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INVESTIGATION IN THE NETHERLANDS OF OPTIMUM NITROGEN FERTILIZATION ON THE BASIS OF THE AMOUNT OF N_{min} IN THE SOIL PROFILE

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1. DEVELOPMENT OF THE NITROGEN-RECOMMENDATION

In the period 1950-1960, Van der Paauw (1972) found that a good relationship existed between the amount of precipitation in the period 1 November-1 March and crop response to nitrogen in the following growing season. The result was that farmers were advised, after a wet autumn and winter, to increase their "average" application by 20-30 kg N/ha. After a dry winter the "average" application could be decreased by 20-30 kg N/ha. It is clear that the farmer had to know what amount constituted the "average" optimum N-dose for the various crops.

Horticultural practice had already progressed further. The optimum rate of nitrogen fertilization for glasshouse tomatoes was determined on the basis of the level of mineral nitrogen in the soil.

The developments in horticulture prompted two staff members of the Agricultural Extension Service, Borst and Mulder, to start an investigation, in collaboration with the Institute for Soil Fertility (IB), on the relation between the amount of mineral nitrogen in the soil profile (0-100 cm) at the end of winter (about 1 March) and the optimum dose of nitrogen for winter-wheat. The advantage would be that the farmer, besides his experience, would have an additional aid in determining an optimum N-dose in which, besides the weather conditions in the preceding months, also differences in soil type, crop rotation, and organic-matter supply would be taken into account.

Under the direction of Ris, the investigation was soon expanded to include also other crops. This led to close cooperation with the Research Station for Arable Farming and Field Production of Vegetables (PAGV) in Lelystad, and, for sugar beet, with the Sugar Research Institute (IRS) in Bergen op Zoom, as well as with the Agricultural Extension

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Service (Soils) in Wageningen. A more detailed description of this development has been given by Ris (1974) and by Ris *et al.* (1981).

2. PLAN OF THE INVESTIGATIONS

On fields of commercial farms and of regional experimental farms, dispersed over the whole country and comprising different soil types, fertilizing regimes and crop rotation systems, one-year trials with various N-levels were laid out, for the purpose of establishing the optimum N-dose for the test crop in the year of the experiment. In addition, early March, the soil profile in the relevant parcel was sampled in layers from 20, 30, or 40 cm to a depth of 100 cm. The mineral nitrogen content as well as the bulk density of the various layers was determined.

Mineral nitrogen was determined in an aqueous extract according to the method of Cotte & Kahane (1946), which estimates the nitrate and ammonium contents. Field-moist soil (200 g) is shaken for one hour with 500 ml 1 *M* NaCl solution and the extract is filtered.

3. RESULTS

3.1. Relation between optimum N-dose and N_{min}-storage in the profile

The investigations of the past years indicated that a negative relation exists between the amount of mineral nitrogen in the profile around 1 March and the optimum N-dose (N_{op}) needed for maximum yield of the relevant crop in that year.

This negative relation can be described, with sufficient confidence, by a straight line. In this way the "recommendation equations" as shown in table 1 were obtained.

The "constant" factor C is the optimum N-dose (N_{op}) in kg N/ha, if the profile contained no mineral nitrogen in spring ($N_{min} = 0$). The value of this factor is determined especially by the type of crop and by the growing conditions. For instance, in case of drought the development of the crop may be slowed down, resulting in a lower N-requirement and a lower optimum N-dose. A wet period could stimulate growth, but might also cause increased leaching and/or denitrification, thus effecting a higher N_{op}.

The factor m, by which the storage of N_{min} in the profile has to be multiplied, depends on the intensity with which the N_{min} in the profile is utilized by the crop. Thus, rooting density and depth are important. Uptake of nitrogen from layers that were not sampled, or capillary rise of nitrogen will cause the value of factor m to increase.

Factor m includes also the degree of utilization of mineral nitrogen, mineralized after samples were taken or applied in the form of fertilizer.

