Netherlands Journal of Agricultural Science 43 (1995) 195-204

Effects of DCD addition to slurry on nitrate leaching in sandy soils

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Received 28 October 1994; accepted 13 April 1995

Abstract

The effects of the addition of the nitrification inhibitor dicyandiamide (DCD) to cattle slurry, applied in autumn to an arable sandy soil, were investigated in a three-year field experiment. Treatments included application of slurry with DCD in November and December, application of slurry without DCD in November, December and January, and an untreated (slurry or DCD) control. Degradation of DCD, changes in mineral nitrogen in the soil, and leaching of nitrate and DCD were measured.

Degradation of DCD in the topsoil was complete in May after application in the autumn before. However, at a depth of 90 cm, DCD was found three months after application. DCD remained present in leachate sampled at this depth for more than one year after application. Most probably it was then leached to the groundwater.

Application of DCD considerably delayed nitrification. It had a large effect on the vertical distribution of mineral nitrogen in spring; more mineral nitrogen was found in the 0-40 cm soil layer and less in the 40-100 cm soil layer.

However, neither time of application of the slurry nor addition of DCD had a significant effect on nitrate leaching.

Keywords: DCD, slurry, mineral nitrogen, leaching

Introduction

Large amounts of animal slurry are produced by agriculture in the Netherlands. Approximately 50 million tons were produced in 1992 (Anonymous, 1993). It has been spread on agricultural land in such amounts in the past, that pollution of groundwater and fresh water with nutrients has occurred. Legislation was introduced to limit further accumulation and leaching of nutrients. In 1987, the total amount and the time of application of slurry and other organic fertilizers were restricted. In 1991 the application was forbidden in the period between harvest and January for arable land on sandy soils. This period has now been extended until February.

Restrictions on application imply the need for larger storage capacity, and are therefore costly. Hence, techniques which allow slurry application on sandy soils in autumn without increased risk of nitrate leaching could be very valuable. A possible technique is the addition of a nitrification inhibitor, which may prevent the nitrification of ammonium before winter and consequently nitrate leaching should then be similar or less than from a later, untreated manure application.

Van Enckevort (1988a, 1988b), reviewing the literature, concluded that addition of dicyandiamide (DCD) to slurry was a promising technique to prevent nitrate leaching after autumn application of slurry on sandy soils.

Data on the effect of DCD on nitrate leaching, however, were too scarce to be conclusive and, moreover, leaching of DCD was reported from 50-cm deep cores of sandy soil under controlled conditions (Teske & Matzel, 1988) and from 100-cm deep lysimeters with sandy soil (Kjellerup, 1988). Hence, prior to recommending possible legislation on the DCD treatment of autumn application, the effect of DCD on nitrate leaching and its behavior in sandy soils under field conditions needed further study.

Therefore, a three year field experiment was commissioned in 1988, in which the degradation of DCD, changes in mineral nitrogen in the soil, and leaching of nitrate and DCD were measured. The experiment included the application of cattle slurry with DCD in November and December, application of cattle slurry without DCD in November, December and January, and an untreated (slurry or DCD) control.

Materials and methods

Description of the experiment

The experiment was performed on the experimental farm of AB-DLO at Haren, The Nether-lands. The soil was a loamy sand soil with approx. 30% loam (< 0.05 mm) in the 0-50 cm soil layer and approx. 15% loam in the 50–100 cm soil layer. The soil contained 4% organic matter in the upper 40 cm. The groundwater table was normally situated between 100 and 180 cm.

The experiment included six treatments and three replicates: no slurry or DCD, 50 t ha^{-1} cattle slurry in November, in December, or in January, and 50 t ha^{-1} cattle slurry plus 30 kg ha^{-1} DCD in November or in December. The field was divided into three blocks, each with six randomized plots of 10 meters long and 10 meters wide.

The slurry was applied with a spreader with measurement equipment (Schepers, 1978). The amount of slurry applied was measured automatically during application, separately for every 2 m^2. In the first two experimental years the slurry was incorporated into the soil within one hour after application. In the last two experimental years it was directly injected into the soil. After complete degradation 30 kg of DCD provides 20 kg mineral nitrogen. No further nitrogen was applied; other nutrients were applied in quantities according to standard fertilizer recommendations.

