were added. The size of inidividual plots (slurry × starter treatments) was 15 m × 6 m.

Measurements

Maize dry matter (DM) yields and N and P uptakes at silage maturity (at approximately 30 percent DM content) were measured by weighing the fresh yield of the inner 10 m × 3 m area of each plot, followed by the determination of the DM content by drying for 24 h at 105 °C. In a subsample of the chopped and dried product the total N content was assessed according to Dumas (Macro N, Foss Heraeus) and the P content was assessed colorimetrically (Starrcol) after destruction with H_2SO_4/HNO_3.

Soil mineral N (SMN, including NO_3 and NH_4-N) was assessed after extraction from soil cores with 1 *N* KCl, using a continuous flow analyzer (TRAACS 800, Bran & Luebbe). Samples were taken prior to slurry application and about 10 weeks after planting in 20 cm increments of the upper 60 cm in the control and the standard injected slurry plots of the 60 m^3 ha^{-1} treatment of Experiments II-V. Samples taken before the application of slurry were taken at random positions, post-emergence samples were taken from positions in, next to and between the maize rows. Per treatment and position, 6 core samples were taken and pooled over replicates before analysis.

The distribution of the root system was determined 7 and 5 weeks after planting in the standard and banded slurry plots of the 30 m^3 ha^{-1} treatment (without starter-P) of Experiments IV and V, respectively, and expressed as root length per unit soil volume ('root length density'). Observations were confined to the two inner rows of plots from the second replicate. Root length density was determined by inserting a needle board (width 160 cm × depth 40 cm with 10 cm long needles in a 5 cm × 5 cm grid) to the vertical wall of an inspection trench. The trench was dug within the first 2.5 m of the experimental plot and found itself outside the area from which maize DM yield was derived. The needle board was positioned perpendicularly to the maize rows with its centre in between two rows. The board was removed as a monolith. Subsequently, adhering soil was washed away and total root length per 5 cm × 5 cm × 10 cm volume was determined. Handling and processing are described in detail by Schröder *et al.* (1995). Presented root length density data pertain to the average of the two maize rows enclosed by the needle board.

Definitions

The apparent N recovery of slurry N (ANR) was calculated as the difference of the N uptake of a manured crop and the N uptake of the control (without P-starter) and ex-

Table 3. Precipitation (mm) and average daily temperature (°C) in Wageningen.

		Precipitation				Temperature			
Experiment		I	II/III	IV/V	long term average*	I	II/III	IV/V	long term average*
Month	May	89	50	82	61	14.3	14.1	12.5	12.3
	June	33	57	61	68	15.9	15.6	15.0	15.2
	July	184	165	33	75	16.1	16.0	20.8	16.8
	August	59	39	40	71	15.3	14.6	17.4	16.7
	September	153	132	137	67	13.1	12.9	13.7	14.0
	October	90	86	108	72	9.0	8.8	9.2	10.5

* 1961–1990 average at De Bilt.

pressed as a percentage of the total-N input from slurry. The apparent N efficiency of slurry N (ANE) was calculated as the difference of the DM yield of a manured crop and the DM yield of the control (without P-starter) per kg total-N from slurry. The surpluses of N and P of a treatment were defined as the difference between the amounts of total-N and P applied as cattle slurry or starter fertilizer and the amounts exported from the field. Our calculation of the P surplus does not include the broadcast P dressing applied to all plots of Experiments IV and V.

Weather conditions

Precipitation and average daily temperature during the growing season (May-October) were close to the long term average. However, during the first 8 weeks after emergence, maize crops suffered from drought in Experiments I and V and from cold stress in Experiments IV (Table 3).