Table 1

Relation between the economically optimum rate of nitrogen application (N_{op}) and the amount of mineral nitrogen (N_{min}) in the profile around 1 March, based on results from field trials

Crop	Calculation optimum N-dose (kg N/ha) $N_{op} = C - m\, N_{min}$	Depth of profile sampled (cm)
Winter-wheat (1)	$N_{op} = 140 - 1.0\, N_{min}$	0-100
Sugarbeet (2)	$N_{op} = 260 - 1.4\, N_{min}$	0-100
" "	$N_{op} = 220 - 1.7\, N_{min}$	0- 60
Seed potatoes (clay loams)	$N_{op} = 140 - 0.6\, N_{min}$	0- 60
Ware potatoes :		
Loams to clay loams	$N_{op} = 330 - 1.5\, N_{min}$	0- 60
Sands	$N_{op} = 440 - 2.5\, N_{min}$	0- 60

(1) 1st application : max. 100 kg N/ha

2nd application : $N_{min} < 170$ kg N/ha : 60 kg N/ha
N_{min} 170 – 200 kg N/ha : 30 kg N/ha
$N_{min} > 200$ kg N/ha : 0 kg N/ha.

(2) $N_{min} = 112–160$ kg N/ha : recommendation 30 kg N/ha
$N_{min} > 160$ kg N/ha : " 0 " "

Not only the length of the crop growing period plays a role here, but also the mineralization level of the soil, as affected by organic manuring and crop rotation.

It is clear that this m-value is a complicated factor, which may be regarded as an "utilization factor" of the plant-available mineral nitrogen in the profile.

Statistical evaluation shows that the value of m decreases with increasing depth of sampling. This is demonstrated by figure 1 for sugarbeet on 48 experimental fields of IB-series no. 84 and on 95 fields of the IRS-series.

It is apparent that the correlation coefficient for the relation between optimum N-dose and N_{min}-content of the profile after the winter is little affected by the depth of sampling. The coefficients for the three depths of the IRS-series varied from –0.50 to –0.56, those for the four depths of the IB-series no. 84 from –0.55 to –0.64. Because the effect of sampling depth on the relation between optimum N-dose and N_{min}-content around 1 March is only small, the fertilizer recommendations for sugarbeet in The Netherlands are, as of 1981, based on a profile depth of 0-60 cm; this was already the common practice for potatoes, in view of the shallow root system of this crop (Bakker *et al.*, 1981).

The advantage is that now only one core per bore hole is needed in-

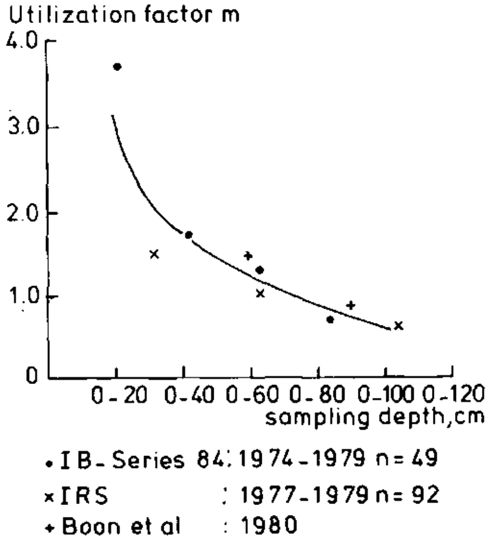

Fig. 1

Relation between "utilization" factor m and sampling depth for sugarbeet (sugar yield).

stead of two, as in the case for a sampling depth of 0-100 cm. This will reduce sampling errors.

Because of this change in sampling depth, also the equation for the optimum N-dose for sugarbeet is changed (table 1); the factor m has increased and the optimum N-dose at $N_{min} = 0$ has decreased.

3.2. Effect of application of animal manure

An application of slurry, depending on type, quantity, and time of application, strongly affects the content of mineral nitrogen and the additional amount that will be mineralized after 1 March.

In the past, a correction based on the efficiency index for the N contained in the manure was applied to the optimum amount as estimated by the farmer. Such a correction is not needed for the amount determined on the basis of a soil test, because the sample taken from the profile in spring contains the mineral nitrogen derived from the soil humus as well as the remaining nitrogen originating from the organic manure applied.

However, the mineralization rate of the organic nitrogen from animal manure and from soil humus may be different, which would give different values for the "utilization factor" m. But this difference has already been taken into account in the average m value obtained from the experimental data including fields both with and without organic manure.