The experiment was started in November 1988 and measurements were made until May 1992. Measurements on the plots with December application of slurry, however, were completed in September 1991.

In 1989, 1990 and 1991 starch potatoes, sugar beet and silage maize were grown, respectively.

Sampling

Soil samples for determining mineral nitrogen in the upper 100 cm were taken monthly from September (for the zero slurry treatment) or from the moment of slurry application until May in five layers of 20 cm. DCD concentration was determined in the same samples, but only for the 0-20 and 20-40 cm layers, and for three treatments: slurry + DCD in November, slurry + DCD in December, and, as a control, slurry without DCD in November. One mixed sample of 10 cores was taken per plot.

Samples of leachate were taken by using porous ceramic cups, placed at a depth of 90–100 cm. On each plot four cups were sampled, with an equal sample volume from each cup mixed to form a composite sample before analysis. Samples were taken after approximately every 35 mm of drainage volume during the period of drainage. The drainage volume was calculated from data on rainfall, evapotranspiration and differences in soil water content (Oosterom & Steenvoorden, 1984). Rainfall was measured daily adjacent to the experimental field and evapotranspiration was defined as half the potential evapotranspiration from a grass crop (published monthly by the Royal Dutch Meteorological Institute (KNMI), de Bilt), since no data for bare soil were available. Differences in soil water content were calculated from data on the groundwater table and the retention characteristics of the soil, assuming an equilibrium between groundwater table and soil water content.

All leachate samples were analyzed for nitrate and ammonium. Leachate samples from the treatments slurry + DCD in November, slurry + DCD in December, and, as a control, slurry without DCD in November were also analyzed for DCD.

Slurry was sampled directly before application and was analyzed for ammonium nitrogen and total nitrogen. Application rates of ammonium nitrogen and total nitrogen are given in Table 1.

Chemical analysis

Mineral nitrogen and DCD in the soil were determined after extraction of one volume of moist soil with five volumes of 1.0 M KCl. The NO_3-N and NH_4-N contents

Table 1. Mineral nitrogen and total nitrogen (kg ha^{-1} N) applied in different years and treatments.

	1988/1989		*1989/1990*		*1990/1991*		*1991/1992*	
Treatment	NH_4-N	N-tot	NH_4-N	N-tot	NH_4-N	N-tot	NH_4-N	N-tot
slurry in November	120	272	119	242	163	242	127	282
slurry + DCD in Nov.	123	292	119	266	182	253	128	265
slurry in December	132	263	138	251	132	308	–	–
slurry + DCD in Dec.	131	287	134	271	125	315	–	–
slurry in January	137	278	155	314	155	231	119	273

of the extracts and the soil water samples were analyzed colorimetrically. The DCD contents of the extracts and the soil water samples were analyzed colorimetrically after Vilsmeier (1979).

Slurry was analyzed for NH_4-N after extraction with water, and for total-N after strong acid digestion.

Statistics

Differences between treatments were tested for statistical significance ($P < 0.05$) with Student's t-test.

