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COMPARISON OF TOLERANCE TO LOW PHOSPHORUS SOILS BETWEEN SWEET POTATO AND POTATO

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Introduction

Phosphorus deficiency is one of the most widespread nutritional problems in the soils such as Ultisols and Oxisols. The tolerance to low phosphorus soils differs among crop species. The tolerance of sweet potato to low phosphorus soils has been reported to be stronger than that of Chinese cabbage and lettuce (Fox *et al.* 1976) and that of potato was stronger than that of sugar beet, tomato and cabbage, but weaker than that of rice, maize and azuki bean (Tadano and Tanaka, 1980).

As important mechanisms in the tolerance of crops to low phosphorus soils, (a) phosphorus absorbing capacity of crops from low phosphorus soils (Loneragan and Asher, 1967 ; Tadano and Tanaka, 1980 ; Itoh and Barber, 1983), (b) tolerance to low phosphorus content in the plants (Tadano and Tanaka, 1980) or low internal phosphorus requirement (Föhse, *et al.* 1988), and (c) phosphorus efficiency expressed by the amount of harvested organ produced by a unit amount of phosphorus absorbed (Tanaka, 1983) have been reported. The importance of the ability of roots to elongate in the soils (Nye, *et al.* 1975), of root hair formation (Itoh and Barber, 1983) and of mycorrhizal association with roots (Sparling and Tinker, 1978) in the tolerance to low phosphorus soils relates to (a).

The objective of this study is to compare the tolerance to low phosphorus soils between sweet potato and potato and to analyze the mechanisms of the different tolerance.

Materials and Methods

Sweet potato var. Beniazuma and potato var. Danshaku were grown in an experimental field of Hokkaido University at two planting seasons in 1987 and 1989.

Two phosphorus application treatments, 0 kg P_2O_5/ha (−P treatment) and 100 kg P_2O_5/ha as superphosphate (+P treatment) were given to those crops. The −P plot, to which only nitrogen and potassium have been supplied for seventy years, was used for the −P treatment. 100 kg N/ha as ammonium

sulfate and 100 kg K_2O/ha as potassium sulfate were supplied to both treatments. The available phosphorus contents of those soils after fertilization, which were determined by Bray II method, were 4.5 and 48.8 mg P_2O_5/100 g, and soil pH were 5.0 and 5.2, respectively. In 1987, plant densities of sweet potato and potato were 40,000 and 55,556 plant/ha, respectively. In 1989, that of sweet potato was increased to 55,556 plant/ha, which was the same as potato. In 1987 sweet potato was covered by tunnel mulch from the planting time to July 15, whereas in 1989 no mulching treatment was given to that crop. Plant samples were collected three times in 1987, at the early stage, maximum shoot growth stage, and harvest. In 1989, they were collected twice, at maximum shoot growth stage and harvest. The maximum shoot growth stage of potato was characterized by the emergence of second flower bud. On the other hand that of sweet potato was defined as a phase when the increasing growth rate of shoot, especially stem, decreased. Planting and sampling dates of sweet potato and potato in both years are shown in Table 1. Seed tubers were planted for potato, while vine cuttings were transplanted for sweet potato. After the plants were collected they were separated into leaves, stem, and tuber or tuberous roots, dried at 80°C and dry weight and phosphorus content were determined.

TABLE. 1. Planting and sampling dates of sweet potato and potato in 1987 and 1989.

	Planting date	Sampling date		
		Early stage	Maximum shoot growth stage	Harvest stage
1 9 8 7				
Sweet potato	May 21*	July 9	Sept. 6	Oct. 2
Potato	May 2	June 25	July 31	Sept. 3
1 9 8 9				
Sweet potato	May 29*	–	Aug. 23	Oct. 12
Potato	May 1	–	July 18	Aug. 19

* Vine cuttings were transplanted

At maximum shoot growth stage of the 1989 experiment, the root distribution of both crops in the different soil depths was observed in the −P treatment. Root length was determined with an image processor KONA 4000.

At the same growth stage, vesicular-arbuscular mycorrhizal (VAM) infection in the root cortex of sweet potato and potato was observed by staining method, simmering the roots in 0.05% trypan blue in lactophenol (Phillips and Hayman, 1970). The root samples collected were cut into 1 cm lengths and the root sections less than 1 mm in diameter were observed under the microscope. Those samples were selected at random.

The density and length of root hairs were observed with the same root samples collected.

Results and Discussion

Although the harvested organ of sweet potato is tuberous roots, the term "tuber" instead of "tuberous roots" will be used in this paper in order to make the explanation of results and the discussion simpler.

