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An analysis of the response of sugar beet and potatoes to fertilizer nitrogen and soil mineral nitrogen

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Abstract

A statistical analysis was performed to investigate if, and to what extent, the response of sugar beet and potatoes to fertilizer nitrogen depended on the amount of mineral nitrogen already present in the soil, soil type, and prior application of organic manures. For this purpose the results of 150 field trials with sugar beet and 98 with potatoes were used. The analysis was focussed on the within-block stratum of variation in yield, where regression models were fitted to describe the response to nitrogen. For both sugar beet and potatoes the best fit was obtained when not only fertilizer nitrogen was taken into account, but also soil mineral nitrogen, soil type, and prior application of organic manures. The response to fertilizer nitrogen was weaker as the amount of soil mineral nitrogen was larger. The optimum amount of fertilizer nitrogen plus soil mineral nitrogen required was larger on sandy soils than on loam and clay soils. The difference was about 20 kg N per ha for sugar beet and 100 kg N per ha for potatoes. When organic manures were applied prior to the aplication of fertilizer nitrogen, the optimum for both sugar beet and potatoes was 15-50 kg N per ha lower than without application of organic manures.

Keywords: fertilizer nitrogen, nitrogen fertilizer recommendation, nitrogen response curve, potatoes, soil mineral nitrogen, sugar beet

Introduction

In the Netherlands, nitrogen fertilizer recommendations for arable crops are based on numerous field trials (Ris et al., 1981). On each experimental site, soil mineral nitrogen was measured in early spring and increasing amounts of fertilizer nitrogen were applied to determine the optimum application rate from the response curve. The recommendations for sugar beet and potatoes are derived from the linear relationship between the amount of mineral nitrogen (ammonium N + nitrate N) present in the soil in early spring and the economically optimum application rate of fertilizer nitrogen (Anon., 1986). The larger the amount of soil mineral nitrogen, the lower the recommended application rate of fertilizer nitrogen.

Many trials were conducted because it was believed that the linear relationship between soil mineral nitrogen and the optimum application rate of fertilizer nitrogen could be reliably established only on the basis of a large number of data points. The relationship was indeed found to be significant, but the variation around the regression line was considerable, e.g. r^2 = 0.30 with 148 sugar-beet trials and r^2 = 0.25 with 83 potato trials (Neeteson, 1982). The wide variation prevented a clear differentiation between soil types and/or fields with or without prior application of organic manures.

Neeteson & Wadman (1987) have shown that the economically optimum application rate of fertilizer nitrogen for sugar beet and potatoes, derived from response curves of individual trials, generally has a large error. It is likely that the considerable variation around regression lines of the relationship between soil mineral nitrogen and the optimum application rate of fertilizer nitrogen is partly due to the large error in the determination of the optima.

To develop a basis for refinement of the current recommendations, a statistical analysis was performed to investigate whether the response of sugar beet and potatoes was not only dependent on the amount of mineral nitrogen already present in the soil, but also on soil type and prior application of organic manures. For this purpose the results of 150 field trials with sugar beet and 98 with potatoes were used. The analysis was focussed on the within-block stratum of variation in yield, where regression models were fitted to describe the response to nitrogen.

Materials and methods

Experimental design

In cooperation with the Sugar Beet Research Institute (IRS, Bergen op Zoom) and the Research Station for Arable Farming and Field Production of Vegetables (PAGV, Lelystad), 150 field trials with sugar beet (*Beta vulgaris* L. cv. Monohil) and 98 field trials with potatoes (*Solanum tuberosum* L. cv. Bintje) were conducted in the period 1973-1982. There were altogether 167 sugar beet and 99 potato trials (Neeteson & Wadman, 1987), but trials with incomplete data on soil mineral nitrogen were omitted. Moreover, some sugar-beet trials were excluded because of unrealistically high levels of soil mineral nitrogen in early spring (>300 kg N per ha in the 0-100 cm layer). The trials were laid out in all parts of the Netherlands. The distribution of the trials over years and soil types is given in Table 1. The soils were classified on the basis of the particle-size distribution in the plough layer (Steur & Heijink, 1987). In 63 of the sugar beet and 50 of the potato trials, organic manures were applied in autumn or early winter preceding sugar beet or potato culture. The organic manures were green manures (mostly Italian ryegrass (*Lolium multiflorum* Lamk.) or vetch (*Vicia sativa* L.) and/or slurries (cattle, pig or poultry slurry; about 50 t ha^{-1}). Table 2 shows the distribution over soil types of the trials with application of organic manures.

