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# Potentials of nitrification inhibitors in modern N-fertilizer management

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## Summary – Zusammenfassung

Modern agricultural practices require a new concept of N-fertilizer management in order to optimize N-utilization and avoid N-losses. Nitrification inhibitors or „N-stabilizers“ fit very good into this conception.

Dicyandiamide (DCD) is an efficient nitrification inhibitor and blocks the first step of nitrification for 1–3 months (depending on temperature). This effect is bacteriostatic (not bactericidal) and does not affect other (esp. C-heterotrophic) soil microorganisms („biological activity“).

DCD is a non-toxic, water soluble compound and will be degraded to $CO_2$, $NH_3$ and $H_2O$ without any residues.

There are various possibilities to use DCD: addition to liquid manure temporarily prevents oxidation of ammonium nitrogen e.g. of slurry or waste water from potato starch production.

In combination with inorganic fertilizers like ammonium sulfate or urea (with 10 % of total-N) it enables the farmer to control $NH_4$-supply to crop plants in certain stages of growth and to gain certain operational advantages by less frequently split applications of N especially on sand and rendzina soils.

Thus, the systematic use of nitrification inhibitors not only represents a progress in agricultural technique but also helps to substantially reduce risks concerning pollution of surface and ground waters that are sometimes inevitable consequences of agricultural production.

## Möglichkeiten von Nitrifikationshemmstoffen in der modernen Stickstoffdüngung

Moderne Landbewirtschaftungsmethoden erfordern ein neues Düngungskonzept mit dem Ziel, die Stickstoffausnutzung zu optimieren und N-Verluste zu verhindern. Nitrifikationshemmstoffe oder „N-Stabilisatoren“ passen gut in dieses Konzept. Dicyandiamid (DCD) ist ein wirksamer Nitrifikationshemmstoff; er blockiert den ersten Schritt der Nitrifikation für die Dauer von 1–3 Monaten (je nach Temperatur). Dieser Effekt ist bakteriostatisch (nicht bakterizid) und beeinträchtigt nicht andere (vor allem C-heterotrophe) Bodenorganismen („biologische Aktivität“). DCD ist eine nicht toxische, wasserlösliche Verbindung, die letztlich zu $CO_2$, $NH_3$ und $H_2O$ abgebaut wird ohne Rückstände.

Es gibt verschiedene Möglichkeiten für den Einsatz von DCD:

Gülle oder Abwasser aus der Kartoffelstärkeproduktion („Kartoffelfruchtwasser“) zugesetzt, verhindert es die Oxidation des Ammoniumstickstoffs für eine gewisse Zeit.

In Kombination mit anorganischen Düngemitteln wie Ammoniumsulfat oder Harnstoff (mit 10 % vom Ges.-N) ist es möglich, die $NH_4$-N-Anlieferung zu Kulturpflanzen in bestimmten Entwicklungsabschnitten zu regulieren. Damit verbunden sind gewisse arbeitswirtschaftliche Vorteile gegenüber üblichen mehreren Teilgaben mit mineralischem Stickstoff vor allem auf Sanden und Rendzina-Böden.

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Die Anwendung von Nitrifikationshemmstoffen stellt somit nicht nur einen Fortschritt dar in agrotechnischer Hinsicht, sondern trägt auch wesentlich dazu bei, mögliche Risiken einer Belastung von Oberflächen- und Grundwasser mit Nitrat zu verringern, die manchmal unvermeidbare Folgen der landwirtschaftlichen Produktion darstellen können.

## Introduction

Nitrogen is required in relatively large quantities for crop production and is therefore in most cases one of the main yield limiting factors.

To produce a certain amount of crop yield of good quality, definite amounts of nitrogen are necessary (e.g. 25 kg N/t of wheat, 60 kg N/t of rape etc., Anonymus 1984). Depending on site conditions and intensity of fertilization, the necessary amount of nitrogen can be calculated with respect to the expected yield and is applied according to the need of plants at various stages of growth; several model systems were presented e.g. by *Hanus* 1978, *Heyland* 1980; *Schönberger* and *Slotta* 1983.

By this way, a relatively good utilization of nitrogen fertilizers can be expected.

Essential progress with regard to this concept of balance-accounting has been made by introducing the $N_{min}$-method. (*Scharpf* and *Wehrmann* 1975, *Wehrmann* and *Scharpf* 1979; *Gutser* and *Teicher* 1976/1980). The value of $N_{min}$ (determined at the end of winter) gives information about the amount of plant-available nitrogen (esp. nitrate) at this time in the soil layer penetrable by roots (about 90 cm) as a result of nitrogen mineralized during fall/winter minus the amount of nitrate leached in the same time.

It is as such a good basis to predict N supply from the soil in early spring depending on site conditions, land use or crop sequence. Furthermore, the mineralization potential of the soil can also be determined by EUF-analysis (*Nemeth* 1979).