The tuber dry weights of sweet potato and totato in the +P treatment in 1987 were 9.0 and 10.7 ton/ha, respectively (Table 2). Although mean air temperature in Sapporo was 16.9°C in June and 21.0°C in August, 1987, sweet potato variety Beniazuma was able to produce tuber yield almost the same as potato in dry weight. In 1989, the yield of sweet potato was lower than in 1987, but it was higher than that of potato. The lower shoot dry weight of sweet potato at maximum shoot growth stage than at harvest in 1989, indicated that the sampling date was earlier and not exactly at maximum growth stage.

Growth responses of sweet potato and potato in each growth stage to low phosphorus soil expressed by relative dry weight of both crops in the −P treat-

TABLE 2. Dry matter production (kg/ha) of sweet potato and potato grown in the −P and +P treatments at the early, maximum shoot growth, and harvest stages in 1987 and 1989.

	1987						1989			
	Early stage		Maximum shoot growth stage		Harvest stage		Maximum shoot growth stage		Harvest stage	
	SP*	P*	SP	P	SP	P	SP	P	SP	P
Leaves										
−P	86	188	1619	949	1576	−	1214	421	1680	−
+P	210	674	2026	827	1856	−	1234	682	1410	−
Stem										
−P	67	127	1719	785	1814	−	938	159	1940	−
+P	125	375	2797	835	2845	−	1102	337	2170	−
Shoot										
−P	153	315	3338	1733	3390	581	2153	581	3620	195
+P	335	1049	4823	1662	4700	929	2336	1019	3580	569
Tuber										
−P	93	227	4757	4739	5960	6492	1443	2601	5690	4063
+P	185	677	6511	8761	9004	10687	2391	4616	6920	5488
Total										
−P	245	541	8095	6472	9350	7072	3596	3182	9310	4258
+P	520	1725	11334	10423	13704	11616	4727	5634	10500	6057

* SP=sweet potato and P=potato

ment compared to the control treatment (+P treatment = 100%) are shown in Fig. 1. In the −P treatment, except for shoot dry weight at maximum shoot growth stage in 1987, relative tuber and shoot dry weights of sweet potato were

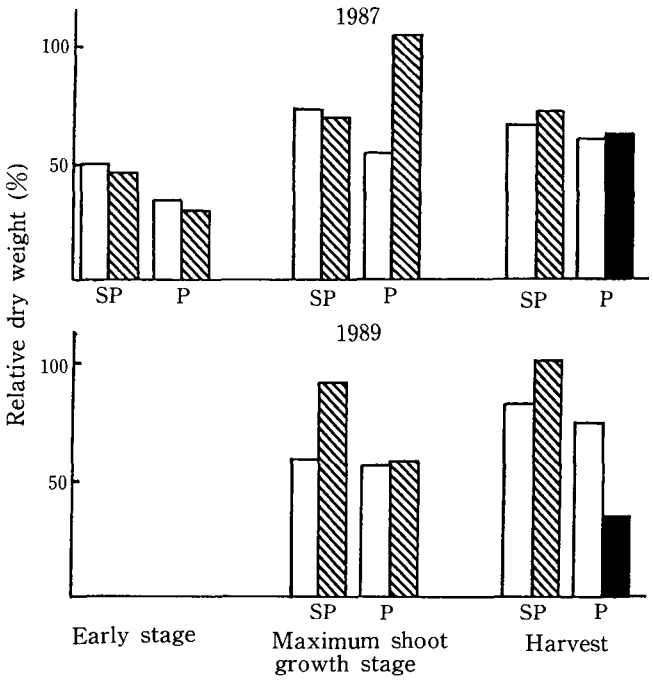

Fig. 1. Relative dry weight of sweet potato (SP) and potato (P) in tuber □, shoot ▨, and dead shoot ■ grown in the −P treatment at different stages in 1987 and 1989 (+P treatment = 100%).

higher than those of potato in all stages of both years.

The phosphorus content in all parts of sweet potato and potato was increased by phosphorus application (Table 3). In the −P treatment, the phosphorus content in the leaves of sweet potato was higher than that of potato in all growth stages in both years. On the other hand the phosphorus content in tuber of sweet potato was lower than that of potato. The phosphorus content in the stem was similar in both crops.

In 1987, the amounts of phosphorus absorbed by sweet potato at the early growth stage were lower than those of potato both in the −P and +P treatments, but at maximum shoot growth stage they were similar (Table 3). At maximum shoot growth stage in 1989, the amount of phosphorus absorbed by potato was higher than that of sweet potato in the +P treatment, while in the −P treatment, that of sweet potato was higher than that of potato. However at harvest, that of sweet potato was higher than that of potato in both treatments.

