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Nitrogen uptake by rice plants from a dry soil at maintained water supply from a greater depth

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Summary

Multiple-compartment systems with nitrogen and water supplied from different compartments were used to demonstrate that plant availability of nitrogen from a dry soil horizon is low.

The separation of nitrogen and water in different soil horizons along with a decreasing input of irrigation water reduced the uptake of nitrogen more than the production was reduced by the decrease in the amount of water supplied to the plants.

Introduction

Water is needed to bring soil nutrients to the roots. If a drought proceeds so far as to cause desiccation of the top soil, the plants make further use of the water from the subsoil but have no access to the nutrients in the upper horizon.

Garwood & Williams (1967b) found a depression in growth of a grass sward during a dry period which was due to a deficiency of nitrogen rather than to water stress. Deeper injection of the applied N at a depth of 45 cm improved plant availability of the dressing so that more grass with a higher leaf N concentration was obtained than with surface application.

If deeper injection improves the availability of the N during a drought, its effect on uptake and yield must be similar to that of applying more N to an irrigated vegetation, which usually is in the nature of Fig. 1.

In Fig. 1 the first small dressing increased N uptake in proportion to the increment in DM: the first two points lie on a straight line through the origin of the graph at a low constant concentration of 2.4 % N in the dried herbage. In the undressed soil the supply of N was limiting the growth, and a further 100 kg increase in DM required the uptake of 2.4 kg more N which needed a dressing. As the application rates increased, more N was absorbed but less DM was produced for each additional unit of absorbed N. This section of the curve is convex with respect to the DM axis.

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Where the plants yielded the highest DM output there was no further gain in DM as the uptake increased following still heavier dressings. The heaviest dressing concentrated the N to 3.8 % N. At this point more N was available than could be used by the grass so that the actual growth was limiting the uptake under maintenance of the maximum concentration at which the N could be stored in the tissues (Alberda 1971).

At the heaviest dressing of 500 kg N, 270 kg more N was absorbed than from the undressed soil. This is a normal return of applied N in grass cuttings (Dilz & Woldendorp, 1961).

In the experiment of Fig. 1 the wide range of application rates permitted the plotting of a complete uptake: yield curve situated between the line of minimum N concentration at which uptake and growth were limited by he supply, and the line of maximum N concentration in the DM at which the uptake was limited by the growth. The convexity of the curve shows that decreasing the supply of N will reduce the uptake relatively more than the DM. Thus if a drought affects plant growth primarily through a decrease in the availability of the N, the smaller yield will be associated with a low concentration in the DM.

If on the other hand the availability of the N remains unchanged because the nutrient is located in the subsoil that remains wet, a dry top soil may reduce the yield by lack of water. Then the available N, once absorbed by the longer roots, will be concentrated to a higher level as the yield of DM becomes smaller under water stress.

Thus, when the yield is low and the concentration of N in the DM is high the supply of water has been limiting. When the yield is low and the concentration of N in the DM is also low, the availability of N from the soil has been limiting and the water supply should be considered of secondary importance.

In Indonesia the cultivation of rice is usually dependent on rainfall for water supply. In regions with a wet season of relatively short duration (Oldeman, 1975), early cessation of the rainfall shortly reduces the growth rate, and eventually the grain yield. At first sight it would seem that water stress is involved, but the large amounts of water stored deeper in the profile of the heavy paddy soil makes its rapid exhaustion from the whole rooting zone unlikely. Van Keulen (personal communication) suggested that the rapid fall in growth rate following the cessation of rainfall should be attributed to a deficiency of nitrogen caused by desiccation of the top soil which normally contains most of the nitrogen to be utilized by the plants.

The present experiments, based on the evidence discussed, have been reported to demonstrate that data on yield and nitrogen content of the plants can be helpful to decide on whether unavailability of the N or a deficient supply of water has been responsible for a growth depression in rice crops hit by drought.

Because rice seeds of the appropriate variety were not available at the time the experiments commenced, the first tests were made with sunflower. The overall results did not specifically involve plant species, but reflected the effect of unequal stratification of N and water in the soil on which they have been grown. The results will be reported in the order in which the experiments have been made, but the situation with rice plants will be emphasized.

