Dicyandiamide as a Nitrification Inhibitor

A. AMBERGER

Technical University Munich

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A. AMBERGER
Institute for Plant Nutrition
Technical University Munich
D-8050 Freising-Weihenstephan

Introduction

The background for beginning the work reported is as follows:

1. With increasing energy costs, mineral fertilizers are getting more and more expensive; in Germany, as much as 40% of the energy input into agricultural production is already due to mineral N-fertilizers.

2. Utilization of mineral N-fertilizers by crop plants is on the average between 60 - 70 %; with organic N-fertilizers (slurry and liquid manure), the utilization rate of N is usually not higher than 30 %; this is the result of more or less serious N losses.

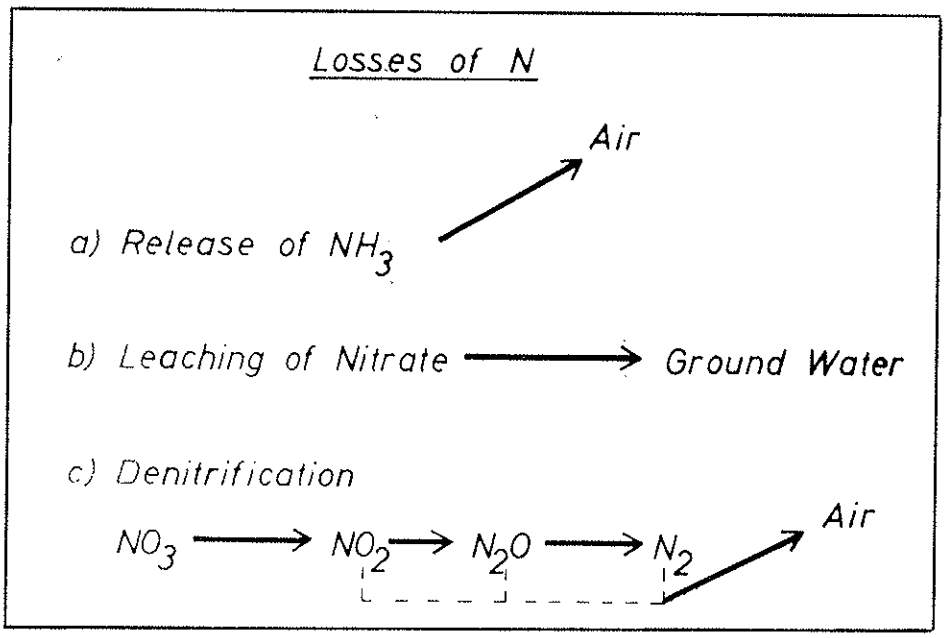
3. These losses of N occur during transformation of these fertilizers (Fig. 1) and are caused by

   a) volatilization of NH_3,
   (especially from urea and anhydrous ammonia)

   b) leaching of nitrate which furthermore results in undesirable pollution of ground- and surface water,

   c) denitrification, that is, gaseous N release into the atmosphere, resulting from the microbial reduction of nitrite and nitrate.

Figure 1.



Consequently, every effort is made to lower these losses of N and thereby increase the utilization of inorganic and organic fertilizers. This is possible by

a) agrotechnical measures (proper application, timing etc.),

b) use of urease or nitrification inhibitors, or both.

Thus, organic wastes are gaining a new and higher importance as fertilizer. A comprehensive presentation of problems, possibilities, and limitations of the use of nitrification inhibitors is given in the publication:

Nitrification Inhibitors -
Potential and Limitation (1980).