In the sugar-beet trials, soil mineral nitrogen content was measured in early spring in samples from the layers 0-30, 30-60, and 60-100 cm, whereas in the potato trials the layers 0-30 and 30-60 cm were sampled. For each soil sample approximately 12 cores were mixed. Nitrate and ammonium were extracted with 1 M NaCl

Table 1. Distribution of the trials over years and soil types.

Year	Sugar beet				Potatoes			
	sand	loam	clay	total	sand	loam	clay	total
1973	0	0	0	0	1	3	1	5
1974	1	6	0	7	1	3	0	4
1975	3	3	2	8	1	3	0	4
1976	3	5	2	10	2	4	1	7
1977	12	20	10	42	1	4	1	6
1978	9	16	15	40	1	5	1	7
1979	8	22	13	43	1	4	1	6
1980	0	0	0	0	5	13	7	25
1981	0	0	0	0	8	11	6	25
1982	0	0	0	0	4	5	0	9
Total	36	72	42	150	25	55	18	98

Table 2. Distribution over soil types of the trials with application of organic manures.

Type(s) of organic manure	Sugar beet				Potatoes			
	sand	loam	clay	total	sand	loam	clay	total
Green manures	2	26	18	46	2	15	7	24
Slurries	10	2	1	13	8	7	1	16
Green manures + slurries	2	1	1	4	1	5	4	10
Total	14	29	20	63	11	27	12	50

and determined colorimetrically with a Technicon Autoanalyser (Ris et al., 1981). For conversion of the measured soil mineral nitrogen contents from mg per kg soil to kg ha^{-1}, the bulk density of each soil layer was measured in each experimental field in four replications. Six rates of fertilizer nitrogen ranging from 0 to 200 or 250 kg ha^{-1} were applied in four replications in the sugar-beet trials. In the potato trials, seven rates ranging from 0 to 400 kg ha^{-1} were applied in three replications. At harvest, fresh yield and sugar content of the beets were determined for each sugar-beet plot, and fresh tuber yield was determined for each potato plot. The nitrogen contents of the potato tubers were determined in the fresh material according to the Kjeldahl-method.

Statistical analysis

When results of field trials performed in different years and at different sites are analysed together, several strata of variation have to be dealt with. Usually the variation between experiments is large and the within-experiment variation differs between experiments. The following statistical model was used to describe the strata of variation and the yield response to nitrogen:

$$\underline{Y}_{klm} = \mu + \underline{T}_k + \underline{B}_{kl} + f(N) + \underline{e}_{klm} \quad (1)$$

where $\underline{Y}_{klm}$ is the yield of a plot and μ is the overall mean yield in t ha^{-1}. Subscripts k, l, and m refer to trial (k = 1. . . . , 150 (for sugar beet) or 98 (for potatoes)), block (l = 1, ... , 4 (for sugar beet) or 3 (for potatoes)), and plot (m = 1, ... , 6 (for sugar beet) or 7 (for potatoes)), respectively. $\underline{T}_k$ describes the stratum of variation between trials ($\Sigma\ \underline{T}_k = 0$), and $\underline{B}_{kl}$ the variation due to blocks within trials ($\Sigma\ \underline{B}_{kl} = 0$). The variation within the blocks is described by f(N), the function which describes yield response to nitrogen; the term $\underline{e}_{klm}$ represents the vector of residuals. This vector is normally distributed ($\underline{e}_{klm} = N(0, \sigma^2)$). No attempt was made to account for the wide variation between experiments, which is due to differences in weather conditions, soils, and crop management practices. The vectors $\underline{T}_k$ and $\underline{B}_{kl}$ were estimated from the data before further analysis was performed. The analysis was focussed on the within-block stratum of variation, where regression models were fitted. To correct for the non-homogeneity of variances, the regression was weighted with the inverse of the square root of the residual variance within each individual experiment.