The use of organic manures with a relatively high N_{min}-fraction will normally lead to high N_{min}-contents in the profile already in early spring. The equation for the recommended dose for sugarbeet (profile

Table 2

The potentially available amount of mineral nitrogen for sugarbeet on the basis of the fertilizer recommendations 1981, with and without cattle slurry applied in spring or autumn

Cattle slurry		Supply of N_{min}, kg/ha, on 1/3 from		Potentially available, kg N_{min}/ha					
		soil	organic manure (1) $N_m + N_e$ = total	N_m in profile on 1/3	recommended (2) amount N_{op}	supply 1/3-1/9 from: org. manure 0.7 N_e	supply 1/3-1/9 from: soil	total	deviation relative to 0 t slurry
spring application about 15 Febr.	0 t/ha	50	0 + 0 = 0	50	135	0	a	185+a	0
	10 "	50	22 + 0 = 22	72	98	8	a	178+a	-7
	30 "	50	66 + 0 = 66	116	30	23	a	169+a	-16
	50 "	50	110 + 0 = 110	160	0	38	a	198+a	+13
	70 "	50	154 + 0 = 154	204	0	54	a	258+a	+73
	100 "	50	222 + 0 = 222	272	0	77	a	349+a	+164
autumn application about 1 Sept.	0 t/ha	50	0 + 0 = 0	50	135	0	a	185+a	0
	10 "	50	11 + 2 = 13	63	113	8	a	184+a	-1
	30 "	50	33 + 7 = 40	90	67	23	a	180+a	-5
	50 "	50	55 + 12 = 67	117	30	38	a	185+a	0
	70 "	50	77 + 17 = 94	144	30	54	a	228+a	+43
	100 "	50	110 + 25 = 135	185	0	77	a	262+a	+77

(1) Average composition of slurry, per ton : 4.4 kg N_t; 2.2. kg N_m; 1.1 kg N_e; 1.1 kg N_r
Leaching loss from sandy soil in period 1/9-1/3 with 275 mm excess precipitation ($R-E_0$) : about 50 % (Rijtema)
(2) Comparison recommendation 1981 : $N_{op} = 220 - 1.7\ N_m$.

of 0-60 cm) indicates that no supplemental mineral fertilizer is needed when the storage on 1 March exceeds 130 kg N_{min}/ha. However, because it is difficult to apply doses of less than 30 kg N/ha, it is recommended to apply a supplemental dose of 30 kg N/ha when the amount found in the profile sampled to 60 cm ranges from 112-160 kg N_{min}/ha (Bakker *et al.*, 1981).

On the basis of average values, table 2 shows how much cattle slurry may be applied to sugarbeet shortly before sampling (spring application) or around 1 September of the preceding year (autumn application).

The composition of the cattle slurry is based on the division into three N-fractions as given by Sluijsmans & Kolenbrander (1977), viz., a mineral fraction (N_{min}) that comprises about 50 % of the total nitrogen content, a fraction organic nitrogen (Ne) that is completely mineralized in the first year after application, and a more resistant fraction (Nr) that only begins to contribute significantly in subsequent years. The fractions Ne and Nr in this case each amount to about 25 % of the total quantity of nitrogen.

In the case of the spring application in table 2 it is assumed that no losses due to volatilization and leaching occur so shortly before sampling and that no mineralization of fraction Ne has occurred on 1 March.

For the autumn application, the leaching model of Rijtema (1980) was used. It assumes that on sandy soils, given an excess of precipitation over evapotranspiration of 275 mm in the period 1 September-1 March, about 50 % of the mineral nitrogen present on 1 September will be lost, so that on 1 March 0.5 N_{min} will remain. In the same period about 30 % of the Ne-fraction may be mineralized, 25 % of which will be lost due to leaching, so that on 1 March 0.75 x 30 = 22.5 % of the Ne-fraction will be left in mineral form.

It is further assumed that, without slurry, the profile (0-60 cm) will contain 50 kg N_{min}/ha on 1 March, while the soil in the period between 1 March and 1 September will release an additional quantity of mineral nitrogen amounting to a kg N/ha.

Table 2 now permits calculation of the amount of potentially available mineral nitrogen for sugarbeet during the period 1 March-1 September by adding the amount in the profile on 1 March, the recommended optimum N-dose, and the expected contribution from mineralization of the Ne-fraction of the slurry on the basis of the average temperature (Sluijsmans & Kolenbrander, 1977) and soil humus in the period 1 March-1 September.