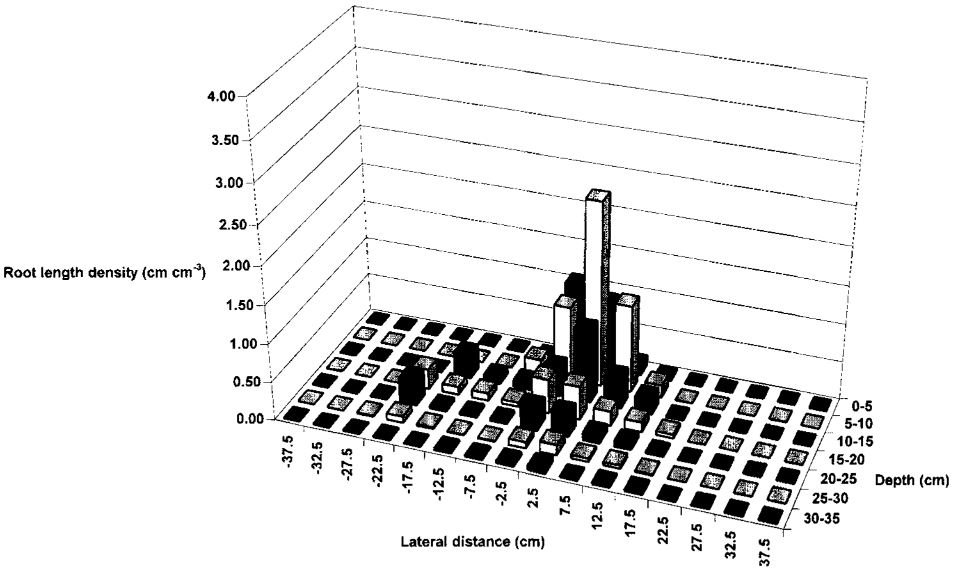
Results

Plant densities amounted to 10–11 plants m^{-2} without significant effects of the slurry application method (Table 4). Measurements of the root length density in

Table 4. Plant density (m^{-2}) as affected by the slurry application method.

Year	Experiment	Treatment			LSD (P<0.10)
		control	standard	banded	
1993	I	10.7	10.7	10.6	0.2
	II	10.8	10.7	10.8	0.4
	III	11.0	11.1	11.3	0.5
1994	IV	10.0	9.9	10.3	0.4
	V	10.0	10.1	9.9	0.3

Experiment IV, 'standard injection'



Experiment IV, 'banded injection'

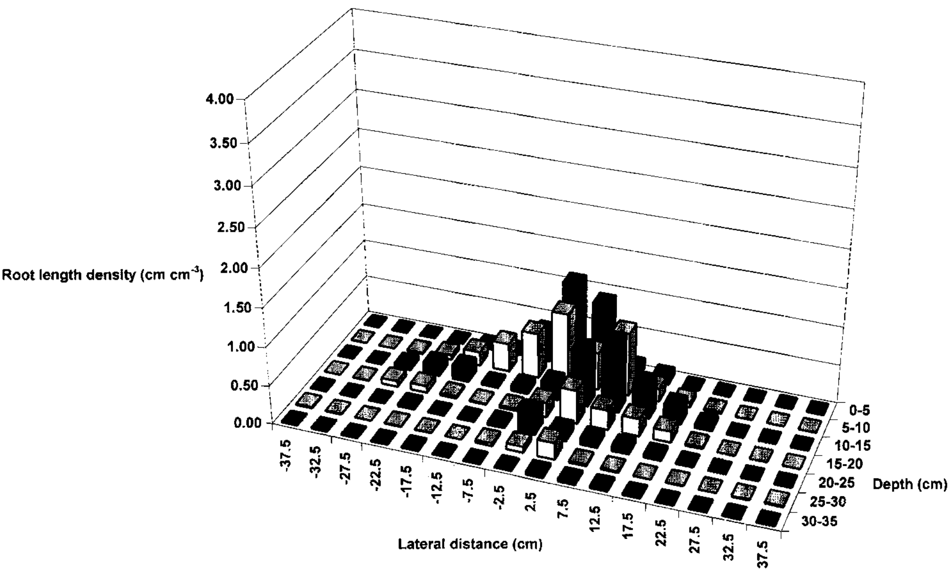
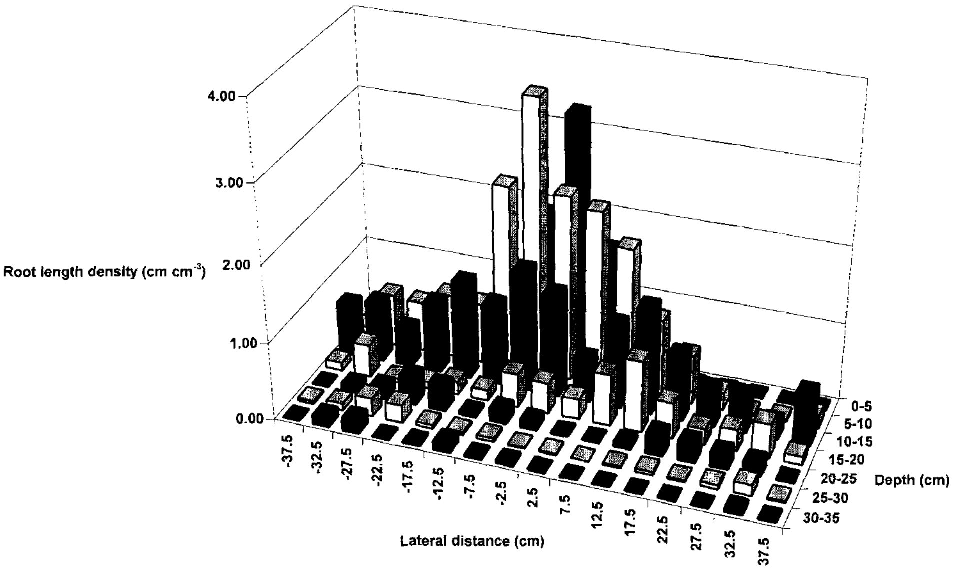