For sugar beet, yield response to nitrogen was described by a modified exponential curve (Neeteson & Wadman, 1987):

$$f(N) = \beta_0 + \beta_1 e^{\alpha N} + \beta_2 N; \qquad \beta_0 > 0; \beta_1, \beta_2, \text{and } \alpha < 0 \quad (2)$$

where f(N) describes fresh beet yield with a sugar content of 16 % (t ha^{-1}) and N is the amount of nitrogen (kg ha^{-1}). β_0, β_1, β_2, and α are coefficients which are estimated by non-linear regression analysis. The linear term $\beta_2 N$ is included in the equation to allow for decreasing yields at nitrogen rates beyond the rate for maximum yield.

For potato, β_2 was never found to be significant. Therefore, response of potato to nitrogen is described by a common exponential curve:

$$f(N) = \beta_0 + \beta_1 e^{\alpha N} \qquad \beta_0 > 0; \beta_1 \text{ and } \alpha < 0 \quad (3)$$

where f(N) describes fresh tuber yield (t ha^{-1}), and β_0, β_1, α and N have the same meaning as in Equation 2.

The economical optimum (N_{op}) of the response curves is calculated by:

$$N_{op} = \ln\{(P - b_2)/ab_1\}/a \quad (4)$$

$$N_{op} = \ln\{P/ab_1\}/a \quad (5)$$

for sugar beet and potatoes, respectively, where P equals ratio of cost of 1 kg nitrogen to the price of 1 tonne crop yield, and b_1, b_2 and a are estimated values of β_1, β_2, and α. The 90 % confidence intervals for the optima were calculated as described by Neeteson and Wadman (1987), but now also account was taken of the variance of the coefficient a.

A kind of forward selection was used to find the best-fitting model for the description of the response of sugar beet and potato to nitrogen. Firstly, the simplest model was fitted. Then, parameters were added so that the models became more complex. Sequential models were compared by means of *F*-tests; the variance in the denominator of the *F*-statistics was taken from the most complex model. As a result of the very large number of degrees of freedom, significant *F*-tests could be obtained with extremely complex models. However, models were not allowed to become too complex. Model selection was terminated before models were obtained which would not be applicable in practical situations.

The statistical analyses were performed with Genstat 5, Release 1.0 (Lawes Agricultural Trust, Rothamsted Experimental Station).

Results

Sugar beet

Yield response to nitrogen was fitted to various models which were based on Equation 2 (Table 3). In Model 1, yield only depends on the amount of fertilizer nitrogen applied, whereas in Models 2, 3, and 4 also soil mineral nitrogen in the various layers is accounted for. Inclusion of soil mineral nitrogen, especially the amounts in the layers 0-30 and 30-60 cm, considerably improved the goodness of fit of response to nitrogen (comparison of Model 2 with Model 1: $F = 303.2$, $P < 0.001$; comparison of Model 3 with Model 2: $F = 106.8$, $P < 0.001$). Inclusion of soil mineral nitrogen in the 60-100 cm layer further improved the goodness of fit significantly (comparison of Model 4 with Model 3: $F = 5.8$, $P < 0.001$). It should be noted here that, due to the large number of observations, even very small effects will tend to be significant. The magnitude of the effect and its practical implication are therefore far more important than its significance. The estimated values of coefficients α_1, α_2, α_3, and α_4 in Model 4 of Table 3 are –0.0143, –0.0115, –0.0122, and –0.0022 ha kg^{-1}, respectively. Apparently, the contribution of soil mineral nitrogen in the 60-100 cm layer (estimation of α_4) was only 15-19 % of that of fertilizer nitrogen or soil mineral nitrogen in the 0-30 and 30-60 cm layer (estimations of α_1, α_2, and α_3). To simplify the model, the minor contribution of soil mineral nitrogen in the 60-100 cm layer was neglected (Model 3). Still, Model 3 remains complicated and cannot be easily interpreted. To simplify the model further, the weighted contributions of fertilizer nitrogen and soil mineral nitrogen were calculated on the basis of the estimated values of α_1 (–0.0147 ha kg^{-1}), α_2 (–0.0120 ha kg^{-1}), and α_3 (–0.0147 ha kg^{-1}) in Model 3:

