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EFFECT OF WINTER RAINFALL ON THE AMOUNT OF NITROGEN AVAILABLE TO CROPS

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INTRODUCTION

The importance of winter rainfall for the availability of nitrogen to the crop in the following season has already been recognised in earlier work.

Russell [11] compared the need for nitrogen of wheat grown successively to that of wheat grown after fallow. During fallow, nitrogen accumulates in the soil. It appeared that the difference between the two pretreatments was considerable after dry winters when a high level of nitrogen was maintained, whereas the difference was small after wet winters, when nitrogen probably was leached.

Fisher [3] found negative correlations between rainfall at different periods of the year and the yield of wheat. This negative effect increases in November and is at its maximum in December and January. It decreases again in February. From a comparison between fields differently dressed with nitrogen it was concluded that the effect of rainfall is attributable to unequal rates of leaching of nitrogen.

Boyd, Garner, and Haines [2] found fairly strong correlations between winter rainfall and the response of sugar beets to dressings of nitrogen. Half of the variance was explained by this factor.

Similarly Baumann [1] recorded correlations between yields of rye, oats, and wheat obtained without application of nitrogen and winter rainfall.

Lehr and Veen [8] investigated the occurrence of nitrogen in different soil layers in relation to winter rainfall. They also were able to show a negative correlation between yields of rye and the amount of rainfall in the preceding winter. Considerable migrations of nitrogen under the influence of the water regime were observed by Harmsen [5].

Larsen and Kohnke [7] and Kurtz, Owens, and Hauck [6] obtained in some cases marked depressions of yield and nitrogen uptake when nitrates were applied in fall or winter due to winter rainfall and irrigation.

Recently Millington [9] has found significant correlations between the yield of wheat and the amount of rainfall in the month following sowing. For "red-brown earth" (Adelaide) it appears that the principal damaging effect of excessive rainfall is due to an increase in the apparent density of the soil which affects plant development and is not due to leaching of available nitrogen.

In the present paper correlations are demonstrated between the amount of winter rainfall and the yields of some crops on experimental fields when different nitrogen dressings were applied in different years.

The question whether the correlations found are really due to different amounts of the nitrogen leached by the rainfall from the top soil into the deeper layers of the sub-soil, has been solved by varying the amount of rain by partially intercepting it with glass covers or by additional watering. In addition the different layers of top- and subsoil from the different treatments have been analysed for soluble nitrogen.

NITROGEN RESPONSE IN RELATION TO WINTER RAINFALL

Two nitrogen experimental fields were started in 1947. Potatoes and rye were grown simultaneously in rotation. Since 1954 and 1955 respectively a third strip was added to the experimental field, whereby oats could be included in the rotation (potato–rye–oats). Nitrogen dressings were applied at six levels. The design of the experiments was changed yearly in order to avoid cumulative effects. Thus duplicates in one year were dressed differently from the preceding year so as to enable the determination of residual effects. These relatively small effects due to pre-treatment have been eliminated by statistical adjustment.

Both experiments were laid out on reclaimed moor soils bearing a humic sandy layer above a sub-soil of peat. One of these soils was reclaimed some three centuries ago, the other one about 1920. The fertility level of the first one, having been dressed with organic matter for a long period, was considerably higher.

1. *Rye*

The yields of rye obtained at 3 levels of nitrogen dressings have been related to the total rainfall for the months November to February (Figs. 1 and 2). Without nitrogen dressing high yields occurred only after dry winters and low yields after wet ones. Differences are more pronounced on the old soil. A relatively high yield was also found in 1960, the preceding winter having been only moderately dry. However, both summer and autumn of 1959 were exceptionnally dry so that no leaching into the subsoil occurred before December. In comparison with other years the amount of rain gave an exaggerated indication of the amount of water really contributing to leaching. Therefore this winter ought probably to be considered as relatively dry. The result agrees with those obtained in really dry winters. The abnormally low grain yield obtained (with ample dressing) in 1953 (Fig. 1) is due to a severe attack of rust. It did not affect the straw yield.

At moderate nitrogen dressing the influence of winter rainfall is still obvious. The correlation ($r = 0.48$) found between winter

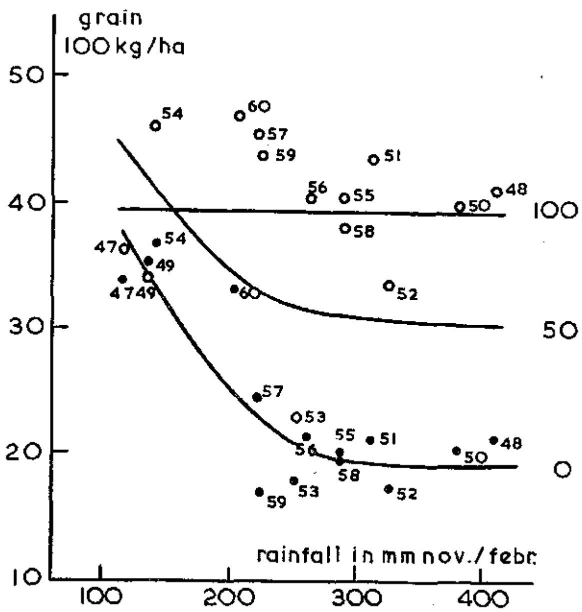

Fig. 1. Relation between rate of winter rainfall and grain yield of rye at 3 levels of nitrogen dressing (dots no N, circlets 100 kg N per ha, results with 50 kg N per ha only indicated by curve) at the exp. field Pr 934 (old soil).