Balancing and optimizing N application, therefore, is quite realizable, but demands a modern conception of nitrogen fertilizing. From both economic and ecological points of view, it is necessary to use as much soil nitrogen as possible for crop production and protect it from leaching to avoid contamination of ground and surface waters by nitrate, saving also expensive mineral nitrogen. With Central European conditions, an especially critical season is autumn (after cereal harvest), when mineralization of the soil biomass is still in full swing, but plant growth is limited due to sinking temperatures. Thus mineralized soil nitrogen as well as N of eventually applied manure slurry cannot be used productively and is leached to a great extent during the following winter months.

This fact must be countered by choosing a suitable crop sequence including straw manuring or fall/winter catch crops, (*Gutser* and *Vilsmeier* 1985, *Bosch* and *Gutser* 1985). By such means, mineralized nitrogen can be largely protected from leaching. However, the nitrogen fixed by biomass is released only in the course of the following cropping season or later at a slow rate.

Such a *conception for N-fertilizer use* comprehends the following:

a) minimization of nitrogen losses by nitrate leaching (in late fall/winter) and denitrification (at temporary water-logged conditions and high temperature) and thus more efficient utilization of soil and fertilizer nitrogen,

b) regulation of nitrogen supply (amount, form and application time of nitrogen) e.g. by offering nitrogen in form of $NH_4$ to crop plants over certain periods to eventually reduce nitrate contents of vegetable and feed crops because of nutritional considerations and to gain labour-saving advantages.

In this conception the recently developed nitrification inhibitors play an essential role: natural mineralization up to the stage of ammonium takes place without hindrance while the first step of nitrification is temporarily inhibited or retarded by inhibitors or „N-stabilizers“.

## Inhibition of nitrification

Mineralization and nitrification are of great ecological importance and an essential characteristic of fertile soils; these processes transform nitrogen most of which is in organic compounds (humus) to a plant available form. While a temporary inhibition of nitrification means an interference with the natural nitrogen cycle, there are hardly any arguments for declaring this process especially worth of protection (*Domsch* 1984) since also natural disturbances like drought conditions, temporary water-logging, low temperatures, acidic pH as well as naturally occuring inhibitors (exudates of roots, tannins etc.) have an even stronger influence (*Olsen* and *Reiners* 1983).

It is essential that the intended inhibition is reversible and limited for a certain time, and that the applied compounds are not harmful to human or animal health. Worldwide hundreds of chemicals have been investigated in this respect. Of practical importance are only nitrapyrin („N-Serve“) in the USA and dicyandiamide („Didin“) in Japan, Great Britain, Netherlands, Austria and FRG (*Hauck* 1980, *Slangen* and *Kerkhoff* 1984).

### *N stabilizer dicyandiamide*

In about 10 years of intensive research in our institute we have studied the effects and potentials of the nitrification inhibitor dicyandiamide (DCD, trade name „Didin“).

This compound ($H_4C_2N_4$) is contained in the fertilizer calcium cyanamide with about 10 % of the total-N and is responsible for its slow-release effect. It is water-soluble and classified as a „non-toxic substance“ ($LD_{50}$ = 10 g/kg body weight, which is about 3 times higher than for NaCl).

When applied at appropriate rates, it specifically inhibits the first step of nitrification (fig. 1).

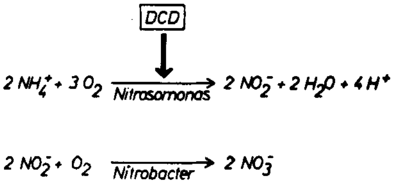


**Figure 1:** Effect of the nitrification inhibitor dicyandiamide

**Abbildung 1:** Wirkung des Nitrifikationshemmstoffes Dicyandiamid

With pure cultures or cell suspensions of Nitrosomonas europea (*Zacherl* and *Amberger* 1984) we could show a specific inhibition of nitrite formation at concentrations of 100 to 300 ppm (fig. 2); the same cultures, after being transferred to a DCD-free medium again developed the capability to oxidize ammonium (to 85–90 %). This means that DCD is a bacteriostatic and not a bactericidal agent.

