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Title	The Nitrogen Balance in Soils Growing Corn
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Citation	Journal of the Faculty of Agriculture, Hokkaido University, 61(3), 323-343
Issue Date	1983-11
Doc URL	http://hdl.handle.net/2115/12994
Type	bulletin (article)
File Information	61(3)_p323-343.pdf

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THE NITROGEN BALANCE IN SOILS GROWING CORN

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Received June 6, 1983

The power of soil to supply nitrogen is one of the most important factors governing crop growth. Most soils, however, are not able to supply nitrogen necessary to meet the requirement of plants for the maximum growth in given conditions, because nitrogen available during one crop season is very limited compared with the ample amounts of organic matters existing in soils as a nitrogen pool. This is the main reason why nitrogen fertilizers are applied every crop season to non-leguminous crops.

Investigations on the nitrogen behavior in soils, including fertilizers in the soils have been carried out since the 19 th century and thus their outlines have been well understood,[1] though these are rather lacking in quantitative value. Recently, however, attention has again been attracted to this issue, and for several reasons: that is, for energy saving, for more efficient use of fertilizer, and for protection of the environment against pollution, etc. In addition, in order to test the soil to determine the amounts of nitrogen fertilizer required for optimum effect, a simulation model of nitrogen balance in soils has been intensively considered. To advance the simulation studies, more and more actual data will be required in all the cases, not only with regard to the behavior of soils but also of plant species. The present paper offers evidence of the nitrogen balance in a corn field for the purpose of providing some actual information about this issue.

Materials and Methods

Field experiment:

The experiment was conducted in 1978 at the experimental farm of Hokkaido University. Soils belong to Brown Lowland soils and some of their

[J. Fac. Agr. Hokkaido Univ., Vol. 61, Pt. 3, 1983]

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TABLE 1. Some chemical properties of soil profiles in the fields used.

Soil layers (cm)	pH (1:2.5)		CEC (me/100g soil)	Exchangeable cations (me/100 g soil)				T-N (%)	T-C (%)	C/N	Available P* (P_2O_5 mg/100g)
	H_2O	KCl		Ca	Mg	K	Na				
0—10	6.54	5.60	38.4	21.8	5.80	1.41	0.25	0.28	4.22	15.1	49.8
10—20	6.40	5.41	37.2	21.2	5.28	1.11	0.29	0.29	4.34	15.0	55.3
20—40	5.55	4.35	29.2	16.4	3.54	0.44	0.33	0.11	1.32	12.0	2.8
45—53	5.71	4.46	19.0	11.2	2.86	0.39	0.23	0.03	0.64	21.3	0.3

* BRAY No. 1

chemical properties are shown in Table 1. The treatments consisted of the addition of 5 nitrogen levels, that is, 0 kg N, 50 kg N, 100 kg N, and 200 kg N/ha as ammonium sulphate; these are called here 0 N, 50 N, 100 N and 200 N treatments, respectively. All treatments were of two replications, arranged in a randomized block design. One plot size was 36 m^2 (6 m × 6 m). Phosphorus (P_2O_5) and potassium (K_2O) were applied to all the plots at the rate of 150 kg/ha as superphosphate and potassium chloride, respectively. They were applied to the depth of 20 cm.

Seeds (Wisconsin hybrid No. 110) were sown on 10 May, 1978, at a hill spacing of 40 cm × 40 cm and thinned one plant per hill on 22 June, when planting density was 62,500/ha. Standard protection measures were taken against weeds, pests and diseases.

Plant and soil samples:

Plants were uprooted from the fields at successive growth stages, that is, on 22 June, 19 July, 3 August, 23 August and 21 September. Plants were separated into stems, leaves, grains and dried in a blowered oven at 70°C for 3 days, weighed and powdered for chemical analysis. Nitrogen was determined by the KJELDAHL method and chlorine was measured by the merculic thiocyanide method after fusing materials with sodium carbonate.

Root systems were investigated 5 times during plant growing period in the 200 N treatment plot. Detailed investigation was carried out on 9 August which was the time of the highest point in root weight and growth. The soils were divided into 250 blocks with a single stalk of stubble at the centre of the soil mass. (Fig. 1). All blocks were taken up and the soil was washed on 2 mm sieves to collect roots. Root lengths of washed samples were measured by the method of ROWSE *et al.*[2], modifing the NEWMAN method.

Soil samples themselves were taken on the same dates as plant sampling

after taking plants from all the plots. The 1st samples of 13 May were taken just after the sowing. Soils were collected by horizons at 6 depths, that is, 0–5, 5–10, 10–20, 20–30, 30–40, and 40–50 cm from the surface, except the first samples. The first samples were collected from the 0–20 cm layer as the one horizon where fertilizers had been mixed. Soils were sampled from 3 sites in each plot and mixed throughly. Fresh soil samples were passed through a 2 mm sieve and stored at 5°C in large polyethlene bags until use. Analyses of soils were carried out as soon as possible after collecting.

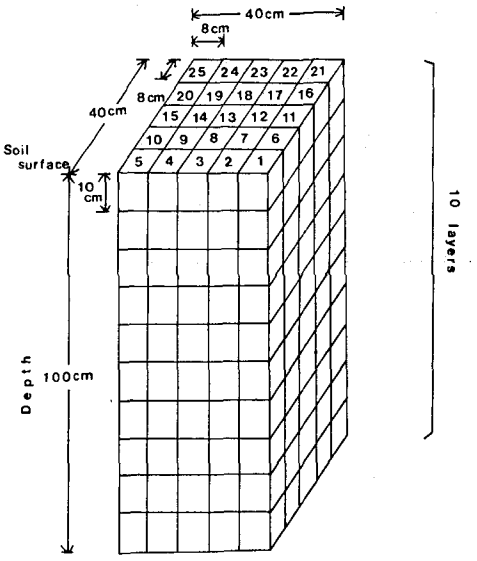

Fig. 1. Sketch of soil sampling blocks (Plant stubble is located in block No. 13).

Soil solution:

Before separating the soil solution, soils were moistured to a 70% moisture content by weight and attained equilibrium condition. Thereafter, soil solutions were separated by means of centrifugation for 30 min. at 14,000 rpm, equilibrated with pF 4.2 moisture intensity[3]. pH and EC were measured in the ordinary way. The NO_3-N was measured by ion meters and Cl was measured by the thiocynaic mercuric acid method.

Exchangeable NH_4-N and NO_3-N in soils:

Fresh soils were extracted with 2 N KCl by shaking the samples in a flask for 1 hour. NH_4-N and NO_3-N were analyzed by means of CORNWAY micro diffusion analysis.

