PERFORMANCE OF CROPS ON SOILS LOW IN pH AND PHOSPHORUS

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Introduction

In Japan the major portion of agricultural lands was on soils derived from alluvium because lowland rice was the most important crop. In the 1950s rice areas were expanded to terraces because of serious food shortage consecutive to the 2nd World War. Production of upland field crops and pastures for cattle has also been intensified on terraces, hills and at the foot of mountains in more recent years. Soils in these areas are more acidic than those in alluvial areas due to higher leaching of cations from the soil. A large portion of these areas is covered with volcanic ash soils which are generally low in available phosphorus. Thus, acidity and characteristics related to phosphorus availability of soils, especially volcanic ash soils, have been intensively studied by soil scientists and plant nutritionists in Japan (Ishizuka and Black, 1977).

In the humid tropics, a large portion of potential agricultural areas is covered with highly weathered soils which are acidic and low in available phosphorus. Although these areas are very low in fertility, they can be reclaimed for crop production if soils are properly ameliorated, because availability of water is rather favorable.

For the amelioration of such soils the technology used to improve acid soils in Japan may be useful.

Characteristics of acid soils

In Table 1 characteristics of some acid soils in Japan are given (unpublished data obtained by Hitsuda). These soils differ from each other:

Hachirogata soil is an acid sulfate soil, very acidic, with a large cation exchange capacity (CEC), and high in cations due to the influence of brackish water in the past. Teshio soil is a peat soil, with a large CEC due to a high organic matter content, and relatively high in cations although low in base saturation degree. Kuromatsunai soil is a volcanic ash soil and Makinogahara soil is a red-yellow soil. These have a moderately large CEC and low base saturation degree.

Responses to liming and phosphorus application are good in all these soils, and responses to potassium or magnesium are also observed in many cases (Fig. 1). All these soils have a high phosphorus absorbing power. Thus, liming as well as heavy application of phosphorus have been practiced by farmers to ameliorate newly reclaimed fields on volcanic ash soils, red-yellow soils, and also peat soils.

Characteristics of soils in the humid tropics are somewhat different from those of above-mentioned acid soils in Japan. Generally speaking in these soils the amount of exchangeable cations and the phosphorus absorbing power are lower (Table 1), the CEC is smaller at near neutral pHs and is more stable against pH changes, and the anion exchange capacity (AEC) is smaller (Matsumiya *et al.*, 1980). These characteristics indicate that the soils in the humid tropics are generally more weathered due to high temperature and heavy rain than the soils in Japan. Some acid soils in southern Japan, such as the yellow-brown forest soils (Saijo soil) or yellow soils (Iriomote soil), however, have similar characteristics to the soils in the humid tropics.

Although there are differences among acid soils, the limiting factors of these soils to crop growth are common. Crops on acid soils suffer frequently from (i) aluminum toxicity (sometimes

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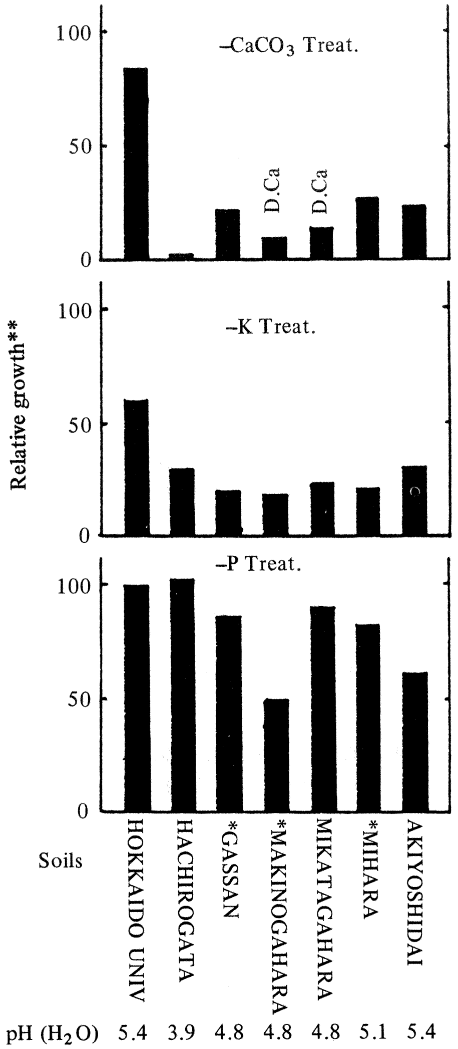

Fig. 1 Relative yield with –CaCO$_3$, –P, –K treatments.
(Average of barley and oat).
*** Mg deficiency symptoms were observed in the complete plot.**
**** The dry weights in the complete plot are taken as 100.**

manganese toxicity), (ii) phosphorus deficiency, and/or (iii) deficiencies of one or more cations or micro-elements.

