23 Effects of Slurry With and Without the Nitrification Inhibitor Dicyandiamide on Soil Mineral Nitrogen and Nitrogen Response of Potatoes

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ABSTRACT

In the period 1983–1985, 18 potato experiments with poultry slurry were conducted on soils reclaimed from cut-over peat and sandy soils in the Netherlands. The experiments consisted of four main treatments: no slurry, autumn-applied slurry, autumn-applied slurry combined with the nitrification inhibitor dicyandiamide (DCD), and spring-applied slurry. As calculated from the amount of soil mineral nitrogen present at the start of the growing season (June), average nitrogen recoveries of 47, 62 and 51% were found for autumn-applied, autumn-applied with DCD and spring-applied slurry respectively. A close relationship was found between the amount of soil mineral nitrogen in June and the amount of nitrogen contained in the tubers of the potatoes at harvest. Soil mineral nitrogen at harvest was increased by even moderate amounts of nitrogen supplied. At the optimum nitrogen supply for crop growth, about 110 kg of mineral nitrogen per ha remained in the soil profile (0–100 cm) at harvest. This could lead to considerable losses of nitrogen in the following winter.

INTRODUCTION

The value of organic manures in crop production in supplying nutrients and organic matter has long been recognized (Allison, 1973). However, during the past decades the production of animal manures has increased drastically and their use has adversely affected the environment in parts of the Netherlands and other regions of Europe (Wadman *et al.*, 1987). One of the harmful effects is the pollution of groundwater due to leaching of nitrate.

One of the measures to reduce nitrogen (N) losses from ammonium-containing organic fertilizers applied in autumn is the use of nitrification inhibitors (Slangen and Kerkhof, 1984). The nitrification inhibitor dicyandiamide (DCD) inhibits the microbial oxidation of ammonium to nitrite and thus the formation of nitrate (Amberger, 1986). The loss of N through leaching or denitrification is therefore reduced.

DCD can be applied effectively together with slurry (Amberger, 1986). In soil, DCD is broken down to the harmless components NH_3, CO_2 and H_2O. The rate of degradation of DCD is largely determined by soil temperature. Vilsmeier (1980) reported that the concentration of DCD in the soil changed little during incubation for 80 days at 8°C. At 14°C, however, an increased breakdown of DCD was observed between 40 and 60 days after its application (Vilsmeier, 1980).

This paper describes experiments conducted in the Netherlands in the period 1983–1985. The response of potatoes grown for industrial starch production to inorganic N fertilizer and the combination of inorganic N fertilizer with slurry N was determined. Slurry was applied in autumn (with and without DCD) and in spring.

The effects of N fertilization on leaching of nitrate were evaluated by means of the amounts of soil mineral N. Preliminary results concerning the N response of the potatoes in the experiments described here were published earlier (de la Lande Cremer, 1986).

MATERIALS AND METHODS

In the period 1983–1985, 6 experiments with potatoes (*Solanum tuberosum* L.) grown for industrial starch production were conducted annually in the north-eastern part of the Netherlands on two soil types. The first soil type (Soil 1) is a soil reclaimed from peatland 50–150 years ago as follows: the peaty top layer was put aside and the underlying peat was removed. The top

Table 1. Characteristics of the soils reclaimed from cut-over peat and the sandy soils (Soils 1 and 2 respectively). All values pertain to the 0–30 cm layer.

Soil	Number of trials	pH-KCl		Organic matter (%)		N total (%)	
		Mean	Range	Mean	Range	Mean	Range
1 (Peat)	11	5.0	4.7–5.7	13.7	7.4–21.7	0.30	0.16–0.54
2 (Sand)	7	4.6	4.0–5.2	5.9	4.4– 7.3	0.15	0.11–0.22

Table 2. Amount of slurry applied and form and amount of N contained in the slurry (including N from DCD in treatment c). Averages of 18 experiments.