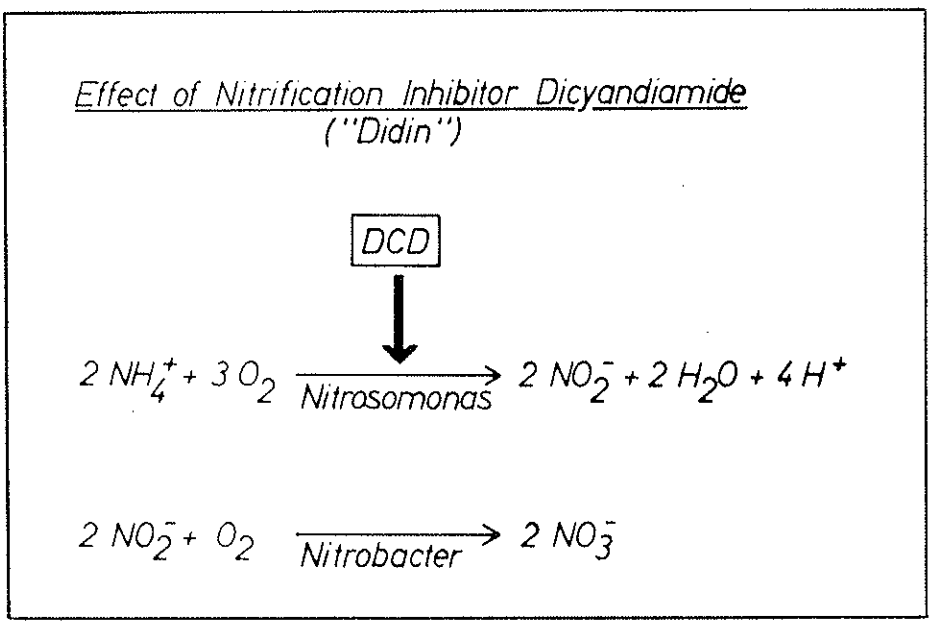
Dicyandiamide (DCD) is a nitrification inhibitor (tradename "Didin"), that we have been working with at my institute very intensively for some years (Vilsmeier and Amberger, 1978; Amberger and Gutser, 1979; Amberger, 1981; Gutser, 1981; Vilsmeier, 1981).

I. What is DCD and how does it work?

1. DCD, the water soluble dimeric form of cyanamide, constitutes about 10 % of total N in the fertilizer "calcium cyanamide" (Lime Nitrogen) and is responsible for its slow action.

   Added to the top soil in an amount of 20 - 30 ppm, DCD stays effective for about 6 - 10 weeks on the average, depending on temperature. During this time, it inhibits the first step of nitrification, the oxidation of ammonium (Fig.2).

Figure 2.



In an incubation trial (for 28 days at 14° C) with ^{15}N labelled ammonium sulfate, ammonium sulfa-nitrate and urea, addition of 10 % DCD-N inhibited nitrification considerably (Table 1).

Table 1.

Turn over of ^{15}N-Ammonium-Sulfate (AS) and Ammonium-Sulfa-Nitrate (ASN) and Urea (Ur) combined with Dicyandiamide (DCD)

(in % of added N after 28 days)
(silty loam) pH 6.5

Incubation experiment: 100g soil
20 mg ^{15}N as AS, ASN or Ur ± 2mg DCD-N
14°C, 50% of max. water holding capacity

DCD-application	AS		ASN		Ur	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
- DCD	21	69	11	81	1	92
+ DCD	82	6	59	28	62	29

This effect of DCD is bacteriostatical (not bactericidal) and specific for Nitrosomas. Presumably, the mode of action might involve a reaction of the C≡N - group of DCD with sulfhydrilic- resp. heavy metal groups of the respiratory enzymes (according to our own results in earlier experiments (Amberger, 1968)).

Other microorganisms, especially heterotrophic ones which are mainly responsible for the so-called biological activity resulting in biomass production in the soil, are not affected by DCD (Fig. 3).

II. What practical applications result for the use of DCD?

1. Addition of DCD to solid N-ferilizers, fertilizer solutions, or anhydrous ammonia at a rate of about 10 % of total N:

   a) In intensive rice cultivation, there is a major problem of high N-losses by denitrification which occur mainly during the time between fertilizer application before seeding (preincubation) and after water logging, when rice seedlings are in the first stages of development.