Material and methods

A sandy soil was used with 5 % organic matter and a $pH(H_2O)$ of 5.0. It contained 83 mmol total N and 72 mmol N, unextractable by 1 *M* KCl per kg oven-dry soil.

The permanent wilting point was determined by exposing potted sunflower plants to drought. The moisture content of soil core samples indicated that permanent wilting occurred when the soil moisture content had dropped to 5 % on dry basis.

Plant availability of the N from the dry soil was studied in a two-compartment system. Shallow plastic containers (diameter 30 cm; depth 9 cm) with 9-mm slits for root penetration in the central 10-cm area of the bottom were filled with 6.5 kg of the moist soil. The soil moisture content was determined and the dry weight of the soil calculated. The relation between container weight and % soil moisture on dry basis was plotted in a graph for translation of container weights into soil moisture percentage. Rough corrections for the increasing plant weights were obtained from visual appraisal of the size of the sunflower plants, or from tiller counts and shoot length in the rice plants, in combination with evidence from parallel cultures.

The planted soil containers were placed on plastic buckets each holding 12 litres of water. The water surface was kept at a few cm below the bottom of the soil container by frequent replenishments.

Irrigation of the soil to the initial weight was continued until sufficient roots had penetrated into the water below the soil. For the daily weighings the containers were removed from the buckets and placed on an empty tray on the balance to accommodate the roots that had emerged from them.

When sufficient root spread was attained, the plants received a dressing of 30 mmol nitrate per container in combination with 10 mmol K, 8 mmol Mg, 2 mmol P and some sulphate and calcium. The nutrient salts were added either to the soil or to the water in the bucket below the soil.

Within each fertilizer placement, one half of the soil containers were allowed to dry out. The decrease in weight indicated that the wilting point was attained within 10 days. In the other half the irrigation was continued.

At the time the treatments were applied enough roots had penetrated into the solution below the soil to prevent the plants on the dry soil from wilting.

In the two experiments seeds of sunflower were planted in the soil, and the seedlings thinned out to two plants per pot.

In one experiment the sunflower plants were harvested three weeks, in the other five weeks after the treatment was started.

In the experiment with rice the soil was planted with seedlings of an upland rice variety which were thinned out to 20 plants per pot. Growth was monitored by periodic shoot length measurements and tiller counts (Ismunadji & Dijkshoorn, 1971). Root penetration into the water below the soil was slower with rice than with sunflower. The rice plants were harvested about three weeks after the beginning of the treatment, and another set of replicates after five weeks of exposure to the treatments when they had produced twice as much DM. The plants remained in the vegetative stage throughout the test period.

The combined effect of a limiting cumulative water input and the immobilization of soil N during a drought was studied in a three-compartment soil system.

Three slightly conical polythene pots, each holding 1 kg of the wet soil, were piled one upon the other. The upper two had three holes in the bottom for root access to the lower pots, but small enough to restrict migration of water and nutrients from one compartment to another. The soil had a basal dressing of K, Mg, and P.

The pots were tightly connected with steel springs between them. Water and a measured amount of ammonium sulphate solution could be added to the lower pots through the marginal narrow open soil surface between the pots. Twenty-seven replicates were prepared.

Eight seedlings of an upland rice variety were transplanted to the upper pot of each triplet. When the plants had become established, the triplets were divided into three groups.

One group received 20 ml 0.5 *M* ammonium sulphate (20 mmol N) in the upper pot. A second group had the same dressing in the middle pot, and the third group had the 20 mmol N added to the lower pot. The solution was added in four daily portions, and watered into the soil by small, frequent irrigations replacing the transpired water.

Judicious adjustment of the supply of N relative to the expected yield secured exhaustion of the N during the last part of the growing period. Ammonium was used because it moves less rapidly and freely from one soil compartment to the other than does nitrate. It was supposed to be reasonably stable because at the more acid soil pH 5 the rate of nitrification is slow (van Tuil & Lampe, 1964).

Soil weight and moisture content indicated that each compartment contained 130 g water. When all the N had been added at one of the three possible depths of application, the water regime was varied within each group of N placement in the following way.