Estimation of the nitrogen mineralization capacity of soils:

100 g of fresh samples was incubated in a polyethylene bag at 30°C in 26 days. The moisture content was controlled at around pF 2.5 by supplying distilled water during the incubation. Amounts of NH_4-N and NO_3-N formed in the incubation period were defined as the nitrogen mineralization capacity of soils.

Estimation of water movements in soil layers:

Amounts of water movement are the product of water conductivity by

suction gradient as given by

$$v = k(\theta)\left(\frac{\partial h}{\partial x} + 1\right)$$

where $k(\theta)$, h and x represent unsaturated hydraulic conductivity, water suction and soil depth, respectively. This estimation is based on the assumption that water movement is controlled by DARCY's law.

Measurements of unsaturated hydraulic conductivity:

These were conducted in the field and laboratory. The field experiments consisted of two methods: infiltration and evaporation.

(i) Infiltration method: Bare plots were established near the planting plots in 1 m^2 to measure the moisture conductivity. The plots were surrounded by a plastic sheet to a depth of 80 cm to prevent the water movement in a horizonal direction; in addition, the surface was also covered with a plastic sheet and a styrol plate to prevent evaporation and water movement by temperature gradient. Tensiometers were placed at 5, 15, 25, 35, 45 and 55 cm soil depth in 2 duplications. 24 hours after the supply of 100 mm water, measurements were conducted at 9.00 a.m. and 6.00 p.m.

(ii) *Evaporation method*: (a) Field: In order to measure the unsaturated hydraulic conductivity in the low moisture content regions, the evaporation method was applied by using a chamber as shown in Fig. 2. The chamber, which was constructed of transparent plastic sheets, was placed on the plot without crops. The capacity of the chamber was 0.036 m^3. Tensiometers were placed at the same depths as for the infiltration methods. Evaporations were measured at the rate of 150 l/min, in the air flow of the chamber, from 6 September to 6 October. 0.1 m^3 chamber in capacity was also used, where the air flow was set 400 l/min. Water suction was measured at 9.00 a.m. every day. (b) Lavoratory: The method was adapted from that proposed by EHLERS[4], using undisturbed soil cores taken from the field. The principle was based on the measurement of soil moisture diffusivity developed by BRUCE *et al*[5]. 100 ml core soils were taken from depths of 5, 15, 25, 35, 45

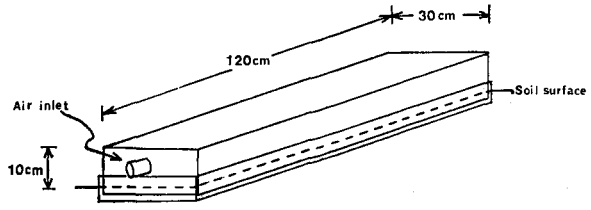

Fig. 2. Chamber for measuring evaporation from soil surface.

and 55 cm in 4 replications. The cores were saturated with water by capillary action, equilibrated in a horizonal position for 1 day, and then subjected to a warm air stream, the open end facing the air. The distance of the electrical drier from the air outlet was set at 10 cm. Water losses due to evaporation were determined by subsequent weighing of the soil core during the procedure. After 9 to 16 minutes, evaporation was discontinued, and within few minutes the soil column was cut into 3-8 mm segments to determine the distributions of the water contents.

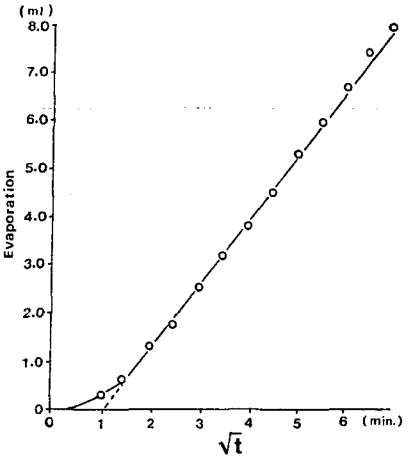

Fig. 3. Relationship between evaporation and drying time.

The reason for fixing 9-16 minutes for evaporation is as follows. There is a distinct linear relation between cumulated evaporation and the square root of the time taken for the period of this evaporation as shown in Fig. 3. At the same time, the water condition was kept air dry at the surface while wet at the bottom of the cores during the 9-16 minute evaporation period.

Figures for water diffusivity were obtained from the measured water content according to the following equation[5].

$$D(\theta x) = -\frac{1}{2t}(dx/d\theta)_{\theta x}\int_{\theta i}^{\theta x} x d\theta$$

θ: volumetric water content (cm^3/cm^3)
x: the distance from the evaporation surface (cm)
θx: θ at x
t: time for evaporation (sec.)
$D(\theta x)$: diffusion coefficient at θx (cm^2/sec.)

The $D(\theta)$ was used for the estimation of the hydraulic conductivity according to the equation,

$$K(\theta) = D(\theta)\cdot\frac{d\theta}{d\psi}$$

$K(\theta)$: hydraulic conductivity at θ (cm/sec.)
ψ: matric potential (cm)