In a field of Hokkaido University (Sapporo soil in Table 1) nine treatments were established after uniform application of ammonium sulfate and potassium sulfate by combining three pH treatments (4.6, 5.3 and 6.0, which were obtained by liming) and three levels of phosphorus application (0, 150 and 1500 kg P_2O_5/ha as superphosphate; equivalent to 0, 1 and 10% of the phosphorus absorbing power, respectively) (Hitsuda and Tanaka, 1980). Concentration of aluminum in the soil solution was high at pH 4.6 but was low at pHs 5.3 and 6.0, and increased with the increase of phosphorus application significantly at pHs 4.6 (Fig. 2). Concentration of phosphorus in the soil solution did not change significantly at phosphorus levels between 0 and 150 kg P_2O_5/ ha but increased with an increase from 150 to 1,500 kg P_2O_5/ha, and was higher at pH 4.5 than at

Table 1 Chemical properties of some acid soils in Japan and in the tropics

Soils			pH 1)	Exchangeable2)			CEC2)	Base3) saturation	Al4) saturation	Soluble5) Al	P 6) absorption
Place	Country		(H_2O)	Ca	Mg	K		(%)	(%)	(mg/100g)	power
				meq /100g							
Kuromatsunai	(Japan)	(Volcanic ash soil)	5.4	2.33	1.07	0.36	21.8	19.1	48.4	268	1540
Teshio	(Japan)	(Peat soil)	4.6	7.35	1.42	0.85	49.0	21.6	–	–	1410
Makinogahara	(Japan)	(Red-yellow soil)	4.6	0.29	0.18	0.21	21.7	3.8	82.8	153	1190
Hachirogata	(Japan)	(Acid sulfate soil)	4.0	24.7	13.0	3.99	53.1	89.9	21.6	57	1740
Sapporo	(Japan)	(Brown forest soil)	5.0	11.5	2.36	0.67	38.0	38.7	25.9	113	1380
Saijo	(Japan)	(Yellow-brown forest soil)	4.8	0.21	0.17	0.23	11.4	5.5	73.0	83	470
Iriomote	(Japan)	(Yellow soil)	5.2	0.16	0.25	0.19	7.5	9.1	69.0	48	377
Seputih-banyak	(Java)	(Red-yellow podzolic soil)	4.6	0.22	0.11	0.11	6.2	7.1	77.9	78	484
Carimagua	(Colombia)	(Oxisol)	4.5	0.26	0.10	0.16	6.7	8.7	83.2	79	730
Santander	(Colombia)	(Ultisol)	4.2	0.51	0.17	0.21	11.0	8.9	83.7	136	1270
Botucatu	(Brazil)	(Red-yellow latosol)	4.5	0.02	0.03	0.05	4.6	2.2	72.5	10	148

1) pH of soil:water = 1:2.5 suspension.
2) Schollenberger method (1M CH_3COONH_4 at pH 7, successive extraction).
3) (Exchangeable Ca + Mg + K + Na)/CEC (Schollenberger method).
4) (Exchangeable Al + H)/(Exchangeable Al + H + Ca + Mg) (by Soil:1M KCl = 1:5 extraction, 30 min shaking).
5) Soil:1M CH_3COONa (pH 4) = 1:40 extraction, 3 hr. shaking.
6) Amount of P absorbed by soil (mg P_2O_3/100g) Soil:2.5% ammonium phosphate (pH 7), 24 hours.