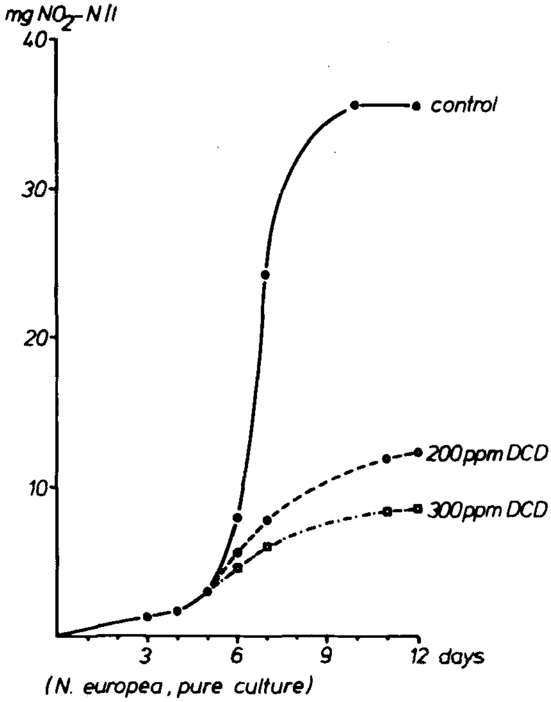


**Figure 2:** Effect of dicyandiamide (DCD) on the nitrite production of a pure culture of *Nitrosomonas europea* (*Zacherl* and *Amberger*, 1984)
**Abbildung 2:** Wirkung von Dicyandiamid (DCD) auf die Nitritproduktion einer Reinkultur von *Nitrosomonas europea* (*Zacherl* und *Amberger*, 1984).

### *Effects on DCD on other soil microorganisms*

N-binding and especially C-heterotrophic microorganisms which are mainly responsible for the so-called „biological activity" of the soil are not affected by DCD (*Bosch* and *Amberger* 1983) (fig. 3).

In soils sampled at the end of the cropping season from a 50 years old field trial with annual application of calcium cyanamide which contains about 10 % of the total N as DCD, the activity of nearly all determined soil enzymes is not negatively affected by DCD but is, due to the regular liming by application of this fertilizer (about 60 % CaO)

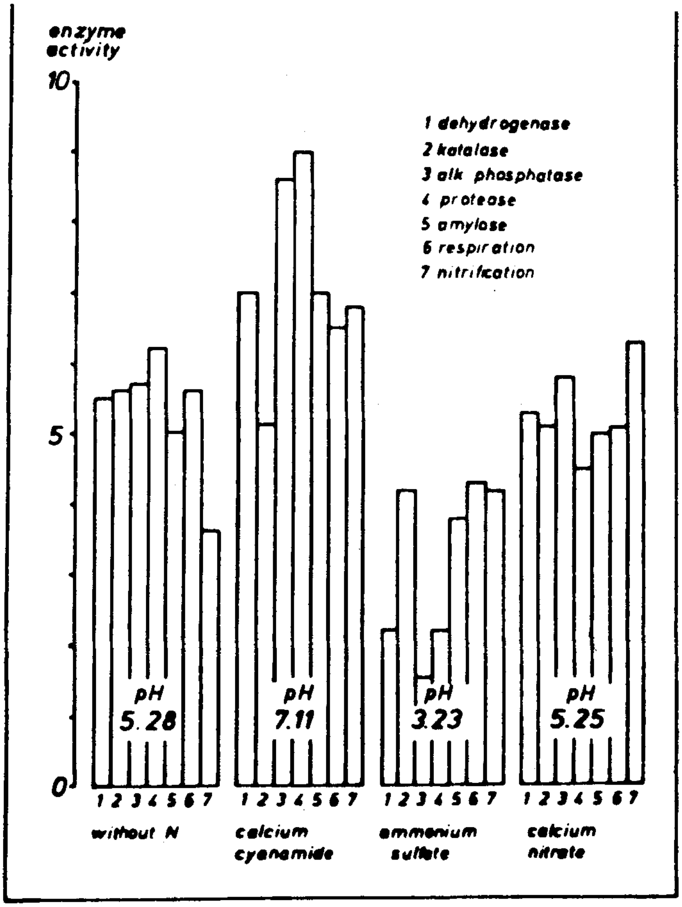


**Figure 3:** Activity of soil-borne enzymes as influenced by different N-fertilizers (results of a 50 year old experiment on sandy silty loam, acc. to *Bosch* and *Amberger,* 1983)
**Abbildung 3:** Beeinflussung der Aktivität von Bodenenzymen durch verschiedene N-Dünger (Ergebnisse eines 50-jährigen Dauerversuchs auf sandig-schluffigem Lehmboden nach *Bosch* und *Amberger,* 1983)

in most cases even higher (pH optimum of the enzymes!) than in control plots. Further investigations with various soil enzymes, biomass and $CO_2$ measurements (*Stichlmair* 1984) fully confirmed these results.

### *Persistence respectively decomposition of DCD in the soil*

The nitrification inhibiting effect of DCD is lasting for 1 to 3 months on the average, depending on ecological conditions (temperature, humidity, organic matter, pH etc.).

Decomposition takes place at first on surface of metal oxides (especially iron oxides and hydroxides) by catalytic addition of water to DCD under formation of guanylic urea (fig. 4). This compound is transformed mainly by microorganisms through further addition of $H_2O$, desamination and decarboxylation to guanidine and finally to urea which is quickly degraded by the enzyme urease. The end products of this inhibitor are therefore plant nutrients like $CO_2$, $NH_3$ and $H_2O$ (*Amberger* and *Vilsmeier* 1979 b, *Vilsmeier* 1980).