Based on the unsaturated hydraulic conductivities recorded in the field

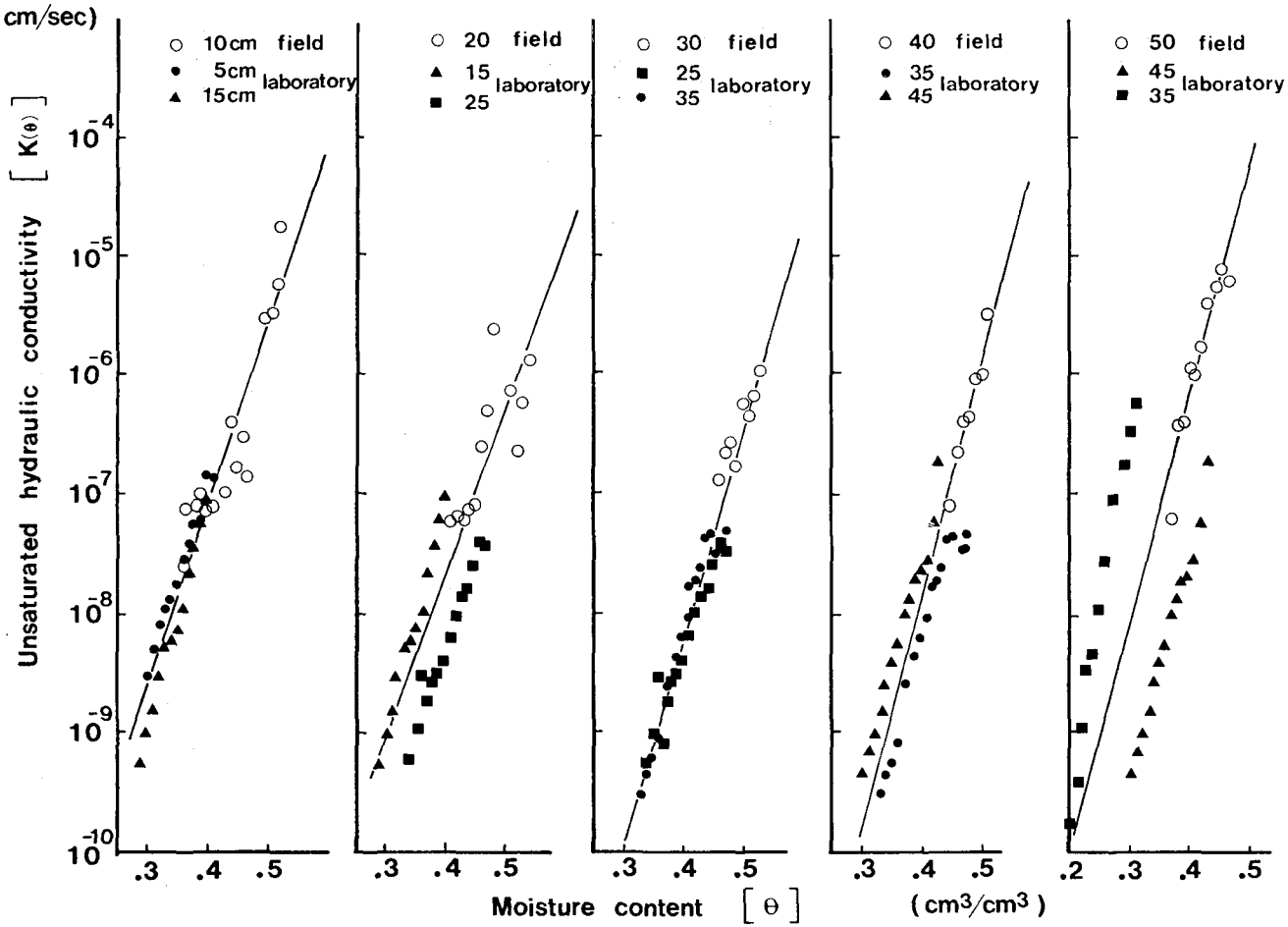

Fig. 4. Relationship between moisture content and unsaturated hydraulic conductivity.

and the laboratory, the relation between the hydraulic conductivity and moisture content is shown in Fig. 4.

Although the measured hydraulic conductivity was mainly derived from the laboratory experiment in the low moisture regions, there was a clear relation between the hydraulic conductivity and the moisture content at each depth of soil.

The regression coefficient and correlation coefficient are as follows.

		soil depth (cm)
$K(\theta) = 10^{(14.7\theta - 13.0)}$	$r = 0.967$	10
$K(\theta) = 10^{(13.7\theta - 13.2)}$	$r = 0.929$	20
$K(\theta) = 10^{(17.3\theta - 15.2)}$	$r = 0.976$	30
$K(\theta) = 10^{(19.5\theta - 15.6)}$	$r = 0.998$	40
$K(\theta) = 10^{(18.5\theta - 13.5)}$	$r = 0.985$	50

Results

Plant growth:

The weather conditions for the year of the experiments conducted are shown in Fig. 5. There were 150 mm of precipitation from the end of May to the beginning of June. Thereafter, however, the precipitation was only 50 mm until the beginning of August. Especially, from the end of July to the beginning of August, no precipitation occurred, resulting in very dry fields. From the middle of August to September, 110 mm of rainfall were observed. The total amount of rainfall in the crop growing period

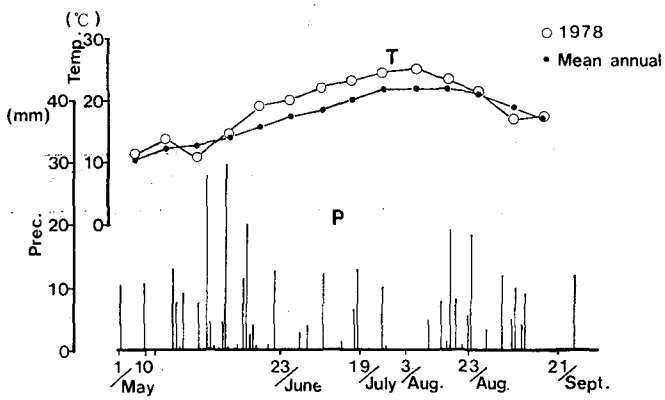

Fig. 5. Climatic condition in the field. (P: Precipitation, T: Average temperature)

was 318 mm. This is relatively higher in temperature and lower in precipitation when compared with the average annual weather conditions for the area. The plowing layer of the soils (0–10 cm, 10–20 cm) is fertile and higher in C, N, available P and CEC. Contents of C, N and available P are low in subsoils (Table 1).

Plant responses to nitrogen application were very clearly observed on dry matter production (Fig. 6). The dry matter increased with the increase of the supply of nitrogen. Symptoms of nitrogen deficiency in the 0 N plot were observed clearly in the middle of July and no silks were observed until the middle of August. A typical symptom of nitrogen deficiency, the yellowing of lower leaves, developed in the 5 N plot from the late of July to August and it was observed slightly in the 100 N plot in August. No symptoms of nitrogen deficiency were observed in the 200 N plot at any of the growth stages. Silks were formed in late July in all the plots that received nitrogen fertilizers. Grain yields reflected these facts, and increased with the increase of the nitrogen supply. The highest grain yield was 10 t/ha in the 200 N plot (Table 2).

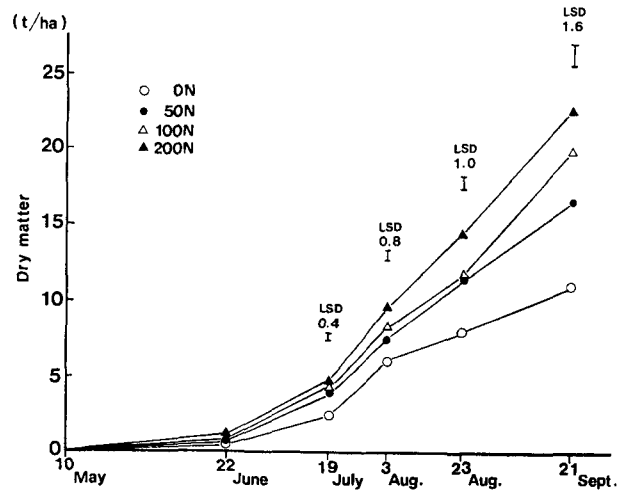

Fig. 6. Successive changes in dry matter of plant with growth.