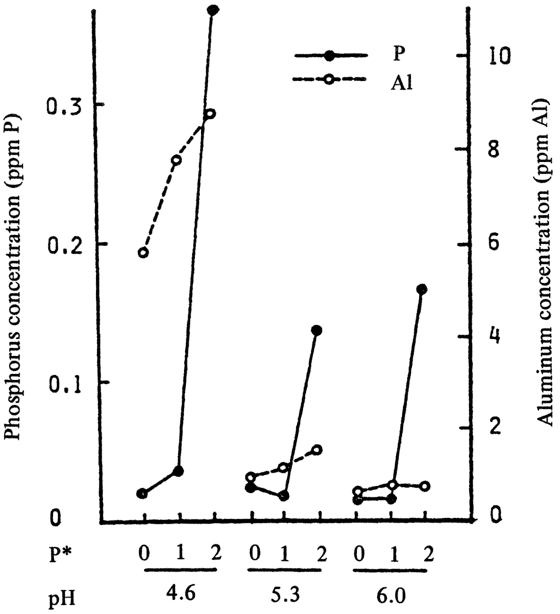

Fig. 2 Concentrations of aluminum and phosphorus in the soil solution at various treatments. *1 & 2 are 150 and 1,500 kg P_2O_5/ha, respectively.

pHs 5.3 and 6.0 at 1,500 kg P_2O_5/ha.

Analysis of the soil solution of more than 30 acid soils collected from Japan as well as from the humid tropics demonstrated that the aluminum concentration in the soil solution was low at pHs above 5 and started to increase by a decrease of pH below 5 (Fig. 3). A similar tendency was also observed by adjusting the pH of the Teshio soil and soils of similar nature with $CaCO_3$ or $CaSO_4$ (Tanaka and Hitsuda, 1980). These data demonstrate that aluminum toxicity can be anticipated only when the soil pH is below 5.0.

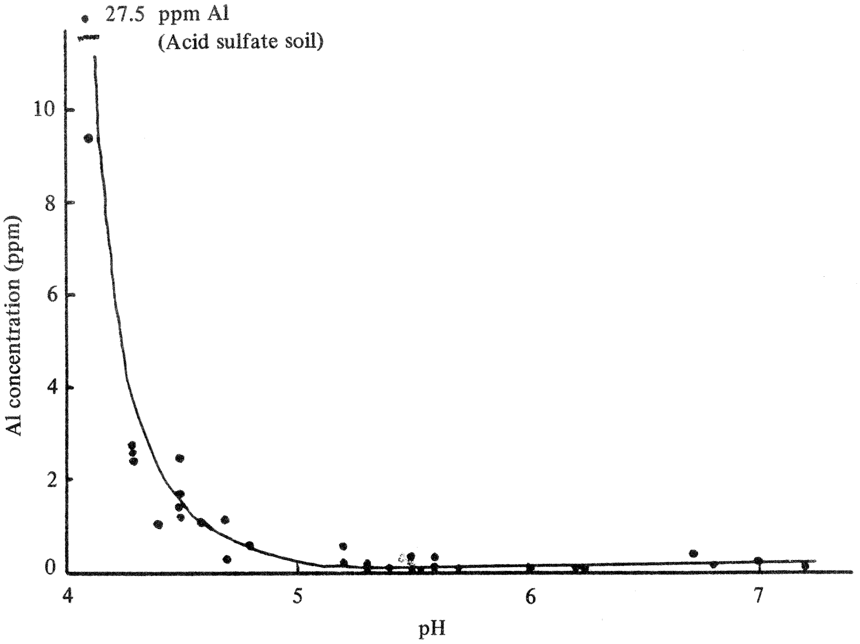

Fig. 3 **Relation between pH and aluminum concentration of the soil solution of various soils.**

Phosphorus concentration in the soil solution can be considered as the phosphorus supplying power of the soil because it indicates the phosphorus supplying intensity and is maintained at a reasonably constant level during plant growth in soils with a high phosphorus absorbing power. Data collected on more than 30 soils, as mentioned above, demonstrate that there is a positive correlation between the soluble aluminum content and phosphorus absorbing power, although paddy soils or acid sulfate soils have a higher phosphorus absorbing power than expected from the soluble aluminum content, probably because in these soils iron compounds which absorb phosphorus are more abundant than in other soils. The phosphorus concentration of the soil solution appears to be governed by the systems of aluminum compounds at low pHs, and it does not neccessarily become lower with a decrease of the pH (Fig. 2).

Acid soils, especially highly weathered acid soils, have a small CEC, low base saturation degree, low AEC, and also small water holding capacity. As the potassium or magnesium deficiencies are frequent, applications of these essential elements are necessary. Nitrogen application is also indispensable. When fertilizers, which contain NH_4^+, K^+ or Mg^{++} as sulfate or chloride, are applied to these soils, these ions remain in the soil solution at high concentrations rather than absorbed by the soil particles (Table 2) (Tanaka and Nunozawa, 1981) Thus, there are problems of retarded crop growth due to excessive ion concentration in the soil solution just after fertilizer application and also depletion of nutrients at later growth stages due to quicker removal of nutrients from the soil by leaching and absorption by crops.

