Effects of Subsoil and Polyolefin-coated Urea Application on Growth and Nitrogen Uptake of Oats and Barley in Andisols

著者	ITO Toyoaki, YAMADA Daigo, SAIGUSA Masahiko
journal or publication title	Tohoku journal of agricultural research
volume	49
number	1/2
page range	25-32
year	1998-09-30
URL	http://hdl.handle.net/10097/30004

Tohoku Journal of Agricultural Research
Vol. 49 No. 1-2, September 1998
Printed in Japan

Effects of Subsoil and Polyolefin-coated Urea Application on Growth and Nitrogen Uptake of Oats and Barley in Andisols

Toyoaki ITO, Daigo YAMADA and Masahiko SAIGUSA

Experimental Farm, Graduate School of Agriculture Science
Tohoku University, Kawatabi Naruko 989-6711, Japan

(Received, July 16, 1998)

Summary

Subsoil, as well as surface soil, is important that it supplies water and nutrients to crops. Applied nutrients easily migrate from surface layer to subsoil by rainfall in the humid regions such as Japan. The objectives of this study are to determine the effects of subsoil on the growth and nitrogen (N) uptake of oats and barley in two representative Japanese Andisols with different clay mineralogy, and the effects of polyolefin-coated urea (POCU), one of the controlled availability fertilizers, on crop growth in soil which inhibits root development in subsoil. Weakly acidic Morioka soil with clay dominated by allophane and strongly acidic Kawatabi soil with clay dominated by 2 : 1 minerals were used in this study. Experimental treatments were surface soil plot where root elongation was limited to surface layer (0-15 cm) and +subsoil plot where crop root can elongate into subsoil (15-60 cm). In both the Morioka and Kawatabi soil, total dry matter and grain yield of oats and barley in +subsoil plots were greater than those in the surface soil plots. The nitrogen uptake of oats and barley in +subsoil plots were 1.7 to 3.3 times greater than those in the surface soil plots. Oats grown on the Morioka and Kawatabi soil absorbed about 70% and 50% of total N from subsoil, respectively. For barley with sensitivity to Al toxicity, the ratios of N absorbed from subsoil to total N in Kawatabi soil (42%) were lower than those in Morioka soil (65%). Barley roots could not extend into deeper subsoil in Kawatabi soil with high toxic Al levels due to the presence of 2 : 1 minerals and low pH. The use of POCU increased growth and the N uptake of oats and barley in each surface soil plot.

Subsoil was important in regard to supplying both fertilizer and soil mineralized N to crops and thus increased crop growth and the grain yield under the humid climate. The contribution of subsoil to crop growth was affected by soil clay mineralogy which is related to soil acidity. The use of POCU was effective for improving crop growth and the grain yield in soil which inhibited root elongation into subsoil.

Subsoil, as well as surface soil, plays an important role in supplying water and nutrients to crops. There have been many studies about the water use of subsoil, which have been mainly studied in dryland area. Applied nutrients, especially nitrate, can easily migrate from surface soil to subsoil by rainfall in humid regions such as Japan, so it appears that subsoil is important for the supply of nutrients that leached from surface soil. The significance of subsoil in nitrogen (N) supply was observed by the studies on the effects of subsoil acidity on the growth and N uptake of crops (1, 2). This study was conducted with the definite depth of surface soil (plow layer) so that the subsoil effects on soil productivity were determined. Andisol is the most important upland soil in Japan and is divided into two types according to its clay mineralogy: allophanic and sonallophanic Andisol. The objectives of this study are to determine the effects of subsoil on the growth and N uptake of oats and barley in two representative Japanese Andisols with special reference to clay mineralogy.

Higher N use efficiency in surface soil is needed to improve crop growth and grain yield in soil that has problem subsoil. Recently, polyolefin-coated urea (POCU), one of the controlled availability fertilizers was deeveloped in Japan (3). A single basal application technique using POCU is labor-saving and shows high recovery of fertilizer N by crops (4). Therefore, the effect of the POCU application on the growth and N uptake of crops in soil inhibiting root elongation into subsoil was also studied.