One-third of the triplets was daily irrigated back to the initial weight with equal distribution of the water between the compartments.

Another third was watered twice a day to the initial weight minus 130 g, and all the water was added to the two lower soil compartments.

The remaining triplets were irrigated three times daily to a final weight of 260 g below the initial weight by watering only the bottom compartment.

Thus the irrigation frequency was increased as the amount of water stored in the triplet decreased with the decrease in the proportion of wet soil. But the cumulative supply of water was smaller and became more growth limiting when the upper compartments were deprived of irrigation water during the test.

The net effect of the treatment variation was a rapid creation of one or two desiccated upper soil horizons, three depths of placement of the dressing of N, and a gradation in the cumulative input of irrigation water, parallel to the situation of even distribution of water over the whole soil profile with the three possible depths of application of the N fertilizer.

After nine weeks of exposure to the treatments the tops of the plants were harvested, and the fresh weight, the dry weight and the N content were determined.

Uptakes were calculated by multiplying the dry weight by mmol N/g DM. Dressings and N contents are given as mmoles N. For conversion into mg N the values should be multiplied by 14.

The sunflower plants were grown under natural light in the greenhouse during the summer at 25-30 °C, the rice plants in a climate room at 27 °C and a 12-h light period at 70 W m^{-2} of visible radiation.

Results and discussion

It is known that a relatively small number of roots can extract the water needed for growth from the deeper soil horizons when the top soil is dry (Garwood & Williams, 1967a). In the two-compartment experiments we anticipated deprivation of soil moisture no longer of direct importance to the growth. Attainment of this situation was judged from root spread in the solution below the soil. Proof that no water stress had developed would be no wilting and equal growth on the dry and the wet soil when the N was added to the solution outside of the soil.

Table I shows the results for sunflower. The first column indicates the placement of the N dressing, the second column the soil moisture status adjusted after the dressing of N. Within each N placement irrigation treatment the successive rows refer to results from replicate pots. Some of the replicates were lost when the plants

Table 1. Effect of placement of the nitrogen fertilizer in the double-compartment experiment on yield in g DM/pot, uptake of N in mmol/pot, and concentration of N in the above-ground parts of the sunflower plants. The wet soil was irrigated daily to initial weight. The dry soil was dried out to the wilting point as soon as sufficent roots had penetrated into the underlying solution.

Placement	Soil	Yield (g DM)	Uptake (mmol N)	Concentration (mmol N/g DM)
Test period 3 weeks				
in soil	dry	7.20	7.01	0.97
	dry	7.55	7.44	0.99
	dry	7.55	7.79	1.03
in soil	wet	10.9	24.2	2.22
	wet	9.50	23.0	2.42
in solution	dry	10.1	23.5	2.33
	dry	9.75	19.7	2.02
in solution	wet	14.6	23.6	1.62
	wet	13.4	24.3	1.82
Test period 5 weeks				
in soil	dry	13.5	12.5	0.92
	dry	13.2	14.4	1.09
in soil	wet	19.0	24.7	1.30
in solution	dry	18.9	25.5	1.35
	dry	14.8	26.1	1.76
in solution	wet	16.2	27.7	1.71

were damaged during the daily transfer of the soil compartment to the balance for weighing.

Among the plants harvested after three weeks exposure to the treatments those with N in the solution made more growth on the wet than on the dry soil. More growth was also produced on the wet soil with N in the solution than when the N had been added to the wet soil. The former difference indicates that the plants were still dependent for water supply on the moisture in the soil. The latter difference may have resulted from stimulated root development in the solution below the soil when the N had to be derived from that source, as was observed in other similar experiments. Between the daily irrigations the soil became more or less depleted of water, and a greater root development in the solution might have secured a more continuous water supply. Thus some unintended water stress had occurred among the dry soil treatments, but the effect was small compared with that of changing the placement of the N from a wet to a dry compartment.

With the N supplied from a wet compartment the uptakes were practically constant at around 25 mmol N/pot. As a consequence, the uptakes per unit dry weight (mmol N/g DM) were inversely proportional to the yield of DM. The highest concentration of 2.4 mmol N/g DM was in the plants with the lowest yield of 10 g DM exposed for three weeks to the treatments. The lowest value of 1.3 mmol N/g DM occurred at the highest yield of 19 g DM among the older, heavier plants with a test period of 5 weeks.