TABLE 2. Corn grain yields*

Treatments	0N	50N	100N	200N
Dry matter	0.91	6.50	8.09	10.09
S. D.	0.69	2.13	1.07	1.36

* t/ha

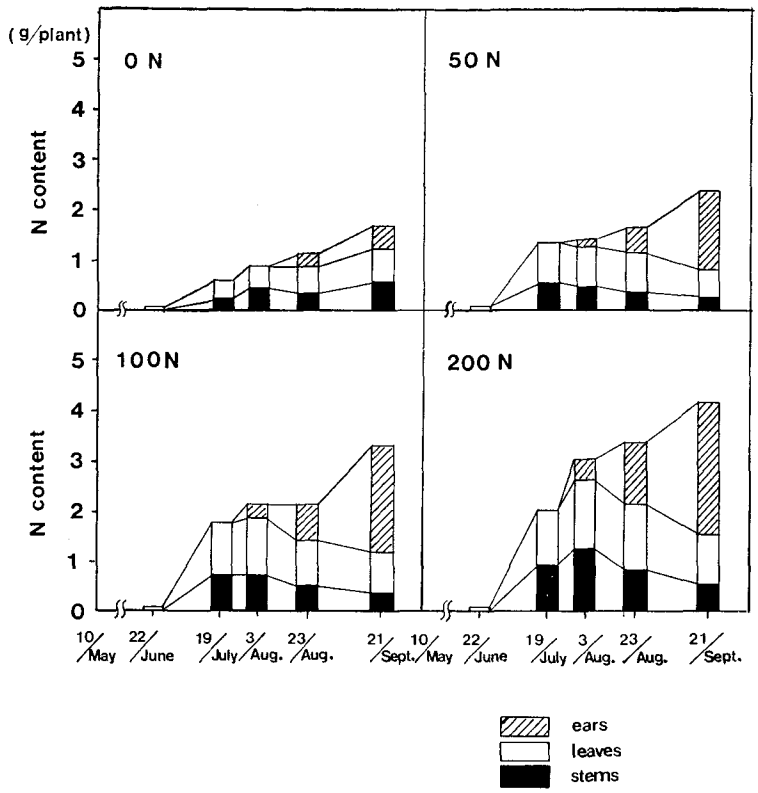

Fig. 7. Successive changes in nitrogen content of plants with growth.

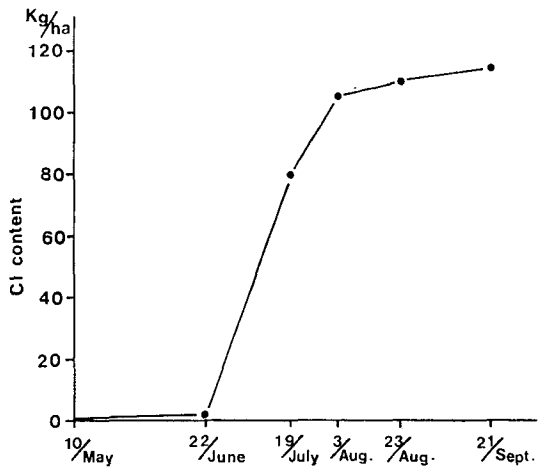

Fig. 8. Successive changes in chlorine content of plants with growth.

Nitrogen accumulation in the plants also showed just the same tendency as for dry matter production or plant growth as shown in Fig. 7. Chlorine accumulation by plants in the 200 N plot is given in Fig. 8. This was quite similar to the nitrogen accumulation of the same plot.

On the root system which was investigated on 9 August in fesh or dry weight, about 50% of roots were distributed at 0–20 cm soil depth (Fig. 9). Root dry weights decreased with the soil depth. The root densities, expressed as cm of root per cm^3 of the soil volume, were almost the same in the layers until 50 cm soil depth while total root lengths within 50 cm soil depth were 72.4%. Activity or function of roots differ in different layers because the weight of roots per unit length decreases with the soil depth and most of the water and the nutrient uptake by plants will depend on a function of the roots distributed within 50 cm depth.

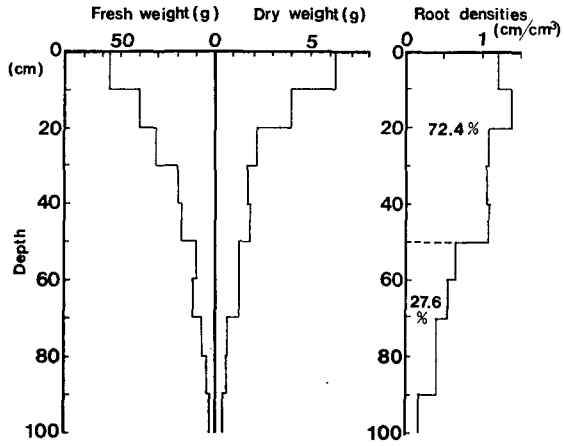

Fig. 9. Distribution of root system in the soil layers (9 Aug.).
(%: Total root lengths as whole plant root lengths 100.)

Soil water and nitrogen:

The water content of the soil layers of the 0 N and 100 N plots responded to the climatic conditions (Fig. 10). From 23 June to 3 August, it decreased with the decrease of rainfall. The upper layers were more dry than the lower layers. After rain in August, the water condition returned to the condition of 23 June. It is not so clear why but there was a tendency for the moisture condition to be more dry in heavily worked plots than in less worked plots; this can be seen in the 0 N and 100 N plots.

Soil pH changed between 5.5 and 6.5 but no special relation between the plots, sampling time and soil layers was observed.

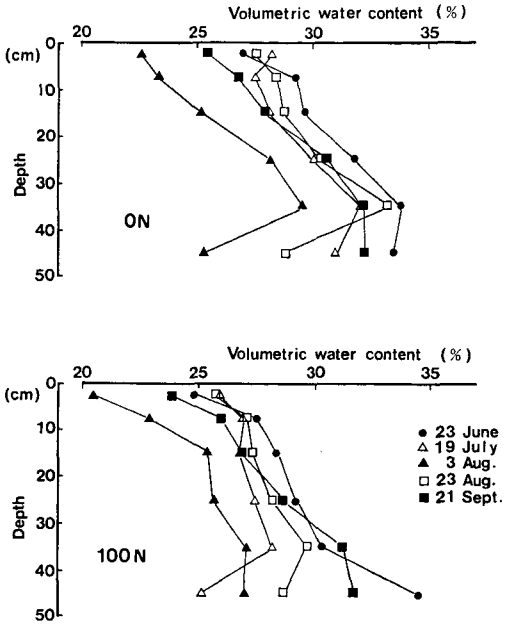

Fig. 10. Changes of water contents in soil layers.