Materials and methods

The soils used in this experiment were representative Japanese Andisols, one was Morioka soil with clay dominated by allophane, and the other was Kawatabi soil with clay dominated by 2:1 minerals. Morioka and Kawatabi soil was classified into Typic Hapludand and Alic Pachic Melanudand according to *Keys to Soil Taxonomy* (5), respectively. Each of these soils was mixed well and repacked to a depth of 60 cm and was reclaimed by calucium and phosphate amendment in the surface layers. Experimental treatments were surface soil plot and +subsoil plot. In the surface soil plot, root elongation was limited to a surface layer 15 cm thick by fine sheet materials placed at the boundary between the surface soil and the subsoil, in the +subsoil plot, the crop roots can develop into subsoil 45 cm thick. We used oats (*Avena sativa* L. cv. new almighty) and barley (*Hordeum vulgare* L. cv. benkei) as test plants. Nitrogen was applied by ammonium sulfate (AS) at a rate of $10\ \mathrm{g\,N\,m^{-2}}$ as basal fertilizer for oats and barley, and spring topdressing of $4\ \mathrm{g\,N\,m^{-2}}$ was applied only for barley. Phosphorus and potassium were applied as calcium superphosphate ($4.4\ \mathrm{g\,P\,m^{-2}}$) and potassium chloride ($8.3\ \mathrm{g\,K\,m^{-2}}$), respectively. Basal fertilizers were incorporated to surface layer and seeding was conducted by broadcasting. POCU was applied at the rate of 10 and $14\ \mathrm{g\,N\,m^{-2}}$ for oats and barley with single basal application near seeds. The POCUs used in this experiment were three types such as POCU-30, 70, 100. For example, POCU-30 releases 80% of its nitrogen in 30 days at 25°C. POCU-30 and POCU-70 were used for oats with a mixture ratio of 1 : 2, and POCU-30 and POCU-100 for barley with a mixture ratio of 1 : 1. The cultivation experiment was conducted from April 24 to August 7 in 1996 for oats and from November 8 in 1996 to June 24 in 1997 for barley.

Results and discussion

Characteristics of Two Andisols

Table 1 shows some of the properties of the two soils. Morioka and Kawatabi soil was derived from volcanic ash and were classified to Andisols according to *Keys to Soil Taxonomy* (5) because of high active Al and Fe (sum of acid oxalate extractable Al and half of Fe > 2.0). Exchange acidity Y_1 is a good index of the toxic Al level and a remakable inhibition of root growth is observed in soil with Y1 > 6 (6). Morioka soil is weakly acidic and causes no acidic injuries to the roots because the clay fraction is dominated by allophane. The Kawatabi subsoil, however shows very strong acidity with low pH and high exchange acidity at a layer that is 30-60 cm deep because of the clay fraction which is dominated by 2 : 1 minerals. It is a nonallophanic Andisol. The available N and P contents are greater in Kawatabi soil than in Morioka soil. Exchangeable K contents are similar between the two soils.

TABLE 1. *Chemical Properties of Two Soils Used in This Study*

Depth (cm)	O.C. %	pH (H_2O)	Exch. acidity Y_1[1] (ml 100 g^{-1})	Mineralizable N[2] (mg N kg^{-1})	Available P[3] (mg P kg^{-1})	Exch. K (cmol (+) kg^{-1})
			Morioka soil			
0-15	5.2	6.5	0.4	35	196	0.33
15-30	5.0	6.4	0.7	20	138	0.38
30-45	4.5	6.2	0.3	16	39.2	0.24
45-60	4.6	6.2	0.6	8.0	35.3	0.21
			Kawatabi soil			
0-15	9.6	6.5	1.0	37	536	0.55
15-30	8.5	5.8	2.8	35	121	0.30
30-45	8.8	5.1	11	26	65.8	0.17
45-60	8.8	5.0	14	26	—	0.20

1) : Y_1 is expressed as milliliters (0.1 M NaOH) 100 g^{-1}.
2) : Mineralizable N was measured by incubation method for 28 days at 30°C.
3) : Available P was measured by the modified Bray 2 method (soil : solution ratio = 1 : 20).