The yield differences due to the duration of the test period had no significant effect on the uptake of the N from the wet soil or the solution. This indicates that the supply of N had been exhausted before the first harvest date, and had restricted the uptake to about 25 mmol N/pot. As a result all N concentrations in the plants were lower than the maximum of 3.6 mmol N/g DM (including 1 mmol nitrate N) found in other plants grown with a maintained supply of nitrate during earlier experiments. Exhaustion of the supply was confirmed by the negative test for nitrate N in the plant samples. The supply of N had been adjusted intentionally to

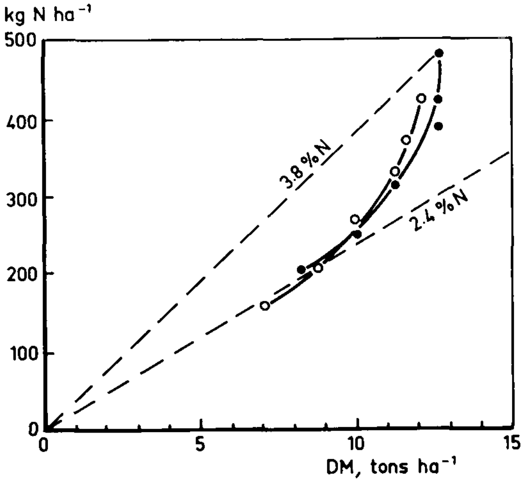

Fig. 1. Relation between the amount of herbage N and the amount of dry matter produced per year on pasture with a dressing of 0; 100; 200; 300; 400; or 500 kg N $ha^{-1} year^{-1}$. Values averaged over 10 years of observation. The solid and open dots refer to two separate experiments. The rate of N application increased in the order of inceasing uptake. From data of van Steenbergen (1977).

Table 2. Effect of placement of the nitrogen fertilizer in the double-compartment experiment on yield in g DM/pot, uptake of N in mmol/pot, and concentration of N in the above-ground parts of the rice plants. The wet soil was irrigated daily to initial weight. The dry soil was dried out to the wilting point as soon as sufficient roots had penetrated into the underlying solution.

Placement	Soil	Yield (g DM)	Uptake (mmol N)	Concentration (mmol N/g DM)
Test period 3 weeks				
in soil	dry	15.3	19.6	1.28
	dry	14.0	16.3	1.16
in soil	wet	15.7	28.3	1.80
	wet	17.0	30.2	1.77
in solution	dry	16.8	30.1	1.79
	dry	19.3	32.8	1.70
in solution	wet	14.2	18.5	1.30
	wet	16.6	28.5	1.72
Test period 5 weeks				
in soil	dry	27.8	24.4	0.88
	dry	20.9	17.6	0.82
in soil	wet	27.4	31.5	1.15
	wet	26.9	30.9	1.15
in solution	dry	30.4	32.3	1.06
	dry	29.8	33.2	1.11
in solution	wet	28.9	34.6	1.20
	wet	33.0	37.3	1.13

make its availability a dominant factor in determining N uptake. Then even a small decrease in availability must reduce the uptake to a relatively greater extent than the growth and is evidenced by a decreased concentration of N in the DM (compare Fig. 1).

When the N was placed in the dry soil, the amount taken up after three weeks was only 30 %, and the dry weight 50-70 % of the values attained with the N in the wet soil or in the solution. In the test with a duration of five weeks, the uptake of N from the dry soil was 40 % with a DM of 80 % of the values attained when the N had been added to the wet soil or to the solution.

Apparently the supply of N was cut off and the plants grew sooner and further into N depletion when the N had to be derived from the dry soil. They produced less growth mainly because they became more deficient of N than at full availability of the N from the wet soil or the solution.

The results obtained with rice plants are shown in Table 2. Root spread into the solution was slower than with sunflower, and the beginning of the treatment had to be postponed to a later date to reduce the risk of water stress among the plants on the dry soil. This made the treatment period shorter relative to the whole life time of the plants than was originally intended. The unknown actual growth rates were probably influenced but not long enough to produce marked differences in the final dry weight of the plants.