Table 2 Composition of the soil solution of Iriomote soil and Kuromatsunai soil one week after incubating 2-liter soil with 300 mg each of N and K_2O as ammonium sulfate and potassium sulfate, respectively, at moisture content of the field capacity without and with $CaCO_3$ application

Soil	$CaCO_3$	NH_4-N	NO_3-N	K	Ca
		(ppm)			
Iriomote	–	69.5	trace	21.6	9.3
	+	27.7	1.1	5.5	19.9
Kuromatsunai	–	3.5	0.04	3.0	1.3
	+	0.7	2.96	2.6	10.7

Tolerance of crops to adverse factors of acid soils

There are differences in the performance on acid soils among crop species. In a field of Hokkaido University plots with a soil pH of 4.5 and pH 6.5 were established by applying H_2SO_4 and $CaCO_3$, respectively; both plots received adequate amounts of nitrogen, phosphorus and potassium; about 50 crop species were grown in these two plots; and the tolerance to soil acidity was compared among these crops by the relative value of growth at pH 4.5 to that at pH 6.5 (Tanaka and Hayakawa, 1975). Generally speaking species belonging to Cucurbitaceae, Solanaceae, Compositae, Umbelliferae and Chenopodiaceae are susceptible, those belonging to Leguminosae are intermediate, and those belonging to Gramineae are tolerant, although there are exceptions. Based on these data crop species are classified into five groups depending upon the tolerance to soil acidity (Fig. 4). The degree of tolerance to soil acidity is almost parallel with the tolerance to aluminum toxicity (except *Luffa cylindrica*) rather than with the tolerance to low pH per se or to manganese toxicity which is evaluated under water culture conditions. Thus, it appears that the tolerance to soil acidity is due mostly to the tolerance to aluminum toxicity.

Among crop species, there are also differences in the performance at low phosphorus levels in the growth media. A water culture experiment demonstrated that rice, maize and Azuki bean were more adapted to low phosphorus conditions than sugarbeet, tomato, and Chinese cabbage (Fig. 5). Such differences are controlled mainly by (i) the tolerance to low phosphorus content in the plant, and partly by (ii) the root size and (iii) the phosphorus absorbing power per unit root weight (Tadano and Tanaka, 1980). Under soil culture conditions the root size plays a more important role in the adaptability to low phosphorus conditions.

These results demonstrate the importance of selection of adequate crop species to economize the cost of soil amelioration. Such differences exist not only among crop species but also among varieties of a given species. Thus, intensive efforts are being made to breed varieties which are more tolerant to aluminum toxicity or more adapted to low phosphorus conditions. However, it is impossible to obtain a cultivar which gives a high yield without an essential element. Thus, such efforts are limited and should be combined with soil amelioration at certain levels.

The tolerance to aluminum toxicity is not necessarily parallel to the adaptability to low phosphorus conditions. Availability of phosphorus of a soil is not related to soil acidity in a simple manner. Thus, the priority given to liming or phosphorus application in ameliorating acid soils

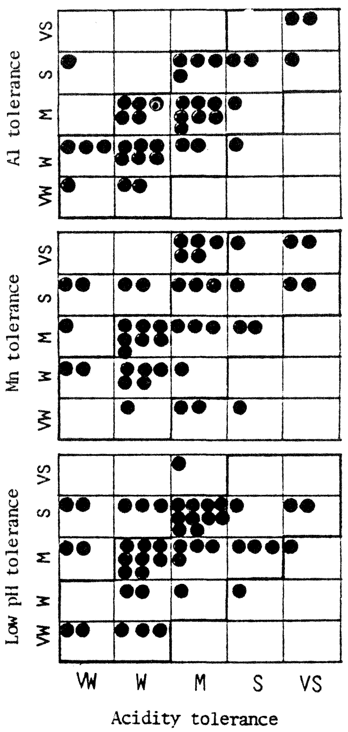

Fig. 4 Relation between tolerance to soil acidity and tolerance to Al, Mn or low pH. VW: very weak, W: weak, M: medium, S: strong, VS: very strong.