TABLE 3. Phosphorus content and amount of phosphorus absorbed by sweet potato and potato grown in the −P and +P treatments at the early, maximum shoot growth and harvest stages in 1987 and 1989.

	1987						1989			
	Early stage		Maximum shoot growth stage		Harvest stage		Maximum shoot growth stage		Harvest stage	
	SP*	P*	SP	P	SP	P	SP	P	SP	P
	P CONTENT (%)									
Leaves										
−P	0.21	0.18	0.24	0.19	0.20	−	0.24	0.20	0.26	−
+P	0.25	0.41	0.30	0.24	0.26	−	0.30	0.26	0.31	−
Stem										
−P	0.11	0.12	0.12	0.14	0.10	−	0.13	0.13	0.10	−
+P	0.17	0.25	0.16	0.18	0.15	−	0.14	0.16	0.12	−
Shoot										
−P	−	−	−	−	−	0.08	−	−	−	0.08
+P	−	−	−	−	−	0.09	−	−	−	0.08
Tuber										
−P	0.13	0.14	0.09	0.17	0.12	0.18	0.10	0.14	0.09	0.17
+P	0.18	0.35	0.13	0.18	0.18	0.20	0.14	0.18	0.12	0.18
	AMOUNT OF P ABSORBED (kg/ha)									
Leaves										
−P	0.18	0.33	3.95	1.84	3.07	−	2.91	0.83	4.37	−
+P	0.51	2.75	6.00	1.98	4.79	−	3.73	1.74	4.36	−
Stem										
−P	0.07	0.15	2.10	1.06	1.85	−	1.24	0.21	1.90	−
+P	0.21	0.93	4.44	1.50	4.19	−	1.52	0.56	2.71	−
Shoot										
−P	0.25	0.48	6.04	2.90	4.92	0.45	4.15	1.04	6.27	0.16
+P	0.73	3.68	10.43	3.49	8.98	0.83	5.25	2.29	7.06	0.56
Tuber										
−P	0.12	0.31	4.19	8.10	7.27	11.62	1.49	3.69	5.06	6.87
+P	0.33	2.35	8.59	15.92	16.48	21.86	3.35	8.10	8.30	9.82
Total										
−P	0.38	0.79	10.23	11.00	12.19	12.07	5.64	4.73	11.33	7.03
+P	1.06	6.03	19.03	19.40	25.46	22.69	8.60	10.39	15.37	10.38

* SP=sweet potato and P=potato

The proportions of phosphorus accumulated in tuber to the total amount of phosphorus absorbed increased linearly with the growth in both crops (Fig. 2). However. it is characteristic that those in potato tuber were significantly higher than those of sweet potato in the maximum shoot growth stage and thereafter in both years.

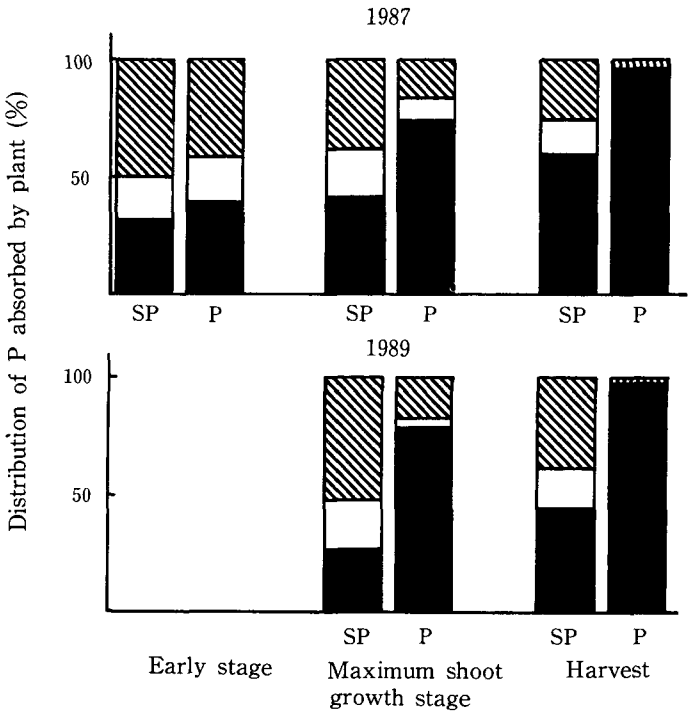

Fig. 2. Proportion of amount of phosphorus accumulated in the tuber ■, stem □, leaves ▨, and dead shoot ▥ of sweet potato (SP) and potato (P) grown in the −P treatment at different stages in 1987 and 1989.

