Soil Amendment and Fertilizer Application Improvement in Upland Fields of Red and Yellow Soils in Japan

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Cultivated lands of Red and Yellow Soils are distributed in the area extending westwards from the Tokai district in Honshu (the main island), and on plateaus or terraces in Shikoku and in northern Kyushu, with a total acreage of more than 400,000 ha, and are being utilized in many cases as upland fields or tree crop fields. From the viewpoint of soil productivity, this soil group is called as mineral soil in Japan, in contrast to Ando soils or Volcanic Ash Soils, and is generally less productive due to its many adverse factors. To increase the productivity, much efforts on soil amendment and fertilization improvement have been made so far.

Characteristics of Red and Yellow Soils of Japan

Major characteristics of Red and Yellow Soils, particularly in contrast to Volcanic Ash Soils in Japan, are as follows:

Firstly, low humus content in plow layer, usually less than 5% and largely less than 2%.

Secondly, great bulk density, usually higher than 1.0 g/ml (more than 40% in ratio of solid phase) even with relatively soft plow layers.

Thirdly, composition of clay minerals is mostly crystalline minerals, with those of 1 : 1 type in many cases.

Forthly, most of the virgin soils (uncultivated) show strong acidity, as a result of leaching of bases under humid climatic conditions.

The soil texture ranges widely from coarse to fine.

Of the physical, chemical and biological properties derived from the above characteristics, the followings are regarded to be closely related to the productivity:

As to the physical properties, pore space is less, due to higher ratio of solid phase. Particularly as the macro-pores with pF values lower than 1.5 are quite less, air- and water-permeability are poor. As the field capacity is also small, available water is less. Particularly, the compact subsoils, with bulk density of more than 1.3 g/ml (50% in ratio of solid phase) and the underdeveloped soil structure aggravate the defects related to water- and air-supply. In addition, the hardness of the soil prevents root elongation. There is also a difficulty in using agricultural machines: a narrow soil moisture range fitted to crushing, land preparation, and running of machines, together with the poor drainage, causes a serious limitation on the use of machines.

The virgin soils are highly acidic with low degrees of base saturation. Even the cultivated lands have a pronounced tendency to become acidic. Cation-exchange capacity (CEC) is generally low, showing less than 10 in many cases, due to low humus content and the 1 : 1 type clay minerals. Total nitrogen content is low, and mineralized nitrogen release is also less, although carbon-nitrogen ratio (C/N) is lower than that of Volcanic Ash Soils. As the virgin soils have very low content of total phosphate, but their phosphate absorption coefficients are mostly less than 500, with less than 1,000 at the highest, it is easy for cultivated soils to accumulate available phosphate. The supplying capacity of potassium is greater than that of Volcanic Ash Soils. Micronutrients tend generally to be deficient due to the tendency of soil to acidify and by heavy leaching.

As to the activities of microorganisms, significant differences from that of Volcanic Ash Soils have not been recognized, when compared in terms of that per given amount of soil. However, when compared per unit amount of carbon, as the substrate, the Red and Yellow Soils show higher activities with a rapid decomposition of added organic matter, resulting in less accumulation of organic matter residues.

Major methods for improvement

Amelioration of soil acidity: This is of primary importance in amending Red and Yellow Soils. Application of liming materials is customarily practiced. Remarkable production decreases occur without the use of liming materials. For example, an experiment conducted in a reclaimed land demonstrated that the yield of wheat, which is regarded as resistant to soil acidity, in a plot without lime application since the beginning of the reclamation was about half of that with lime application, as given in Table 1[1]. Even in a field already under cultivation, continuous cropping of naked barley, susceptible to soil acidity, without lime application resulted in a continued decrease in yield, leading to no yield after 7–8 years, as shown in Fig. 1[2].

Amount of liming materials required are usually calculated by the buffer-curve method, degree of base saturation or soil acidity. In case of Red and Yellow Soils, 3.5 times of exchange acidity, Y_1, corresponds nearly to the total acidity, so that the amount of lime required to neutralize the total acidity per unit area can be calculated. The application of liming materials corresponding to that amount is nearly adequate in most cases.

Supply of phosphate: Originally the phosphate content in Red and Yellow Soils is very low so that the fertilizer response for phosphate is very high during a initial period after reclamation. However, in mature fields no apparent effect of phosphate application is observed, because applied phosphate has been

Table 1. Effects of liming on reclaimed land of Red and Yellow Soils

Treatment	Yield of wheat kg/a (%)			Soil acidity after three-year croppings	
	First year	Second year	Third year	pH (H_2O)	Exchange acidity Y_1
No liming	18.3 (53)	12.6 (59)	18.4 (68)	5.2	10.3
Liming*	34.3 (100)	23.7 (100)	28.6 (100)	5.9	0.1

* $CaCO_3$ (about 50 kg per are) applied in the first year.