   In a pot trial with combination compounds of urea/DCD and ammonium sulfate/DCD (Tab. 2), losses of N by denitrification were higher the longer the preincubation period, (that is, the time between fertilizer application and seeding)(Amberger and Gutser, 1978). Accordingly, less N was available to the rice crop, as indicated by decreased N uptake.

Table 2.

Effect of Urea-Dicyandiamide (Ur/DCD) and Ammoniumsulfate-Dicyandiamide (AS/DCD) on N-uptake by green rice

(mg N/pot)

Treatment: pot trial: 10 kg soil (sL), pH 6.1
preincubation: 0-2-4 weeks (aerobic), followed by rice sowing and waterlogging

Preincubation weeks	*Ur*	*Ur/DCD*	*AS*	*AS/DCD*
0	*1273*	*1316*	*1672*	*1623*
2	*716*	*1051*	*984*	*1156*
4	*754*	*1227*	*908*	*1226*

b) In intensive cereal production, use of DCD-combinati n compounds facilitates dosage and application of N fertilizers, for instance, by combining two fertiliz applications into one and thus reducing labour costs while maintaining high yields (Tab.3).

Table 3.

Ammonium-Sulfa-Nitrate (ASN/DCD) applied to Winter-Wheat

(Loess-Brown Earth)

Fert added kg N/ha stage of devel.				*Grain Yield dt/ha (14 % water)*
Start of veget.	*Tillering*	*Shooting*	*Late applic.*	
Σ 80	–	–	–	*60*
Σ 140	*30 (CAN)*	–	*50 (CAN)*	*75*
Σ 140	–	*80 (ASN/DCD)*	–	*76*

$\Sigma N_{Soil} + N_{Fert.}$

CAN = Calcium ammonium nitrate

c) In shallow or light, sandy soils, where considerable leaching often takes place even during the cropping season, losses of nitrate (Table 4 and 5) can be reduced by this means, thus economizing the total fertilizer expenditure.

d) In cultivation of vegetable crops, a high N supply is necessary during the early growth stages to produce high yields. Undesirably high contents of nitrate which usually occur in this case, e.g. in spinach, carrots, cabbage, etc. can be avoided by the use of DCD (Kick and Massen, 1973).

Table 4.

Ammonium-Sulfa-Nitrate (ASN/DCD) applied to potatoes

(Rendzina east of Munich)

Partitioning: ASN in 4 applications
ASN/DCD in 3 applications

Fertilizer added		green matter dt/ha	starch dt/ha
without N		215	41
200 N	ASN	325	55
	ASN/DCD	354	58
240 N	ASN	326	55
	ASN/DCD	347	56
280 N	ASN	333	54
	ASN/DCD	351	57

Table 5.

EFFECT of UREA + DCD and AMMONIUM - SULFA - NITRATE (ASN) + DCD on SILAGE-CORN

Location/soil: Rendzina from Lime-gravel; pH 7,2

N-Form and -Amount	Yield (t/ha D.M.)	N-Uptake (kg/ha)
1979		
125 N as Urea	14,3	106
Urea/DCD	15,5	129
235 N as Urea	15,3	123
Urea/DCD	14,4	119
1980		
200 N as Urea	8,1	94
Urea/DCD	9,5	112
ASN	8,7	100
ASN/DCD	9,2	115
LSD 5%	10	13

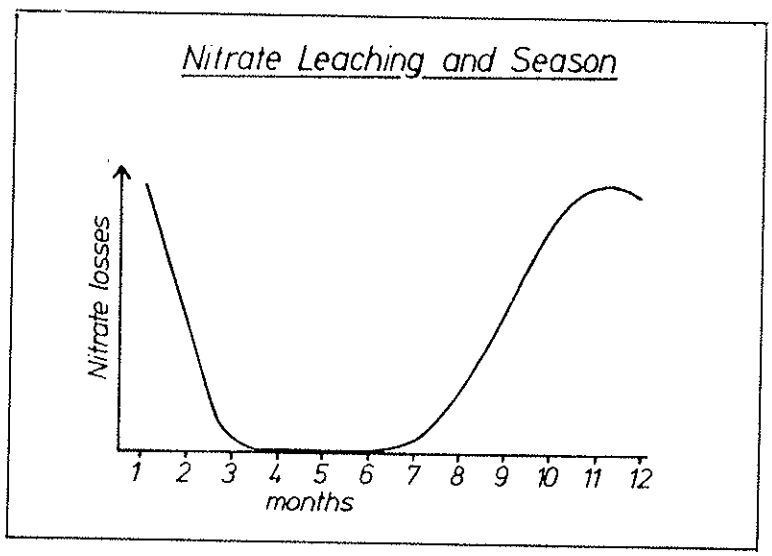
2. Addition of DCD to organic wastes of animal production.