Table 2 shows that, without slurry, this supply amounts to (185 + a) kg N_{min}/ha and that only small deviations from this value occur up to 50 t slurry per ha. Larger amounts, however, produce an excess that increases with increasing application of slurry.

This calculation shows why in the original experiments, in which the maximum slurry application was 60 t/ha, no significant difference could be found between treatments with and without slurry.

It may be concluded that the fertilizer recommendations need no correction as long as the cattle slurry applications do not exceed 50 t/ha. This maximum will probably be somewhat lower for pig slurry and poultry slurry in view of their higher N_t-contents. However, applications in excess of 50 t slurry per ha are risky, because too much nitrogen may become available to the beet, also in the case of autumn application, which may reduce sugar yield and lower sap quality through formation of α-amino compounds in the beet. Moreover, the excess nitrogen poses a potential threat to the quality of our ground- and surface-waters.

3.3. The efficiency of the N-recommendation

Another point that deserves attention is the fact that the farmer gets an average N-recommendation. That considerable deviations occur from the mean optimum N-dose for the same amount of N_{min} in the profile is indicated by the correlation coefficients for this relation. Ris *et al.* (1981) reported the following values :

winter-wheat	r = – 0.53
potatoes	r = – 0.65
sugarbeet	r = – 0.68

Figure 2 shows the frequency distribution for the difference between the optimum N-dose as determined from the yields from the experimental fields and the N-recommendation for the same fields on the basis of the N_{min}-supply in a 0-100 cm profile in spring. The results concern sugarbeet in the years 1977, 1978 and 1979 on IRS experimental fields.

A positive deviation indicates that the real optimum N-dose, determined on the experimental field, was higher than the recommended dose. A negative deviation denotes the inverse.

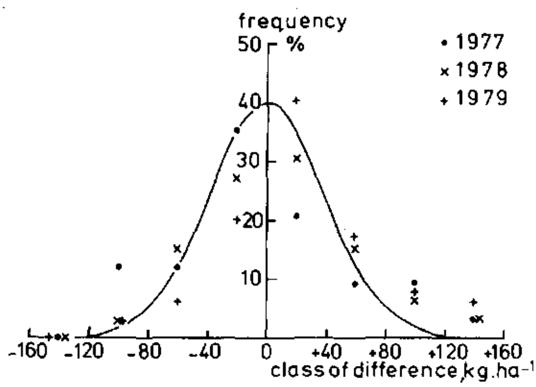

Fig. 2

Frequency distribution of the differences between recommended N-dose and optimum N-dose in the I.R.S. experimental fields in the years 1977, 1978, 1979 (sugarbeet).

It is apparent from figure 2 that the results fit reasonably well a normal distribution in which 3 S = about 120 kg N/ha, so that the standard deviation S amounts to about 40 kg N/ha.

This standard deviation is made up of errors arising from profile sampling, insufficient care in the preservation of the sample, analytical errors, and differences among trial fields, which are a consequence of other factors such as differences in weather, organic matter supply, moisture level, diseases, etc.

Ris & Wolf (1979) found that the sampling error in a profile of 0-60 cm and 0-100 cm with 10 cores per sample was about 12 1/2 % of the N_{min}-content in ppm. They observed that the error is only little affected when also bulk density and layer thickness are included in the determination, so that this value can also be used for the amount of mineral nitrogen (kg N/ha) in the profile.

At an N_{min}-level of 25 kg N/ha, this error gives a standard deviation of about 3 kg N/ha. In the recommendation, this deviation is multiplied by 1.7, so that it becomes about 5 kg N_{min}/ha. At a level of 100 kg N_{min}/ha (for instance after an application of organic manure) the standard deviation may increase to about 21 kg N_{min}/ha.

In addition, these values have to be increased by the error that is made in establishing the optimum N-dose, which may be the source of relatively large deviations, especially in the case of level yield curves. If we assume that such a standard deviation is about 20 kg N/ha, then the "total" standard deviation on the basis of these two factors for a profile of 0-60 cm and an average N_{min}-content of 50 kg/ha (when S = 10 kg N_{min}/ha) becomes :

$$\sqrt{10^2 + 20^2} = 22 \text{ kg N/ha.}$$

This value constitutes about 50 % of the total standard deviation of 40 kg N_{min}/ha. The remaining 50 % will have to be accounted for by other factors that are responsible for the differences among experimental fields, such as weather conditions. These may act indirectly via the nitrogen cycle, but may also affect crop growth directly. For instance, an attack by disease in winter-wheat is clearly demonstrated by figure 3. The strongly different data for the year 1971/1972, resulting from a mildew attack (*Erysiphe graminis*), are clear.