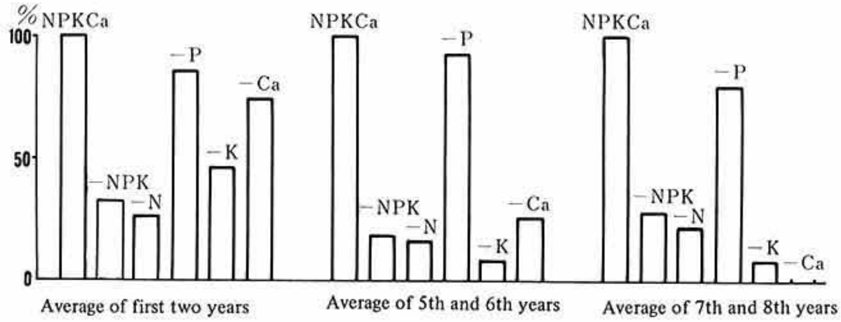


Fig. 1. Yields of naked barley in a three elements experiment on Red and Yellow Soils (Cultivated field)

Note: Yield of NPKCa plot is taken as 100.

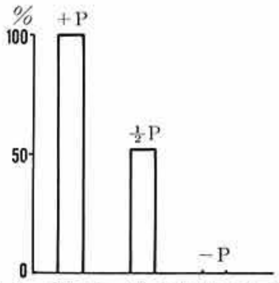


Fig. 2. Yields of wheat in an experiment on phosphate effect on Red and Yellow Soils (Newly reclaimed land)

accumulated in the soil in an available form to reach an enough level, due to the low phosphate absorption coefficient of the soil. As shown in Fig. 2, no yield was obtained without phosphate application in a newly reclaimed land, while a three elements experiment in a mature field showed that the yield of naked barley without phosphate application continued to be close to that with phosphate application for more than 10 years, as given in Fig. 1[2]. For reclaimed lands or for cultivated fields deficient of phosphate, it is necessary to bring up the available phosphate content to a level higher than 10 mg/100 g of soil by applying a large amount of phosphate, as a soil amending material, at a time.

Supply of organic matter: This is of prime importance because of the low content of organic matter in the soil, that causes many limiting factors for production. As given in Table 2, as an example[3], it has been confirmed that the application of organic matter exerts good effects on almost all factors constituting soil productivity. Particularly with Red and Yellow Soils, an increased nitrogen supplying capacity and an improved physical properties of soil caused by organic matter have been recognized as of great significance. Another way to expect the similar effect is the cultivation of crops: even with virgin soils extremely low in nitrogen and carbon contents, an increase in the contents occurred to some extent after 1–2 croppings. With the common crops, however, the contents were stabilized at low levels without further increase, whereas the cropping of grasses caused a marked increase.. As given in Fig. 3, it was confirmed that the mixed cropping of ladino clover and orchardgrass caused a marked increase in productivity of Red and Yellow Soils. A main reason for that was analysed to be an increased capacity of the soil to supply inorganic nitrogen[4].

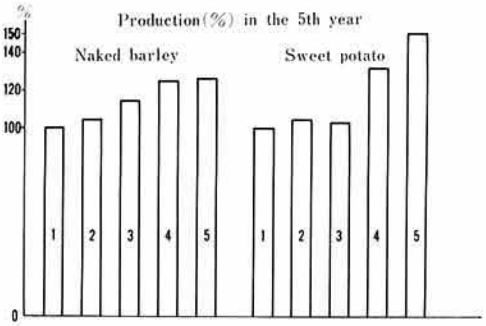
Deep tillage and subsoil plowing: These practices are very advantageous as poor subsoil

Table 2. Effects of organic matter application on the soil properties*

Organic matter	Soil layer	Inorganic-N mg/100g A-N	N-N	Sum.	Available P_2O_5 mg/100 g	E. C. (1 : 2.5) μ℧/cm	Exchange base m. e. Ca	Mg	K	pH (H_2O)	Exchange acidity Y_1	T-C %	T-N %
Non-applied	Plow layer	1.23	1.14	2.37	32.3	92	6.5	1.6	0.8	6.6	0.0	1.26	0.104
	Subsoil	0.62	0.62	1.24	2.8	113	4.5	1.5	0.1	5.9	0.6	0.96	0.070
Applied*	Plow layer	2.02	0.76	2.77	31.3	130	6.8	1.6	0.7	5.8	0.3	2.61	0.186
	Subsoil	1.11	0.76	1.81	11.3	134	6.2	1.6	0.2	5.9	0.3	1.54	0.102

Organic matter	Soil layer	Mineralized N in 14 days mg/100 g	Mineralized C in 14 days mg/100 g	CEC	Volume of solid phase %	Vol. of liquid phase at pF 1.5 %	Vol. of gaseous phase at pF 1.5 %	Crumb (1 mm<) %
Non-applied	Plow layer	3.24	27.8	10.0	44.7	20.3	34.8	43.8
	Subsoil	−0.8	34.4	7.7				
Applied*	Plow layer	5.77	41.2	12.2	41.7	21.9	36.4	51.1
	Subsoil	−1.0	59.2	10.2				

* After eight successive croppings with 200 kg/a of sewage sludge applied for each cropping.