$$N_t = N_f + 0.82\,N_{m30} + 1.00\,N_{m60} \tag{6}$$

where N_f is the amount of fertilizer nitrogen applied in kg ha^{-1}, and N_{m30} and N_{m60} are the amounts of soil mineral nitrogen in the 0-30 and 30-60 cm layer in kg ha^{-1}, respectively. The estimated values of β_2 were not weighted in Equation 6, because the linear part of the model has a far less pronounced effect on the optimum than

Table 3. Analysis of variance of yields in the 150 sugar beet trials.

Source of variation	Sum of squares	Degrees of freedom
Total	156470	3599
Trial stratum	117347	149
Trial × block stratum	3186	450
Trial × block × units stratum	35937	3000
Model 1: $f(N) = \beta_0 + \beta_1 e^{\alpha N_f} + \beta_2 N_f$	12115	3
Model 2: $f(N) = \beta_0 + \beta_1 e^{(\alpha_1 N_f + \alpha_2 N_{m30})} + \beta_{21} N_f + \beta_{22} N_{m30}$	15856	5
Model 3: $f(N) = \beta_0 + \beta_1 e^{(\alpha_1 N_f + \alpha_2 N_{m30} + \alpha_3 N_{m60})} + \beta_{21} N_f + \beta_{22} N_{m30} + \beta_{23} N_{m60}$	17173	7
Model 4: $f(N) = \beta_0 + \beta_1 e^{(\alpha_1 N_f + \alpha_2 N_{m30} + \alpha_3 N_{m60} + \alpha_4 N_{m100})} + \beta_{21} N_f + \beta_{22} N_{m30} + \beta_{23} N_{m60} + \beta_{24} N_{m100}$	17245	9
Model 5: $f(N) = \beta_0 + \beta_1 e^{\alpha N_t} + \beta_2 N_t$	16513	3
Model 6: $f(N) = \beta_{0j} + \beta_{1j} e^{\alpha_j N_t} + \beta_{2j} N_t$	17223	7
Model 7: $f(N) = \beta_{0ij} + \beta_{1ij} e^{\alpha_{ij} N_t} + \beta_{2ij} N_t$	17579	23
Residual of Model 7	18358	2977

See Equation 2 for meaning of f(N), $\beta_0, \beta_1, \beta_2$ and α; N_f = fertilizer-N rate in kg ha^{-1}; N_{m30} = soil mineral N in the layer 0-30 cm in kg ha^{-1}; N_{m60} = soil mineral N in the layer 30-60 cm in kg ha^{-1}; N_{m100} = soil mineral N in the layer 60-100 cm in kg ha^{-1}; $N_t = N_f + 0.82\ N_{m30} + 1.00\ N_{m60}$; i = index for soil type; j = index for application of organic manures.

the exponential part. In Models 5, 6 and 7 the amount of available nitrogen was assumed to equal N_t. Somewhat less of the variance in yield was accounted for in Model 5 than in Model 3, but the number of degrees of freedom in Model 5 was also less than half of that in Model 3. Compared with Model 5, a significantly better fit of the nitrogen response was obtained in Model 6, in which a distinction is made between fields which did and did not receive organic manures prior to the application of inorganic fertilizer nitrogen (comparison of Model 6 with Model 5: $F = 28.8$, $P < 0.001$). The best fit, however, was obtained in Model 7, in which not only the application of organic manures is taken into account, but also the soil type (comparison of Model 7 with Model 6: $F = 3.6$, $P < 0.001$).