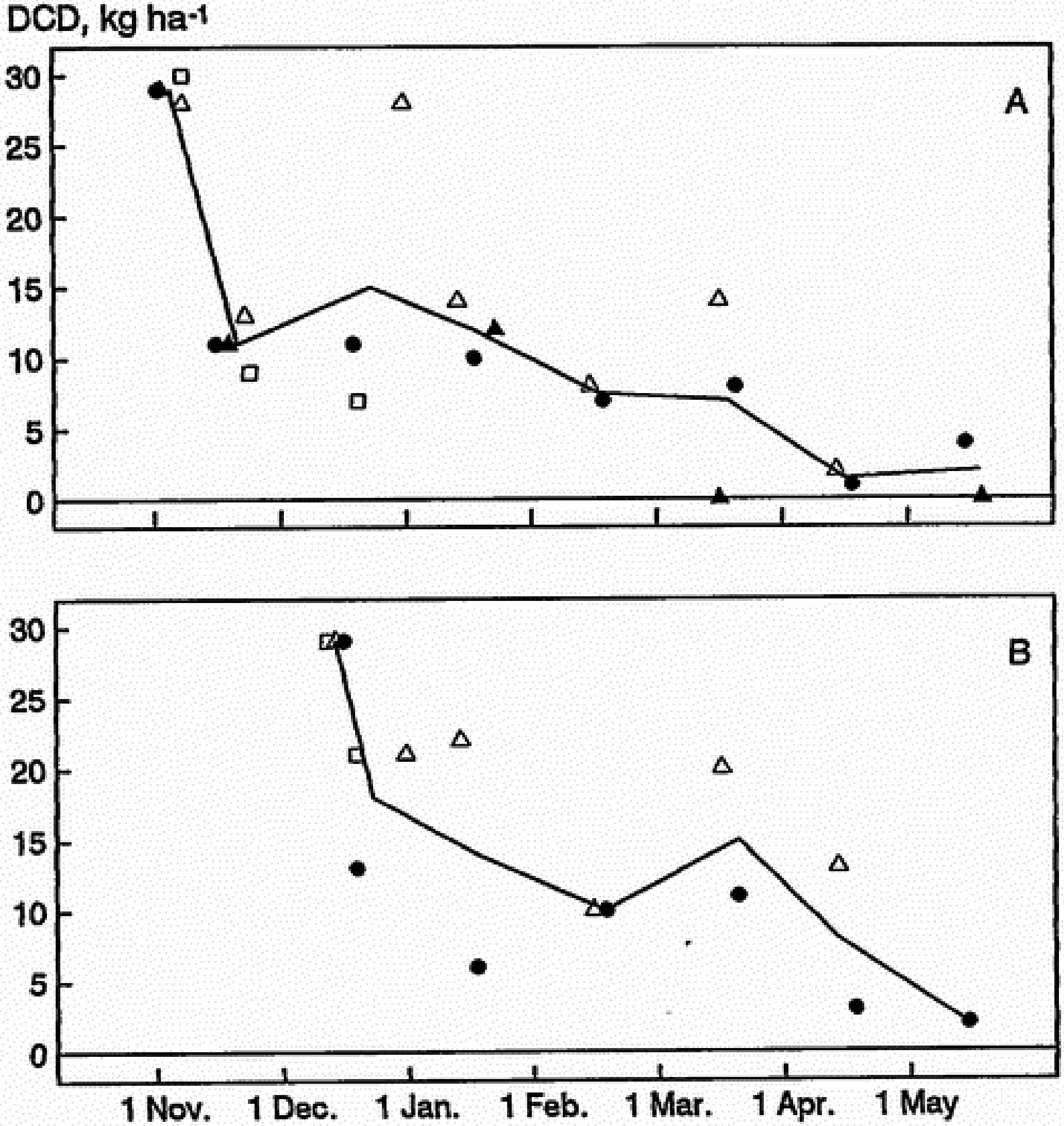

Figure 1. DCD contents (kg ha^{-1}) in the 0–40 cm soil layer after application in November (A) or in December (B). Remark: on the day of application the amounts applied (28–30 kg ha^{-1}) are drawn in; the lines are drawn between the calculated mean values for the different years of application.
△ 88/89 ● 89/90 □ 90/91 ▲ 91/92

Results

Degradation and leaching of DCD

The concentration of DCD in the upper 40 cm of the soil after application in November and in December is shown in Figure 1. In general, the amount of DCD decreased rapidly shortly after application. The decrease was slow during the winter, while the remaining part quickly disappeared in spring.

The disappearance of DCD from the upper 40 cm of the soil was not the result of degradation alone. Figure 2 shows that DCD was detected in the leachates, sampled at a depth of 90-100 cm, within two to three months after application. After application in November, DCD could be found in the leachates from that depth for at least one year, after which freshly applied DCD was found in addition. After application in December, however, DCD was completely leached from the sampled layer within about one year after application, and for a period of a few months in winter no DCD could be detected in the sampled leachate. The DCD concentration in the leachate sampled in autumn was still considerable, indicating that the degradation was very slow in deeper soil layers, even in summer. In the summer of 1991 DCD disappeared almost completely. This, however, was probably the result of leaching to deeper layers after unusual heavy rains in June and July, and not the result of degradation.