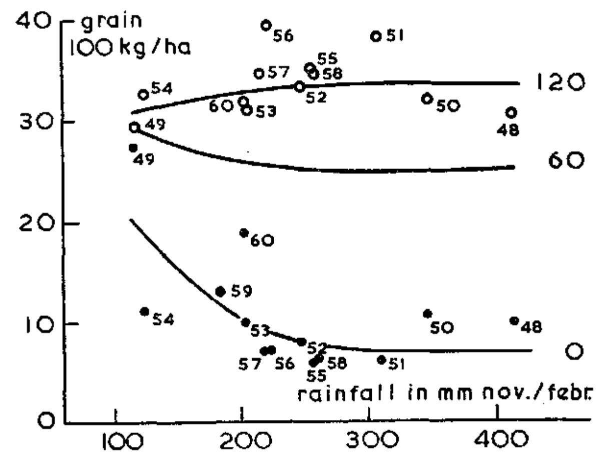

Fig. 2. Same as Fig. 1 at the exp. field Pr 935 (new soil).

rainfall and yields of rye in practical farming (Lehr and Veen [8], van der Paauw [10]) might partly be attributed to sub-optimal dressing *.

With high nitrogen dressing (100 kg N per ha) yields do not appear to be affected by winter rainfall. This result is more or less fortuitous. After dry winters a higher yield was obtained with a lower amount of nitrogen. After wet winters dressings higher than

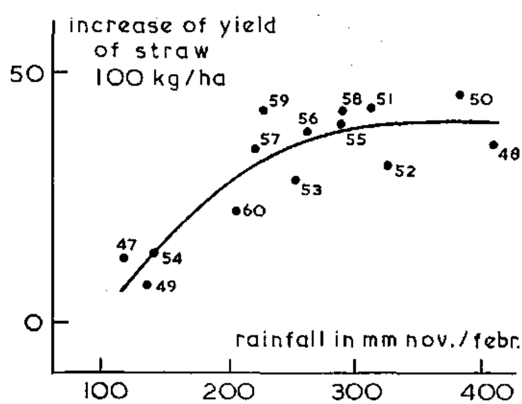

Fig. 3. Relation between rate of winter rainfall and increase of yield of straw obtained with a dressing of 100 kg N per ha (72 kg in 1953 the optimum being attained at this level) at the experimental field Pr 934.

* The correlation is also due to cumulative effects of weather which will be discussed elsewhere.

100 kg per ha give still higher yields. Obviously it must be possible to reduce greatly the variation in annual yield by adjusting the nitrogen dressing on the basis of the amount of rainfall in the preceding winter. Probably leaching of nitrogen and deeper penetration in the subsoil occur during wet winters (see below).

Yields of straw obtained without nitrogen dressing are similarly correlated with rainfall. The variation of yields is greater. It is clear, however, that the maximum increase of yields effected by nitrogen dressing largely depends on rainfall (Fig. 3).

2. *Potatoes*

Results obtained with potatoes are less convincing. Data from the old soil seem to indicate that rainfall in the beginning of summer (June) also influences the response to nitrogen dressing. A marked effect of rainfall in this period on the conversion of added organic matter has been noted by Grootenhuis [4]. The number of observations is as yet too scanty to enable a partial analysis.

More pronounced results have been obtained on the new soil (Fig. 4). The better correlation with winter rainfall in this experi-

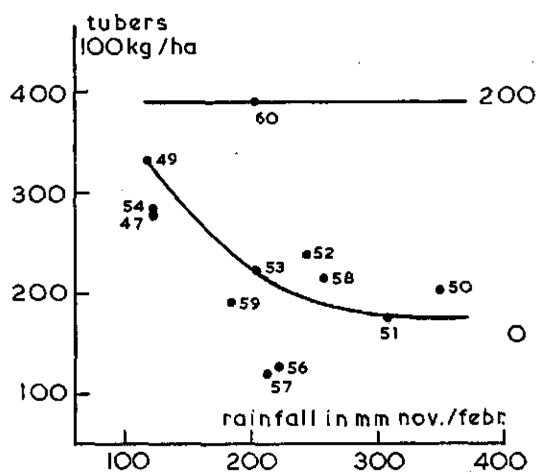

Fig. 4. Relation between winter rainfall and yield of potatoes at 2 levels of nitrogen dressing at the exp. field Pr 935.

ment may be due to the fact that the effect of rain in June on nitrogen mobilisation is only moderate on this rather infertile soil. In this case too, the result obtained in 1960 is somewhat divergent.

3. *Oats*

This crop probably behaves like rye. After the moderately wet winters of 1955–1958 (rainfall 217 to 271 mm) yields without nitrogen dressing varied on the old soil between 2600 and 2720 kg per ha (mean 2650). After the dry winter of 1954 and the winter of 1960 the yields were 3540 and 3800 respectively. On the new soil the yields without nitrogen were very low, varying between 470 and 690 after moderate winters. After the dry winters of 1947 (125 mm) and 1960 (relatively dry) 1320 and 1950 were found respectively.

The equal responses of a winter and a summer cereal to winter rainfall point to an action through the soil as an intermediary. Obviously no definite damage to the rye crop resulted from a wet winter.

EXPERIMENTS WITH VARIED AMOUNTS OF WINTER RAINFALL

Rainfall was intercepted on a small area of 10 × 2.50 metres by means of glass covers during showers in winter. This interception was made preferably at night and for short periods only. It may be assumed that the winter crop was not affected by the treatment. In one experiment (IB 476) additional supplies of water were given at a rate of 4 mm once a week. Small trial plots were laid out on the strips to compare with 2 similar trial plots on adjacent untreated strips. Nitrogen was applied in 5 different amounts on plots of 1.80 × 1.20 metres in duplicate.