Figure 1a. Vertical and horizontal distribution of a maize root system (expressed as root length density) under maize 7 weeks after planting after conventionally injected slurry ('standard injection') and banded slurry ('banded injection') in Experiment IV (maize row positioned at 0 cm, standard injection positioned at 3 random positions between –37.5 cm and +37.5 cm, banded injection positioned at +10 cm).

Experiment V, 'standard injection'



Experiment V, 'banded injection'

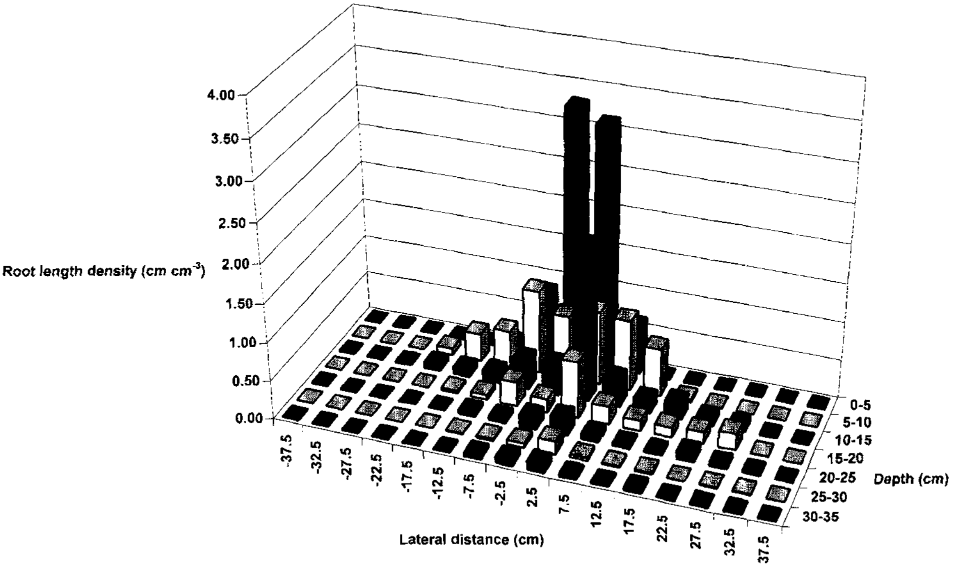


Figure 1b. Vertical and horizontal distribution of a maize root system (expressed as root length density) under maize 5 weeks after planting after conventionally injected slurry ('standard injection') and banded slurry ('banded injection') in Experiment V (maize row positioned at 0 cm, standard injection positioned at 3 random positions between –37.5 cm and +37.5 cm, banded injection positioned at +10 cm).