Treatment	Amount of slurry applied ($t\ ha^{-1}$)	Amount of N contained in the slurry ($kg\ ha^{-1}$) Inorganic	Organic	Total
b (slurry in autumn)	26	116	148	264
c (slurry in autumn + DCD)	26	119	144	263
d (slurry in spring)	18	96	83	179

layer was then replaced onto, and mixed with, the subsoil. The second soil type (Soil 2) is a sand. Relevant characteristics of the two soil types are given in Table 1.

At each site four treatments with poultry slurry were combined with six inorganic N fertilizer rates (0, 60, 120, 180, 240 and 300 kg N ha^{-1}). Each treatment was replicated three times. The slurry treatments were (a) no slurry application, (b) slurry applied in late autumn (end of November to beginning of December), (c) slurry applied in late autumn with 20 kg DCD ha^{-1}, and (d) slurry applied in spring (March or April). The amounts of slurry and slurry N applied are given in Table 2.

After the slurry was applied it was incorporated into the soil as soon as possible to reduce N losses due to ammonia volatilization. The inorganic N fertilizer (ammonium nitrate limestone) was applied in spring as a single dressing.

Soil mineral N (N in the form of ammonium or nitrate) was determined in three layers (0–30, 30–60 and 60–100 cm) in the autumn and the spring preceding the growing season of the potatoes, during the growing season, and after the harvest of the potatoes. The mineral N content of the soil was found by extracting soil samples with 1.0 M NaCl and determining the ammonium and the nitrate contents of the extract colorimetrically with an AutoAnalyzer (Ris *et al.*, 1981).

At harvest (end of September to beginning of October) the tuber yield was determined and the tubers were analyzed for their N content using a Kjeldahl destruction and a mixture of Na_2SO_4, Cu and Se as a catalyst (Vierveijzer *et al.*, 1979).

RESULTS

In the autumn preceding the growing season and before slurry was applied, on average 97 kg ha^{-1} mineral N was found in the 0–100 cm layer of the soil

Table 3. Ammonium and mineral N contents (N kg ha^{-1}) of the 0–100 cm soil layer in the autumn and spring prior to the growing season. Averages of 18 experiments and their standard error.

	Ammonium		Mineral N	
Treatment	Autumn	Spring	Autumn	Spring
Means				
a (no slurry)	15	23	100	75
b (slurry in autumn)	15	107	93	240
c (slurry in autumn + DCD)	17	149	95	210
d (slurry in spring)	17	24	99	82
Standard errors of means	1.0	12.7	3.5	15.2

(Table 3). In the following spring the ammonium and nitrate contents of the soil were determined before slurry was applied (treatment d). Slurry applied in autumn had increased the ammonium and mineral N content of the soil considerably (Table 3, treatments b and c). DCD had increased the ammonium content of the soil significantly ($P < 5\%$), but, on average, had decreased soil mineral N in spring (Table 3).

In June, at the start of the growing season, the ammonium content of the soil of treatments b and c had decreased. The effect of DCD on the ammonium content of the soil remained about the same as in spring (the difference between treatments c and b in Table 3 equals about the difference in Table 4).

Application of inorganic fertilizer N in April had increased the ammonium content of the soil in June (Table 4).

Table 4. Ammonium and mineral N contents (N kg ha^{-1}) of the 0–100 cm soil layer in June. Averages of 18 experiments and their standard error.

	Ammonium				Mineral N			
Treatment	(0)*	(180)*	(300)*	Mean	(0)*	(180)*	(300)*	Mean
Means								
a (no slurry)	10	41	58	37	93	300	402	265
b (slurry in autumn)	22	44	76	47	231	403	531	388
c (slurry in autumn + DCD)	54	91	142	96	250	458	581	429
d (slurry in spring)	18	34	63	38	231	364	474	356
Standard errors of means		9.1†		7.4		14.4‡		11.5

*(0) (180) and (300): inorganic fertilizer N applied (kg ha^{-1}).
†,‡Except when comparing means within the same treatment a,b,c or d; then the standard errors of means are 6.4 and 10.6 kg ha^{-1} respectively.