Completely new modes of employing DCD have been developed in my institute in the last few years by adding this nitrification inhibitor to slurry resp. liquid manure.

In liquid organic wastes, about 50 % (slurry) or 75 % (liquid manure) of the total N is in the form of ammonium; the remainder of the N cannot be considered plant available (Amberger, Vilsmeier and Gutser; Amber, Gutser and Vilsmeier; Amberger, Gutser and Vilsmeier in preparation).

Since these fertilizers, however, cannot be applied for technical reasons to growing crops, and since storage capacities of farms are very limited, application is mainly restricted to the fall/winter season. Besides considerable losses of ammonia in the absence of, or imperfect ploughing in of the manure, very high losses of nitrate can occur, the amount of loss depending on climate and soil conditions, especially if nitrate leaching is especially serious when it occurs outside of the cropping season, as is the case with our climate (Fig. 4).

Figure 4.

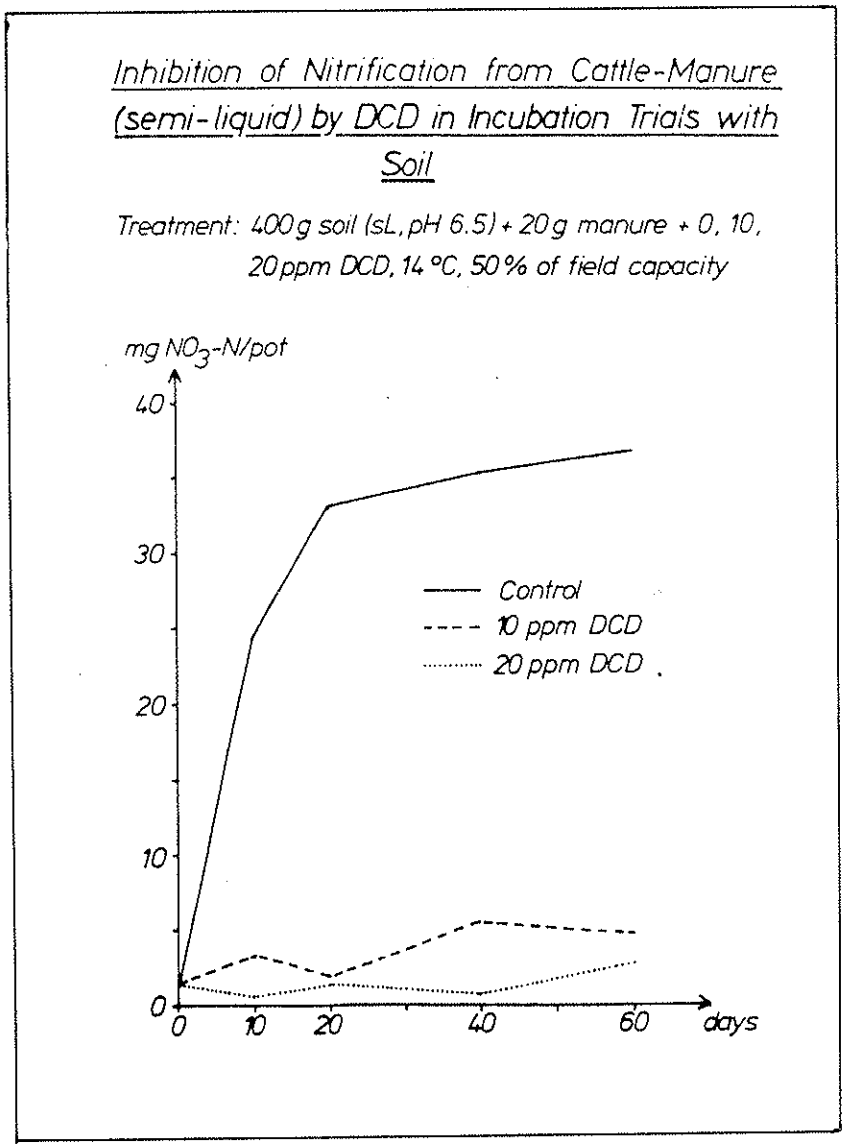


Addition of 15-30 g DCD/ha, depending on the rate of slurry application and on the time interval before cropping, can "preserve" plant available ammonium N from liquid organic wastes for a period of about 6 weeks and more.

Some results follow:

In an incubation experiment, (14 °C, 50 % of maximum water holding capacity) nitrification of cattle slurry was suppressed almost completely for 60 days by as little as 10 ppm DCD (Fig. 5) (Amberger and Vilsmeier, 1979 b).

Figure 5.



From a two years pot trial under natural climate conditions, it can be seen that slurry applied at different times is nitrified relatively fast. Addition of DCD (≙ 30 kg/ha), however, resulted in considerably less N loss by leaching and increased N uptake by the following crop (Table 6).

Table 6.

Effect of Cattle-Slurry Nitrogen on Rye Grass Leaching and Removal of N in Pot Trials (mg N/Pot)

Slurry	DCD	N-Leaching 1978/79	N-Removal Veget. 79	N-Leaching 1979/80	N-Removal Veget. 80