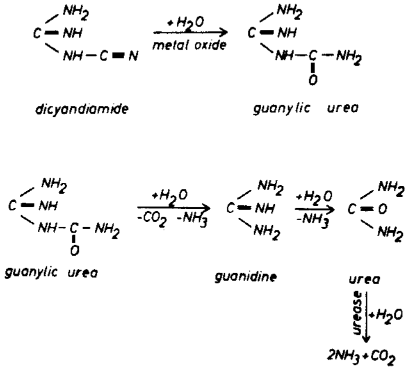


**Figure 4:** Decomposition of dicyandiamide (*Amberger* and *Vilsmeier,* 1979, *Vilsmeier,* 1980)
**Abbildung 4:** Abbau von Dicyandiamid (*Amberger* und *Vilsmeier,* 1979, *Vilsmeier,* 1980)

It is important to emphasize that only DCD but none of its metabolites is effective as inhibitor.

*Physical and physiological properties of DCD*

The big advantage of the compound DCD is its relatively good solubility in water (23 g/l at 13 °C) and therefore its suitability to combine with liquid and solid inorganic and organic fertilizers. When used in higher amounts, especially directly at onset of growth or in nutrient solution – which is however a rather unusual fertilizer practice and does not comply with fertilizing recommendations – it can be taken up by plants in small amounts, but without essential disadvantages (eventually minor necroses), is transported in the xylem and exuded at the leaf margins by way of transpiration (*Amberger* and *Vilsmeier* 1983, *Vilsmeier* 1984).

## Possibilities for DCD use

### *DCD as an additive to manure slurry and waste water*

a) Slurry accumulated in intensive animal farming in large amounts contains on the average 2 kg ammonium nitrogen/$m^3$; it is nitrified depending on soil temperature between 1 and 3 weeks (in fall) or 1 and 3 months (during winter) resp. 5 and 6 weeks (end of winter) (*Amberger* 1984 a). The resulting nitrate can be quite a problem being a real loss of nitrogen that causes lower yields of the subsequent crop as well as a possible pollutant of ground water. The organic N residue is hardly available and therefore not important for these considerations.

DCD added to manure slurry can reduce these problems considerably (*Amberger* and *Vilsmeier* 1979 a; *Amberger* et al. 1982, *Gutser* 1981) (table 1). Its use is especially promising when the utilization of slurry nitrogen by catch crops and green manure or a „biological N-fixation“ by straw manuring is not possible (late fall/winter).

**Table 1:** Effect of dicyandiamide (DCD) on the nitrification of cattle slurry (pot experiment: 400 g of soil + 10 g slurry, corresponding to 75 $m^3$ slurry/ha; DCD: 10 mg/kg soil, corresponding to 30 kg DCD/ha (*Amberger* and *Vilsmeier,* 1979 a)

**Tabelle 1:** Wirkung von Dicyandiamid (DCD) auf die Nitrifikation von Rindergülle (Gefäßversuch: 400 g Boden + 10 g Gülle, entspr. 75 $m^3$ Gülle/ha; DCD: 10 mg/kg Boden entspr. 30 kg DCD/ha) (*Amberger* und *Vilsmeier,* 1979 a)

| days after DCD-application | 14 °C | | temperature 8 °C | |
|---|---|---|---|---|
| | control mg $NO_3$-N/pot | + DCD mg $NO_3$-N/pot | control mg $NO_3$-N/pot | + DCD mg $NO_3$-N/pot |
| 20 | 21.7 | 3.9 (18 %) | 15.2 | 1.4 ( 9 %) |
| 40 | 20.7 | 6.0 (29 %) | 18.4 | 2.6 (14 %) |
| 60 | 20.3 | 10.8 (53 %) | 19.0 | 3.4 (18 %) |

**Table 2:**N-effect of cattle slurry in combination with straw and DCD (pot experiment under field conditions, *Amberger, Gutser* and *Vilsmeier,* 1982)

**Tabelle 2:** N-Wirkung von Rindergülle in Kombination mit Stroh und DCD (Gefäßversuch unter Freilandbedingungen) (*Amberger, Gutser* und *Vilsmeier,* 1982) (a: N-Auswaschung nach der Vegetationsperiode, b: N-Aufnahme durch Weidelgras

| Manure application (1.23 g $N_{tot.}$/pot) | a) N-leaching after cropping season mg N/pot (Aug. 22.78 – April 27.79) | | | | b) N-uptake by rye grass (mg N/pot) | | | |
|---|---|---|---|---|---|---|---|---|
| | without straw | | with straw | | without straw | | with straw | |
| | – DCD | + DCD | – DCD | + DCD | – DCD | + DCD | – DCD | + DCD |
| Control | 160 | 186 | 15 | 40 | 49 | 59 | 36 | 44 |
| August | 564 | 478 | 164 | 189 | 68 | 85 | 67 | 81 |
| September | 434 | 269 | 280 | 172 | 64 | 163 | 58 | 121 |
| October | 264 | 83 | 109 | 14 | 82 | 203 | 74 | 172 |
| March | 347 | 242 | 242 | 175 | 50 | 81 | 53 | 69 |