1. *Experiment on reclaimed peat soil in three winters differing appreciably in rainfall (IB 360)*

On this reclaimed peat soil with a humic sandy topsoil 3 experiments each of one year duration were laid out in 1959–1961 on different plots of the Experimental Farm at Borgercompagnie. They were registered together as IB 360. In the first two years rye and in the last year oats were grown.

The years were very different with respect to precipitation. Rainfall during the winter of 1959 was moderate amounting to 224 mm between November and February, of which 62 mm were intercepted on the plot with temporary glass cover. As has been mentioned before (p. 363), the winter of 1960 ought to be considered as relatively dry though the total amount of rainfall (205 mm) was only slightly less than in 1959. From this amount, 41 mm were intercepted. Owing to the severe drought in the preceding summer

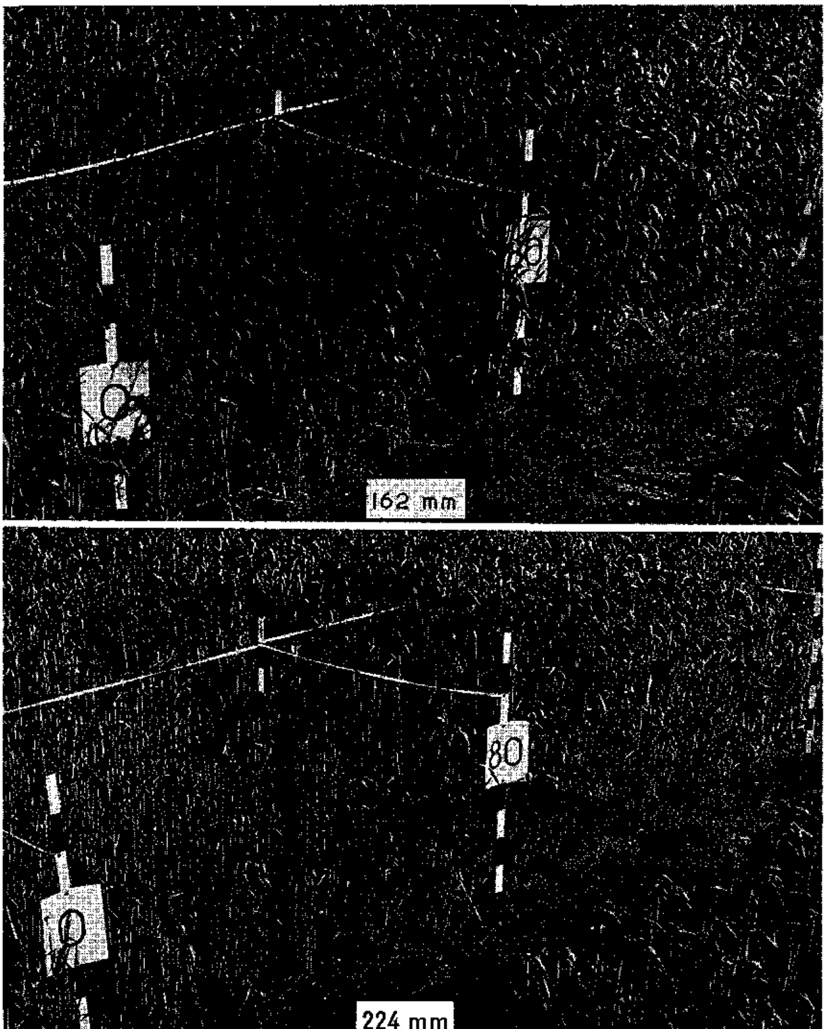

Fig. 5. Rye grown at different amounts of winter rainfall, *viz* 162 mm and 224 mm (*bottom*). The plots on the foreground not dressed with N, on the background dressed with 80 kg N per ha.

and autumn and the rather insufficient growth of sugar beets which had been amply dressed with nitrogen and manure, a soil well supplied with nitrogen was left. Rainfall in the winter of 1961 following an extremely wet summer and autumn was high and amounted to 394 mm from which 172 mm were intercepted.

a. IB 360 in 1959 with moderate winter rainfall. Distinct differences in nitrogen response were observed, most especially between plots which had not been supplied with nitrogen. A more luxurious growth was observed with all nitrogen dressings at lower rainfall (Fig. 5). Yields were also higher especially at the lowest nitrogen levels (Fig. 6). The effect of the decrease of rainfall caused

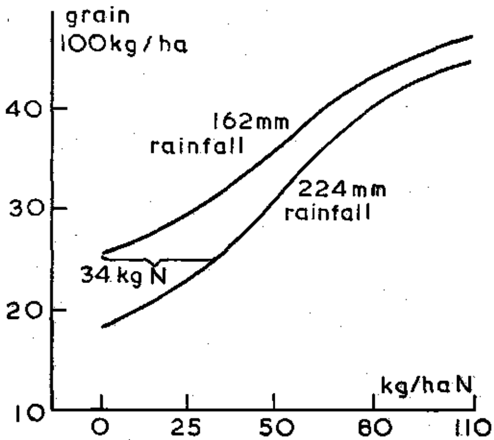

Fig. 6. Relation between nitrogen dressing and yield of rye grown at 2 levels of winter rainfall at the exp. field IB 360 in 1959 (moderate rainfall).

by intercepting 62 mm was, under these conditions, equivalent to that of a supply of 34 kg per ha of nitrogen. At higher nitrogen dressings the effect was smaller. Nevertheless at a dressing considered as normal (70 kg N per ha) the yield increased from 3700 up to 4100 kg per ha, *i.e.* about 10 per cent.

An estimate of nitrogen uptake was obtained by counting the total number of stalks on each plot and determining weight and nitrogen content of samples of 12 stalks.