The estimated values of the regression coefficients of Model 7 are given in Table 4. The economically optimum nitrogen requirement for the various soil types with and without application of organic manures was then calculated (Table 5). The ratio of the cost of 1 kg nitrogen (fertilizer + soil mineral nitrogen according to Equation 6) to the price of 1 tonne sugar beet, P in Equation 4 was assumed to be 0.008. Without organic manures the optimum nitrogen requirement (fertilizer + soil mineral nitrogen) on sandy soils was about 20 kg N per ha higher than that on loam and clay soils. When organic manures were applied prior to the application of fertilizer

Table 4. Response curves of sugar beet. Estimated values of the regression coefficients of Model 7 in Table 3. Standard errors are given in parentheses.

Soil type	Organic manures	b_0 ($t\,ha^{-1}$)	b_1 ($t\,ha^{-1}$)	b_2 ($t\,kg^{-1}$)	a ($ha\,kg^{-1}$)
Sand	no	70.8 (4.35)	-32.7 (3.34)	-0.022 (0.013)	-0.0129 (0.003)
	yes	67.8 (2.55)	-26.6 (4.49)	-0.024 (0.008)	-0.0178 (0.006)
Loam	no	94.3 (10.69)	-53.9 (10.03)	-0.095 (0.027)	-0.0083 (0.002)
	yes	82.8 (8.61)	-36.6 (7.61)	-0.066 (0.022)	-0.0091 (0.003)
Clay	no	78.7 (4.39)	-40.6 (3.68)	-0.051 (0.012)	-0.0115 (0.002)
	yes	69.6 (2.45)	-32.3 (2.92)	-0.031 (0.009)	-0.0196 (0.004)

Table 5. Economically optimum nitrogen requirement (fertilizer + soil mineral nitrogen according to Equation 6 of sugar beet as affected by soil type and application of organic manures. The 90 % confidence interval for the optima is given in parentheses.

Soil type	Organic manures	Optimum nitrogen requirement ($kg\,ha^{-1}$)
Sand	no	205 (192-235)
	yes	153 (136-172)
Loam	no	176 (170-183)
	yes	165 (155-171)
Clay	no	180 (172-193)
	yes	142 (134-158)

nitrogen, the optimum was 15-50 kg N per ha lower than without application of organic manures.

Potatoes

Yield response to nitrogen was fitted to various models which were based on Equation 3 (Table 6). In Model 1, yield was fitted as being dependent only on the amount of fertilizer nitrogen applied, whereas in Models 2 and 3 also soil mineral nitrogen in the various layers was taken into account. Inclusion of soil mineral nitrogen, especially the amount in the layer 0-30 cm, significantly improved the fit of response to nitrogen (comparison of Model 2 with Model 1: $F = 152.5$, $P < 0.001$; comparison of Model 3 to Model 2: $F = 19.8$, $P < 0.001$). The estimated values of coefficients α_1, α_2, and α_3 are −0.012, −0.008, and −0.004 ha kg^{-1}, respectively. The total contribution of soil mineral nitrogen and fertilizer nitrogen to the nitrogen response, N_t, can thus be described as:

$$N_t = N_f + 0.67\,N_{m30} + 0.33\,N_{m60} \qquad (7)$$

where N_f, N_{m30}, and N_{m60} have the same meaning as in Equation 6. Apparently, the

Table 6. Analysis of variance of yields in the 98 potato trials.