Experiment IV showed that the extension of the roots had not yet passed a depth of 30 cm. The lateral extension was restricted to a 25 cm wide strip on both sides of the plant row. Root length densities were less than 1 cm cm^{-3} except for the soil volume directly underneath the seed (Figure 1a). Similar measurements in Experiment V also showed marked horizontal and vertical gradients of the root length density. In most of the profile root length density was less than 1 cm cm^{-3}. The lateral root extension had progressed further when slurry had been conventionally injected ('standard injection') than when it had been banded ('banded injection') (Figure 1b).

During the first 10 weeks after planting, SMN was predominantly taken up from the soil compartments directly under the plant as indicated by measurements under and in between the maize rows. Horizontal gradients were stronger in fertilized treatments than in the corresponding controls, except for Experiment IV (Figure 2).

A significant positive response of the DM yield of silage maize to P-starter fertilizer was only observed in Experiments II and III. Such a response was not observed in Experiment I, despite a similar soil P content (Table 5). In all experiments, slurry placement increased the DM yields markedly when no P-starter fertilizer had been applied, as compared to the conventional slurry injection. The response to placement was strongest and significant on sites where crops were most responsive to P-starter fertilizer.

DM yields responded positively ($P < 0.05$) to the application of 30 m^3 ha^{-1} slurry in all five experiments. Doubling the slurry rate to 60 m^3 ha^{-1}, however, only resulted in a significant further yield increase of the DM yield of the maize in Experiment II (Table 5).

P-starter fertilizer increased the apparent recovery of slurry-N on average by 7 percent and increased the N-deficit by 7–9 kg ha^{-1} (Table 6). Refraining from P-starter fertilizer reduced the P-surplus considerably ($P < 0.05$), be it at the expense

Table 5. DM yield of silage maize (t ha^{-1}) as affected by the slurry application method and rate and P-starter fertilizer.

Treatment			Experiment					Average	
slurry application		P-starter	I	II	III	IV	V	I-V	II-V
method	rate (m^3 ha^{-1})	(kg ha^{-1})							
control	0	0	8.4	10.6	9.8	10.4	11.4	10.1	–
standard	30	0	11.4	11.8	10.8	12.6	12.7	11.9	–
banded	30	0	12.0	13.2	11.9	13.2	13.3	12.7	–
control	0	22	7.4	12.0	12.1	9.7	12.5	10.7	11.6
standard	30	22	11.2	13.7	12.7	13.0	14.4	13.0	13.4
banded	30	22	12.2	13.9	13.3	13.0	12.6	13.0	13.2
standard	60	22	–	15.5	12.9	15.3	13.2	–	14.2
banded	60	22	–	15.4	13.3	13.8	14.6	–	14.3
LSD ($p<0.05$)			1.7	0.9	0.8	1.6	1.7	0.7	0.7