The effect of decreased rainfall on nitrogen uptake corresponds to that of a dressing of 28 kg N per ha (Fig. 7) and the extra amount

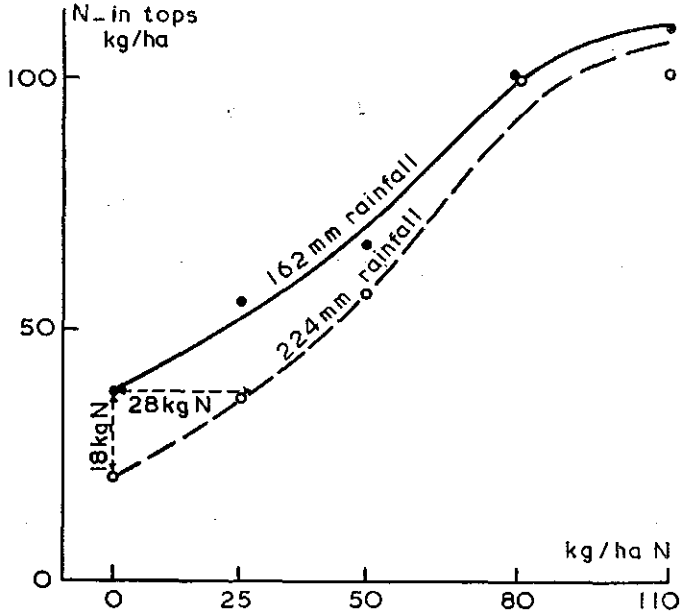

Fig. 7. Relation between nitrogen dressing and amounts of N taken up by tops of plants at 2 levels of winter rainfall at the exp. field IB 350 in 1959 (moderate rainfall). Dots low, circlets high rainfall levels.

of nitrogen absorbed by the green parts at low rainfall is 18 kg per ha.

Similarly it might be concluded from the relation between nitrogen level and the numbers of tillers per ha that the effect of the difference of rainfall equalled that of a supply of 33 kg N per ha. From a similar comparison of the yields of straw a value of 30 kg was derived. It can be concluded in this experiment that each millimetre of rainfall corresponded to a loss of about 0.5 kg of nitrogen per ha.

b. IB 360 in 1960 with relatively dry winter. As has been suggested the moderate rainfall of the winter of 1960 (205 mm in November to February) fell on a very dry soil which probably prevented a substantial loss of nitrogen. The nitrogen response was less pronounced than in 1959 and the reduction of the amount of rain from 205 to 164 mm markedly diminished the nitrogen response (Fig. 8).

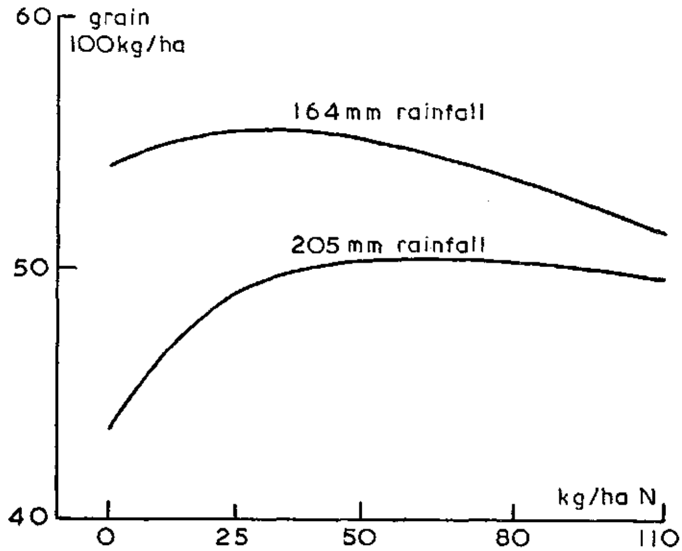

Fig. 8. Same as Fig. 6 at the exp. field IB 360 in 1960 ("dry" winter).

The different slopings of both curves is of higher importance than the difference in their levels, the latter presumably being due to slight fertility differences. Hardly any response was found on the strip with partly intercepted rainfall. Further increase of nitrogen supply gave rise to a moderate lodging and yield depression. The depression of the straw yields with ample dressing was even more pronounced. With normal rainfall nitrogen dressing resulted in an increase of the yield of 650 kg per ha. In this case no lodging and no depression of yields of corn or straw occurred at a high nitrogen supply.

The nitrogen content of dry matter of the tops on 28th May was highest with low rainfall at all nitrogen levels (averages 1.87 per cent at low and 1.66 per cent at high rainfall). From nitrogen–yield curves it can be concluded that the effect of decreased rainfall equalled the effect of a dressing of about 52 kg per ha of nitrogen (Fig. 9). At a low nitrogen dressing the amount taken up by the green parts was about 42 kg per ha greater at low rainfall. Obviously rain which had fallen on the soil well supplied with nitrogen had leached considerable amounts.