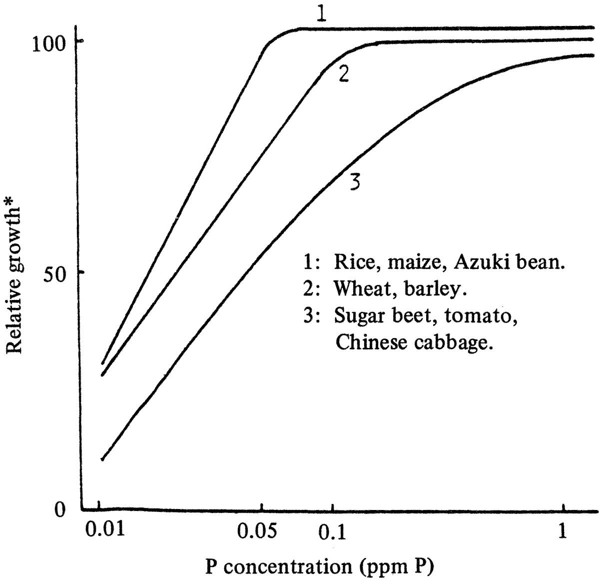

Fig. 5 Diagram showing growth response of various crop species to P concentration in culture solution.
* The dry weights at 1 ppm P are taken as 100.

depends upon the nature of crop species or varieties to be grown and also upon the nature of soils.

On the nine plots established by applying graded amounts of lime and phosphorus, several field crops, which differ in their tolerance to aluminum toxicity and adaptability to low phosphorus conditions were grown (Hitsuda and Tanaka, 1980). In oats (tolerant to Al toxicity) the response to liming was low and the response to phosphorus was high even without liming, whereas in barley (susceptible to Al toxicity) the response to liming was remarkable and response to phosphorus was observed only after liming (Fig. 6). Behavior of soybeans and sugarbeet was somewhat similar to that of oats and barley, respectively.

In the next year after the experiment with field crops, various forage crops were planted in these nine plots. In the 1st cutting the responses to lime or phosphorus were observed in all crops although there were marked differences in responses among species (Fig. 7). In the 2nd cutting, however, there was no response at all in orchard grass or white clover.

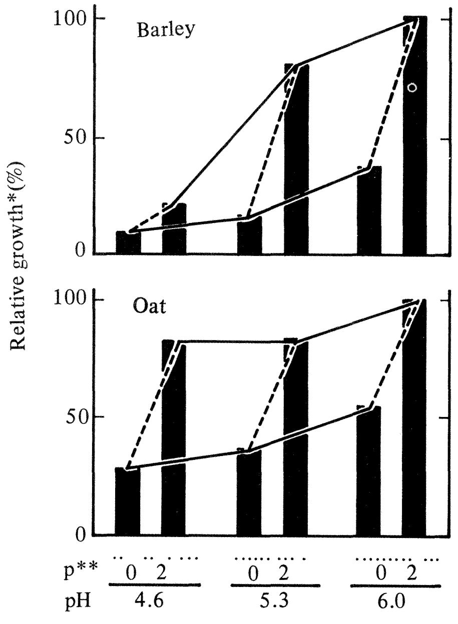

Fig. 6 Growth response to applications of superphosphate and $CaCO_3$ in barley and oat.
* Dry weight at 1,500 kg P_2O_5/ha•pH 6.0 is taken as 100.
**2 is 1500 kg P_2O_5/ha.

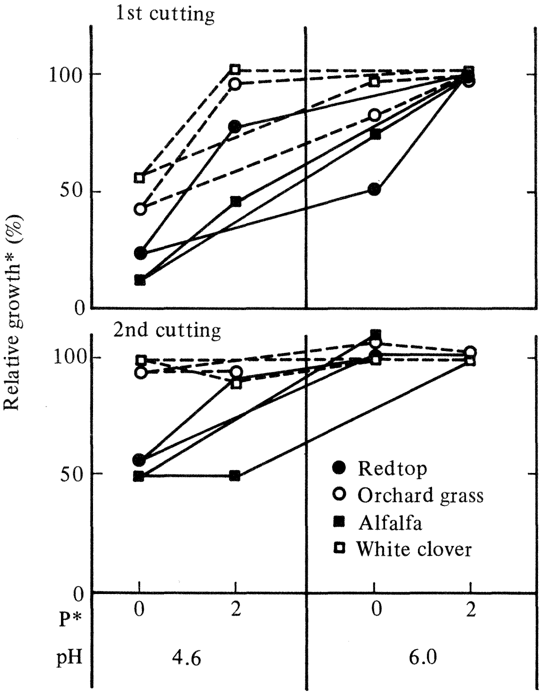

Fig. 7 Growth response to application of superphosphate and $CaCO_3$ in various forage crops at 1st and 2nd cuttings. (* The same as in Fig. 6).