The root distribution patterns of sweet potato and potato were different at different soil depths (Fig. 3). Roots of sweet potato elongated to deeper soil horizons than those of potato. Thus, it is considered that the ability of sweet potato roots to absorb more phosphorus from the deeper soil horizon was stronger than that of potato, although the available phosphorus content in the lower soil horizons may have been quite low. It has been reported that potato has shallow roots and they seldom extend deeper than 40 to 50 cm and none penetrated deeper than 1 m (Horton, 1987), while roots of sweet potato are able to penetrate the soil to depth of over 2 m (Onwueme, 1978).

Infection of vesicular-arbuscular mycorrhiza (VAM) in roots was observed both in sweet potato and totato (Table 4). The frequency of infected roots in sweet potato and potato roots was higher in the −P treatment than in the +P treatment. VAM fungi seem to produce specific alkaline phosphatases that may be involved in phosphorus uptake and transfer, and both phosphatase production and VAM formation are inhibited by high concentrations of phosphorus in host tissue (Gianinazzi-Pearson and Gianinazzi, 1978).

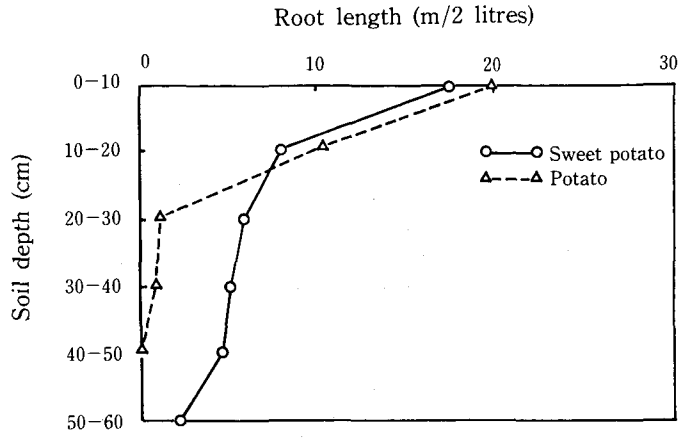

Fig. 3. Root distribution of sweet potato and potato in different soil depth of the −P treatment at maximum shoot growth stage in 1987.

TABLE 4. Rate of mycorrhizal association with roots in sweet potato and potato at maximum shoot growth stage in 1989.

	Number of root* sections observed	Number of infected root sections	Index (%)
Sweet potato			
−P	147	125	85
+P	155	70	45
Potato			
−P	148	109	74
+P	108	45	42

* The diameter of root sample observed was less than 1 mm

The rate of VAM infected roots was slightly higher in sweet potato than in potato. Yost and Fox (1979) reported that phosphorus uptake by mycorrhizal plants in phosphorus deficient soils was 25 times greater than in those without mycorrhizal association. Higher mycorrhizal association in sweet potato than in potato might be a favorable characteristic for phosphorus absorption.

Densities of root hairs were different between the two crops, while no difference was observed in the length of root hairs (Table 5). In the +P treatment, densities of root hairs were slightly higher in potato than in sweet potato, and the difference became larger in the −P treatment. Although the difference was not very large, it might become a demerit for the phosphorus absorption (Itoh and Barber, 1983) in sweet potato compared to potato. As a result of longer root elongation, slightly higher mycorrhizal association, and slightly lower formation

TABLE 5. Distribution of root hairs in fine roots of sweet potato and potato under −P treatment at maximum shoot growth stage in 1989

	root hairs density ± SD*	root hairs length ± SD (mm)
Sweet potato		
−P	1.74 ± 0.84	0.18 ± 0.05
+P	1.92 ± 0.84	0.17 ± 0.06
Potato		
−P	2.12 ± 0.81	0.18 ± 0.05
+P	2.03 ± 0.74	0.15 ± 0.05

* density score: 1 = low, 2 = medium, and 3 = high

of root hairs in sweet potato than in potato under low phosphorus condition, the phosphorus absorbing power of sweet potato from low phosphorus soils was considered to be similar to or stronger than that of totato.

The longer growth duration of sweet potato compared with that of potato (10 days longer in 1987 and 26 days longer in 1989) was apparently a favorable characteristic of sweet potato for the larger amount of phosphorus absorption at harvest.