Trends of nitrate and ammonium nitrogen in soil layers:

Nitrate nitrogen contents per kg soil of the soil solution, generally showed an increase with the increase of nitrogen applications (Fig. 11). Electrical conductivity (EC) showed the same trend although the data of EC are omitted here.

On 23 June, accumulations of NO_3-N were observed in all the plots. After that, in the 0 N and 50 N plots, NO_3-N was observed mostly in the top layers 0-5 cm and gradually decreased with the plant growth. In the case of the 100 N and 200 N plots, double peaks of accumulations of NO_3-N were observed in the 0-5 cm and 20-30 cm soil layers; thereafter, NO_3-N decreased gradually as well as in the 0 N and 50 N plots though the residue in the 100 and 200 N plots was a little bit higher.

Amounts of ammonium nitrogen given in the Figures are almost derived from the exchangeable NH_4, because NH_4-N was found only in traces in the soil solutions. Characteristic changes of NH_4-N were observed in the 5 th samples. NH_4-N increased in all the soil layers and all the plots between 3 August and 23 August, though it decreased again in the last samples.

The trend of Cl in the 200 N plot (Fig. 12) was nearly the same as that of mineral nitrogen (NH_4-N+NO_3-N) but its accumulation in the top layer was less than that of mineral nitrogen.

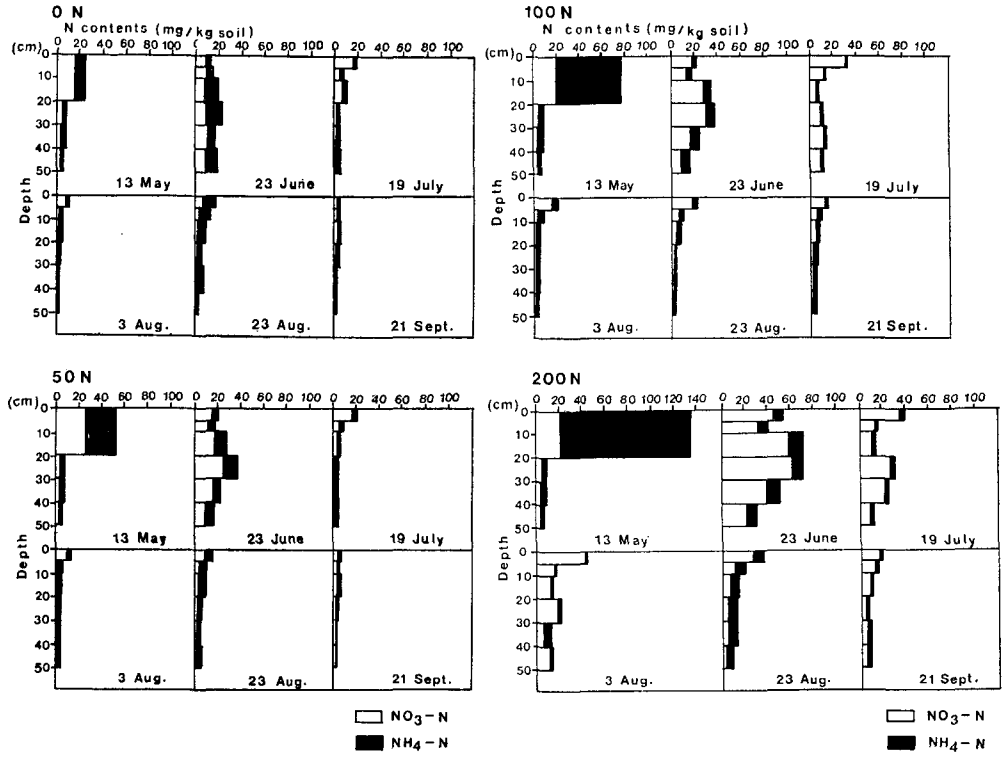

Fig. 11. Changes of nitrate and ammonium nitrogen contents in soil layers.

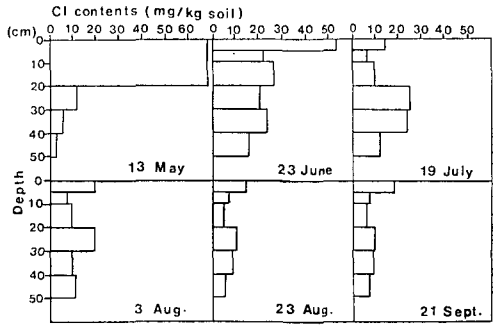

Fig. 12. Changes of chlorine content in the soil solution (200 N).

A Balance of nitrogen in soils and plants :

Trends of mineral nitrogen including exchangeable NH_4 and NO_3–N within a 50 cm depth of soil and that of nitrogen accumulation in plants are

given in Fig. 13. In the first samples (10 June), the mineral nitrogen contents in the soils increased with the increases of nitrogen supply. This trend was still retained for the second samples (23 June), although mineral nitrogen somewhat increased in the 0 N and 50 N plots while it decreased in the 100 N and 200 N plots. In the third samples, the proportion of soil nitrogen dropped to half the level or much lower levels than at the beginning. In its place, nitrogen accumulation in plants increased alternatively to compensate for the decrease of nitrogen in soils. It appears that plants extensively absorb nitrogen located within 50 cm depth of soils from the second to the third sampling time. After the silking stage, the increase of nitrogen uptake became gradual until harvest, while the mineral nitrogen in soils decreased. At the final sampling time, there was a tendency for total nitrogen (soils plus plants) to increase a little, especially in the 0 N plot.