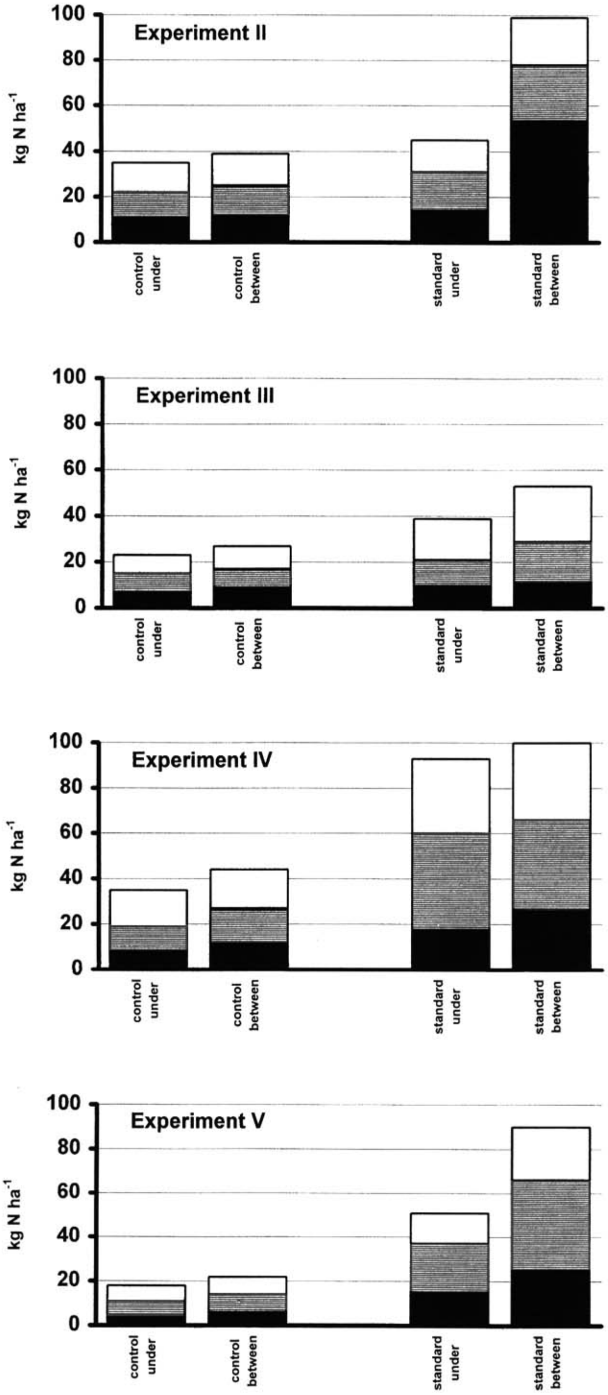


Figure 2. Vertical and horizontal distribution of soil mineral N under a maize crop about 10 weeks after planting in controls without slurry and after conventionally injected slurry ('standard injection') (under = under the plant row; between = in the middle between two plant rows; ■ = 0–20 cm depth, ▤ = 20–40 cm depth, □ = 40–60 cm depth).

Table 6. P- and N-surplus (kg ha^{-1}), apparent N-recovery (ANR, kg kg^{-1}), apparent N efficiency (ANE, kg kg^{-1}) and N content of silage maize DM (kg kg^{-1}) as affected by the slurry application method and P-starter fertilizer (averaged over Experiments I-V).

Treatment			Surplus		ANR	ANE	N content
slurry application		P-starter	N	P			
method	rate (m^3 ha^{-1})	(kg ha^{-1})					
control	0	0	–110	–20	–	–	0.0109
standard	30	0	–23	–2	0.29	15	0.0122
banded	30	0	–30	–4	0.35	22	0.0122
control	0	22	–118	8	–	–	0.0110
standard	30	22	–32	24	0.36	24	0.0118
banded	30	22	–37	23	0.42	24	0.0124
LSD ($P<0.05$)			17	4	0.13	6	0.0009

of DM yield. Slurry placement compensated for this yield loss (Table 5). The N-surplus and the apparent recovery of slurry N in treatments with banded slurry without a P-starter were similar to the conventionally injected slurry treatment combined with a P-starter.

Increases in the uptake of N from slurry due to placement were proportional to increases in the DM yield when no starter-P was used, as indicated by a significant increase of the apparent N efficiency and the absence of any response of the N-content of the crop. In combination with a P-starter, the recovery of slurry-N was not significantly increased by placement and effects of placement on the DM yield and the ANE were not observed.

Discussion

A poor synchronisation and synlocalisation of roots and nutrients can limit the actual availability of nutrients to crops (De Willigen & Van Noordwijk, 1987). Consequently, nutrient uptake and DM production may be reduced. Such a situation is most likely when the soil volume is not fully exploited by the root system due to plant or soil properties or row spacings. Farmers tend to respond to this by applying extra nutrients. This may ensure timely nutrient availability but will inevitably lead to larger nutrient surpluses and may eventually increase the losses to the environment.

Observations on the distribution of the root system in two of the five experiments confirm that the exploitation of the soil is far from complete during the juvenile stage of a maize crop. This is a direct result of the wide row spacing. Low temperatures may aggravate this through negative effects on the specific root length (Kiel & Stamp, 1992; Schröder *et al.*, 1995).