The total amounts of DCD leached over the winter periods are presented in Table 2. On average 7% and 2% of the DCD applied was leached after application in November or December, respectively. In the winter of 1991/1992 leaching was higher, due to the very large amount of rainfall during that period.

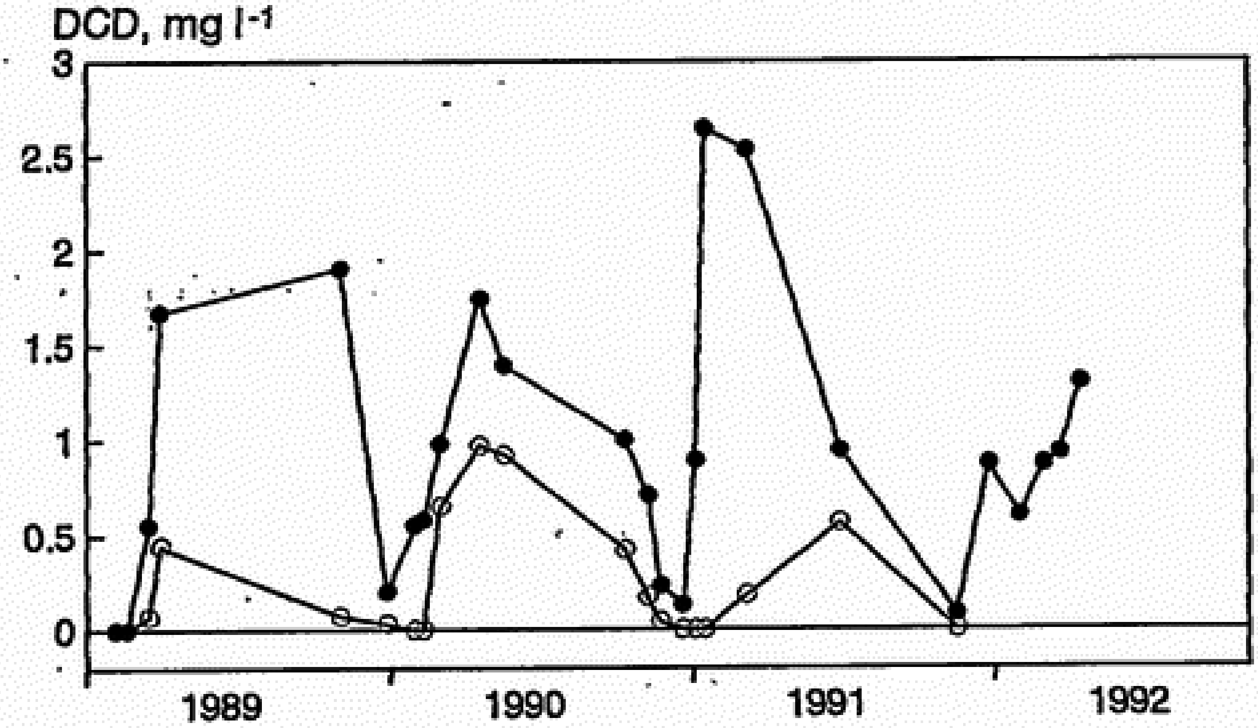

Figure 2. DCD contents in percolation water sampled at 90–100 cm depth after application of slurry with DCD in November or in December.
—●—November ——December

Table 2. Amounts of DCD (kg ha^{-1}) leached in the period between September and May after application of 30 kg ha^{-1} in November or in December.

Application	1988/1989	1989/1990	1990/1991	1991/1992
November	1.5	1.9	1.9	2.8
December	0.3	0.8	0.6	–

Mineral nitrogen in the soil

Addition of DCD to slurry retarded nitrification very effectively, as is illustrated in Figure 3. After application of slurry with DCD in November 1988, the nitrate content of the fertilized soil remained even lower than in the unfertilized plots until March.