TABLE 2. *Growth and N Uptake of Oats and Barley at Harvest Time in Surface Soil and +Subsoil Plot with Ammonium Sulfate Application*

	Total dry matter ($g\,m^{-2}$)		Grain yield ($g\,m^{-2}$)		Amount of N uptake ($g\,m^{-2}$)	
	Surface soil	+Subsoil	Surface soil	+Subsoil	Surface soil	+Subsoil
			Morioka soil			
Oats	582	1,378	276	579	4.61	15.3
Barley	757	1,639	314	741	5.68	16.3
			Kawatabi soil			
Oats	688	963	355	369	6.38	12.5
Barley	761	970	365	481	5.44	9.34

Growth and N Uptake in Surffce Soil and +Subsoil Plot

Table 2 shows the total dry matter, grain yield, and N uptake of the plants in two soils at harvest time. Oats and barley grew better in +subsoil plots than in surface soil ones. Total dry matter of oats and barley in the +subsoil plots were 2.4 and 2.2 times greater than those in the surface soil plots in Morioka soil, while they were 1.4 and 1.3 times in Kawatabi soil. Grain yields of oats and barley in the +subsoil plots were 2.1 and 2.4 times and 1.1 and 1.3 times as great as those in the surface soil plots in Morioka and Kawatabi soil, respectively. The reason for less growth in the surface soil plots is that oats and barley grown on surface soil plots could not absorb leached inorganic N in subsoil, and showed a N deficiency. Oats and barley in the +subsoil plots of two soils absorbed 1.7 to 3.3 times N compared to the surface soil plots. It appears that oats and barley more efficiently absorbed both fertilizer and soil-mineralized N in the +subsoil plots than in the surface soil plots.

The contribution of subsoil to barley growth was different between two soils. The dry matter, grain yield, and N uptake of barley in Kawatabi +subsoil plot were about 40% lower than those in Morioka +subsoil plot. As barley is sensitive to Al toxicity (6, 7), these differences seem to be attributed to the inhibition of root elogation toward subsoil in Kawatabi soil. On the other hand, the ratios of Kawatabi +subsoil plot to Morioka +subsoil plot in dry matter and N uptake of oats increased because oats is relatively tolerant to Al toxicity (7). Similar results were obtained using wheat and barley (1) and sorghum (2).

Significance of Subsoil on Supplying N to Crops under Humid Climate

In a humid climate such as Japan, nitrate in surface layer easily migrates downwards with rainfall. Therefore, the subsoil appears to be important in supplying leached fertilizer and soil-mineralized N to crops. In this study, the N supplying ability of subsoil could be estimated by the difference in N uptake

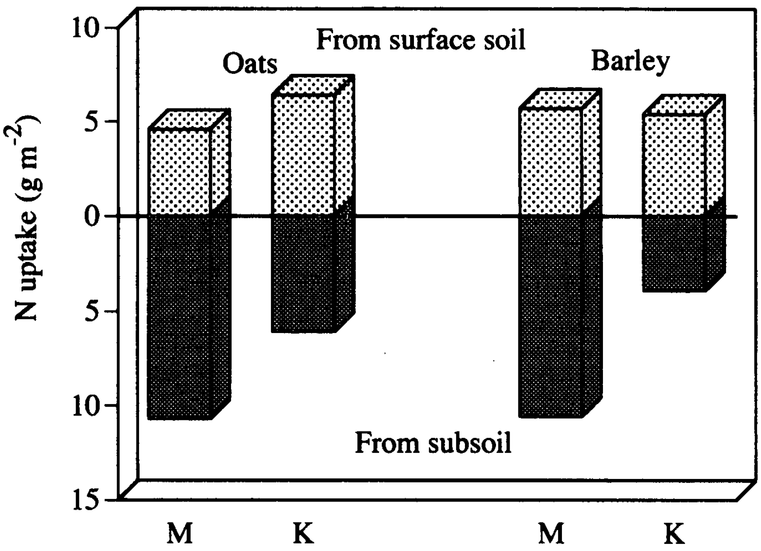

FIG. 1. N uptake of oats and barley from surface soil and subsoil in AS application plots. (M : Morioka soil, K : Kawatabi soil)

