A Role of Subsoil of Paddy Field in Nitrogen Supply to Rice Plants

By SHINICHIRO SEKIYA* and HITOICHI SHIGA**

* Agricultural Chemistry Division, Hokkaido National Agricultural Experiment Station
** Environment Research Division, Central Agricultural Experiment Station

Studies on the subsoil of paddy field have been carried out from the standpoint of soil genesis and classification, water percolation and fertility. Although the latter two are closely related to the rice culture, studies on the fertility aspect are rather few as compared with those on water percolation. However, it has been known that the characteristics of subsoils influence directly the growth of rice plant, when subsoil is mixed with the topsoil by deep plowing or it is exposed by land-levelling. Many reports concerning the deep plowing and ameriolation of exposed subsoil were published. Fertility of subsoil is generally lower than that of topsoil, so that good effects of deep plowing are rather attributable to an increased space for root development and fertilizer placement. When the subsoil is exposed, application of compost and other soil ameliorating matters is desirable to obtain a good crop of rice.

The role of subsoil in nutrient supply has been studied by several workers especially in the high yielding paddy fields. Aomine (1955)[1] and Shiroshita (1958) discussed the fertility of subsoil in relation to the properties of topsoil and estimated that the role of subsoil was rather low in the nutrient supply. Honya (1966)[3] found that an existence of fertile subsoil was a common character in the high yielding paddy fields in Tohoku district, and Shiga et al. (1971)[11] noted the nitrogen supplying ability of subsoil in some high yielding paddy fields in Hokkaido district. Fujimori et al. (1961)[2] reported that the continuous uptake of nitrogen in the late growing stage in a peaty paddy field was due to the root development into the fertile subsoil. Okajima et al. (1973)[5] suggested that the function of subsoil might be very high in the nutrient supply. Nakayama (1968)[4] and Yoshino (1973)[12] stated that the nitrogen supplying ability of paddy fields could not be estimated only by the characteristics of topsoil, and suggested that the role of subsoil in the nitrogen supply should be considered.

Root development into subsoil is necessary to utilize the nutrients in subsoil. It was observed that the root development into subsoil began at the young panicle formation stage, but it was prevented if a compact soil layer existed.

As cited above, many investigators paid attentions to the role of subsoil in nutrient supply. However, almost all of their discussions were based on qualitative estimates. The authors (1975)[6] observed that the uptake of fertilizer nitrogen continued after the disappearance of NH_4-N in the topsoil and the fertilizer NH_4-N accumulated in subsoil in Hokkaido. Based on this finding the authors have continued to investigate the role of subsoil in nitrogen supply to rice plants[6,7,8,9].

Method of experiment

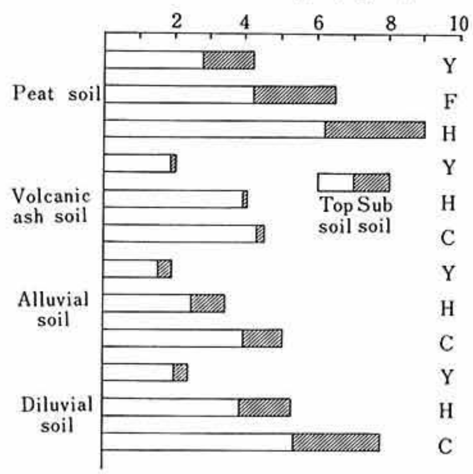
It is difficult to measure directly the amount of nutrients supplied from subsoil under the natural field condition, so that an indirect method was used in this series of experiments.

Namely, the nutrient contribution of subsoil was estimated by the difference in the amount of nutrients absorbed by rice plants between control (natural) plots and topsoil plots. In the topsoil plots, filter paper or tetron made cloth for industrial use was inserted between topsoil and subsoil layers to prevent plant roots from entering into the subsoil. This treatment, however, had no effect on the water movement in the soil column. After removing the topsoil of experimental field, the film was spread above the subsoil and then the topsoil was returned over the film. Both the control plots (without film) and topsoil plots were flooded, fertilized, puddled and transplanted with rice seedlings in the same way as the ordinary cultivation in Hokkaido. Plants were sampled three or four times during the growth period and nitrogen absorbed was determined.

Nitrogen supplying ability of subsoil

Nitrogen supplying ability of subsoil was measured by the use of above mentioned method with paddy fields of different soils including peat, alluvial, diluvial and volcanic ash soils. The characteristics of the soils are shown in Table 1.