These results demonstrate that (i) if funds for soil amelioration are limited, forage crops which are tolerant to adverse soil conditions may be planted; (ii) if funds are available, it is advisable to grow field crops which are tolerant to aluminum toxicity with application of phosphorus alone; and (iii) if field crops which are susceptible to aluminum toxicity are planted, it is indispensable to apply lime along with phosphorus. Needless to say if the initial pH of a soil is extremely low, liming is necessary even if the crops to be grown are tolerant to aluminum toxicity.

For example, the tea plant is very unique: aluminum at a certain concentration, which is toxic to other crops, is rather beneficial (Matsuda *et al.*, 1979). Thus, such crops can be adequately grown without liming even on very acid soils.

Problems related to soil management

As mentioned previously there are various acid soils. For example, acid sulfate soils are strongly acidic when they are well aerated. The amount of lime, which is needed to adjust the pH properly, is sometimes beyond farmers' means. However, if the soil layer, which contains ferrous sulfide, can be kept under anaerobic conditions by adjusting the ground water table, a reasonable yield, if not very high, can be obtained. To employ this method, however, it is necessary to grow crops which are tolerant to excess water conditions.

For the amelioration of volcanic ash soils or red-yellow soils large amounts of lime and phosphorus are necessary because the buffering capacity to pH and to phosphorus is large. However, owing to their strong buffering capacity, (i) chances of over-liming or adverse effect of excessive phosphorus application are rare (Fig. 8) (Tanaka and Nunozawa, 1981), and (ii) once the pH and phosphorus status of these soils are properly adjusted, the favorable condition persists for a long time. Thus, although a large input is initially required to ameliorate these soils, a high productivity can be maintained for a long time. For example, Japanese farmers, who reclaimed volcanic ash soils, were able to apply large amounts of lime (frequently dolomitic limestone) and calcium magnesium fused phosphate owing to subsidies from the government, and these soils are now productive.

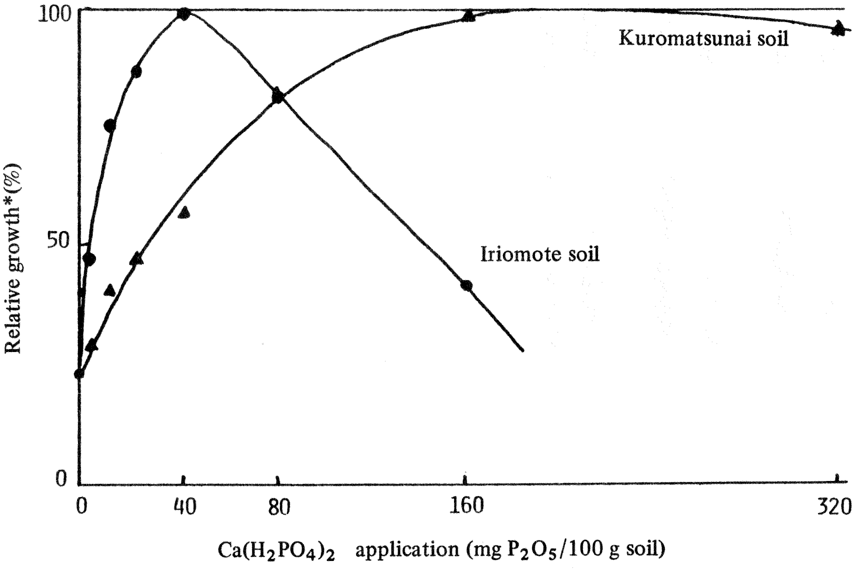

Fig. 8 **Growth of oat on Iriomote and Kuromatsunai soils as affected by amount of $Ca(H_2PO_4)_2$ applied.**
*** Maximum weight in each soil is taken as 100.**

In contrast to the above-mentioned soils, acid soils in the humid tropics or similar soils in southern Japan are more difficult to manage. In these soils the optimum ranges of liming and phosphorus application are narrow (Fig. 8). There are dangers of over-liming and of excessive application of phosphorus. Moreover, a large amount of fertilizer application makes the concentration of ions in the soil solution very high. Thus, it is necessary to identify the necessary amount of lime, phosphorus, and other fertilizers more precisely. Moreover, after amelioration the favorable condition does not persist for a long time.