(135 mg DCD/pot)

While nitrate leaching can be drastically reduced by straw manuring (table 2), this „biologically blocked“ nitrogen is hardly available for the subsequent crop or only slowly released in the case of green manuring (*Gutser* and *Vilsmeier* 1985), quite unlike the ammonium nitrogen „preserved“ by DCD which is fully available to plants.

In lysimeter experiments (table 3), slurry applied in March („March Slurry“) as compared to „October slurry“ resulted in somewhat higher beet and sugar yields and markedly decreased N leaching (*Gutser* and *Amberger* 1984). „August slurry + rape manuring“ gave similar yields of beets, but lower sugar yields at minimal leaching. Slurry nitrogen taken up by the green manure crop therefore was not yet fully available to the following crop during the early growth. DCD addition to slurry resulted in partly higher beet or sugar yields, in case of October application also in higher N uptake and considerably less leaching of N.

**Table 3:** Slurry application to sugar beets: effect of different application times on beet and sugar yields, N-uptake and leaching losses; results of a lysimeter experiment at „Weihenstephan“ (800 mm annual rainfall; loess brown earth) (*Gutser* and *Amberger,* 1984)

**Tabelle 3:** Gülledüngung zu Zuckerrüben: Auswirkung verschiedener Ausbringungszeitpunkte auf Rüben- und Zuckerertrag sowie N-Aufnahme und Auswaschungsverluste; Ergebnisse eines Lysimeterversuchs in „Weihenstephan“ (800 mm Jahresniederschlag; Löß-Braunerde); nach *Gutser* und *Amberger,* 1984.

| slurry application (100 kg $NH_4$-N/ha) | | beet yields (fresh) dt/ha | sugar yields corrected dt/ha | removal by beets + leaves kg N/ha | leaching kg N/ha |
|---|---|---|---|---|---|
| August rape as green manure | | 713 | 142 | 164 | 50 |
| October „Didin“ | without | 695 | 142 | 165 | 116 |
| | with | 715 | 147 | 187 | 91 |
| March „Didin“ | without | 711 | 150 | 166 | 68 |
| | with | 728 | 149 | 166 | 75 |
| $LSD_{5\%}$ | | 36 | 9 | 22 | 18 |

(25 kg „Didin“/ha)

In a field trial with silage maize, DCD addition increased yields by 23 up to 45 % and N uptakes by 10–27 % depending on weather and time of application (table 4).

The good effect of DCD even in combination with „spring slurry“ (when little leaching occurs) might be explained by a decrease of denitrification losses together with temporarily very high precipitation.

**Table 4:** Effect of DCD („Didin“) on the yield and N-removal of silage maize after slurry application. Results of a large plot experiment on a loess brown earth (pH 6.3, Weihenstephan), (*Amberger* 1984 b).

**Tabelle 4:** Wirkung von DCD („Didin“) auf Ertrag und N-Entzug von Silomais nach Gülledüngung. Ergebnisse eines Großparzellenversuchs auf einer Löß-Braunerde, (pH 6.3, Weihenstephan), (*Amberger* 1984 b).

| slurry application (kg $NH_4$-N/ha) | | | silage maize yields dt dry m./ha | removal kg N/ha |
|---|---|---|---|---|
| Nov. | „Didin“ | without | 169 | 63 |
| (145) | | with | 303 | 111 |
| *1982/83* | | | | |
| Febr. | „Didin“ | without | 268 | 88 |
| (140) | | with | 286 | 95 |
| Oct. | „Didin“ | without | 84 | 81 |
| (182) | | with | 108 | 109 |
| *1983/84* | | | | |
| April | „Didin“ | without | 92 | 79 |
| (108) | | with | 110 | 93 |

(30 kg „Didin“/ha)

In another experiment, effect of N in cattle slurry applied in November with silage maize was markedly improved by „Didin“; to achieve a maximum yield 60 kg N as mineral fertilizer could be saved in spring (table 5). The slurry nitrogen was markedly nitrified already by December; the nitrification inhibiting effect of „Didin“ was expressed in higher $NH_4$ concentrations of the soil up to February. $N_{min}$-analysis at this point, however, did not show the higher N supply in the plot „slurry + DCD“ (stronger sorption of $NH_4$). Similar results were found by *Hege* (1985).

b) Waste water from potato starch production contains about 0.6 kg N/m$^3$ in form of organic N compounds (amino acids, amides) and ammonia. Amounts customarily used for sprinkling irrigation supply 300–400 kg N/ha and are microbially degraded within about 2 weeks (*Amberger* and *Gutser* 1984).