Amounts of nitrogen taken up by rice plants are shown in Fig. 1. Although the amounts of absorbed nitrogen in the control plots at the harvesting stage varied with soil types, ranging from 9.0 g/m^2 in the peat soil to 4.5 g/m^2 in the volcanic ash soil, nitrogen supply from the subsoil was recognized in all fields; 3 g/m^2 in the peat soil, 0.2 g/m^2 in the volcanic ash soil, 1.1 g/m^2 in the alluvial soil and 2.4 g/m^2 in the diluvial soil. These amounts correspond to 5–30% of nitrogen absorbed in the control plots. Similar values were obtained in another



Y : young panicle formation stage
F : flag leaf stage
H : heading stage
C : harvesting stage

Fig. 1. Nitrogen absorbed from topsoils and subsoils in paddy fields without nitrogen fertilizer application

Table 1. Characteristics of the paddy soils used

Soil	Layer	Texture	T-C (%)	T-N (%)	NH_4-N*	Percolation
Peat	Top	C L	7.01	0.47	4.16	20mm/day
	Sub	—	11.80	0.77	9.28	
Volcanic ash	Top	C L	4.34	0.31	1.78	24
	Sub	L	2.69	0.20	0.70	
Alluvial	Top	C L	4.12	0.30	2.00	12
	Sub	C L	4.40	0.31	2.78	
Diluvial	Top	LiC	3.39	0.25	2.45	below 3
	Sub	LiC	3.16	0.23	2.55	

*: Nmg/100g dry soil, after incubation at 25℃ for 4 weeks.

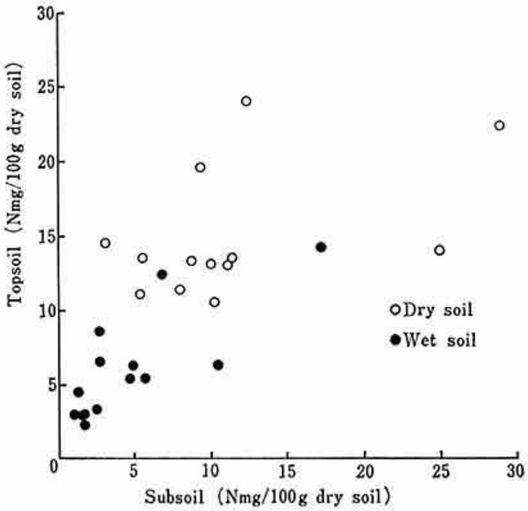


Fig. 2. Relation between the amounts of NH_4-N released from topsoils and subsoils after an incubation (30℃, 4 weeks) under submergence (Nakayama 1968)[4]

experiment using 9 soils (1977).

About 30–40% of total nitrogen of plant were absorbed by the time of young panicle formation stage and 80–90% by the heading stage in the control plots. However, the nitrogen uptake from subsoil took place rather late in the growing period, i.e., the uptake after the young panicle formation stage accounted for 70% or more of the total uptake in alluvial and diluvial soils.

Fig. 2 shows the amounts of NH_4-N released after the incubation of 15 kinds of topsoil and their subsoils under submerged condition[4]. The amount of NH_4-N ranges from 2.1 to 12.4N mg/100 g dry soil for topsoils and from 0.8 to 10.5N mg for subsoils. These values suggest that the nitrogen supplying potentiality of the subsoils is 1/3–2/3 of that of topsoils. However, the nitrogen which can actually be absorbed by rice plants seems to be much less than these values. It might not be appropriate to estimate the nitrogen supplying ability of subsoil by using the same method as used for topsoil, because in the actual cultivation of rice topsoil is mixed well with sufficient amount of water for submerging whereas subsoil is not tilled and puddled usually. On the other hand, the amounts of nitrogen absorbed by rice seedlings which were planted to subsoils, collected from the fields by using a stainless cylinder (ϕ:8 cm, H:10 cm) and used without any treatment except submerging, were highly correlated to the amounts of nitrogen absorbed from subsoils under field condition. This fact indicates that the measurement of nitrogen supplying ability of subsoil has to be done with the subsoil kept under the similar conditions as in a field.

