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# The Dutch approach to the optimum nitrogen fertilization of crops.

by

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CONTENTS

## 1. INTRODUCTION

The main objective of the Dutch farmer has always been the economically efficient use of fertilizer. Therefore, the research work which has been conducted with respect to the problem of N fertilization of crops has aimed at maximizing crop yields by applying economically optimal dressings.

During the period after 1930 many field experiments were laid out to study the optimal crop yields in relation to the increase of N, P, and K rates. These experiments, both short- and long-term, laid out on well chosen plots using various parameters, were accompanied by chemical, physical and biological research in the laboratory (Bruin, 1952; Ferrari, 1966; Bruin en Grootenhuis, 1968).

While problems with P and K have been more or less successfully solved, with N they have been less so due to its dynamic nature in the soil.

In the Netherlands, N fertilizers are mainly used on grassland which covers 60% of the total agricultural area, and secondarily on arable land covering 33% of the agricultural land. (Landbouwcijfers, 1977). The rate of application of N has been increasing steadily, in 1975/76 being 150 kg/ha on arable land and 300 kg/ha on grassland (Stikstof-nieuws, 1977).

In recent years, Dutch agriculturists have been very much concerned with the problem of optimum N dressings, considering it not only from the viewpoint of maximum crop production and quality, but also from the point of view of water pollution (Kolenbrander, 1977), as well as energy shortage. Therefore, as pollution is a public concern and increasing energy prices affect fertilizer cost, much attention has been focussed on this problem in this country.

The purpose of the present report is to summarize the research work done in the Netherlands on arable land towards maximizing yields with proper N fertilization, and to point out the main features of this effort by referring to the past, emphasizing the present trends and perspectives for the future.

## 2. THE PROBLEM DEFINED

According to Dahnke and Vasey (1973), about 97-99% of soil N is present in very complex organic compounds which become gradually available to plants via microbial decomposition, namely mineralization, the rate of which depends on temperature, pH, moisture, type of organic matter, and perhaps other unknown factors. The ease of leaching, denitrification of the nitrate component, immobilization and volatilization of ammonium, further complicate the problem. These factors, coupled with the general variability of plant response to N fertilization due to variations in winter rainfall, previous cropping and manuring as well as summer weather conditions (Cooke, 1972), make the problem of assessing the N status of soils very complicated and extremely difficult, and consequently hinder the application of an advisory scheme on a wider (national) scale.

Due to the dynamic nature of soil N, simple chemical methods as the determination of total N ($N_t$), or incubation tests, have failed to give an estimation of available soil N to be used as a reliable basis for practical recommendations. This has been the main reason that these chemical methods have not been used for advisory work with respect to N fertilization of crops.

## 3. EARLY ATTEMPTS (1900-1955).

Attempts made before 1900 to evaluate the N status of soils were mainly based on $N_t$. Since, however, $N_t$ failed to give a good estimate of available soil N, even though recent work by van Dijk (1972) shows that under certain conditions, such as in the case of uniform soils, a good relation may exist between potentially available N (mineral N) and total N, the research work was oriented towards other possibilities.

The introduction by Bogdanow in 1900 of the determination of ammonifying and nitrifying capacities of soils gave better results. (Harmsen and van Schreven, 1955).

Gerretsen (1921) used the nitrification capacity in the study of soil fertility of sugar cane and rice field soils. He found that the nitrifying capacity of soils varied significantly, but these variations did not influence the general appearance of sugar cane. He worked, however, with soils under climatic conditions strongly different from those in the Netherlands.

Harmsen and Lindenberg (1949) developed a new method for the determination of the rate of N-mineralization from soil humus. The method was based on the consideration that the determination of the mineralization rate is more reliable for practical purposes when done on soils with a very low mineral N-content. They observed that mineralization was high in all soils studied. The rate of mineralization proved to be more rapid, the lower the nitrate content was at the moment of sampling.

They obtained best results when they used N-depleted soils. The best depletion of soil N was obtained not by extracting it by percolating water through the soil, but by cultivation of fast growing crops, e.g. spinach, whereby the soil N was absorbed very quickly. In this way soil structure was altered less than by water treatment. However, in later work, this N depletion of soil was abandoned as it was found that only a very high soluble N content in the samples, as never observed in natural soils, proved to inhibit the mineralization of humus.