Source of variation	Sum of squares	Degrees of freedom
Total	82149	2057
Trial stratum	58878	97
Trial × block stratum	1459	196
Trial × block × units stratum	21812	1764
Model 1: $f(N) = \beta_0 + \beta_1 e^{\alpha N_f}$	11878	2
Model 2: $f(N) = \beta_0 + \beta_1 e^{(\alpha_1 N_f + \alpha_2 N_{m30})}$	12640	3
Model 3: $f(N) = \beta_0 + \beta_1 e^{(\alpha_1 N_f + \alpha_2 N_{m30} + \alpha_3 N_{m60})}$	12739	4
Model 4: $f(N) = \beta_0 + \beta_1 e^{\alpha N_t}$	12739	2
Model 5: $f(N) = \beta_{0j} + \beta_{1j} e^{\alpha_j N_t}$	12897	5
Model 6: $f(N) = \beta_{0ij} + \beta_{1ij} e^{\alpha_{ij} N_t}$	13082	17
Residual of Model 6	8730	1747

See Equation 3 for meaning of f(N), β_0, β_1, and α; $N_t = N_f + 0.67\ N_{m30} + 0.33\ N_{m60}$; see Table 3 for meaning of other symbols.

Table 7. Response curves of potatoes. Estimated values of the regression coefficients of Model 6 in Table 6. Standard errors are given in parentheses.

Soil type	Organic manures	b_0 (t ha^{-1})	b_1 (t ha^{-1})	a (ha kg^{-1})
Sand	no	59.0 (0.76)	−19.7 (1.09)	−0.0086 (0.0013)
	yes	57.2 (0.58)	−13.2 (0.97)	−0.0084 (0.0015)
Loam	no	57.7 (0.32)	−18.9 (0.67)	−0.0119 (0.0010)
	yes	56.6 (0.25)	−17.3 (0.79)	−0.0149 (0.0015)
Clay	no	57.0 (0.90)	−14.7 (1.78)	−0.0115 (0.0036)
	yes	56.2 (0.52)	−13.4 (1.59)	−0.0117 (0.0027)

effect of soil mineral nitrogen in the 0-30 cm layer was twice as large as that of the nitrogen in the 30-60 cm layer. In Models 4, 5 and 6 the amount of available nitrogen was assumed to equal N_t. Compared with Model 4 a significantly better fit of the nitrogen response was obtained in Model 5, where a distinction is made between fields which did and did not receive organic manures prior to the application of the inorganic fertilizer nitrogen (comparison of Model 5 with Model 4: $F = 10.5$, $P < 0.001$). The best fit was obtained in Model 6, in which not only the application of organic manures is taken into account, but also the type of soil (comparison of Model 6 with Model 5: $F = 3.1$, $P < 0.001$).

Table 8. Economically optimum nitrogen requirement (fertilizer + soil mineral nitrogen according to Equation 7) of potatoes as affected by soil type and application of organic manures. The 90 % confidence interval for the optima is given in parentheses.

Soil type	Organic manures	Optimum nitrogen requirement (kg ha^{-1})
Sand	no	410 (356-486)
	yes	370 (280-467)
Loam	no	320 (294-351)
	yes	265 (236-307)
Clay	no	306 (254-388)
	yes	295 (265-353)

Table 9. Average values of measured maximum tuber yield and amount of nitrogen in the tubers of potatoes. The standard error is given in parentheses; n = number of trials.

Soil type	Organic manures	n	Maximum tuber yield (t ha^{-1})	N in tubers at maximum tuber yield (kg ha^{-1})	N in tubers (kg t^{-1})
Sand	no	14	61.4 (1.34)	244 (5.59)	3.97
	yes	11	60.9 (2.60)	231 (9.28)	3.79
Loam	no	28	53.1 (1.59)	199* (7.41)	3.75
	yes	27	57.3 (1.69)	214 (7.08)	3.73
Clay	no	6	58.4 (4.09)	226 (16.41)	3.87
	yes	12	59.4 (2.74)	231 (11.68)	3.89

* $n = 26$.