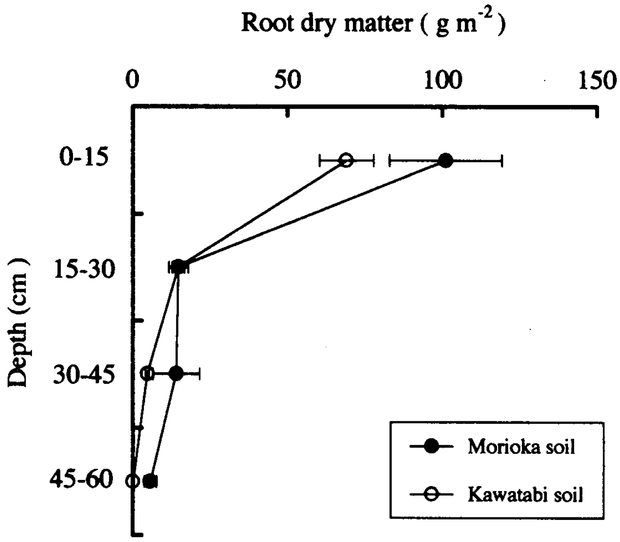

FIG. 2. Root distribution of barley in Morioka and Kawatabi soil. Symbols show means of 4 replications with S.E.

between the +subsoil plot and the surface soil plot. Figure 1 shows the amounts of N absorbed from surface soil and subsoil. Oats absorbed about 70% and 50% of total uptake N from subsoil in Morioka and Kawatabi soil, respectively. For barley, the ratio of N absorbed from subsoil to total uptake in the Kawatabi soil (42%) was lower than that in the Morioka soil (65%). As shown in Fig. 2, barley roots could not extend to deeper subsoil (30-60 cm in depth) in Kawatabi soil because these layers have high toxic Al levels due to major clay with 2 : 1 minerals and low base saturation. Inhibition of root development in the strongly acid subsoil contribute to a low N supplying ability of subsoil. It is clear that subsoil had very important role in supplying leached N to upland crops under humid climate and that the N supplying ability of subsoil varied depending on soil clay mineralogy in relation to soil acidity.

Improving Growth and N Uptake of Crops in Soils Inhibiting Root Elongation to Subsoil by POCU Application

POCU showly and continuously releases its N in response to soil temperature. Figure 3 shows the percentage of N releases of mixed POCUs during the growing periods of oats and barley, which were determined using the buried mesh bag method (8). POCU-30 plus POCU-70 dissolved 58% of its total N at the middle heading time (78 days after seeding) and 72% at harvest time (105 days after seeding) of oats, respectivly. POCU-30 plus POCU-100 dissolved 28% of its total N at early spring (164 days after seeding) and 72% at harvest time (230 days after seeding) of barley, respectively.

The dry matter of oats and barley increased about 20 to 30% with POCU application relative to AS application in each surface soil plot (Table 3). POCU

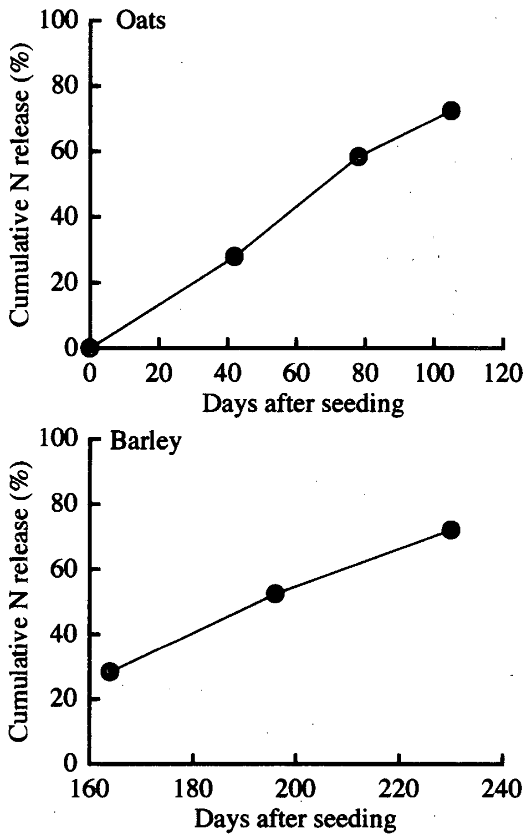

FIG. 3. Cumulative N relase percentage of mixed POCUs during the growing periods of oats and barley.