August	-	564	68	621	67
August	+(Oct)	131	99	541	102
October	-	264	82	287	67
October	+	83	203	179	82
March	-	347*	50	539*	83
March	+	242*	81	179*	169
LSD 5%		25	10	56	13

* with additional simulation of rainfall

Similar results were found in field trials. Addition of "Didin" to "fall"- or "spring"-slurry normally increased yields and N uptake by about 8 - 20 percent.

Table 7.

Effect of Cattle-Slurry Nitrogen on Silage Maize Yield and N-Removal in Field Trials

Time	Slurry added: Amount kg tot. N/ha 1978/79	Slurry added: Amount kg tot. N/ha 1979/80	Removal (kg N/ha) 1979 -DCD	Removal (kg N/ha) 1979 +DCD	Removal (kg N/ha) 1980 -DCD	Removal (kg N/ha) 1980 +DCD
	no slurry added		82	76	61	57
August	322	407	104	121	71	75
September	237	333	122	123	81	94
November/Oct.	366	509	132	144	81	90
March (a)	241	488	112	128	113	126
March (b)	544	877	151	181	107	117
$LSD_{5\%}$			11		6	

Summary and Conclusion

Dicyandiamide is a nitrification inhibitor which blocks transformation of ammonium-N in mineral or organic N fertilizers for a period of 2 - 3 months, depending on site conditions. It is decomposed in the soil without leaving any residues, eventually acting as a largely plant available N fertilizer.

Dicyandiamide as a complement to solid N fertilizers, fertilizer solutions, or anhydrous ammonia, at a rate of 10 % of the total N, reduces in particular denitrification losses during rice cultivation and leaching losses of nitrate in shallow and sandy soils, lowers undesirable nitrate contents in vegetables, and offers savings in labour costs with respect to application and timing of N fertilizers. Added to organic animal wastes (slurry or liquid manure) at a rate of 15 - 30 kg/ha it inhibits nitrification of ammonium-N for a few months, depending on temperature, thus "preserving" N for the following crop.

By this means, utilization of expensive inorganic fertilizers or of inevitably supplied organic manure is increased and pollution of waters with nitrate is reduced.

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