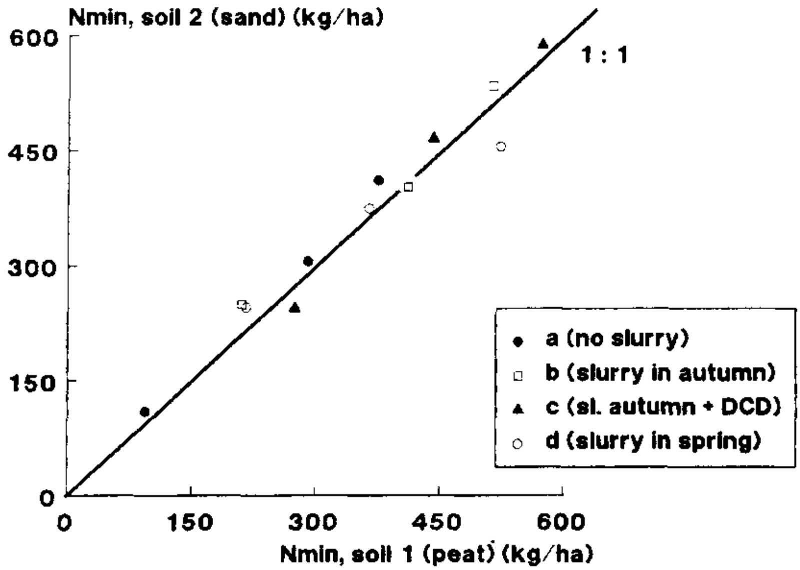

Fig. 1. Effect of soil type on soil mineral N (Nmin) content in June (0–100 cm) following various treatments with slurry combined with inorganic N fertilization. The line is the line of perfect agreement.

In June, soil mineral N was higher than in spring (Tables 3 and 4) due to mineralization (all treatments), inorganic fertilizer application (all treatments) and slurry application (treatment d). On average, DCD had increased soil mineral N by 41 kg ha^{-1} (standard error = 16.3 kg ha^{-1}). This equals about the increase in ammonium content of the soil in June due to the application of DCD. The two soil types under consideration responded in much the same way with respect to the effect of the treatments on the mineral N content of the soil in June (Fig. 1).

As compared with treatment a, treatments b, c and d increased soil mineral N by 123, 164 and 91 kg ha^{-1}, respectively (Table 4, standard error = 16.3 kg ha^{-1}). From the data in Table 2 it can be calculated that the N recovered from the autumn-applied slurry as soil mineral N in June amounted to 123/263 = 47% of the slurry N applied (standard error = 16.3/263 = 6%). The N recoveries from the autumn-applied slurry with DCD and from the spring-applied slurry amounted to 62% (standard error = 6%) and 51% (standard error = 9%) of the N applied with the slurry (and contained in DCD, 13 kg N ha^{-1}, in treatment c) respectively.

Table 5. Average fresh tuber yield of potatoes (t ha^{-1}) grown for industrial starch production on the soil reclaimed from cut-over peat (Soil 1) and the sandy soil (Soil 2). Standard error of means on Soils 1 and 2 are 1.1 and 1.3 t ha^{-1} respectively (except when comparing means within the same treatment a,b,c or d; then the standard errors of means on Soils 1 and 2 are 1.0 and 1.2, respectively).