The following contents of water-soluble nitrogen were found in

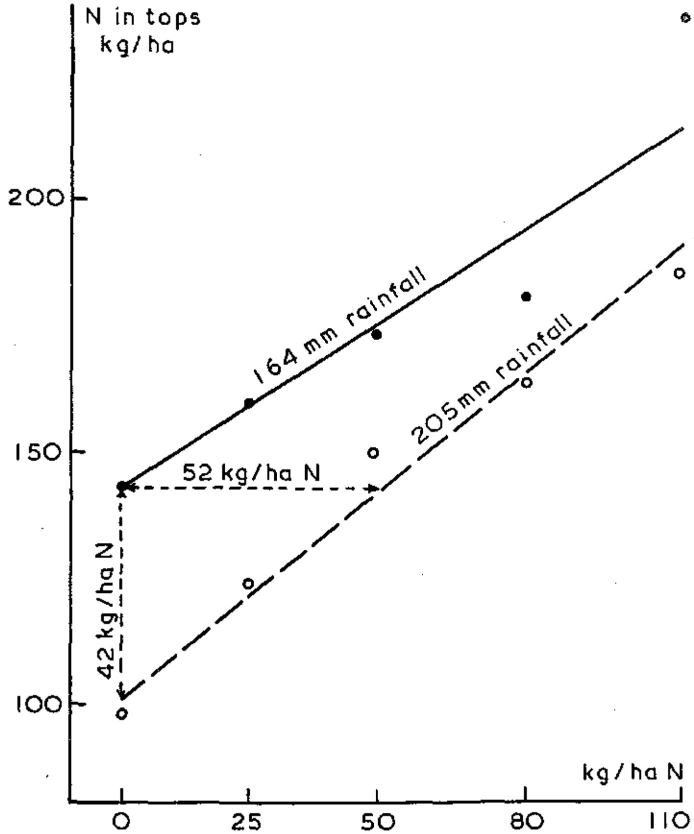

Fig. 9. Same as Fig. 7 at the exp. field IB 360 in 1960 ("dry" winter).

three soil layers on 4th December: * – 0–20 cm 15 ppm, 20–40 cm 33 ppm, and 40–60 cm 8 ppm.

Nitrogen appears to have leached from the arable layer to the upper subsoil layer.

An investigation of the soil in different layers with 2 nitrogen levels was performed on 28th April (Fig. 10). One determination in the 10–20 cm layer failed so that here the course of the relevant curve has been estimated.

In the soil lacking a nitrogen dressing no large differences were found in the 0–30 cm layer between the rainfall levels. Between

* All determinations of soil nitrogen have kindly been done by the Department of Soil Biology of the Institute under the direction of the head Dr. G. W. Harmsen.

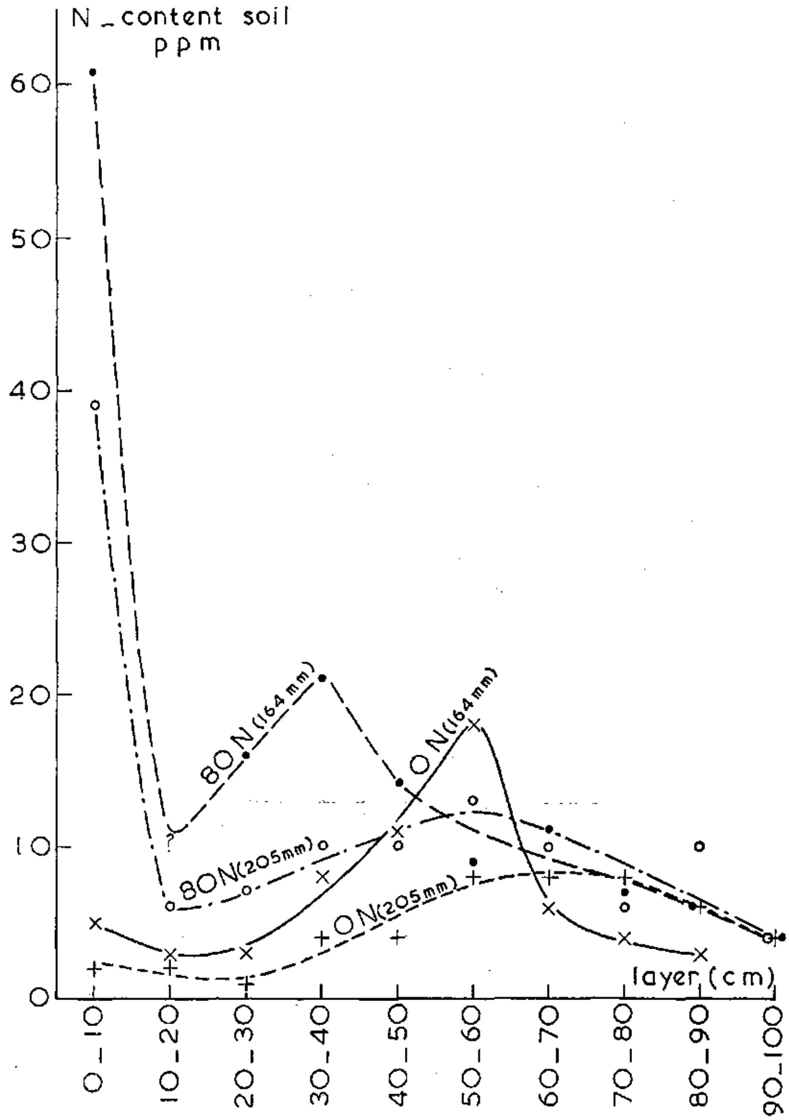

Fig. 10. Nitrogen content of soil layers at 2 levels of winter rainfall and of nitrogen dressing at IB 360 in 1960.

30 and 60 cm the nitrogen content was higher at a lower amount of rain, but the reverse was found in deeper layers.

Plants supplied with nitrogen (on 1st March) took up a proportionately smaller fraction of the soil nitrogen. Therefore, differences between the rainfall levels were more pronounced. With low rainfall a surplus of 20 to 25 kg of mineral nitrogen per ha was still present in the upper layer (1 ppm in the arable layer corresponds approximately to 1 kg nitrogen per ha). More nitrogen was also to be found in the subsoil. The largest amount of nitrogen had penetrated into the deepest layers with the highest amount of rainfall. Since the crops must already have taken up considerable amounts by 28th April it becomes clear that the differences in nitrogen content originally present in arable layer and subsoil may largely account for the different nitrogen response of the crops.

c. IB 360 in 1961 with very wet winter. Differences in growth between the rainfall levels appeared rather late and remained small. The covered plot differed slightly more with one of the uncovered plots than with the other. The rainfall effect appeared to be somewhat greater at high nitrogen dressing but it was never estimated to be higher than the equivalent of a dressing of about 10 kg of nitrogen per ha.