After five weeks of treatment the plants had produced two times more dry weight than those exposed during three weeks to the treatments, but the uptakes differed by not much more than one-tenth. Reduced availability of the N form the desiccated soil was apparent from the smaller uptakes of about two-thirds of the amount absorbed when the N was placed in the wet soil or in the solution.

One of the replicates with N in the solution and the soil irrigated for three weeks had a small uptake which compared with the uptake from the dry N amended soil. An erroneous omission of the dressing must account for this apparent anomaly.

With no yield response to the treatments the results were less illustrative then those obtained with sunflower. However, the low availability of the N from the desiccated soil was as conspicuous from the decrease in uptake and concentration of N when the nutrient had to come from that source.

Table 3. Effect of placement of the nitrogen fertilizer in the triple-compartment experiment on yield in g DM/pot, uptake of N in mmol/pot, N concentration in the DM, and % DM in fresh material of the above-ground parts of the rice plants. Application of N : 20 mmol ammonium in the upper, middle or lower pot which either a wet or a dry soil.

Placement	Soil	Yield (g DM)	Uptake (mmol N)	Concentration (mmol N/g DM)	In fresh % DM
upper pot	wet	9.20	15.9	1.72	27.7
	wet	8.66	15.1	1.75	27.3
	wet	10.3	16.9	1.64	26.4
middle pot	wet	9.55	17.4	1.82	27.3
	wet	9.55	17.3	1.87	28.4
	wet	10.9	18.6	1.70	29.1
lower pot	wet	10.5	17.9	1.70	28.1
	wet	11.6	18.3	1.58	28.1
	wet	10.1	18.0	1.77	27.2
upper pot	dry	6.12	6.06	0.99	33.7
	dry	6.62	5.96	0.90	34.8
	dry	7.52	6.35	0.84	34.7
middle pot	wet	6.39	12.5	1.95	31.3
	wet	8.12	14.5	1.78	30.4
	wet	7.14	14.1	1.97	31.1
lower pot	wet	9.33	17.1	1.83	30.5
	wet	7.98	15.0	1.88	29.6
	wet	9.30	17.3	1.86	30.1
upper pot	dry	5.76	5.37	0.93	36.8
	dry	6.10	5.75	0.94	35.5
	dry	4.84	5.43	1.12	35.8
middle pot	dry	4.86	6.00	1.23	36.6
	dry	5.53	6.19	1.12	34.6
	dry	5.60	6.34	1.13	35.1
lower pot	wet	6.50	13.0	2.00	33.1
	wet	4.67	9.73	2.08	32.8
	wet	6.18	11.8	1.91	31.8

As a substitute for a natural soil profile with unequal stratifications of the N and the soil moisture the soil columns, constructed from piles of three pots as described in the experimental section, were tested with the upland rice variety.

The results are presented in Table 3. The first column indicates the depth of N application, the second column the soil moisture status of the soil compartments maintained after the dressing. Each irrigation treatment included the three possible placements of the N fertilizer. The three rows for each N placement irrigation treatment refer to results from three replicate triplets.

The treatments were initiated when it was likely that root growth had secured equal access to the water and the nutrients in each of the three compartments.

The first nine rows of Table 3 show that the uptake of N from the evenly wetted soil increased slightly with the depth of placement of the fertilizer. A possible cause of this unexpected gradient might have been that some of the ammonium placed in the upper more aerobic compartment was nitrified and had moved to the lower less aerobic compartments where some of the N was lost by denitrification, while the ammonium placed in the lower compartments was not nitrified with, as a consequence, no loss of N by denitrification. Another cause, greater volatilization of ammonia from the top soil, seemed less likely because the soil pH was on the acid side at pH 5. However, this effect of depth of application of the nutrient was small compared with that of allocation of the N and the water to different soil horizons.