Treatment	Inorganic fertilizer N (kg ha^{-1})					
	0	60	120	180	240	300
Soil 1 (Peat)						
a (no slurry)	36.7	44.4	48.7	51.5	52.5	53.6
b (slurry in autumn)	49.5	52.5	55.4	53.7	54.8	52.8
c (slurry in autumn + DCD)	52.0	54.4	55.3	56.6	56.1	53.7
d (slurry in spring)	49.6	51.2	53.3	53.0	54.9	54.2
Soil 2 (Sand)						
a (no slurry)	31.6	38.1	41.2	43.3	42.3	44.8
b (slurry in autumn)	39.4	43.2	45.2	44.6	44.6	44.4
c (slurry in autumn + DCD)	43.1	44.2	44.9	44.8	43.7	45.5
d (slurry in spring)	38.2	39.8	42.4	43.7	43.5	44.6

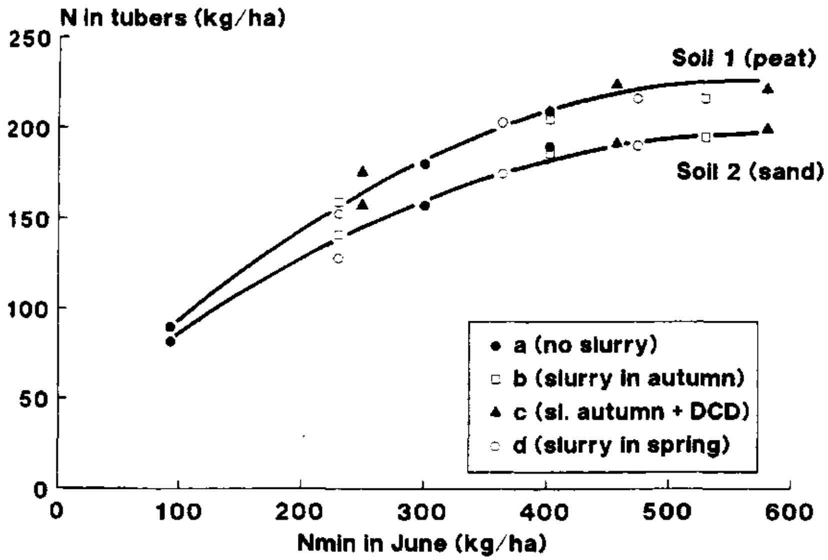

Fig. 2. Effect of soil mineral N content (Nmin) in June (0–100 cm) following various treatments with slurry combined with inorganic N fertilization on amount of N contained in the tubers at harvest.

N response of potatoes

The two soil types differed substantially in maximum yield level (Table 5). The different treatments led to differences in N supply. However, yields were apparently not only affected by differences in N supply, but also by other unknown factors connected with the different treatments on Soil 1. When Tables 4 and 5 are combined it can be estimated that, at the optimum N fertilization level, about 350 kg ha^{-1} soil mineral N was present in June.

Figure 2 gives the amount of N in the potato tubers as affected by the supply of N with slurry and inorganic fertilizer on both soil types. The values on the horizontal axis are the values of soil mineral N in June, taken from Table 4. Although the differences in amount of N in the tubers between the soil types are not as large as could be expected from the differences in maximum yield (Table 5), the higher yield level of Soil 1 resulted in a larger amount of N in the tubers. The results suggest that the amount of N in the tubers is closely related to the mineral N contents of the soil in June, irrespective of the form in which N was added in these experiments (Fig. 2).

Residual soil mineral N

Contents of residual soil mineral N, i.e. soil mineral N in the 0–100 cm layer at the harvest of the potatoes, are presented in Fig. 3. At the optimum level of N supply (soil mineral N in June was about 350 kg N ha^{-1}) the amount of residual soil mineral N was about 110 kg N ha^{-1}. On average, the larger amount of N in the tubers on Soil 1 (Fig. 2) corresponds to a lower amount of residual soil mineral N in this soil type than that in Soil 2 (Fig. 3). At harvest the ammonium contents of the soil amounted to less than 10% of the mineral N contents of the soil.