By adding DCD, leaching between cropping seasons could be reduced by 40–70 %, yields of the subsequent crop (2 cuts of rye grass) were therefore two or three times higher (table 6).

Addition of DCD to potato starch waste water thus proves to be a very efficient measure for conserving nitrogen and avoiding leaching and denitrification losses.

**Table 5:** Effect of cattle slurry without and with „Didin“ on the yield of silage maize and mineral nitrogen ($N_{min}$) (site „Memmingen“, soil: brown earth)

**Tabelle 5:** Wirkung von Rindergülle ohne und mit 25 kg/ha „Didin“ auf den Ertrag von Silomais und $N_{min}$-Gehalte („Memmingen“, Boden: Braunerde)

| November | yield (dt dry m./ha) | |
|---|---|---|
| 60 m$^3$ slurry/ha | mineral. fert. (kg N/ha) at seeding | |
| (= 78 kg $NH_4$-N) | 0 | 60 |
| without slurry | 107 | 130 |
| slurry without DCD | 116 | 126 |
| with DCD | 130 | 130 |
| LSD$_{5\%}$ | 4 | |

| | $N_{min}$ ($CaCl_2$) (kg N/ha in 90 cm soil profil) Dec. 84 | | | Feb. 85 | | |
|---|---|---|---|---|---|---|
| | $NH_4$ | $NO_3$ | Σ | $NH_4$ | $NO_3$ | Σ |
| without slurry | 7 | 77 | 84 | 10 | 61 | 71 |
| slurry without DCD | 14 | 120 | 134 | 9 | 130 | 139 |
| with DCD | 86 | 98 | 184 | 39 | 104 | 143 |

**Table 6:** Effect of „Didin“ on N leaching and uptake by rye-grass after application of potato starch waste water (pot experiments with 6 kg/pot of a sandy loam, pH 5.9) (*Amberger* and *Gutser*, 1984)

**Tabelle 6:** Wirkung von „Didin“ auf die N-Auswaschung nach Verabreichung von Kartoffelfruchtwasser (Gefäßversuch mit 6 kg/Gef. eines sandigen Lehms, pH 5.9) (*Amberger* und *Gutser*, 1984)

| waste water application<br>(≈ 384 mg $NH_4$-N/pot) | | leaching (during winter)<br>mg N/pot | removal<br>mg N/pot |
|---|---|---|---|
| | „Didin“ | | |
| August | without | 128 | 89 |
| | with | 79 | 231 |
| | „Didin“ | | |
| November | without | 143 | 104 |
| | with | 42 | 255 |
| | LSD$_{5\%}$ | 15 | 12 |

(120 mg „Didin“/pot)

*Use of DCD-amended inorganic fertilizers*

a) DCD-amended N-fertilizers, e.g. ammonium sulfate („Alzon 22“) or urea („Alzon 47“) with 10 % of total N in form of DCD make it possible to supply nitrogen in form of $NH_4$ to crop plants for a certain time and to reduce nitrate and oxalate contents of vegetables and feed crops (*Kick* and *Massen* 1973, *Vilsmeier* and *Amberger* 1978).

b) The pooled application of otherwise split N fertilizer dressings (table 7) enabled by use of these products (on very light sand or rendzina soils) to potatoes can bring advantages on the labour-economic side and save mineral N fertilizers or utilize them more efficiently (*Amberger* 1981).

**Table 7:** Fresh matter and starch yield of potatoes after application of ammonium-sulfa-nitrate (ASN) with or without DCD; ASN was given in four, ASN/DCD in only three doses (site: rendzina, east of Munich) (*Amberger,* 1981)

**Tabelle 7:** Frischmasse- und Stärkeertrag von Kartoffeln nach Düngung mit Ammonsulfatsalpeter (ASN) mit oder ohne DCD; ASN wurde in vier, ASN/DCD dagegen nur in drei Gaben verabreicht (*Amberger,* 1981)

| Fertilizer added | | fresh 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 |
| $LSD_{5\%}$ | | 25 | 4 |

c) In intensive cereal production, dividing total N dressing into several split applications is indispensable to improve its utilization. Thereby, a temporary oversupply of nitrate, an exuberant development of leaves and thus a high susceptibility to diseases is also avoided. By employing „Alzon 22“, combination of several split application in one is possible offering considerable labour-saving advantages (table 8).

On the basis of $N_{min}$ values of 80 kg/ha in spring, at two population densities (300 resp. 450 kernels/$m^2$) and different levels of N, almost the same yields were obtained after combining the first and second N-application as a result of higher spike numbers/$m^2$. With a relatively dry and cold spring, a higher N-application at the beginning of growth in form of „Alzon“ was favourable.