Van Schreven (1956) incubated soils from 57 experimental plots (period 1948-51) in the North East Polder for six weeks at 29$^{o}$C. He found a good correlation between the amount of N mineralized and the optimum amount of N needed for maximum yields of winter wheat (Fig. 1).

It can be seen from this figure that at 30 mg of mineralized N/kg soil an application of 90 kg N/ha is necessary for maximum crop yield, and that the needed rate of application at this mineralization level varies between 35 and 165 kg N/ha. This wide variation in optimum N level is attributed by Van Schreven to differences in weather conditions (winter and summer), soil type, pH, structure (Ferrari, 1956), and wheat varieties used. Therefore, the incubation method, as done in the laboratory under the conditions mentioned, failed to be successful in making reliable predictions for optimal N dressings. Therefore, the climatic factor ought to be taken into account. This was made possible by the introduction of pilot plots by Harmsen (1956). He established such plots in 1955 on arable sandy, heavy clay, and peaty soils. By intensive sampling throughout the year it was possible to follow the mineral N content in the soil profile as influenced by the downward movement of nitrates due to leaching, or the upward movement due to water evaporation.

The above work, though it was useful in so far as to obtain an insight into the dynamics of soil N, from the practical point of view proved to be very costly, laborious and therefore inapplicable.

Gerretsen (1950) developed an "indirect mineralization" method, which however was not generally used for routine work (Harmsen, 1956). According to this method. an excess of cellulose is added to the incubated soil samples. All potentially available nitrogen is therefore tied up in organic form, and no accumulation of soluble N is possible. The production of $CO_2$, however, is considerably stimulated and is only curbed by the amount of N that is mineralized and subsequently immediately immobilized. The development of $CO_2$ therefore is proportional to the latent mineralization of N.