The distribution of mineral N in the soil profile at harvest is given in Table 6. The layers 0–60 cm and 60–100 cm are both significantly affected by the application of organic and/or inorganic fertilizers ($P < 5\%$). The differences between treatments b and c in Table 6 are small and not significant (at $P <$ 5%)

DISCUSSION

In slurry, N is present in an inorganic (mainly ammonium) and an organic form. Losses of inorganic N may seriously lower the efficiency of slurry N and adversely affect the environment. In the experiments reported here, the efficiency of slurry N was calculated from the amount of slurry N which

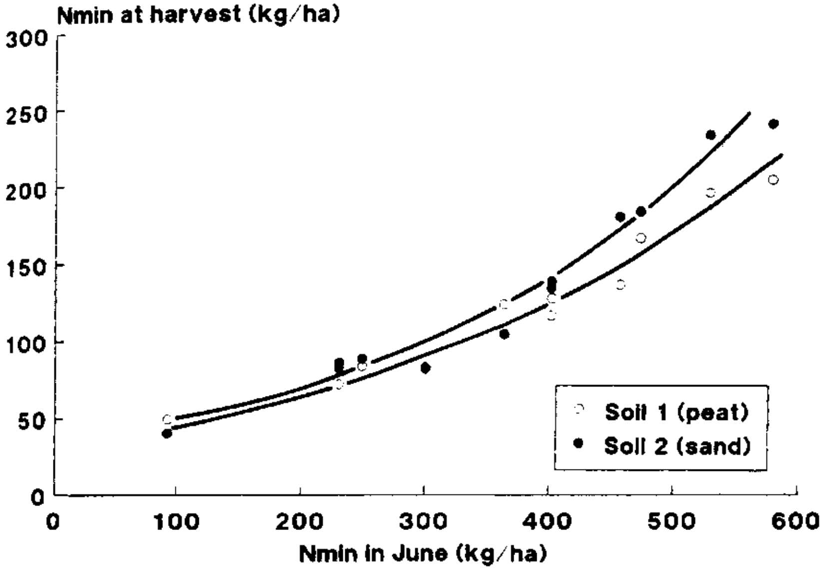

Fig. 3. Effect of soil mineral N (Nmin) content in June (0–100 cm) following various treatments with slurry combined with inorganic N fertilization on soil mineral N content (0–100 cm) at harvest.

Table 6. Soil mineral N content of the 0–60 and 60–100 cm layers at harvest. Averages of 18 experiments and their standard error.

	Soil mineral N (kg ha^{-1})							
	0–60 (cm)				60–100 (cm)			
Treatment	(0)*	(180)*	(300)*	Mean	(0)*	(180)*	(300)*	Mean
Means								
a (no slurry)	27	52	84	54	14	25	35	25
b (slurry in autumn)	46	85	144	92	31	47	66	48
c (slurry in autumn + DCD)	53	103	160	105	28	45	56	43
d (slurry in spring)	47	77	123	82	24	37	54	38
Standard errors of means		7.8†		4.8		3.5‡		2.2

*(0), (180) and (300): inorganic fertilizer N applied (kg ha^{-1}).

†‡Except when comparing means within the same treatment a,b,c or d; then the standard errors of means are 7.6 and 3.3 kg ha^{-1} respectively.

could be measured as soil mineral N in June. This method was preferred to the method of comparing the yield response to inorganic N fertilizers, because yield might be affected by factors other than the supply of N (see the section 'N response of potatoes'). Moreover, yield response to a wide range of levels of inorganic fertilizers was rather small in the experiments, so the scope for errors was great (Neeteson and Wadman, 1987). It was found that the N recovered in the soil as mineral N in June from autumn-applied poultry slurry amounted to 47% of the N contained in the slurry applied. This is a rather high value, as Sluijsmans *et al.* (1978) have estimated that the efficiency index of autumn-applied slurry would be around 30%. An explanation for the high recovery of autumn-applied slurry could be that nitrification was rather slow on these soils; in spring the ammonium content of the soil was substantially increased by the autumn-applied slurry.