With the N placed in the invariably wet lowest compartment, the yield of DM decreased by 40 % as the number of dry compartments was raised from nil to two, but the uptake of N decreased by only 30 % As a consequence, the concentration of N increased from 1.7 mmol N/g DM on the evenly wetted soil to 2.0 mmol N/g DM with the two upper compartments dry. The increase in water stress at unchanged availability of the N from the lowest wet compartment had concentrated the absorbed N to a higher concentration as a result of the smaller growth. Similar but smaller concentrating effects of drought on the leaf N derived from a wet compartment are shown by the treatments at which only the upper compartment was deprived of irrigation water.

A general evaluation of the results of Table 3 is more readily made by plotting the uptakes against the corresponding dry weights for all the treatments in one graph.

The solid dots in Fig. 2 refer to the treatments with the N placed in one of the wet compartments. The curve drawn through the points is bordered by a tangent to the curve which passes through the origin and has a constant slope of 2 mmol N/g DM. This represents the maximum uptake rate per unit dry weight produced by the rice plants.

The highest uptake per pot was around 18 mmol N at a dry weight of about 11 g, and was attained when the three compartments were irrigated. As the water stress increased in response to the stepwise desiccation of the upper compartments, it caused the DM yield to decrease relatively more than the uptake. As a consequence the concentration of N in the DM increased from 1.6 mmol N/g DM to the maximum of 2 mmol N/g DM. This part of the curve represents the concentrating effect on leaf N of the decrease in yield by water shortage at unchanged

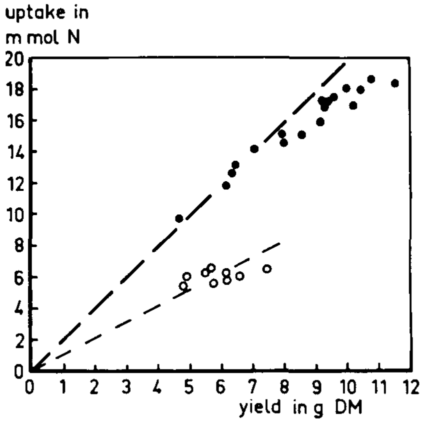

Fig. 2. Relation between the amount of N absorbed (mmol N/pot) and the DM produced by the rice plants grown on the soil columns with the N and the soil moisture in a common soil compartment (solid dots) or in a separate soil compartment (open dots). For explanation see text and Table 3.

availability of the N due to its placement in a wet compartment.

The lower section of the curve coincides with the straight line through the origin with a slope of 2.0 mmol N/g DM which is the maximum concentration at which N can accumulate in the tissues. In this range water stress had reduced plant size and the capacity to store N in the plants to such an extent than the available N was no longer limiting the uptake. Uptake, now completely controlled by the growth, continued to fall in direct proportion to the dry weight.

The nine treatments that had the N placed in a dry compartment are indicated by the open circles.The reduction in the availability of the N caused by positional drought had reduced the uptake to a small nearly constant amount of 6 mmol N/pot. The concentration of N was at a deficient level of the order of 1 mmol N/g DM and varied to some extent with the yield of DM because the small amount which had remained available was limiting the uptake. With unequal stratification of the soil moisture and the N, the main effect of drougt was deficiency of nitrogen with low yields associated with a low plant concentration of the nutrient.

The last column of Table 3 indicates the %DM in the fresh plant material. Its increase is a common response to various forms of stress.

The two forms of stress, water stress and N stress, which acted in a different way upon uptake and yield (Fig. 2), can also be differentiated by the relationship between %DM and concentration of N in the DM. In Fig. 3 the values are indicated by figures denoting the number of wet compartments in the soil columns.

The encircled figures refer to the dry applications of N. With no access to the dressing, depleted growth had reduced the N concentration to less than 1.2 mmol N/g DM. Owing to additional N stress, the %DM values were all higher than in the plants supplied with the N from a wet compartment.

The figures that are not encircled concern the treatments with the N in a wet compartment. With the decrease in the proportion of wet soil, the absorbed N concentrated from 1.6 to 2 mmol N/g DM as the yield declined due to the decrease in supply of water. The parallel increase in water stress caused the %DM to increase again from 27 at the highest (3) to 33 at the lowest (1) rate of irrigation.