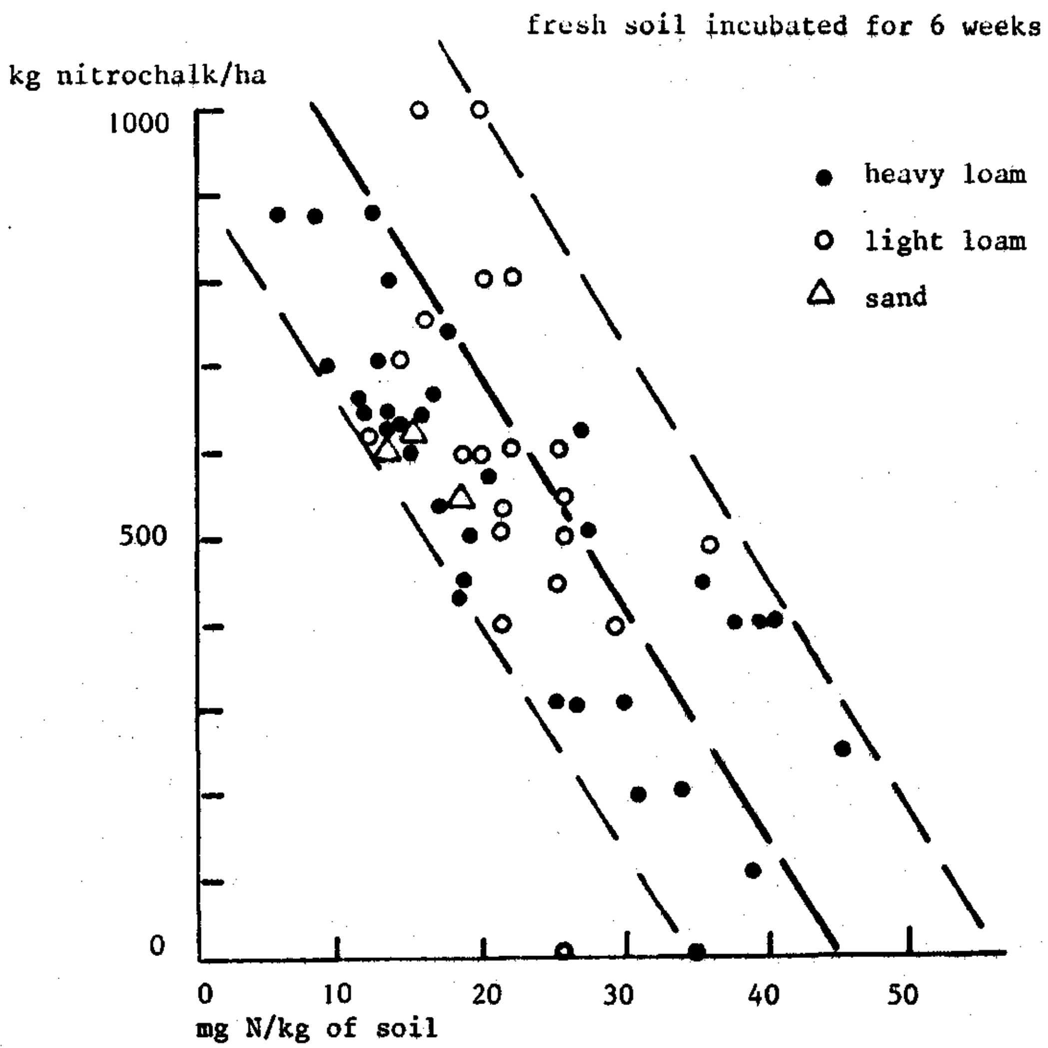


Fig. 1. The inverse relationship between the amount of mineral N produced in 6 weeks (in freshly incubated soils and in soils which previously had been grown with a mixture of spinach and oats) and the amount of nitrochalk needed for an optimum yield of grain of winter wheat on 57 experimental fields in the Noordoostpolder in the years 1948, 1949, 1950 and 1951. (After Van Schreven, 1956).

## 4. THE EFFECT OF RHYTHMIC CYCLING OF WEATHER CONDITIONS ON THE DETERMINATION OF OPTIMAL N DRESSINGS

The study of the relationship between weather conditions and soil fertility was perhaps initiated around 1940. More specific data were reported after the second world war. Thus, Van der Paauw (1958) found significant correlations between responses of potatoes, spring wheat, and to some extent canary grass to application of potash and the number of rainfall days during the growing period of plants.

In further studies with N, he reported that the N response of crops depends also to a great extent on the amount of rainfall during the previous winter. He states that cyclic alternations of periods of different rainfall have been observed in the Netherlands since 1854. Also periodic differences in N responses of crops are found on soils with poor N mineralization. As a matter of fact the amount of available N is negatively affected by winter rainfall (Nov. - Febr.) (Van der Paauw, 1962b) due to leaching of accumulated N mineralized in autumn (Van der Paauw, 1967). He also found similar results working with rye (Van der Paauw, 1962a). From these studies he concluded that the negative effect of rainfall on winter cereals is determined by its effects on the soil. The weaker negative correlation found with potatoes was most probably due to summer weather influence.

By determining the soluble N in different soil layers, he could demonstrate that variations in nitrogen response after partial interception of rainfall, were principally related to different leaching and distribution patterns in the subsoil. Thus, dressing a soil poor in mineral N with a higher amount of N fertilizer has a more significant effect after a wet than after a dry winter. In dry seasons, large amounts of N accumulate, which contribute heavily to subsequent crops when N is given at suboptimum levels. It is concluded from these results that the fluctuations in N uptake by crops from various soils follow a pattern similar to the one of rainfall distribution.

Van der Paauw (1968), even though he recognizes the importance of climatic factors in plant growth, states that the significance of climatic factors which affect plant growth directly is overestimated in many cases. So far as these factors are not extreme, it is unlikely that they can explain yield differences of more than or equal to 100%. Therefore, he concludes that the adaptability of the plant should not be underestimated, as temporary limitations in plant growth due to unfavorable climatic conditions are often counterbalanced by accelerated growth in the period that follows.