Furthermore, in June, an increase in ammonium due to the application of the inorganic N fertilizer in April was observed.

The use of DCD increased the N recovery of autumn-applied slurry as soil mineral N in June: it was 62% of the N contained in the slurry applied (N from DCD included). However, the amount of N saved by using DCD (about 41 kg ha^{-1}) would not cover the costs of DCD. This could have been caused in part by the high recovery of N from the autumn-applied slurry (without DCD). The recovery of N from the spring-applied slurry as soil mineral N in June was 51% of the N contained in the slurry. This is in good agreement with the efficiency index of 57%, as can be estimated on the basis of the assumptions of Sluijsmans *et al.* (1978) for this type of slurry. On average, the efficiency of the spring-applied slurry is rather low compared with the autumn-applied slurry with DCD (the difference was not significant at $P <$ 5%). An explanation might be that ammonia volatilization following slurry application was higher in spring. However, this was not verified in the field.

As a close relationship was found between soil mineral N in June and the amount of N found in the tubers (Fig. 3), the amount of soil mineral N in June appears to be a good measure of the differences in N supply to the crop due to the various slurry treatments. Apparently there was little difference between the slurry treatments in the amounts of N mineralized between June and the end of N uptake by the crop, which also contribute to the total N supply. In spring (March or April) a decrease in the soil mineral N content was observed due to DCD (not significant at $P < 5\%$, Table 3). This is neither in agreement with the observed tuber yields and the amount of N found in the tubers, nor with the soil mineral N data in June, which are all increased by the use of DCD (Tables 4 and 5, Fig. 2). Similar results were reported by Amberger (1986) for a loess soil, where DCD applied with slurry in the autumn affected the N response of silage maize grown the next year, but had no effect on the mineral N content of the soil in February. This was attributed to stronger sorption of ammonium. In the experiments described in this paper, stronger ammonium sorption does not explain the differences in the effects of DCD observed in spring and later in the season, because in these light soils strong sorption of ammonium is not a major process; also, high ammonium contents of the soil were observed in spring as a result of slurry application (with and without DCD) in the preceding autumn (Table 3).

The increase in N recovery, due to addition of DCD to slurry applied in autumn, suggests that nitrate leaching was reduced. However, this increase may have been caused in part by a decrease in denitrification.

In a lysimeter experiment in which slurry was applied in autumn before sugar beets were grown, it was found that addition of DCD reduced nitrate leaching significantly ($P < 5\%$) compared to slurry application without DCD (Gutser and Amberger, 1984). However, the amount of N leached increased from 71 kg ha^{-1} when no slurry was applied to 91 kg ha^{-1} when slurry was applied with DCD (the difference being significant, $P < 5\%$; Gutser and Amberger, 1984). So, to evaluate the usefulness of DCD combined with slurry in reducing nitrate leaching, the amount of nitrate leached from autumn-applied slurry with DCD should be known. This was not measured in these experiments.

When no fertilizer was applied the amount of residual soil mineral N was about 50 kg ha^{-1}. In experiments with sugar beet and winter wheat Neeteson *et al.* (1989) found that optimum rates of inorganic N fertilizer produced only slight increases in residual soil mineral N compared to the no-fertilizer treatment. In our potato experiments, application of even moderate amounts of inorganic and/or organic fertilizer N increased the amount of residual soil mineral N. This may lead to increased leaching of nitrate in the next autumn and winter. The use of DCD increased the N supply to the crop and, therefore, the residual soil mineral N content. The results suggest that the use of DCD in autumn prior to the growing season will not lead to extra residual soil mineral N, provided that the amounts of additional inorganic N fertilizers are adjusted so as to take the effect of DCD into account.

ACKNOWLEDGMENT

The cooperation of the regional research centre 'Stichting Interprovinciaal Onderzoekcentrum voor de akkerbouw op zand- en veenkoloniale grond in Middenoost- en Noordoost-Nederland' is gratefully acknowledged.

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