After addition of DCD to slurry applied in November, 161 kg ha^{-1} mineral nitrogen remained in the upper 40 cm of the soil in May 1989 versus 84 kg ha^{-1} without addition of DCD ($P < 0.05$, 3 replicates). Only slightly more mineral nitrogen was found in the upper 100 cm of the soil (225 vs. 195 kg ha^{-1} N in May 1989, $P > 0.05$; not significant). This situation is apparent in all years, both for application of DCD in November and December (Table 3).

The remarkably low mineral nitrogen content of the soil on 22 November 1989, three weeks after application of slurry without DCD (Figure 3b), suggests a large nitrogen loss in this treatment. Apparently this is not true because in February the mineral nitrogen content was much higher than in November and only slightly lower than the mineral nitrogen content after application of slurry with DCD (Figure 3c).

Leaching of nitrate

The amounts of nitrate leached and the drainage volumes are summarized in Table 4. In general, large amounts of nitrate (90-240 kg ha^{-1} yr^{-1} NO_3-N) were leached, especially in the wet winter of 1991/1992. The relatively small differences between the treatments were rather unexpected. In the unfertilized plots, after three years without

Table 3. Mineral nitrogen (kg ha^{-1} N) in the 0–40 and 0–100 cm soil layers in May.

	1989		1990		1991		1992	
Treatment	0–40	0–100	0–40	0–100	0–40	0–100	0–40	0–100
no slurry	63^{a}	123^{a}	53^{a}	95^{a}	63^{a}	93^{a}	34^{a}	6^{a}
slurry in November	84^{ab}	195^{b}	80^{b}	187^{b}	126^{b}	213^{b}	66^{c}	160^{b}
slurry + DCD in Nov.	161^{cd}	225^{b}	113^{bc}	199^{b}	149^{b}	214^{b}	90^{d}	170^{b}
slurry in December	95^{b}	217^{b}	84^{ab}	184^{b}	164^{bc}	231^{bc}	–	–
slurry + DCD in Dec.	178^{d}	248^{b}	142^{c}	209^{b}	261^{d}	320^{d}	–	–
slurry in January	145^{c}	242^{b}	96^{c}	208^{b}	196^{c}	240^{c}	85^{d}	169^{b}

^{abc}: differences are significant ($P < 0.05$) in the absence of an identical character.