Root observations in Experiment V show that the lateral extension of the roots was less for banded slurry than for conventionally injected slurry. Such an interaction between the proliferation of roots and the presence of nutrients was also reported by Granato & Raper (1989), Shaviv & Hagen (1991) and Schröder *et al.* (1996). In accordance with observations made by Schröder *et al.* (1996), lateral extension occurred at depths of 10–20 cm rather than the upper 10 cm. This can explain why maize may respond weakly to N when applied in between the rows under dry conditions (Jokela & Randall, 1989; Bundy *et al.*, 1992).

Results from our experiments indicated that the benefits of fertilizer placement also hold for cattle slurry. The nutrient uptake and DM production of maize were increased by planting maize in rows next to equidistant slurry injection slots ('banded injection') as compared to maize planted in a soil where slurry had been injected more evenly ('standard injection'). Effects may result from a better N or a better P availability, as placement benefits are reported for N and P and slurry contains both. Effects in our experiments were strongest and significant on sites with a marked response to subsurface banded P-starters. Therefore, we conclude that slurry placement has mainly improved the availability of P. Significant positive effects of slurry placement were absent when P-starter had been used. In Experiment V maize yields even responded negatively ($P < 0.05$) to slurry placement when combined with a P-starter.

The positive response to an increase of the slurry rate from 30 to 60 m^3 ha^{-1} apparently resulted from a demand for N rather than a demand for extra P, since slurry placement had no effect on maize DM yields when P-starter had been used. Contrary to the effect observed in the 30 m^3 ha^{-1} treatment, placement of 60 m^3 ha^{-1} in combination with P-starter had no negative effect on maize yield in Experiment V. Hence, salt damage is an unlikely explanation for the observed negative placement effect in the 30 m^3 ha^{-1} treatment.

In experiments where SMN was recorded we observed a marked lateral gradient, suggesting that N was predominantly taken up from zones in the soil with the largest root length density. Apparently, N was not instantaneously replenished from the neighbouring volume. Such persistent N gradients were reported earlier by Aufhammer *et al.* (1991), Lorenz (1992), Schröder *et al.* (1996) and Clay *et al.* (1995) and may explain why maize also responded positively to placement on sites and in treatments where P-starter had no or only minor effects on maize DM yields. Such positive N-placement effects are most likely to occur under dry conditions (De Willigen & Van Noordwijk, 1995) and may therefore explain the positive response to placement in Experiments I and V.

We did not observe a weaker response to P-starter or slurry placement when planting dates were postponed. This may be so because early and late planted maize grew up under similar temperatures in 1993 (Table 3). In 1994 when temperature during the juvenile stage of the early planted crop was considerably lower than it was in the late planted crop, P-starter did not significantly affect the DM yield of the early planted maize. Probably, P-starters were ineffective on that site due to a higher initial soil P status and the overall dressing of 45 kg P ha^{-1} applied to all treatments.

A better availability of P appeared to have a positive effect on the apparent recovery of slurry-N (Table 6). Such an effect was reported earlier by Schlegel & Havlin (1995). Slurry placement increased the apparent recovery of slurry N up to a value that was obtained with conventionally injected slurry in combination with a P-starter. Recoveries were 6 percent larger with banding than with the conventionally injected slurry. This increase was not significant at the 95% probability level but trends were the same both with and without P-starter. Such an increase of the recovery is less than what one can calculate from the mathematical description of the placement effects of mineral fertilizers proposed by De Wit (1953). According to his formula, recovery would have been about 20 percent larger (absolute) when slurry is banded in 15–20 cm wide strips than when the same amount of slurry is homogeneously distributed through a soil volume of similar depth. Possibly, our conventionally injected slurry was less evenly distributed than we assumed and banded slurry may have been redistributed in the soil over a larger width. Moreover, banding may have created spots with a greater risk for denitrification (Rice *et al.*, 1988).

In conclusion, slurry placement can minimize the risk of yield loss associated with reduced fertilizer inputs and contribute to a better balance of fertilizer inputs and crop nutrient offtakes. Therefore, slurry placement can be a useful tool in any farming system that wishes to or is forced to improve its fertilizer use efficiency.

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