The results for three years of sugarbeet (IRS-fields) are shown in table 3. Averaged over 33-35 experimental fields, the mean difference between the optimum N-dose and the recommended dose over the years 1977, 1978 and 1979 increases from - 7 kg via + 7 kg to + 22 kg N/ha. It is also apparent that in this period the number of fields with a positive difference increases and that with a negative difference decreases.

These effects suggest the presence of a systematic factor. An excess

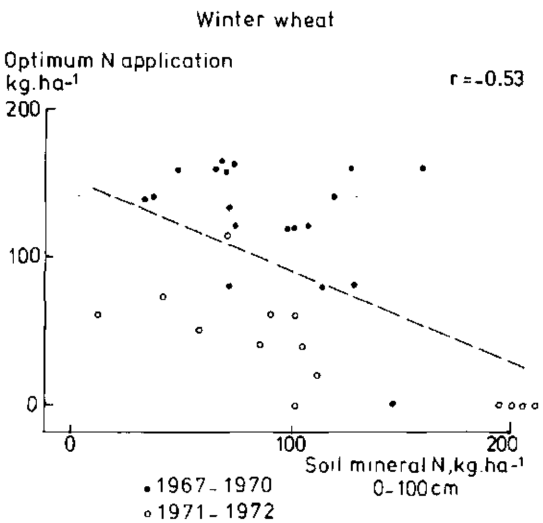

Fig. 3

Relationship between soil mineral N in the 0-100 cm layer around 1 March and optimum N application for winter-wheat in field experiments from 1967 to 1972 exclusive.

Table 3

Average difference per year between recommended N-dose and optimum N-dose in about 35 IRS field experiments with sugarbeet, and the excess precipitation (R-E_0) at De Bilt in the period March-June in the years 1977, 1978, 1979

		1977	1978	1979
No. of field experiments	positive	12	15	24
Difference relative to recommendation	none	2	3	1
	negative	20	15	10
	total	34	33	35
Average deviation, kg N/ha		−7	+7	+22
Precipitation R, mm	March	42	81	98
	April	62	38	81
	May	60	25	120
	R total	164	144	299
Evaporation according to Penman (ave.)	E_0	229	229	229
	R-E_0	−65	−85	+70
Precipitation R, mm	June	39	68	93

of rainfall in the period 1 March-1 June could be considered; in 1979, it was the highest of the preceding 40 years.

Uptake of N by sugarbeet is only small in this period, but the N_{min}-

concentration in the profile is high as a consequence of the application of the recommended N-dose and of N-mineralization of soil humus taking place as the temperature rises in spring.

Table 3 shows that, in the years 1977 and 1978, the excess precipitation over evapotranspiration ($R-E_0$) was negative in the period 1 March-1 June, so that no immediate losses due to leaching were to be expected. However, ($R-E_0$) was positive in 1979, viz. + 70 mm, which is probably the result of the extremely high rainfall in the relevant period of that year.

Leaching data collected by Kolenbrander (1980) for the autumn and winter period 15 September-1 March indicate that an excess of 100 mm above the normal precipitation causes a leaching loss of 32 kg N/ha; the excess of + 70 mm in a saturated soil, could give a leaching loss of

$$70/100 \times 32 = 22 \text{ kg N/ha}.$$

This estimate is in agreement with the mean difference between optimum N-dose and recommended N-dose for 1979. This could indicate that the period 1 March-1 June 1979 was so wet that leaching could occur, owing to which the recommended dose in 1979 was low by average amount of 22 kg N/ha.

Table 3 shows also that the relation of the differences between optimum and recommended N-dose in 1977, 1978 and 1979 with precipitation in June, when the crop is strongly developing, is even better than with precipitation in the period 1 March-1 June. This could mean that June 1977 was somewhat on the dry side, resulting in reduced growth and giving an optimum N-dose that averaged 7 kg lower than the recommended dose. In 1978 there was about 30 mm more rain than in 1977; growth of the crop was then apparently such that more nitrogen was needed for optimum yields than was indicated by the recommended dose.