Absorption of fertilizer nitrogen from subsoil

To clarify the absorption by plants of fertilizer nitrogen moved into subsoil, fertilizer nitrogen was applied at three levels (0, 8, 16 gN/m^2) to a volcanic ash soil paddy field, which was well drained and low in nitrogen supplying ability. Using the method consisted of control and topsoil plots, absorption of nitrogen from topsoil and subsoil was determined. The result is shown in Table 2; in which the levels of nitrogen application are indicated as N_0, N_8 and N_{16} respectively. Nitrogen uptake from subsoil was observed in all plots even at 30 days after transplanting. The ratio of subsoil nitrogen to the total nitrogen absorbed reached 20% in N_0-plot, but in fertilized plots rather less amount of nitrogen was absorbed than in N_0-plot. It was related to the difference of root developments among nitrogen levels. However, after 18th of July, the young panicle formation stage, the higher the nitrogen level the more nitrogen was observed from subsoil. The nitrogen uptake terminated by the flag leaf stage in N_0- and N_8-plots, but it continued even after the flag leaf stage in N_{16}-plot. Nitrogen absorbed from 30 days after transplanting to the young panicle formation stage was 0.55 g/m^2 in N_0-plot, 1.03 g/m^2 in N_8-plot and 1.68 g/m^2 in N_{16}-plot, and that from the young panicle formation stage to the flag leaf stage was 0.82 g/m^2 in N_0-plot and 1.13 g/m^2 in N_8- and

Table 2. Nitrogen absorbed by rice plants from topsoils and subsoils at three levels of nitrogen application (Nmg/m²)

N level	Layer	June 28	July 18	August 8	August 28
N_0	Top	0.54	1.98	3.06	4.20
	Sub	0.14	0.69	1.51	1.47
	Total	0.68	2.66	4.57	5.66
N_8	Top	0.82	4.66	6.64	7.79
	Sub	0.08	1.11	2.24	2.20
	Total	0.90	5.77	8.88	9.99
N_{16}	Top	0.93	5.55	9.95	10.83
	Sub	0.12	1.80	2.93	3.95
	Total	1.05	7.35	12.88	14.79

N_{16}-plots, indiacting that a large amount of fertilizer nitrogen was supplied from subsoils in that growth period.

Distribution of NH_4-N in soil column was examined periodically and shown in Fig. 3. Some accumulation of NH_4-N was observed in the 0–5 cm layer of subsoil on 6th of June, about 10 days after fertilization. At the young panicle formation stage, NH_4-N in topsoil decreased while that of subsoil increased, so that the concentration of NH_4-N was reversed between the topsoil and subsoil. Until this stage, the concentration of NH_4-N in soil layers was higher in the fertilized plots, but the difference disappeared in the flag leaf stage. Apparently this pattern of NH_4-N distribution reflects the pattern of nitrogen absorption by rice plants shown above.

Figs. 4 and 5 show the fertilizer nitrogen absorption from subsoil of several soils, including alluvial, diluvial and volcanic ash soil

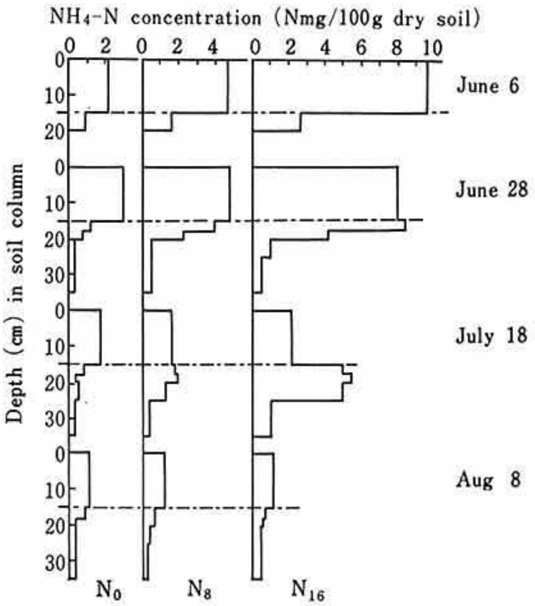


Fig. 3. Horizontal distribution of NH_4-N in paddy fields of N_0, N_8, and N_{16} plots.