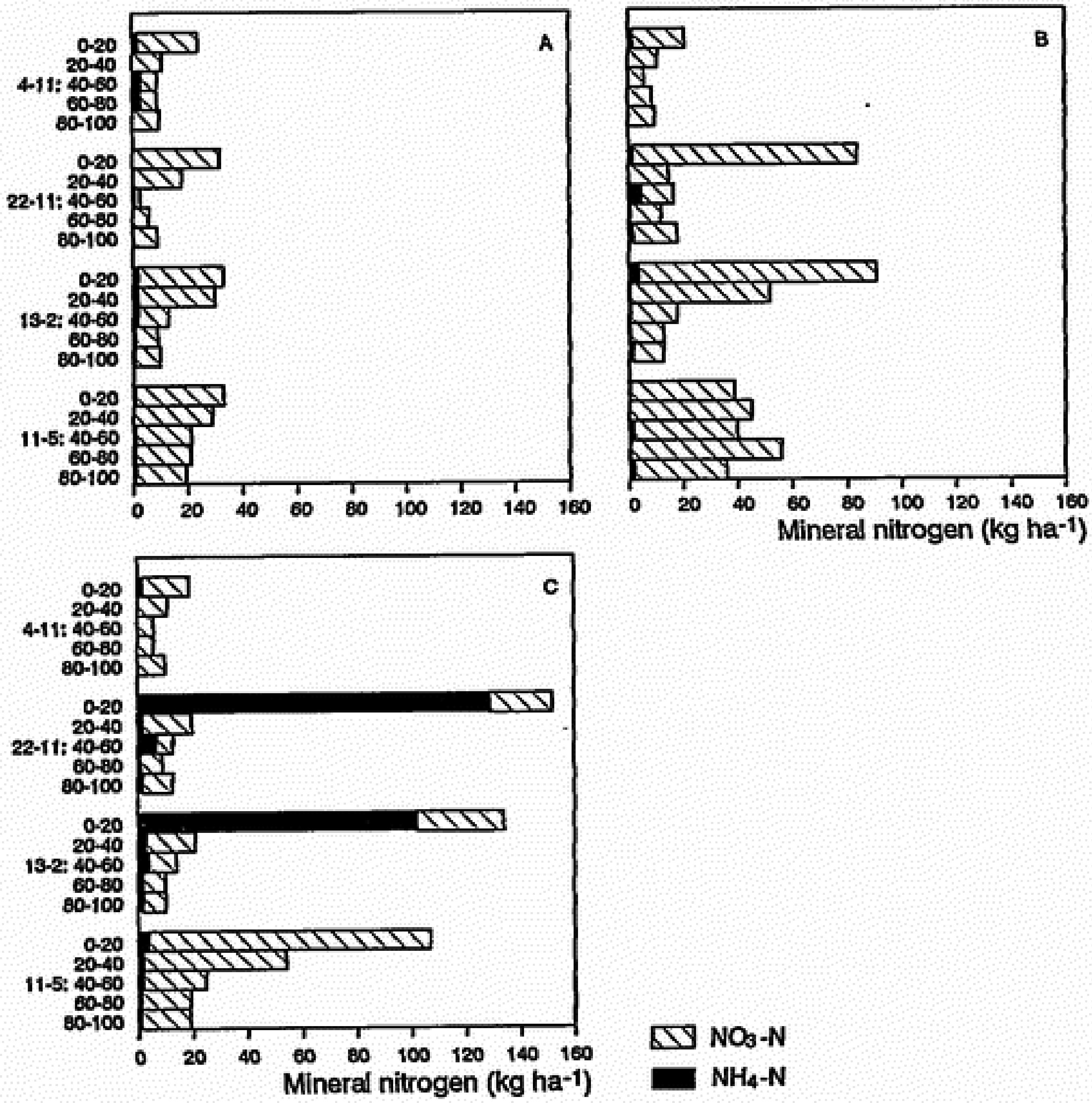

Figure 3. Mineral nitrogen contents in different soil layers during the winter, without slurry (A), and after application of slurry without (B) or with DCD (C). Slurry was applied on 8 November 1988.

any nitrogen fertilization, the dry matter production of the crop was 30% lower than after slurry application in winter. Still, an average NO_3-N concentration of 20 mg l^{-1} was found in the sampled leachate.

Nitrate leaching was generally highest after slurry application in November without DCD. After slurry application in December the nitrate leaching was only slightly higher than after application in January. However, differences were never statistically significant.

In contrast to the large effect of DCD on the nitrate contents of the soil in winter, DCD had a small and statistically non-significant effect on nitrate leaching. The average decrease in leaching of nitrate-nitrogen after addition of DCD was approxi-

Table 4. Amounts of nitrate (kg ha^{-1} N) leached and drainage volume (mm) in the period between September and May.

Treatment	1988/1989*	1989/1990	1990/1991	1991/1992
no slurry	90^{a}	130^{a}	90^{a}	90^{a}
slurry in November	100^{a}	200^{ab}	180^{bc}	240^{b}
slurry + DCD in Nov.	70^{a}	170^{ab}	190^{c}	230^{b}
slurry in December	100^{a}	160^{ab}	150^{b}	–
slurry + DCD in Dec.	90^{a}	140^{ab}	130^{b}	–
slurry in January	70^{a}	160^{b}	150^{b}	180^{b}
drainage volume	260	280	350	440

* : measured after 9 November 1988, before this date an estimated 20 kg N ha^{-1} and 120 mm water was leached in all treatments.

abc: differences are significant ($P < 0.05$) in the absence of an identical character.

mately 10%, or 15 kg ha^{-1}, both for application in November and in December.

Leaching of ammonium never exceeded 1 kg ha^{-1} yr^{-1} N.

Discussion

As expected on a sandy soil (Amberger & Vilsmeier, 1979), the degradation of DCD in winter was slow, but the remaining DCD in the upper soil layers disappeared quickly in spring. In the deeper soil layer (90-100 cm), however, the degradation of DCD proceeded very slowly, even in summer. The DCD content of the leachate sampled at that depth in early autumn was almost as high as in the preceding spring (Figure 2). This slow degradation suggests that a large part of the leached DCD may have reached the groundwater. In winter the groundwater table ranges from about 100 to 150 cm depth, only slightly beneath the sampling depth of the percolating soil water.