The long-term systematic research work by van der Paauw laid the foundations for the new outlook on evaluating the N status of soils, and thereby the optimal N dressing for maximum crop yield. This work has been used as a basis for forecasting optimum N fertilizer dressings in the Netherlands by taking into account the rainfall in the previous winter (Nov. - Febr.) for clay, sand, and peaty soils. Thus, in the recommendations for spring-application of N-fertilizer, allowance is made for the previous winter rainfall; between 25-125 kg of N/ha is needed to compensate for the effect of 100 mm of rain above average winter rainfall. After a drier than average winter, at least 25 kg/ha less N than the value calculated for average seasons should be given, after a wet winter at least 25 kg/ha more (Cooke, 1972).

It can be seen, however, that the variation in the above range is considerable and of the same order as that found by van Schreven and by Kolenbrander (1968) who reported a standard deviation of 20% of the amount of mineral N in a profile of 0-100 cm.

## 5. PRESENT STATUS OF RESEARCH ON OPTIMAL N FERTILIZATION

The main characteristics of the present approach are: a. Mineralization as well as weather in autumn and winter, under natural conditions, are taken into account by sampling the soil profile early in spring.

b. The amount of mineral N so determined in soil samples taken to a depth of 0-60 or 100 cm correlates well with the amount of N needed for maximum yield. For example, for wheat, potatoes (Ris, 1974) and sugar beets (Ris, 1976), it was found that a suitable period for soil sampling could be the end of February (Ris, 1975). Also, work done with sugar beets in 1977 when 40 experiments were laid out throughout the Netherlands, involving six N treatments (0, 50, 100, 150, 200, and 250 kg N/ha) showed that the optimum N dressings derived from N-curves drawn by graphical or mathematical methods, give a good negative correlation with the amount of mineral N found in samples taken about the end of February from a depth of 0-60 cm.

This type of correlation gives a reliable basis for predicting optimum N dressings.

## 6. PRICE/COST RATIO

Recent work performed at the Institute for Soil Fertility aims at introducing economic parameters as well, thus finally determining the economically optimal N dressing.

The purpose of this work is to establish relationships between crop N requirements and price/cost ratios (price of produce/cost of fertilizer).

It was found that the influence of price/cost ratio on optimum N rate as dependent on profile mineral N in spring was rather small (Ris 1975).

## 7. EFFECT OF ORGANIC MATTER ON OPTIMUM N DRESSINGS

The study of the organic matter was initiated at the institute around 1920 (Bruin 1969). However, till the end of the second world war organic matter investigations had no priority. After the second world war a strong emphasis was placed on organic matter research work. These efforts aimed at studying the effect of organic matter on soil physical properties, as well as on soil fertility as expressed by its N content derived from FYM or green manure.

Recent work reported by Sluijsmans and Kolenbrander (1977) opens the way to the study of the effect of organic manure on optimum N dressings. These scientists developed a model which may contribute to the improvement of the recommendations for optimum N application. According to the proposed model the N in manure is considered to be present in three fractions, namely: a- Readily available mineral N ($N_m$). b- Easily decomposable fraction becoming available in the first year ($N_e$), and c- An organic fraction relatively resistant to decomposition ($N_r$), becoming available in subsequent years. Chemical quantification of these fractions and expressing their availability in terms of equivalent amounts of fertilizer N (Efficiency index), makes possible the calculation of the efficiency of the total N, the size and efficiency of each fraction being known. According to the above model, annually repeated dressings of the same magnitude have an annual total effect (kg fertilizer-N per 100 kg manure-N) under Dutch conditions equal to:

First year: $0.8 \times N_m + 0.7 \times N_e$ (1)

In the long run after repeated applications: $0.8\ N_m + 0.73\ N_e + 0.64\ N_r$ (2)

Sluijsmans and Kolenbrander have calculated the $N_m$, $N_e$ and $N_r$ fractions of various organic manure substances such as farmyard manure (FYM), cattle slurry etc. (Table 1).

On the basis of the information of table 1, and with formula's (1) and (2), it can be found that the efficiency index of FYM is in the first year 40% and after a long time of repeated applications 70%.

These calculations are very useful for making more accurate recommendations with respect to optimum N dressings, as will be pointed out in the following section.