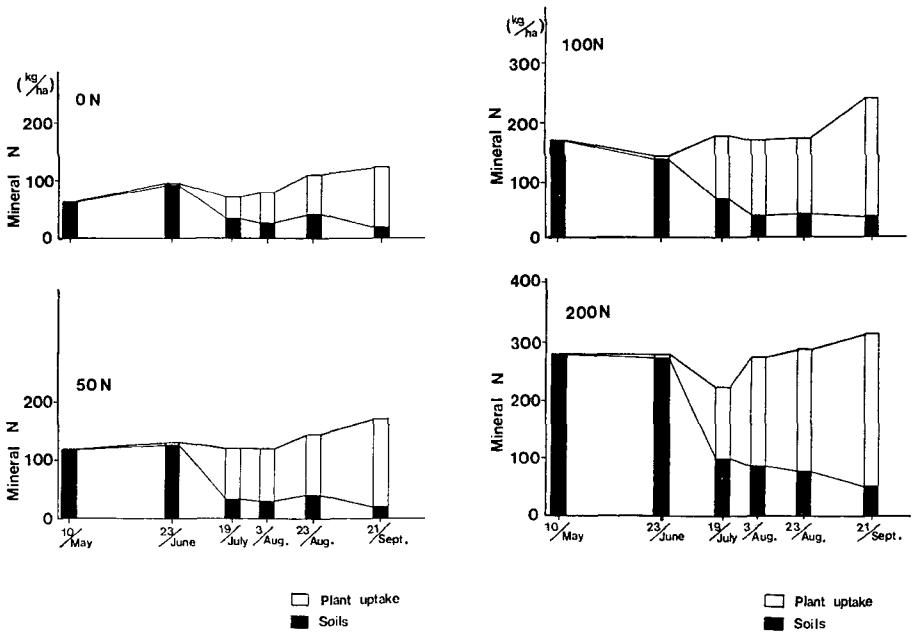

Fig. 13. Trends of mineral nitrogen of soils in a depth of 50 cm and plant uptake nitrogen with growth.

Changes of nitrogen mineralization capacity:

At the first sampling time, the soil capacity for nitrogen mineralization in the plowed layer increased with the increase of nitrogen supply as if due to the priming effect of nitrogen applications[6,7] (Table 3). At the second

sampling time, on the other hand, this capacity had a tendency to decrease in the 100 N and 200 N plots. Negative values were also obtained in the lower layers in all the plots, indicating an immobilization of fertilizer nitrogen in soils. During the third and forth sampling time, the increase of the capacity were found in all the plots, especially in the plowed layers.

The dehydration effect on the acceleration of mineralization[8] has been defined as a drying effect for mineralization of soil nitrogen. The increase

TABLE 3. Nitrogen mineralization capacity of soil layers*.

Treatment	Soil layers (cm)	Dates			
		13 May	23 June	19 July	23 August
0 N	0— 5	17.3	43.9	43.1	57.9
	5—10		31.0	37.3	41.3
	10—20		12.2	21.3	25.2
	20—30	20.8	−7.8	7.1	10.1
	30—40	19.4	−2.7	2.9	2.7
	40—50	5.1	−4.9	0.9	5.2
50 N	0— 5	38.0	34.1	35.7	65.2
	5—10		32.5	38.4	46.9
	10—20		7.7	26.5	41.2
	20—30	20.8	−6.6	10.3	13.3
	30—40	19.4	−3.6	4.6	5.5
	40—50	5.1	−2.0	2.0	4.2
100 N	0— 5	58.1	32.0	49.4	62.3
	5—10		27.2	33.4	45.2
	10—20		12.8	23.8	38.5
	20—30	20.8	5.1	8.2	15.7
	30—40	19.4	0.9	7.3	8.6
	40—50	5.1	−3.4	4.5	6.1
200 N	0— 5	56.7	22.7	49.6	54.3
	5—10		15.2	29.3	36.0
	10—20		2.5	23.4	30.4
	20—30	20.8	−0.7	13.8	7.7
	30—40	19.4	−2.0	9.2	4.4
	40—50	5.1	−3.5	6.1	2.9

* mg N/kg soil

TABLE 4. Amounts of potential nitrogen for the mineralization in a depth of 50 cm*.

Treatments	Dates			
	13 May	23 June	19 July	23 August
0 N	79.6	33.1	71.4	93.4
50 N	120.1	27.4	79.7	121.0
100 N	159.5	45.3	83.4	123.1
200 N	156.8	15.1	90.7	91.0

* kg/ha

of the capacity for the mineralization of the soils after the third sampling time may be due to the dry condition in the preceeding period. Table 4 shows the trends of the potential of nitrogen mineralization at effective soil depths, by summing up the nitrogen mineralization capacity of each soil layer. They demonstrate that there are seasonal changes in the potential for nitrogen mineralization.

Water movement in soils during plant growth:

Results obtained for the water movement are shown in Figs. 14 and 15. The negative signs or the points above the axis of abscissas indicate the upward movement of water while the points below the axis indicate the downward movement.

In the plot without crops (Fig. 14), the movement of water changed from upward to downward immediately after rainfall and afterwards it changed again to an upward movement at 10 cm depth. During the drying period, the upward movement of water reached a peak within 3 or 4 days after rainfall; thereafter it decreased gradually. At the 20 and 30 cm depth, the downward and upward movements of water after rainfall were observed about 1 day later. In the 40 and 50 cm depth, the downward movement started 2 or 3 days after rainfall and continued for several days; afterwards, water movement gradually changed upward in the drying period from the end of July to August.

The plots with crops (Fig. 15) were generally more dry and changes of water movement were considerably less when compared with the plot without crops. At the 10 cm depth, the downward movements continued throughout crop growth and their amounts increased at the time of rainfall. At the 20 cm depth, water moved downward a little bit just after rainfall, but then returned to an upward movement. Below 30 cm in depth,