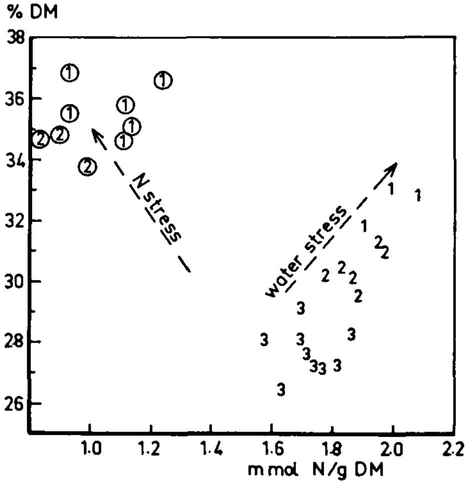

Fig. 3. Relation between the DM percentage in the fresh material and the concentration of N in the DM of the above-ground parts of the rice plants from the experiment of Table 3 and Fig. 2. The values are shown by figures denoting the number of soil compartments in which irrigation was continued during the test period. The encircled figures refer to the treatments with the N and the irrigation water added to different compartments.

Proof that the points lie along a continuous minimum curve with the two branches extending upward would require comparitive studies in which, for example, the dressing of N is distributed at various proportions between wet and dry soil compartments to make the treatment variance more continuous.

Conclusions

Earlier cessation of the rainfall in many regions of Java exposes rice crops during a longer part of the growing period to a progressive water deficit. However, it is unlikely that the large amount of water stored in the heavy paddy soils becomes depleted from the entire rooting zone fast enough to explain the quick retardation of the growth. The adverse effect on growth on soils with the N more concentrated in the upper horizon is more likely to be due to N defiency caused by reduced plant access to the nutrient, long before desiccation proceeds to a greater depth and the supply of water from the soil becomes limiting.

Reduced availability of the N is evidenced by a cessation of uptake, which results in a low concentration of N in the plant material compared with normal plants or plants exposed to a deficiency of soil moisture.

Van Keulen (1977) has shown that the final grain yield correlates closely with the amount of N taken up by the plants. Hence, if access to the N in the soil is the limiting factor, the final grain yield will be lower in the N deficient plants than in plants of similar size which have grown under water stress.

The prediction of the grain yield and recommendations for deeper placement of the N dressing can be improved by analysis for N plant samples taken at regular intervals.

Poor growth due to a lack of water is evidenced by an increase in the concentration of N as the growth slows down during a drought. Poor growth caused by demobilization of the N in the desiccated soil layer can be recognized from a decrease in the concentration of N in the DM to a deficient level.

References

Alberda, Th., 1971. Stikstofbemesting van grasland en de kwaliteit van het oppervlaktewater. *Stikstof* 69: 377-383.

Dilz, K. & J. W. Woldendorp, 1961 .Distribution and nitrogen balance of 15N-labelled nitrate applied on grass sods. *Proc. 8th int. Grassld Congr.* (1960) 150-153.

Garwood, E. A. & T. E. Williams, 1967a. Soil water use and growth of a grass sward. *J. agric. Sci., Camb.* 68: 281-292.

Garwood, E. A. &. T. E. Williams, 1967b. Growth, water use and nutrient uptake from the subsoil by grass swards. *J. agric. Sci., Camb.* 69: 125-130.

Ismunadji, M. & W. Dijkshoorn, 1971. Nitrogen nutrition of rice plants measured by growth and nutrient in pot experiments. *Neth. J. agric. Sci.* 19: 223-236.

Keulen, H. van, 1977. Nitrogen requirements of rice with special reference to Java. *Contr. Centr. Res. Inst. Agric., Bogor* No 30, 67 p.

Oldeman, L. R., 1975. An agroclimatic map of Java. *Contr. Centr. Res. Inst. Agric., Bogor* No 7, 22 p.

Steenbergen, T. van, 1977. Invloed van grondsoort en jaar op het effect van stikstofbemesting op de graslandopbrengst. *Stikstof* 85: 9-15.

Tuil, H. D. W. van & J. E. M. Lampe, 1964. Control of nitrification by 2-chloro-6-(trichloromethyl) pyridine. Jaarb. *Inst. biol. scheik. Onderz. LandbGewassen* 1964: 161-163.