Further degradation of DCD in the groundwater cannot be excluded, but the conditions in the groundwater of sandy soils are very unfavorable for degradation (Van Enckevort, 1988a).

The amount of DCD leached was not large; after application in November and in December only 7% and 2% was leached, respectively. Kjellerup (1988) reported leaching losses from lysimeters of 30% and 50% after application in September and in December.

Despite the large reducing effect of DCD on nitrification, the reduction of nitrate leaching was only small. It can be concluded from Figure 3 and Table 3 that the addition of DCD affected the distribution of mineral nitrogen in the soil in spring, rather than the total amount of mineral nitrogen. This conclusion is confirmed by Amberger *et al.* (1982a) and Wadman *et al.* (1993). They also found more mineral nitrogen in the topsoil (0–30 and 0–60 cm, respectively) and less mineral nitrogen in deeper soil layers (30–90 and 60–100 cm, respectively) in spring after addition of DCD to autumn-applied slurry.

As in this experiment, the reported differences in total amounts of mineral nitrogen in the upper 90 or 100 cm of the soil were generally not or hardly larger than the amount of nitrogen present in the added DCD. Much higher total differences were reported (e.g. Ten Holte, 1984; Titulaer, 1984) when only the upper 60 cm of the soil was sampled.

By its effect on the distribution of the mineral nitrogen, the addition of DCD is likely to improve the plant-availability of nitrogen in spring and, depending on rooting depth, possibly also in summer. It may also reduce the chances of nitrate leaching during wet periods in the growing season.

Although the experimental conditions (e.g. the levels of slurry N application) of studies reported in the literature and the present study were different, the results appear to be very similar. The mean difference in nitrate leaching of the reported experiments ranged from 0 to 30 kg ha^{-1} yr^{-1} N (Amberger *et al.*, 1982b; Gutser & Amberger, 1984; Kjellerup, 1988; Scheffer *et al.*, 1984; Van den Toorn & Pankow, 1987), while it was 15 kg ha^{-1} yr^{-1} N in our experiment. The much larger differences (10 to 100 kg ha^{-1} yr^{-1} N) reported by Pankow and Van den Toorn (1988) could have resulted from the very high groundwater table in spring. In combination with a different distribution of nitrate, a late leaching period in spring might well increase the benefit of the addition of DCD.

The small differences in nitrate leaching of the different treatments during the winter also suggest that leaching is only weakly related to the amount of nitrate or to the amount of mineral nitrogen in the soil in autumn, i.e. in November or in December. The same conclusion follows from the small differences in nitrate leaching between fertilized and unfertilized plots (Table 4, 1988/1989), despite the large differences in amounts of mineral nitrogen in autumn (Figures 3A and 3B).

A possible explanation for the small differences in leaching between treatments might be that mineral nitrogen, present in the top soil in November, is not leached deeper than 1 meter. However, then a smaller increase in leaching after adding DCD would be expected in the wet winter of 1991/1992, while leaching was equally increased after the November application with and without DCD.

In the present study nitrate leaching generally was very high. Even after three years without any nitrogen fertilization, a mean NO_3-N content of 20 mg l^{-1} was found in the percolation water of the unfertilized plots. This concentration is still well above the drinking water standard of 11.3 mg l^{-1}. Crop yield (data not shown) decreased by about 30% during this period. Hence, economic farming without large leaching losses under these conditions may be hard to achieve.

It is concluded that application of slurry with DCD in November or in December did not result in increased nitrate leaching compared to application of slurry in January. On the other hand, the addition of DCD failed to decrease nitrate leaching significantly and DCD leaching to a depth of 1 meter was confirmed by the results. Due to the slow degradation in the deeper soil layers, it is likely that DCD also leached to the groundwater.

Since legislation should primarily lead to an improvement in groundwater quality, autumn application of slurry with DCD cannot be recommended.

References

Amberger, A. & K. Vilsmeier, 1979. Dicyandiamideabbau in Quarzsand und Böden. *Zeitschrift für Pflanzenernährung und Bodenkunde* 142:778–785.