The yields confirmed this conclusion (Fig. 11). According to the grain yields the effect of the considerable decrease of rainfall by interception of 167 mm corresponded to the effect of 6 (mean of 9 and 2) kg of nitrogen pro ha at a low nitrogen level. At a normal dressing (70 to 80 kg per ha) it is probably greater though not exceeding 10 kg. The yields of straw gave the same result, indicating an average effect of 6 kg (mean of 10 and 2).

It appears that an important increase of rainfall above a certain limit has had little further effect. This confirms the results obtained in years with different amounts of rainfall (Fig. 1) indicating that a difference in rainfall on this soil is significant only if the precipitation is at a rather low level.

In this wet winter almost all available nitrogen was probably removed to deeper subsoil layers. The contents of soluble nitrogen during winter in the temporarily covered soil were only slightly higher than in the uncovered one. The average of determinations made at three dates amounted to 7 ppm in one and to 5 ppm in the other case. Hardly any differences were found in April. The topsoil of the plot dressed with 80 kg of nitrogen per ha contained 42 ppm in both cases on 13th April. An investigation into the con-

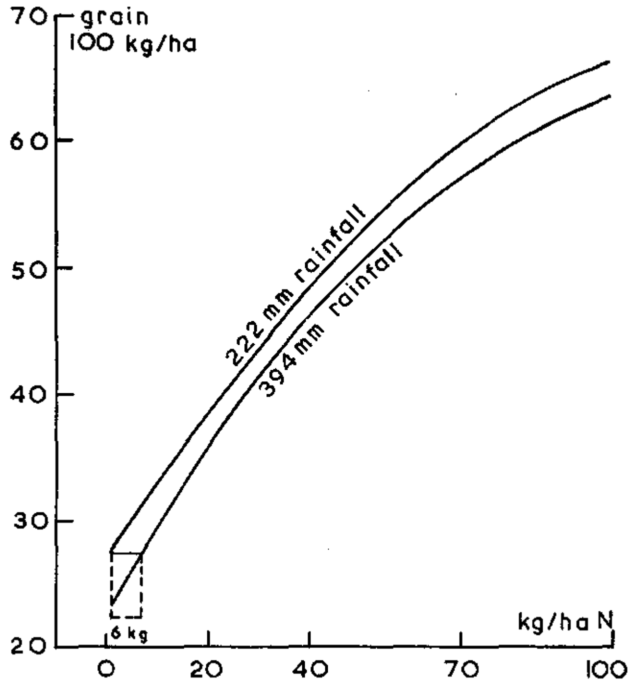

Fig. 11. Relation between nitrogen dressing and yield of oats grown at 2 levels of winter rainfall at the exp. field IB 360 in 1961 (wet winter).

tents of layers from a depth of 0–10 to 90–100 cm on 21st April showed in the covered soil: 5, 6, 2, 1, –, 0, 0, 1, 0, 1 ppm nitrogen and in the uncovered soil: 7, 5, 3, 0, 0, 0, 0, 0, 1, 1, ppm. These values are very low in comparison to those found in the preceding year (Fig. 10). It is obvious, therefore, that the soil was almost free of soluble nitrogen after the very wet winter and that the differences between the treatments are very small in agreement with the nitrogen response of the crop.

2. *Experiment with rye in 1960 on a humic sandy soil (IB 476).*

The arrangement of this experiment was as follows.

A layer with a humus content of 5,5% (0–40 cm) overlying a subsoil of yellow sand (40–100 cm) was artificially placed above an original loamy subsoil. There were one plot with partial interception of rainfall, two plots with normal rain and another one with additional weekly watering. The quantities added in period November to February amounted to 155, 199, and 239 mm per plot respectively.

Due to a strong nitrogen response spectacular differences between crops grown with different rainfall were observed. Differences were largest between the plots with intercepted rainfall and additional watering; the appearance of plants grown on both plots with normal rainfall was intermediate. The differences increased with time. The largest difference corresponded to the effect of a nitrogen dressing of 20 to 25 kg N per ha. Lodging with heavy nitrogen dressing was markedly stronger in the case of the smallest rainfall.

Yields obtained with low nitrogen supplies were highest at low rainfall (Fig. 11). The effect of a difference of 84 mm of rainfall equalled that of a nitrogen dressing of 19 kg per ha on grain yield and of 11 kg per ha on straw yield.

With normal rainfall yields were approximately intermediate, especially for straw. At the lower rainfall high nitrogen dressings caused decrease of yield.

Nitrogen contents per unit dry matter on 28th May were higher at all nitrogen levels the smaller the rainfall (mean 1.27 per cent against 1.09 per cent with highest rainfall).

The nitrogen content of the soil in the arable layer was determined on 7th April. This amounted to 1 ppm on all plots without nitrogen dressing. Probably about all the available nitrogen had been taken up by the plants. With a nitrogen supply of 80 kg per ha 8 ppm were found with the highest, 16 ppm with the normal, and 20 ppm with the lowest rainfall.

3. *Experiment with winter wheat in 1960 on a heavy clay soil (IB 564).*

The soil in this experiment contained 70 per cent of particles less than 16μ diameter. Sugar beets grown in the preceding dry summer had left it well supplied with nutrients.

The rainfall in November to February only amounted to 152 mm from which 47 mm were intercepted. The soil was very dry in autumn, so diminished leaching in winter would be expected.