In further 2 years trials with differing spring weather (1983 wet and warm, 1984 dry and cool), it was even possible to achieve same yields with a single total N dosis in form

**Table 8:** Effect of different fertilizer combinations on the yield parameters of winter wheat (cv „Kronjuwel") at different seed rates (soil: loess brown earth, pH 6.4, $N_{min}$ 80 kg/ha, *Mokry* and *Amberger,* 1984)

**Tabelle 8:** Beeinflussung der Ertragsparameter von Winterweizen („Kronjuwel") durch verschiedene Düngerkombinationen bei unterschiedlichen Saatstärken (Boden: Löß-Braunerde, pH 6.4, $N_{min}$ 80 kg/ha, *Mokry* und *Amberger,* 1984)

| | fertilizer appl. (kg N/ha) | | | | yield parameter | | | yield |
|---|---|---|---|---|---|---|---|---|
| | early veg. | late till. | late dressing | | spikes/m$^2$ | weight/ 1000 seeds | kern./ spike | (86 % dr.m.) dt/ha |
| *I seed quantity: 140 kg/ha* | | | | | | | | |
| 1 | 60 CAN | 30 CAN | – | 50 CAN | 602 | 40.6 | 28 | 69.1 |
| 2 | 90 AS/DCD | – | – | 50 CAN | 598 | 40.8 | 29 | 70.6 |
| 3 | 60 CAN | – | 80 AS/DCD | – | 607 | 41.6 | 29 | 72.5 |
| 4 | 140 AS/DCD | – | – | – | 712 | 39.4 | 26 | 72.6 |
| | | | | | | | LSD$_{5\%}$ | 5.2 |
| *II seed quantity: 205 kg/ha* | | | | | | | | |
| 1 | 60 CAN | 30 CAN | – | 50 CAN | 639 | 41.8 | 26 | 69.1 |
| 2 | 90 AS/DCD | – | – | 50 CAN | 689 | 40.8 | 26 | 72.3 |
| 3 | 60 CAN | – | 80 AS/DCD | – | 666 | 41.6 | 26 | 72.5 |
| 4 | 140 AS/DCD | – | – | – | 775 | 40.6 | 23 | 73.9 |
| | | | | | | | LSD$_{5\%}$ | 7.3 |

CAN = Calcium ammonium nitrate, AS = Ammonium sulfate

**Table 9:** Influence of two different fertilizer regimes on the yield and yield parameters of winter wheat (cv Kronjuwel) (soil: loess brown earth, pH 6.4, $N_{min}$ 75 kg/ha)

**Tabelle 9:** Einfluß verschiedener Düngungssysteme auf Ertrag und Ertragsparameter von Winterweizen ("Kronjuwel") (Boden: Löß-Braunerde, pH 6.4; $N_{min}$ 75 kg/ha)

| | fertilizer appl. (kg N/ha) | | | yield parameter | | | yield |
|---|---|---|---|---|---|---|---|
| | early veg. | late till. | late dressing | spikes/m$^2$ | weight/ 1000 seeds | kern./ spike | (86 % dr.m.) dt/ha |
| *1983* | | | | | | | |
| 1 | 65 CAN | 30 CAN | 50 CAN | 638 | 39.8 | 27 | 68.0 |
| 2 | 145 AS/DCD | – | – | 723 | 40.0 | 24 | 68.0 |
| *1984* | | | | | | | |
| 1 | 65 CAN | 30 CAN | 50 CAN | 633 | 41.8 | 29 | 77.2 |
| 2 | 145 AS/DCD | – | – | 702 | 39.6 | 28 | 77.3 |
| | | | | | | LSD$_{5\%}$ | 4.0 |

CAN = Calcium ammonium nitrate, AS = Ammonium sulfate of „Alzon" as compared to a conventional three times split N-application, also due to higher number of spikes/m$^2$, but with less kernels/spike. A high initial dressing rate as Alzon therefore promotes population density, while very high applications of nitrate in spring result in an excessive tillering rate (table 9). Similar results of pot trials had been published by *Mokry* and *Amberger* (1984).

When comparing various cropping systems (differing crop sequences, no livestock versus intensive livestock production), the level of yield is generally lower without animal manure (table 10).

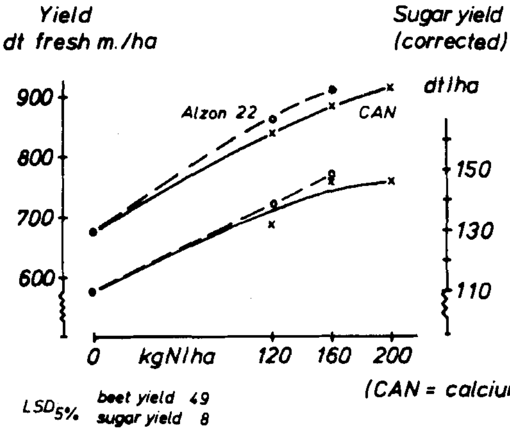
Application of the total N dosis in form of „Alzon" in spring, again resulted in both years in similar yields with increased spike numbers/m$^2$, but somewhat lower kernel weights. The use of Didin therefore enables a better crop management as compared to the usually split N-applications and furthermore offers considerable advantages with respect to labour economy.