Amberger, A., R. Gutser & K. Vilsmeier, 1982a. N-Wirkung von Rindergülle bzw. Jauche mit Dicyandiamid in Feldversuchen. *Zeitschrift für Pflanzenernährung und Bodenkunde* 145:315–324.

Amberger, A., R. Gutser & K. Vilsmeier, 1982b. N-Wirkung von Rindergülle unter Zusatz von Dicyandiamid bzw. Stroh in Gefass- und Lysimeterversuchen. *Zeitschrift für Pflanzenernährung und Bodenkunde* 145:337–346.

Anonymous, 1993. Agricultural Data 1992. (In Dutch.) Agricultural Economics Research Institute, Den Haag; Netherlands Central Bureau of Statistics, Voorburg, 273 pp.

Gutser, R. & A. Amberger, 1984. Nitratauswaschung nach Gülledüngung mit Didinzusatz. *Landwirtschaftliche Forschung* Kongressband 1984:137–145.

Kjellerup, V., 1988. Nitrogen effect of slurry mixed with nitrification inhibitors – lysimeter and field experiments. In: E. Welte & I. Szabolcs (Eds.). Agricultural waste management and environmental protection. CIEC, Belgrade, pp. 143–148.

Oosterom, H.P. & J.H.A.M. Steenvoorden, 1984. Slurry application on silage maize fields (sandy soil) and leaching losses to the groundwater. (In Dutch.) ICW nota 1499. ICW, Wageningen, 26 pp.

Pankow, J. & H. Van den Toorn, 1988. Effects of nitrification inhibitors on the groundwater quality of arable land on sandy soils. Droevendaal 1986/1987. (In Dutch.) ICW nota 1844. ICW, Wageningen, 17 pp.

Scheffer, B., H. Kuntze & R. Bartels, 1984. Reduzierung des Nitrataustrages aus einem Sandboden durch Einsatz von Didin. *VDLUFA Schriftenreihe* 11:87–96

Schepers, J.H., 1978. Specifications and instructions slurry dose-measurement machine (Schepan MMM). (In Dutch.). IB Rapport 1978 no. 31. IB, Haren, 11 pp.

Ten Holte, L., 1984. Gülleanwendung mit Nitrifikationshemmern: Einfluss auf N-gehalt des Bodens und Ertrag von Silomais. *VDLUFA Schriftenreihe* 11:290–304.

Teske, W. & W. Matzel, 1988. Die beeinflussung der nitrifikationshemmenden Wirkung van Dicyandiamid durch Abbau und Verlagerung im Boden. *Archiv für Acker-, Pflanzenbau und Bodenkunde* 32:241–246.

Titulaer, H.H.H., 1984. Erfahrungen mit Didin zu Gülle in den Niederlanden. *VDLUFA Schriftenreihe* 11:305–309.

Van den Toorn, A. & J. Pankow, 1987. Effects of nitrification inhibitors on the groundwater quality of arable land on sandy soils. Droevendaal 1985/1986. (In Dutch.) ICW nota 1765. ICW, Wageningen, 13 pp.

Van Enckevort, P., 1988a. Nitrification inhibitors and nitrate leaching with application of animal manure. II. Effects and behavior of nitrification inhibitors in the soil. (In Dutch.) IB-nota no. 192. IB-DLO, Haren, Netherlands, 49 pp.

Van Enckevort, P., 1988b. Nitrification inhibitors and nitrate leaching with application of animal manure. III. Action of nitrification inhibitors and their effects on the nitrogen cycle of the soil. (In Dutch.) IB-nota nr. 193. IB-DLO, Haren, Netherlands, 58 pp.

Vilsmeier, K, 1979. Kolorimetrisch Bestimmung von Dicyandiamid in Böden. *Zeitschrift für Pflanzenernährung und Bodenkunde* 142:792–798.

Wadman, W.P., J.J. Neeteson & G.J. Wijnen, 1993. Field experiments with slurry and dicyandiamide: response of potatoes and effects on soil mineral nitrogen. *Netherlands Journal of Agricultural Science* 41:95–109.