Finally, June 1979 was in turn about 30 mm wetter than June 1978, and moreover, the period 1 March-1 June of that year was extremely wet. The combination of these two effects led to a recommended N-dose that was 22 kg N/ha lower than the optimum N-dose in the field. It was made clear in the foregoing that the difference may be attributed largely to leaching in the period 1 March-1 June.

The question arises if this quantity of, on average, 22 kg N/ha should be applied in the beginning of June as a correction to the amount recommended in spring to sugarbeet on the basis of precipitation in the period 1 March-1 June.

Looking back, this would have been favourable in 1979 in about 70 % of the cases in which the difference was positive. However, 1979 has been the most extreme year in the period 1940-1980, insofar as precipitation in the period 1 March-1 June is concerned. Under less extreme conditions the supplemental dose for sugarbeet will be so low that a top-dressing in the beginning of June, based on rainfall data in the period 1 March-1 June, is of little or no use.

Kolenbrander's (1980) conclusion with respect to sugarbeet of the IB-series no. 84 is also valid for the IRS-data mentioned above, namely that reduction in the deviations from the recommended N-dose for sugar-beet by taking into account rainfall data between 1 March and 1 June offers few possibilities.

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Summary

The negative relation between the amount of mineral nitrogen in the soil profile at the end of the winter and the optimum N-dose can be described satisfactorily by a straight line. The slope of this line increases as sampling depth is decreased.

It has been calculated that the recommended dose needs no correction when amounts of cattle slurry of up to about 50 t/ha are applied before sampling.

The standard deviation for the scatter about the mean recommendation line is about 40 kg N/ha. About 50 % of it is caused by errors in sampling, analysis, preservation of the samples during transport to the laboratory, and by inaccuracies in determining the optimum N-dose.

On average, rainfall in the period March-June gives no cause to adjust the recommended dose for sugarbeet by applying a topdressing in June.

La recherche aux Pays Bas au sujet du dosage optimal de la fumure azotée à base de la quantité de N_{min} disponible du sol

Résumé

La corrélation négative qui existe entre la réserve d'azote minéral du sol après l'hiver et l'apport optimal d'azote pour différentes cultures est très bien décrite par une ligne droite. L'angle d'inclinaison de cette ligne est fonction de la profondeur d'échantillonage et diminuera avec celle-ci.

D'après les calculs il n'y aura pas lieu d'adapter les recommendations de fumure lorsque les amendements de lisier bovin faits avant le prélèvement d'échantillons de sol ne dépassent pas 50 t/ha.

La variation autour de la ligne d'avis médiane a une déviation standard de ± 40 kg N/ha. De celle-ci 50 % peut être expliquée par les fautes d'échantillonage, de laboratoire, de conservation pendant le transport des échantillons au laboratoire, ainsi que par les inexactitudes dans la détermination de la dose d'azote optimale.

Les précipitations aux mois de mars à juin ne donnent pas lieu à une adaptation des conseils de fumure dans le sens d'une fumure supplémentaire éventuelle au mois de juin.

Het onderzoek in Nederland naar de optimale stikstofbemesting op basis van N_{min} in het profiel

Samenvatting

De negatieve samenhang tussen de voorraad minerale stikstof aan het eind van de winter en de optimale N-gift wordt voor verschillende gewassen goed beschreven door een rechte lijn. De richtingscoëfficiënt van deze lijn is groter naarmate minder diep bemonsterd wordt.

Berekend is dat op het bemestingsadvies geen correctie behoeft te worden toegepast wanneer runderdrijfmestgiften tot ca. 50 ton/ha worden toegediend voor de be-

monstering.

De spreiding rond de gemiddelde advieslijn vertoont een standaardafwijking van ca. 40 kg N/ha. Hiervan wordt ca. 50 % veroorzaakt door fouten bij de bemonstering, analyse en de conservering van de stalen tijdens het transport naar het laboratorium, alsmede door onnauwkeurigheden in de vaststelling van de optimale N-gift.

De regenval in de periode maart tot juni geeft gemiddeld geen aanleiding om het bemestingsadvies voor suikerbieten bij te stellen, door in juni (eventueel) een overbemesting te geven.