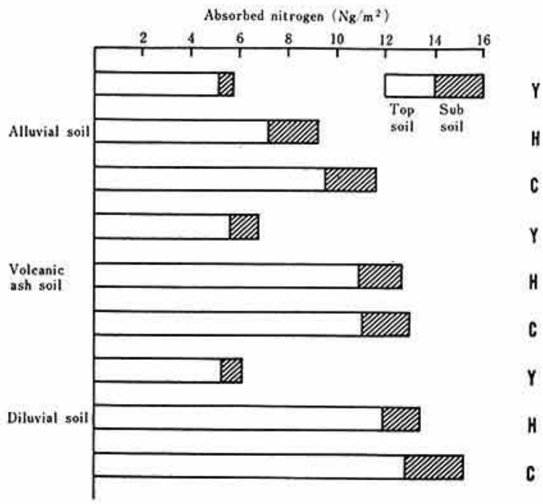


Fig. 4. Total nitrogen absorbed from topsoils and subsoils in paddy fields to which ^{15}N-labelled fertilizer was applied.

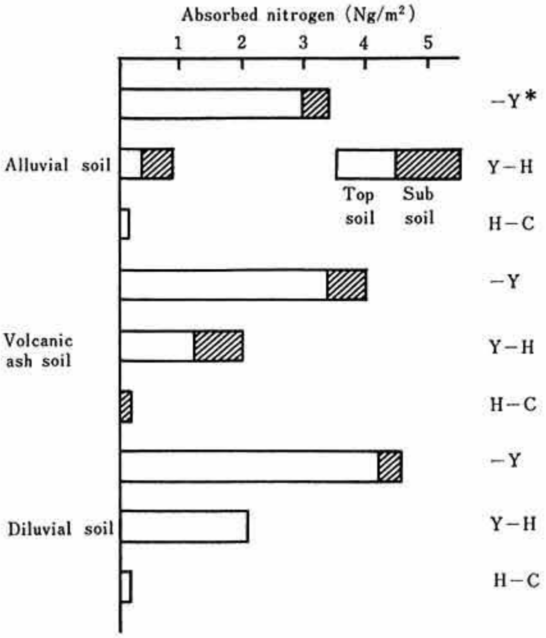


Fig. 5. Fertilizer nitrogen absorbed from topsoils and subsoils in successive growth stage in the experiment shown in Fig. 4.

shown in Table 1. In this experiment, the fertilizer nitrogen was labelled by 3.1% ^{15}N. Both fertilizer nitrogen and soil-bone nitrogen were absorbed from subsoil in all paddy fields, and the nitrogen supplied from subsoils contributed in an average 15% of the total nitrogen absorbed during the whole period from transplanting to harvesting stage. However, differences were observed among the soils: the ratio of fertilizer nitrogen from subsoil to the total fertilizer nitrogen absorbed during the ripening stage was only few percent in the diluvial soil with high nitrogen fertility and low percolation, but it was almost 100% in the volcanic ash soil with low fertility and high percolation.

Fertilizer nitrogen absorbed by the time of young panicle formation stage constituted more than half of the total fertilizer nitrogen absorbed by the time of harvesting in the three paddy fields, but it contained only small amount of fertilizer nitrogen from subsoil. However, during a period from young panicle formation stage to the heading stage, the fertilizer nitrogen from subsoil contributed 40% and 60% of the total fertilizer nitrogen absorbed in that period in the alluvial soil and volcanic ash soil respectively.

Grain yields in the topsoil plots of three paddy fields were 85% of those of control plots.

Thus, it was made clear that the fertilizer nitrogen applied to topsoils moved down by percolating water, accumulated in the subsoil, and was absorbed by rice plants in the later stage with the development of root system into the subsoil.

Conclusion

Results of the present experiments demonstrate clearly that subsoil has a considerable nitrogen supplying ability, and also the fertilizer nitrogen moved down and accumulated in subsoil is absorbed by plants with the root development. Furthermore, it is shown that nitrogen from subsoil is mainly utilized by plants in the middle of growing period by these experiments conducted in Hokkaido. This pattern of nitrogen supply has an important bearing on the growth and yield of rice plants. Number of panicles, dry matter production and yield were reduced in the fields without subsoil, showing an important role of subsoil in nitrogen supply. However, the extent of nutrient supply from subsoil is considered to be different with different paddy fields because of varied characters of subsoil as indicated by soil survey, and of differences in root system development in the subsoils as effected by redox-condition, temperature as well as physical properties of subsoils. Quantitative understanding of this role of subsoil will be useful in knowing the characteristics of nutrient supply of soil to rice plants and in determining the direction of subsoil amendment.

Soil compaction caused by big machines, introduced recently, impedes the percolation of paddy fields and inhibits the developments of root system into subsoil. This is an urgent problem to be investigated in relation to the nutrient supply from subsoil.

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