TABLE 3. *Growth and N Uptake of Oats and Barley at Harvest Time in Surface Soil Plot with AS and POCU Application*

	Total dry matter ($g\ m^{-2}$)		Grain yield ($g\ m^{-2}$)		Amount of N uptake ($g\ m^{-2}$)	
	AS[1]	POCU[2]	AS	POCU	AS	POCU
			Morioka soil			
Oats	582	716	276	346	4.61	8.24
Barley	757	966	314	458	5.68	10.4
			Kawatabi soil			
Oats	688	842	355	373	6.38	10.1
Barley	761	960	365	509	5.44	11.2

1) : Ammonium sulfate
2) : Polyolefin-coated urea

application also increased the grain yields of oats and barley by 25 and 46% in Morioka soil, and by 5 and 39% in Kawatabi soil, respectively. The use of POCU increased the N uptake of oat s and barley by 79 and 83% in Morioka soil, and by 58 and 106% in Kawatabi soil, respectively. The increase in N uptake by POCU application resulted in the improvement of the dry matter and the grain yield for each crop. A single basal application using POCU is more effective for improving crop growth than the conventional use of AS in soil which crop roots can't elongate into the subsoil. The reason is that POCU releases N continuously during the growing period and the crop can more efficiently absorb N supplied by POCU in the surface layer than by AS, which leaches easily into the subsoil with the nitrate form under a humid climate.

Conclusions

Subsoil plays an important role in supplying N to upland crops and in increasing crop growth under humid climate. It is the place where crops absorb fertilizer and soil-mineralized N which migrates from the surface layer and it is likely that crops absorb N mineralized in the subsoil. The contribution of subsoil to crop growth and the N uptake is affected by soil clay mineralogy related to soil acidity. New fertilizer application techniques using POCU are effective for improving crop growth in soil which crop root elongation to the subsoil is suppressed.

References

1) Saigusa, M., Shoji, S. and Sakai, H., The effects of subsoil acidity of

Andosols on the growth and nitrogen uptake of barley and wheat., *Jpn. J. Soil Sci. Plant Nutr.*, **54**, 460-466 (1983)

2) Shoji, S., Saigusa, M., and Goto, J., Acidity of subsoils of Andisols and nitrogen uptake and growth of sorghum., *Jpn. J. Soil Sci. Plant Nutr.*, **57**, 264-271 (1986)

3) Fujita, T., Takahashi, C., Yoshida, S. and Shimizu, H., *United States Patent* **4**, 369, 055 (1983)

4) Shoji, S. and Kanno, H., Use of polyolefin-coated fertilizers for increasing fertilizer efficiency and reducing nitrate leaching and nitrous oxide emmissions., *Fert. Res.*, **38**, 147-152 (1994)

5) Soil Survey Staff, *Keys to Soil Taxonomy, Seventh Edition*, United States Department of Agriculture, Natural Resources Conservation service, Washington, D.C. (1996)

6) Saigusa, M., Shoji S. and Takahashi, T., Plant root growth in acid Andosols from Northeastern Japan. 2. Exchange acidity Y1 as a realistic measure of aluminum toxicity potential., *Soil Sci.*, **130**, 242-250 (1980)

7) Tanaka, A. and Hayakawa, Y., Comparison of tolerance to soil acidity among crop plants. Part 2. Torelance to high levels of aluminum and manganese. —Studies on the comparative plant nutrition—. *Jpn. J. Soil Sci. Plant Nutr.*, **46**, 19-25 (1975)

8) Gandeza, A.T., Shoji, S., and Yamada, I., Simulation of crop response to polyolefin-coated urea: I. Field dissolution., *Soil Sci. Soc. Am. J.*, **55**, 1462-1467 (1991)