The nitrogen response of the crop was small in the beginning. Without a nitrogen dressing the leaves of the wheat were yellowish at normal but bright green at lower winter rainfall.

Small yield differences in favour of low rainfall were found (Fig. 12). The effect of partly intercepting the rain without nitrogen

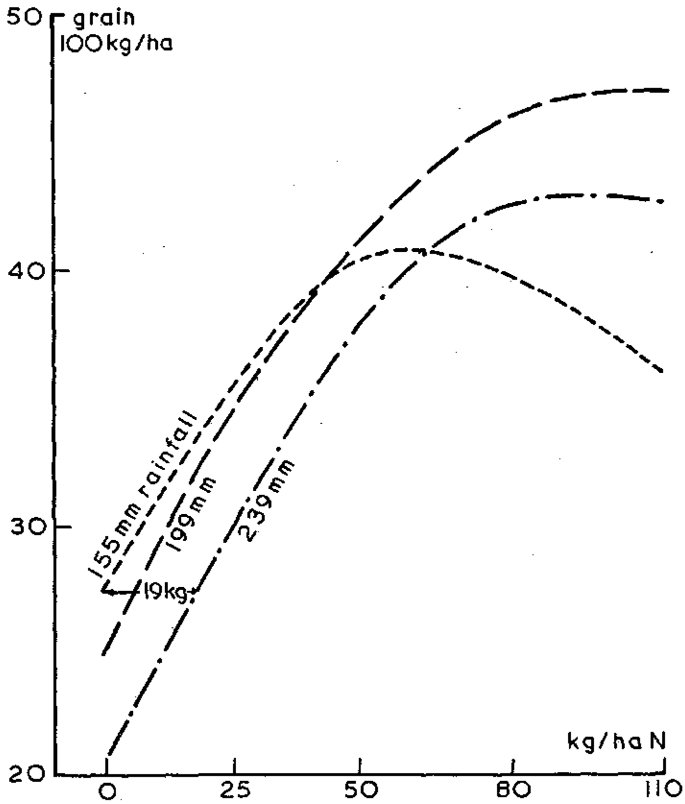

Fig. 12. Relation between nitrogen dressing and yield of rye at 3 levels of winter rainfall at the exp. field IB 476 in 1960 ("dry" winter).

dressing is equal to that of a nitrogen dressing of 7 kg per ha for the corn and of 12 kg per ha for the straw, being about 10 kg on the average. Though the rainfall was low, apparently a slight effect was obtained on this heavy soil.

The nitrogen content of the tops was only slightly higher at low rainfall; on 15th July (rather late) the averages amounted to 0.95 and 0.93 per cent respectively.

Nitrogen contents (ppm) of the arable layer (20 cm) were determined on 8th April:

Rainfall, mm	152	105
No nitrogen	4	16
54 kg nitrogen per ha	31	49

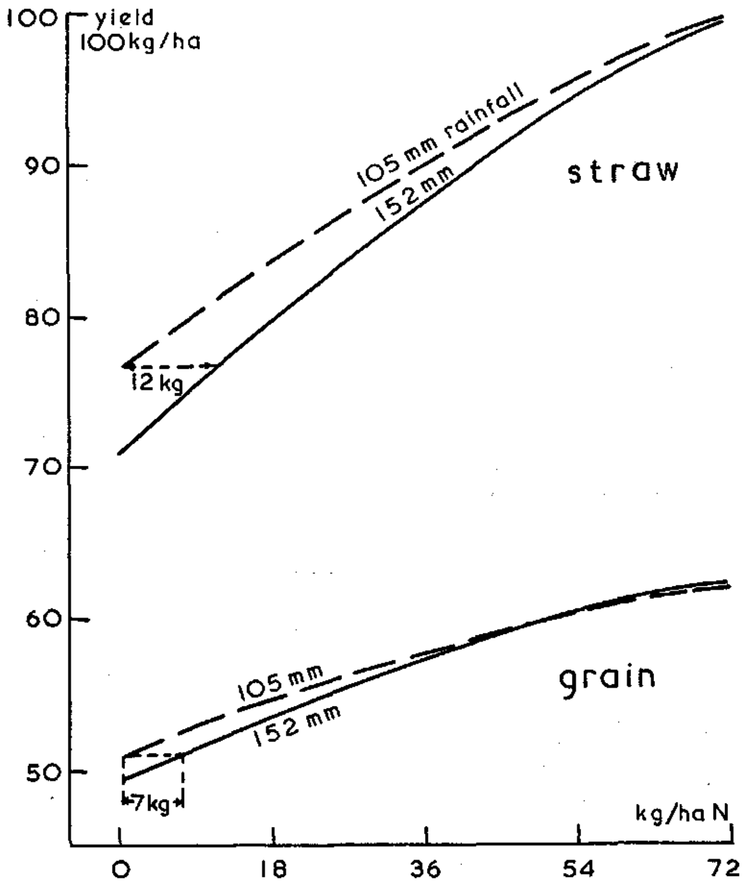

Fig. 13. Relation between nitrogen dressing and yield of wheat (corn and straw) at 2 levels of winter rain fall at the exp. field IB 564 in 1960 ("dry" winter).

The differences (12 to 18 ppm) correspond at average to an amount of about 30 kg per ha. The amount leached from the arable layer is considerably larger than that indicated by the response of the crop. Probably nitrogen leached from the arable layer into the upper subsoil layers is less available to the crop.