The estimated values of the regression coefficients of Model 6 are given in Table 7. The economically optimum nitrogen requirement for the various soil types with and without application of organic manures was then calculated (Table 8). In the optima of Table 8, fertilizer nitrogen and soil mineral nitrogen are both included according to Equation 7. The ratio of the cost of 1 kg nitrogen (fertilizer + soil mineral nitrogen according to Equation 7) to the price of 1 tonne potato tubers, P in Equation 5, was assumed to be 0.005. Without organic manures the optimum nitrogen requirement (fertilizer and soil mineral nitrogen) on sandy soils was about 100 kg N per ha higher than on loam and clay soils. When organic manures were applied prior to the application of fertilizer nitrogen, the optimum was 15-50 kg N per ha lower than that obtained without application of organic manures.

To help explain the differences in response to nitrogen, the measured maximum tuber yields and the corresponding amounts of nitrogen in the tubers are given in Table 9. The highest yields and nitrogen uptakes were generally obtained on the sandy soils.

Discussion

Soil mineral nitrogen

The results presented show that response of sugar beet and potatoes to nitrogen is not only dependent on the rate of fertilizer nitrogen application but also on the amount of soil mineral nitrogen present in early spring before fertilizer is applied. This finding is not new, and has been reported extensively in the literature (Greenwood, 1986). However, no differentiation has been made so far between the contribution of mineral nitrogen in the various soil layers to the nitrogen response. When more than one layer was taken into account, the contributions of soil mineral nitrogen in the different layers were given equal weight (Boon & Vanstallen, 1983; Lindén, 1987; Maidl & Fischbeck, 1986; Müller & Moritz, 1982; Stieberitz et al., 1986).

The results presented in this paper demonstrated that, for sugar beet, the contribution of soil mineral nitrogen in the 0-30 cm layer was about the same as that in the 30-60 cm layer and that it was about 80 % of the contribution of fertilizer nitrogen. The contribution of soil mineral nitrogen in the 60-100 cm layer, however, was 5-6 times smaller and was assumed to be negligible. For potatoes the contribution of soil mineral nitrogen in the 0-30 cm layer to the response to nitrogen was 67 % of that of fertilizer nitrogen, and it was 33 % for the 30-60 cm layer. The relatively larger contribution of fertilizer nitrogen in the case of potatoes compared with sugar beet is probably the result of the fact that potatoes are grown in ridges. When the ridges are made and the tubers are planted, the fertilizer, which is usually broadcast shortly before, is moved close to the tubers. The results further suggest that uptake of nitrogen by sugar beet and potatoes predominantly takes place in the 0-60 and 0-30 cm layer, respectively. It was reasoned that the differences between the two crops in uptake from these layers could be attributable to differences in root density. However, in the literature no large differences in root density between sugar beet and potatoes in the 0-30 and 30-60 cm layer could be found, but root density in the 60-90 cm layer was found to be higher for sugar beet than for potatoes (de Willigen & van Noordwijk, 1987). Downward movement of nitrate can occur in spring, and the nitrate originally present in the 30-60 cm layer is then partly leached into the 60-90 cm layer, where it is still available to sugar beet, but not to potatoes.

For potatoes, another reason for the relatively low contribution of the amount of soil mineral nitrogen in the 30-60 cm layer in Equation 7 is the high correlation between the amount of mineral nitrogen present in the 0-30 cm layer and that in the 30-60 cm layer ($r^2 = 0.83$).

Soil type

The response of potatoes to fertilizer nitrogen and soil mineral nitrogen was much higher on sandy soils than on clay and loam soils. Lauer (1986) and Müller et al. (1986) also found a stronger response of potatoes on sandy soils and attributed it to a higher susceptibility to nitrate leaching and/or a lower nitrogen mineralization rate. Heavier nitrogen losses in sandy soils through leaching in the interval between early spring and the end of the uptake period of nitrogen by the potatoes played probably a role. It is unlikely, however, that the rate of mineralization was lower in sandy soils, because in the present experiments uptake of nitrogen by the crop on plots without fertilizer nitrogen (0N plots) varied little among the soil types: calculated on the basis of the measured values of the amount of nitrogen present in the tubers and the assumption that total nitrogen uptake is 1.2 times the amount of nitrogen present in the tubers (Neeteson et al., 1987), crop uptake on the 0N plots of fields without organic manures was, on average, 139 kg ha^{-1} on the sandy soils, 120 kg ha^{-1} on the loam soils, and 144 kg ha^{-1} on the clay soils.