**Table 10:** Yield and yield parameters of winter wheat (cv. „Caribo") under two different fertilizer regimes as influenced by farming system and preceding crop (*Mokry* and *Amberger*, 1984)
**Tabelle 10:** Ertrag und Ertragsparameter von Winterweizen („Caribo") unter zwei verschiedenen Düngungssystemen in Abhängigkeit von Betriebssystem und Vorfrucht (*Mokry* und *Amberger*, 1984)

| | fertilizer appl. (kg N/ha) | | | yield parameter | | | yield |
|---|---|---|---|---|---|---|---|
| | early veg. | late till. | late dressing | spikes/m$^2$ | weight/ 1000 seeds | kern./ spike | (86 % dr.m.) dt/ha |
| *I* | *basis: $N_{min}$ 30 kg N/ha, prec. crop: oats, no livestock* | | | | | | |
| 1 | 110 CAN | 30 CAN | 50 CAN | 663 | 32.0 | 26 | 55.7 |
| 2 | 190 AS/DCD | – | – | 688 | 31.8 | 25 | 54.2 |
| | | | | | | $LSD_{5\%}$ | 2.8 |
| *II* | *basis: $N_{min}$ 55 kg N/ha, prec. crop: grain rape, slurry manuring* | | | | | | |
| 1 | 85 CAN | 30 CAN | 50 CAN | 732 | 35.8 | 26 | 67.7 |
| 2 | 165 AS/DCD | – | – | 824 | 32.0 | 26 | 67.7 |

CAN = Calcium ammonium nitrate, AS = Ammonium sulfate

d) In experiments with sugar beets, nitrogen supply could also be optimized with „Alzon 22". On a brown earth (loess) in Weihenstephan, the maximum attainable yield of beets and sugar (corrected) was already achieved with 160 N as Alzon 22 in one single application when compared to 160 N (120 + 40) resp. 200 N (140 + 60) with calcium ammonium nitrate (fig. 5). Wet weather in spring resulted in markedly higher N losses after calcium ammonium nitrate application than with Alzon 22 if measured by $N_{min}$-values in the soil in June.



| | $N_{min}$ - June 85<br>kg N/ha |
|---|---|
| $N_0$ | 72 |
| $N_{120}$ CAN | 102 |
| $N_{120}$ Alzon | 153 |
| $N_{160}$ CAN | 130 |
| $N_{160}$ Alzon | 184 |
| $N_{200}$ CAN | – |

(CAN = calcium ammonium nitrate)

**Figure 5:** Effect of „Alzon 22" on the yield of sugar beets on a loess brown earth at Weihenstephan (1985)

**Abbildung 5:** Wirkung von „Alzon 22" auf Frischmasse- und korrigierten Zuckerertrag von Zuckerrüben auf einer Löß-Braunerde (Weihenstephan – 1985)

e) In intensive rice cultivation, high losses by denitrification are a severe problem especially when the nitrogen fertilizer is applied several weeks before water-logging and is largely nitrified in the meantime.

In a pot trial to test combination compounds of urea/DCD resp. ammonium sulfate/DCD, losses of N by denitrification were higher with longer preincubation periods, consequently resulting in lower nitrogen uptake by plants (*Amberger* and *Gutser* 1978). With DCD, the denitrification losses decreased considerably and N uptake increased (table 11).

**Table 11:** Effect of DCD in combination with urea or ammoniumsulfate on the N-uptake (mg/pot) by green rice; results of an pot experiment (10 kg of a sandy loam, pH 6.1) after 0, 2 or 4 weeks aerobic preincubation, followed by rice sowing and waterlogging (*Amberger* and *Gutser*, 1978)

**Tabelle 11:** Wirkung von DCD in Kombination mit Harnstoff (Ur) oder Ammoniumsulfat (AS) auf die N-Aufnahme (mg/Gef.) von Reis; Ergebnisse eines Gefäßversuches (10 kg sandiger Lehm, pH 6.1) nach 0, 2 oder 4 wöchiger aerober Vorbehandlung, gefolgt von Aussaat und Überstauung (*Amberger* und *Gutser*, 1978)

| Preincubation weeks | Ur | Ur/DCD | AS | AS/DCD |
|---|---|---|---|---|
| 0 | 1 273 | 1 316 | 1 672 | 1 623 |
| 2 | 716 | 1 051 | 984 | 1 156 |
| 4 | 754 | 1 227 | 908 | 1 226 |

(Ur = Urea; AS = ammonium sulfate)

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