DISCUSSION

The correlations found between the amount of rainfall during the winter months and the nitrogen response of crops must largely be attributed to a different degree of leaching of nitrogen. The effect of variations in rainfall is probably slight when the total amount is small. In that case the nitrogen does not penetrate deeply and remains in large part available to the crop. The effect is greater in case of a moderate rainfall and amounted to 0.25–1.25 kg N per ha per millimeter of rain. This ratio decreases further in very wet winters when there is an almost total leaching of soluble nitrogen into deeper soil layers inaccessible to the roots. It must be realized that soils will behave different in accordance with nitrogen content, profile, water capacity, *etc.*

The farmer may suffer great losses of nitrogen which are more or less inevitable and in addition – since he is unable to adjust for this – the depression of crop yield may be still more serious. Nor has he any idea of the amount of available nitrogen in the soil after dry winters. In both cases "normal" dressings with nitrogen are unsatisfactory since they result in serious yield depressions due to deficiency after wet winters and increased possibilities of lodging causing loss of yield after dry ones. Fertilisation adjusted to weather conditions in the preceding winter might contribute considerably to an increase of average yield and would also tend to an improved stabilisation of agricultural production. For these reasons in the Netherlands during the last three years general advice about the most profitable nitrogen dressing has been given to the farmers. For instance additional amounts up to 20 and 30 kg nitrogen per ha were recommended in 1959 and 1961 respectively for winter cereals. A reduction with 20 kg per ha was advised in 1960. "Normal" dressings amount to about 70 to 80 kg/ha. A noticeable increase of yield might be expected from the former advice without dangerously increasing the chance of lodging. In the latter case a decrease of lodging was to be expected without depressing the yield and with a saving of fertilizer costs. The experience obtained thus far appears to be encouraging.

SUMMARY

Relations between rainfall during the winter and crop response to nitrogen were studied.

Two experimental fields were started in 1947 and both were cropped annually with potatoes–rye–oats grown in rotation, and a range of nitrogen dressings applied to the soils. In order to avoid cumulative effects the amounts

applied to any plot were changed each year. Small residual effects of nitrogen supplied in the preceding year could be determined and were eliminated statistically.

A clear negative correlation was found between the sum of rainfall in winter (November to February) and the yields of rye grown without nitrogen dressing (Fig. 1 and 2). The depressions of yields occurring after wet winters could be eliminated by supplying additional amounts of nitrogen (Figs. 1 to 3). Decrease of fertilisation preventing lodging and yield depression is favourable after dry winters.

The results with winter rye were confirmed by those with oats (grown in spring) proving that the effect of rainfall on a winter cereal is mainly determined by its effect on the soil.

The correlations found with potatoes were weaker (p. 365 and Fig. 4) probably due to a more pronounced influence of the weather during the summer on the nitrogen response than is the case with cereals.

The correlations are attributed to losses of nitrogen during winter. This was confirmed by varying the amount of rainfall by partially intercepting it with glass during showers and determinating the nitrogen response at both the actual and reduced winter rainfall levels (Figs. 5 to 9, 11 to 13). The response to nitrogen dressing was considerably lower after interception of relative small amounts of rainfall. On different soils the effect of 1 mm additional rainfall in relatively dry winters equalled that of 0.25 to 1,25 kg nitrogen per hectare.

The effect of interception was found to be smaller after dry winters when leaching is slight, and also after very wet ones when almost all available nitrogen has been leached deeply in the subsoil.

Soluble nitrogen was determined in different soil layers. It could be demonstrated that differences in nitrogen response after partial interception of rainfall are principally due to different leaching and distribution of nitrogen in the sub-soil (Fig. 10).

In the last few years advices given to farmers on nitrogen dressing were adjusted with caution to the weather conditions in the preceding winter. Thus far this practice appears to have been successful.

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LITERATURE

1 Baumann, H., Die Abhängigkeit der Düngerwirkung von der Witterung im Dikopshofer Dauerdüngungsversuch 1906–1957. Z. Pflanzenernähr. Düng. Bodenk. **95**, 1–9 (1961).

2 Boyd, D. A., Garner, H. V., and Haines, W. B., The fertiliser requirements of sugar beet. J. Agr. Sci. **49**, 464–476 (1957).

3 Fisher, R. A., The influence of rainfall on the yield of wheat at Rothamsted. Phil. Trans. Roy. Soc. London Ser. B **213**, 89–124 (1924).

4 Grootenhuis, J. A., Invloed van gescheurde kunstweiden op het produktievermogen van zavelgronden. Stikstof **30**, 242–252 (1961).

5 Harmsen, G. W., Einfluss von Witterung, Düngung und Vegetation auf den Stickstoffgehalt des Bodens. Land. Forsch. Sonderheft **15**, 61–73 (1961).

6 Kurtz, L. T., Owens, L. D., and Hauck, R. D., Influence of moisture on the effectiveness of winter applied nitrogen fertilisers. Soil Sci. Soc. Am. Proc. **25**, 40–43 (1961).

7 Larsen, J. E. and Kohnke, H., Relative merits of fall- and spring-applied nitrogen fertiliser. Soil Sci. Soc. Am. Proc. **11**, 378–383 (1946).

8 Lehr, J. J. and Veen, B., Nitrogen economy of the soil in relation to seasonal and periodical climatic variations. Internat. Soc. Soil Sci. Trans. Dublin 1952. **II**, 61–67 (1952).

9 Millington, R. J., Relation between yield of wheat, soil factors, and rainfall. Australian J. Agr. Research **12**, 397–408 (1961).

10 Paauw, F. van der, Anpassung der Düngung an die Witterungsverhältnisse. Internat. Bodenkundl. Ges. Verhandl. Hamburg 1958 **II**, 78–82 (1958).

11 Russell, E. J., The nature and amount of the fluctuations in nitrate contents of arable soils. J. Agr. Research **6**, 18–57 (1914).