Another reason for the stronger response of potatoes on sands could be the higher yield level obtained (Table 9). The amount of nitrogen in the tubers per unit of yield was largely independent of the maximum yield level (Table 9), and as the amount of nitrogen in the tubers is linearly related to total uptake of nitrogen (Neeteson et al., 1987), higher yields are accompanied by higher nitrogen requirements.

The response of sugar beet to fertilizer nitrogen and soil mineral nitrogen was also higher on sandy soils, although to a much lesser extent than in the case of potatoes. Draycott & Durrant (1973) and Webster et al. (1977) also found that sugar beet required more nitrogen on sandy soils than on heavier soils. Nitrogen losses as a result of the higher risk of leaching are probably responsible for the somewhat stronger response on sands. Because there are no data available on nitrogen uptake by sugar beet in the experiments described in this paper, it cannot be checked whether nitrogen mineralization rates on the sugar-beet fields were different for the different soil types. Again, it is unlikely that the soils differed in mineralization rate, because generally the same fields were used for sugar beet as well as potato production. It is unlikely either that the yield level obtained by the sugar beet on sands played a role. On the contrary, without application of organic manures the maximum yields on the heavier soils tended to be higher. They were 58.2 ± 2.69, 64.5 ± 1.24 and 62.3 ± 2.56 t ha^{-1}, on sandy, loam, and clay soils, respectively.

Organic manures

When organic manures were applied prior to the application of fertilizer nitrogen, the response of both sugar beet and potatoes to fertilizer nitrogen and soil mineral nitrogen was weaker than when no organic manures were applied. To get an estimate of the amount of nitrogen mineralized from the organic manures, the average total uptake, i.e. 1.2 times the measured amount of nitrogen in the tubers (Neeteson et al., 1987), on 0N plots on fields without organic manures was subtracted from the uptake on fields with organic manures. The extra uptake on fields with organic manures averaged 30 kg ha^{-1} on sandy soils, 43 kg ha^{-1} on loam soils, and 49 kg ha^{-1} on clay soils. These figures are in agreement with the amount expected when 50 t cattle slurry per ha is applied in autumn containing 0.44 % N and having an efficiency index of 20 % (Kolenbrander, 1981), or when ryegrass or a legume is grown as a green manure (Last et al., 1981). The extra uptake of 30-50 kg N per ha is partly the result of nitrogen which was mineralized from the organic manures during autumn and winter and which was included in the measurement of soil mineral nitrogen in early spring, and partly from the amount of nitrogen mineralized afterwards. When organic manures had been applied, the amount of soil mineral nitrogen in the 0-60 cm layer in early spring was on sandy soils on average 24, on loam soils 25, and on clay soils 52 kg N per ha larger than when no organic manures had been applied. When it is assumed that the recovery by the crop of soil mineral nitrogen in early spring was 50 % and that the nitrogen mineralized in the growing season is entirely taken up by the crop, the amount of nitrogen mineralized from the organic manures in the growing season was on average 18, 31, and 23 kg N per ha, on sandy, loam, and clay soils, respectively.

Apparently, a substantial part of the nitrogen from organic manures is mineralized in the growing season, but is not explicitly accounted for in the current nitrogen fertilizer recommendations in the Netherlands (Anon., 1986). It therefore appears to be better to take the extra amount of nitrogen mineralized from organic manures during the growing season into account in the nitrogen fertilizer recommendations, as is currently practised in the Federal Republic of Germany (Wehrmann & Scharpf, 1986).

Nitrogen fertilizer recommendations

On the basis of the results presented in Tables 5 and 8, general guidelines for the economically optimum application rate of fertilizer nitrogen for sugar beet and potatoes can be drawn up. It remains to be investigated whether these refined recommendations, which not only take soil mineral nitrogen into account, but also soil type and prior application of organic manures, are more effective than the current recommendations.

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