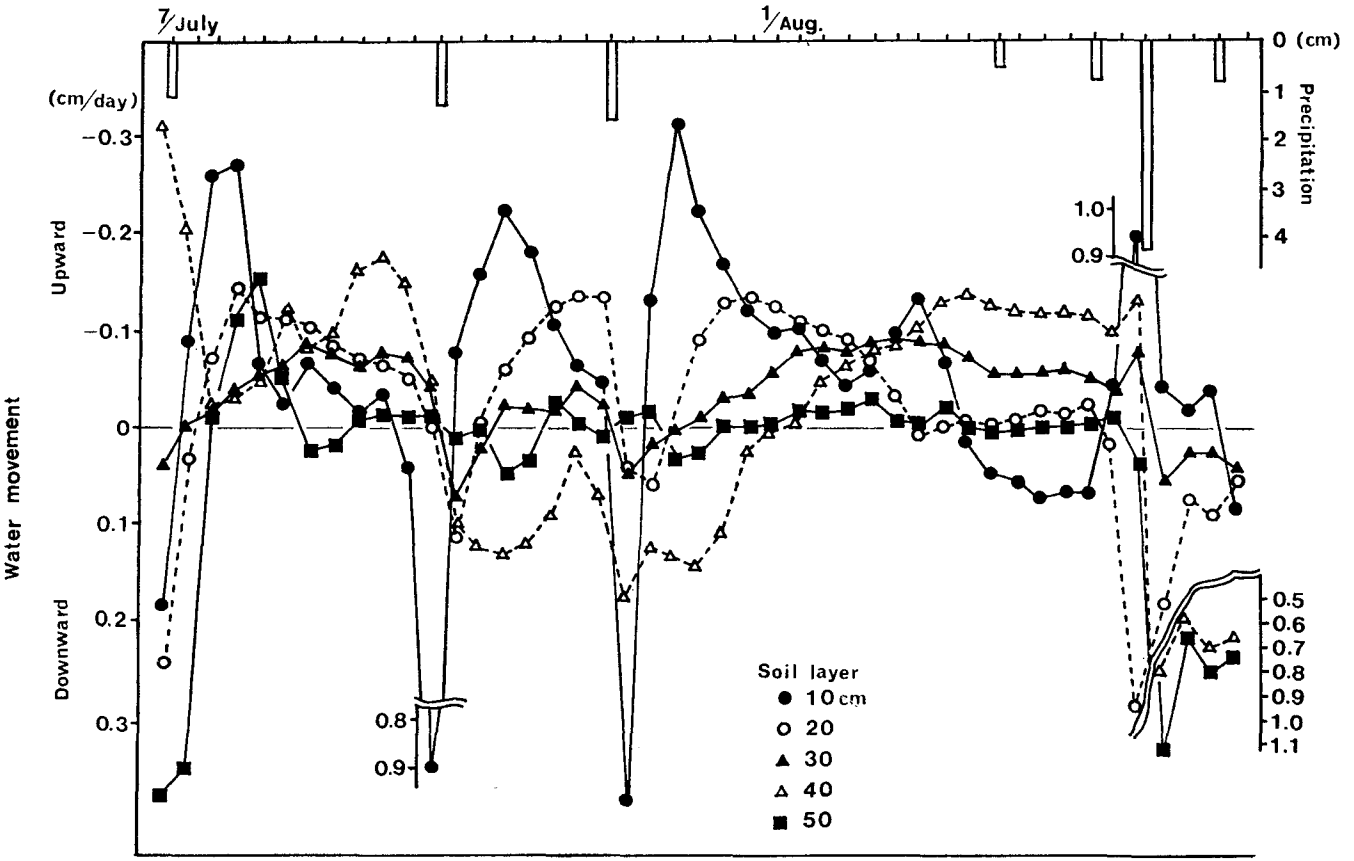

Fig. 14. Successive changes in vertical water movement (bare plot).

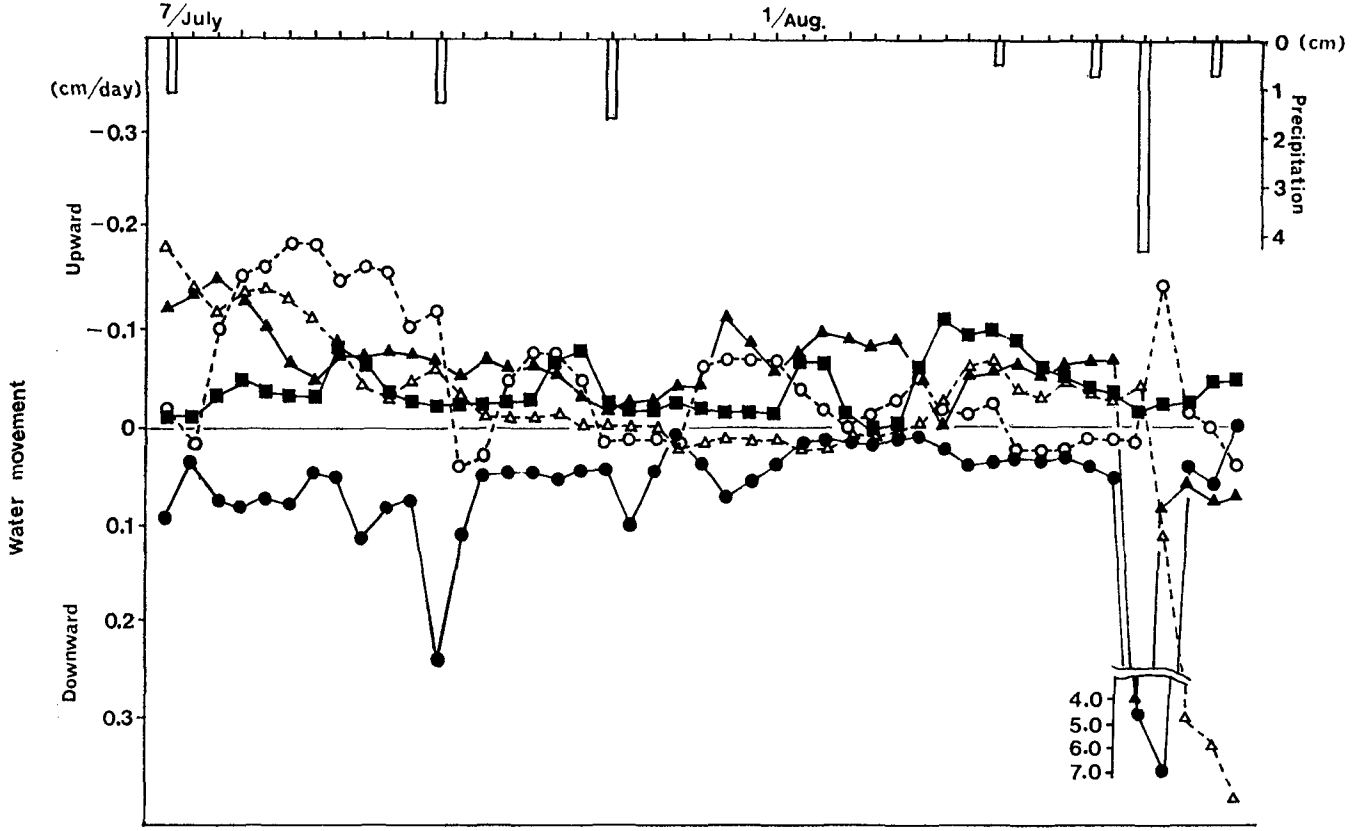

Fig. 15. Successive changes in vertical water movement (planted plot, 200 N, symbols are the same as Fig. 14).

it was difficult to observe the effect of rainfall on the water movement except on 16 August. In 40 or 50 cm depth, water movements were very small in amount.