Notes 1. Check (successive cropping of naked barley-sweet potato (B-S)).
2. Grass cropping for 1 year before B-S cropping for 4 years.
3. Grass croppings for 2 years before B-S croppings for 3 years.
4. Grass croppings for 3 years before B-S croppings for 2 years.
5. Grass Croppings for 4 years before B-S cropping for 1 year.

Fig. 3. Effects of grass croppings on soil productivity

often impedes productivity in Red and Yellow Soils. For example, studies[5,6,7] on the effect of different methods of tillage by machines on the soil productivity demonstrated that the effectiveness was in the order of tractor with plow and disk harrow>tractor with rotary tiller>power tiller of rotary type, i.e., the deeper the depth of tillage, the higher was the yield of wheat, naked barley, Chinese cabbage, and Japanese radish, etc. and the effectiveness became more conspicuous year after year. This was due to the fact that the entire subsoil layer down to the depth of tillage has been improved to the state similar to top soil by repeating yearly deep tillage and application of soil amending materials and organic matter. Deep tillage practiced only once is mostly ineffective. Although the subsoil plowing is also effective, it is not often employed due to lack of convenient method.

Points of fertilizer application to Red and Yellow Soils

Crops are generally most sensitive to nitrogen, being liable to be influenced by its deficiency or excess. Nitrogen in upland soils is easily changed to nitrate-nitrogen and leached away. Particularly in Red and Yellow Soils with greater leaching and less mineralization of nitrogen, the nitrogen deficiency often occurs. Therefore, the problem of nitrogen application is most important. In a three elements experiment shown in Fig. 1, remarkable yield decreases were observed in the -N plot. The yield decrease was severe with naked barley and vegetables, though it was not so with sweet potato which requires less nitrogen.

As to the method of nitrogen application, it is necessary to maintain the optimum concentration of inorganic nitrogen in the soil at each growth stage of crop plants, in addition to the supply of necessary amount which crop plants require. For example, in case of cabbage, it was proved that the most rational method of nitrogen application is to

Table 3. Effects of plowing at different depths on yields of crops

Method of plowing	Yields in %, taking the yield of the first plot as 100					
	1st year H_1 ryegrass	2nd year Wheat	3rd year Wheat	4th year Naked barley	5th year Chinese cabbage	6th year Japanese radish
Power tiller rotary type (plowing depth, 12 cm)	100	100	100	100	100	100
Tractor with rotary tiller (plowing depth, 18 cm)	108	105	116	121	110	109
Tractor with plow and disk harrow (plowing depth, 25 cm)	95	107	131	128	128	112

Note: Up to fourth year each plot had been plowed at different depths, after that all plots were plowed by power tiller uniformly.

supply a minimum amount of basic dressing which is just enough to keep the optimum concentration of inorganic nitrogen for the early growth stage, about 20 mg of N/100 g of soil, within a narrow width of soil around plants in order to minimize the leaching loss, and then supply enough amount of top dressings during the middle and late growth stages requiring more nitrogen[8].

As to the phosphate, phosphatic materials are used to amend the soil. When the content of available phosphate has reached the enough level, it is sufficient in general to compensate the amount absorbed by plants. The same is applied to potassium.

It is always necessary to pay attention on micronutrients because their deficiency, especially of Mg, B, and Mo, tends to occur.

Conclusion

To increase productivity of upland fields of Red and Yellow Soils, it is inevitable to apply liming materials, phosphatic materials and organic matters, and furthermore deep tillage or subsoil plowing and the consideration to the soil conservation are needed.

Of fertilizer elements, nitrogen is most influential to growth and yield of crops, and the factor which determines the effectiveness of applied nitrogen to the greatest extent is the leaching associated with heavy rains. Therefore, ammonium nitrogen, which is less liable to be leached, is usually more effective than nitrate nitrogen when used as the basal dressing, irrespective of the preference of crop plants to either form of nitrogen. It is also very useful to adopt cultural methods which prevent leaching, such as mulching and ridging, and also fertilizer formulations which minimize leaching, such as slow release fertilizers, fertilizers containing nitrification inhibitors, coated fertilizers or ball fertilizers.

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