TABLE 1. Nitrogen fractions in manures expressed as percentages of total N ($N_t$). (After Sluijsmans and Kolenbrander, 1977)

| Kind of manure | $N_m$ % | $N_e$ % | $N_r$ % |
|---|---|---|---|
| FYM | 10 | 46 | 44 |
| Cattle slurry | 50 | 25 | 25 |
| Poultry slurry | 54 | 32 | 14 |
| Pig slurry | 51 | 34 | 15 |
| Liquid manure | 94 | 3 | 3 |

## 8. PRESENT TRENDS AND PERSPECTIVES FOR THE FUTURE

The research work currently being performed at the institute on the problem of optimum N fertilization is based on relating optimum N application to the amount of soil mineral N ($NO_3^-$ + $NH_4^+$) found in early spring in soils sampled to a depth of 0-60 or 100 cm.

However, as tempting as this correlation may be for a general application, it is necessary that its shortcomings be taken into account for further improvement of the recommendations based on it, and thereby for accomplishing a better advisory scheme for N fertilization of crops.

The main shortcoming is that it takes into account only part of the N which is mineralized from the easily decomposable fraction ($N_e$) of manure added before sampling. Nitrogen mineralized from manure applied after soil sampling (March) is not taken into account at all. This mineral N undoubtedly contributes to plant growth when released after March. The recommendations given may therefore result in larger applications of fertilizer N than are necessary.

The model proposed by Sluijsmans and Kolenbrander may contribute to solving this problem. From the mineralization curve developed by these workers under Dutch conditions, it is possible to find the fraction of $N_e$ that can be used by crops after March. For example, cereals can use 50%, root crops (potatoes, sugar beets) about 70% and grasses 90% before harvest. It is obvious that since the efficiency index of the $N_e$ fraction is known, corrections of the recommended amount of N can easily be brought about. However, further corrections with respect to the kind of manure added and cropping system followed must be made to increase the efficiency in N fertilizer usage, in view of the mineralization taking place after sampling in early spring.

Future research effort will be oriented towards determining the optimum N fertilizer applications on the basis of weather conditions (rainfall and temperature), mineralization, and previous organic amendments (FYM, green manure, and cropping system).

The perspectives based on the results obtained so far seem to be encouraging for the conditions of the Netherlands.

The extent to which this approach can be useful under climatic conditions diferent from those in the Netherlands, has to be found by experimental research work in the country concerned.

# 9. SUMMARY


An account is given of the approach used in the Netherlands to the question of optimum N fertilization of crops.

Early attempts, especially after 1930, consisted of laying out experiments on well chosen plots using various parameters, accompanied by chemical, physical and biological research work in the laboratory.

From 1935-1955, both Harmsen and Van Schreven determined the rate of mineralization by incubating soils under laboratory conditions for six weeks at 29°C. They obtained a strong negative correlation between the amount of N mineralized and optimum N rates for maximum winter wheat yields.

By 1955, Harmsen introduced pilot plots in which mineralization could be studied under the direct influence of weather conditions. Thus, weather parameters (rainfall and temperature) were being taken into account.

The study of the effect of rhythmic weather cycling on the availability of soil N, made by Van der Paauw in the period from 1950 to 1970, showed that winter rainfall (Nov. - Febr.) is negatively correlated with crop response to N.

This conclusion has been used for advisory work in the Netherlands during the last few years. However, research work conducted by Ris after 1970, based on mineral-N content in the soil profile, showed a strong negative correlation between optimum N rate and mineral N found in soil sampled on 1 March to depths of 0-60 or 0-100 cm. This correlation has been used as a reliable basis for advisory work especially in the fertilization of wheat, potatoes and sugar beets.

This approach takes into account not only winter rainfall (weather factor), but also cropping and manuring history which affects mineralization via the amount of residual N ($N_r$) (i.e. the organic N which is not mineralized in the year after application of organic manure).

Attempts are currently being made to correct the N dressings based on the above correlation, by taking into account the effect of the organic N fraction, mineralized in the first year ($N_e$) from FYM and green manure after soil sampling on 1 March.

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