Discussion

On a nitrogen balance sheet, the main inputs are rain, seeds, fertilizers, biological nitrogen fixation while the main outputs are nitrogen removal by crops, leaching and denitrification. During the present study, accurate values were obtained only for the amounts of fertilizers and nitrogen removal of crops. The outline of the nitrogen balance sheet may be estimated from Fig. 13 which indicates the successive changes of mineral nitrogen within the 50 cm depth of soils and nitrogen accumulation by plants. At the time of seeding, the amounts of mineral nitrogen that existed in soils were about 60, 120, 170 and 280 kg/ha in the 0 N, 50 N, 100 N and 200 N plots, respectively. They nearly equal the values of applied nitrogen plus mineral nitrogen already present in soils.

Mineral nitrogen in soils decreased with the successive growth of plants, as if consumed by plants, because the sum of nitrogen in plants and soils was able to keep its characteristic values throughout plant growth in all the plots, although the final amounts increased to the some extent. Differences between the final and initial amounts were from 40 to 70 kg N/ha and the average was 55 kg N/ha.

It was estimated that 55 kg N was added as an input item besides fertilizers during the plant growth. Most of this input will be considered as the mineralization of soil nitrogen, although we must not neglect the inputs by rain or non symbiotic microbial nitrogen fixation. The mineralization capacity indicates seasonal changes as already mentioned (Table 4) and soils sampled on 23 June were below 50 kg N/ha in capacity. Soils have enough potential to supply 50 kg N/ha by means of mineralization throughout cropping season. In the first sampled soils, the mineralization capacity increased with nitrogen fertilizers, which might be partially due to priming effects and increases of available nitrogen in soils by the fixation of fertilizer nitrogen. Other seasonal changes may depend on drying or wetting effects due to climatic conditions. Of the second sampled soils on a nitrogen balance sheet, decreases in total nitrogen (plants plus soils) were observed. This might be due to denitrification. It has been pointed out that nitrogen losses due to denitrification are nearly 20%[9], though these will depend on overall conditions.

Chlorine also showed the same tendency as the mineral nitrogen, that

is, Cl decreased until 23 June (Fig. 16). Some Cl may be leached out below 50 cm depth. But, afterwards, it again returned to the original level. The NO_3-N, which usually shows the same behavior in soils as Cl, may partially move downward below 50 cm, but it is absorbed by plants or returned to the upper layers, because the distribution of roots within 50 cm depth was about 70%. And as no drainage water was observed below 100 cm depth, leaching losses of N and Cl can be left out of consideration.

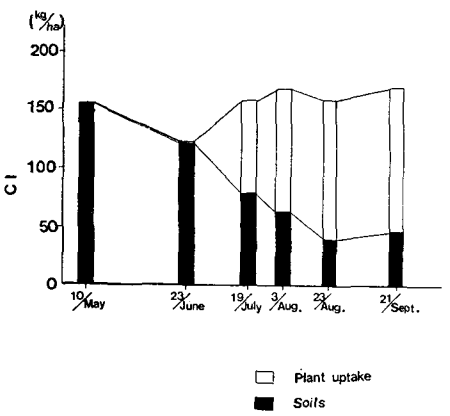

Fig. 16. Trends of chlorine of soils in a depth of 50 cm and plant uptake chlorine with growth.

Convection flow or mass flow has an important role in the distribution of NO_3-N or Cl in soil profiles. NO_3-N and Cl accumulate in the soil surface layer by means of the upwardmovement of water[10]. These phenomena were also observed in the present study. The amount of accumulated Cl in the surface layers was relatively low compared with that of NO_3-N. NO_3-N accumulation in the surface layers may be due not only to the convection flow but also to the mineralization of soil nitrogen in the top soils. This consideration will also be supported by the fact that the water movement in soil layers was relatively small in the plots with crops, compared with that in the plots without crops. Although they differ from one soil layer to another soil layer, corn plants may absorb water and NO_3-N from all the soil layers, thus disturbing the movements of water and NO_3-N in the soils.

It has been necessary to test soils for nitrogen to determine the adequate amounts of fertilizer that need to be added to the fields, but still we do not have an ideal method, because of the complexity of nitrogen behavior in soils. The results obtained here, however, may support the method proposed by Netherland[11] that the amounts of NO_3-N at a depth of 1 m will give us favorable information. The Netherland method says that if 120 kg N are required for plants and if there are 80 kg NO_3-N in the soil, only 40 kg N will have to be added as fertilizers. It seems, in the nitrogen balance sheet obtained here, that NO_3-N in the effective soil layers at sowing time will apparently be consumed by crops successively and their amounts will contribute greatly to the crop growth as nitrogen sources. Therefore, as a rule, the NO_3-N of the soil solution will change cyclically during every crop

season, as we have already mentioned[12].

Summary

The investigation of nitrogen behavior in soils has been carried out to provide some actual data on the nitrogen balance in fields. Corn plants were planted at the University experimental farm. Treatments of fertilization consisted of 0, 50, 100 and 200 kg N/ha. Plant and soil samples were collected for successive stages of plant growth. We investigated trends of mineral nitrogen in soils and plants, the water movement in soils and the mineralization capacity of soil nitrogen. The results obtained were summarized as follows.

1. Dry matter and nitrogen accumulation of the plants increased with the increase of the nitrogen supply. Grain yields were 0.91, 6.50, 8.09 and 10.09 t/ha in the 0, 50, 100 and 200 N kg/ha plots, respectively.

2. The water conditions of soil layers responded to both climatic conditions and plant growth. After rainfall, the downward movement of soil water was observed; thereafter the water movement changed to an upward direction. The fluctuations of the soil water movement were large in the fields without crops. Crops disturbed water movement in the soil layers partly due to the water absorption of the root system distributed in the soil layers.

3. The NO_3-N in the soil solutions moved with the water movement. Dry conditions accelerated the increase of the NO_3-N concentrations in the upper layer with the convection flow, though some of the accumulation of NO_3-N in the upper layer was due to the mineralization of soil nitrogen there, judging from the behavior of Cl movements.

4. The mineral nitrogen contents in a depth of 50 cm at the time of sowing increased proportionally with the increase of nitrogen applied. The initial mineral nitrogen contents in soils, however, decreased with plant growth while nitrogen accumulation in plants increased alternatively just as the decrease of nitrogen in soils would be due to the plant absorption.

5. In the nitrogen balance sheet, 55 kg N/ha on average were added during the plant growth which may be mostly derived from the mineralization of soil nitrogen.

6. Uncountable nitrogen losses were observed in the early growth stages, mostly due to denitrification.

7. The significance of NO_3-N in the effective soil layers as nitrogen sources for plant growth is also discussed.

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