These soils are frequently low in water-holding capacity, become very hard when they are dry, and are susceptible to erosion when it rains heavily. Thus, after reclamation, the soil fertility drops rapidly and the field is destroyed by erosion if field crops are grown continuously for several seasons due to depletion of nutrients and quick decomposition of organic substances in the soil.

Bush fallowing is frequently practiced in such areas to maintain reasonable yields of field crops with limited inputs. Extensive livestock raising is practiced in some areas. Such practices, however, can not be used when population pressure becomes high. Tree crops, such as rubber, oil palm, cacao, etc. are suitable in such areas, because the soil surface is protected from direct effect of rain and also organic substances are continuously supplied as fallen leaves. With this practice, however, small farmers may suffer from difficulty in securing their own food supply.

There is a question whether the yield of field crops on these soils can be maintained for a long time or even increased by proper management or not. Mulching may be one way to preserve soil moisture and to minimize erosion; no-tillage practice may be another approach for the same purpose; slow release fertilizers may be a better way to supply nutrients, etc.

New technology should be developed (i) to evaluate relative suitability of various cropping systems in which annual crops, perennial crops and tree crops are included in various combinations, and (ii) to manage various cropping systems at various levels of input. For this purpose the technology employed to ameliorate acid soils in Japan is not adequate at all as it is, but may provide some approaches if soil scientists or plant nutritionists in Japan look into the situation more closely by cooperating with scientists in the tropics.

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Discussion

Schlichting, E. (Germany): Soil acidity damage is related to aluminum and/or manganese toxicity and phosphorus deficiency as well as to calcium deficiency and these causes should be distinguished. Since phosphorus was added under the form of calcium phosphate in the treatment, the effects may partly have been due to improved calcium supply to the plant. Also, the effect may have resulted from the mobilization of molybdenum and you may have exchanged molybdenum when you applied phosphorus.

Answer: Calcium deficiency is not common at least in Japan. It may occur if one applies magnesium carbonate to adjust the pH, due to the antagonism between calcium and magnesium. There may be some cases of calcium deficiency in the tropics. As for your second question, I cannot answer you as I do not know enough about the interrelationship between phosphorus and molybdenum or molybdenum, phosphorus and zinc.

Li, C.K. (China): You determined phosphorus absorption by shaking the soil in a rather concentrated solution of NH_4-PO_4 (2.5%). Phosphorus absorption is thus evidently determined in an equilibrium condition between soil and PO_4 solution. In adopting the soil/solution ratio, the actual capacity of PO_4 absorption by the soil may not be demonstrated. I also find that the PO_4 solution may be too concentrated.

Answer: The soil/solution ratio is 100g dry soil/250 ml solution. I agree that the concentration of ammonium phosphate is very high. However, this method has been used as the standard method in Japan for a long time. I think that it is necessary to compare the Japanese method with other methods.

von Uexkull, H.R. (Singapore): You mentioned the efforts by breeders to develop varieties adapted to low phosphorus soil conditions. What is the physiological basis for such adaptability? Is it a lower phosphorus requirement or a root system which is able to extract enough phosphorus even from a deficient soil? If it were the latter mechanism, would it not lead to a gradual depletion in soil phosphorus, i.e. "rich fathers, poor sons"?

Answer: I believe that the varieties adapted to low phosphorus soil conditions are able to extract more phosphorus in the soil. Thus, by growing such varieties soil phosphorus is likely to become exhausted.

Hew, C.K.: 1) You mentioned that there was magnesium deficiency in the "complete plot". What kind of fertilizers did you apply? 2) Did the varieties of plants used in the experiment differ genetically in their susceptibility to magnesium?

Answer: 1) No magnesium had been applied in the "complete plot" which had received nitrogen, phosphorus, potassium and calcium carbonate. 2) I am not certain. In the case of maize, varietal difference in the susceptibility to magnesium deficiency has been reported. It seems to be easier to apply magnesium fertilizers than breed varieties tolerant of magnesium deficiency.