Phosphorus efficiency, which is expressed by the amount (g dry weight) of the harvested organ produced by a unit amount (1 g) of phosphorus absorbed by sweet potato and potato, is shown in Table 6. Phosphorus efficiency of potato was higher than that of sweet potato in the +P treatment. One advantageous characteristic of potato for higher efficiency is the capacity for self-destruction of shoot during tuber enlargement, which enhances the translocation of photosynthates from shoot to tuber and which may be induced by a strong sink power of the tuber. On the other hand, the lower phosphorus efficiency of sweet potato

TABLE 6. Phosphorus efficiency of sweet potato and potato under −P treatment at harvest

	1987		1989	
	P efficiency* (g DW/g P)	%	P efficiency (g DW/g P)	%
Sweet potato				
−P	489	138	502	112
+P	354	100	450	100
Potato				
−P	538	114	578	109
+P	471	100	528	100

* P efficiency = Total amount of harvested organ (g DW) produced by 1 g P absorbed by plant

was considered to be due to the longer growth duration of the shoot. Amounts of phosphorus remaining in the shoot of sweet potato in the +P treatment at harvest in 1987 and 1989 were 8.98 and 7.06 kg/ha (Table 3), that is 35.3 and 45.9% of total amount of phosphorus absorbed, respectively.

However, the phosphorus efficiency in the −P treatment increased more strongly in sweet potato than in potato as shown in table 6, when it is compared with that in the +P treatment. It is considered that the main reason for the significant increase in phosphorus efficiency in sweet potato under low phosphorus soil conditions, might be (1) the longer growth duration of leaves and (2) the maintenance of higher phosphorus content in the leaves under low phosphorus condition (Table 3). It is apparent that the higher phosphorus content in the leaves up to harvest was due to the weaker sink power of the tuber for phosphorus (Fig. 2), which was caused by the lower internal requirement of the tuber for phosphorus than that of potato (Table 3).

The internal phosphorus requirements in the leaves of those crops is also an important factor for the tolerance to low phosphorus soils. From Fig. 4, it is, however, difficult to conclude that the internal phosphorus requirement in the leaves of sweet potato is lower than that of potato, because, the higher relative total dry weight obtained in sweet potato under the −P treatment appeared to be caused by the higher phosphorus content of leaves that was due to the weaker sink power of tuber of this crop. The internal phosphorus requirements in the leaves of both crops may be more or less similar.

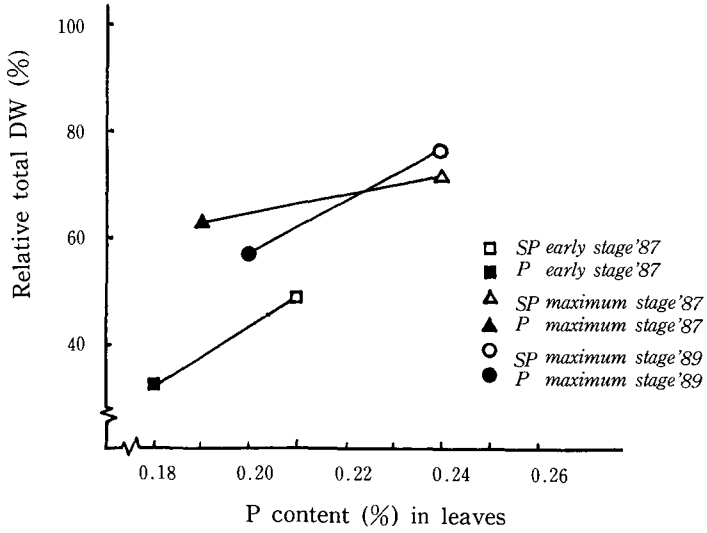

Fig. 4. Relation between phosphorus content in the leaves and relative total dry weight of sweet potato (SP) and potato (P) grown in the −P treatment in 1987 and 1989.

As a conclusion, the tolerance of sweet potato to low phosphorus soils was stronger than that of potato. The stronger tolerance of sweet potato to low phosphorus soils was considered to be mainly due to (1) maintenance of higher phosphorus content in the leaves for the longer growth duration and (2) increased phosphorus efficiency under low phosphorus soil conditions which was caused by (1).

Summary

The tolerance to low phosphorus soils of sweet potato and potato was studied in field conditions during two seasons in 1987 and 1989, and the following results were obtained :

a) The tolerance to low phosphorus soils of sweet potato was stronger than that of potato.

b) Stronger ability of roots to elongate in the deeper soil horizons, slightly higher mycorrhizal association of roots and longer growth duration of sweet potato than those of potato were three favorable characteristics of sweet potato for phosphorus absorption, but less formation of root hairs was an unfavorable characteristic.

c) Sink power for phosphorus of sweet potato tuber was weaker than that of potato tuber which was caused by the lower internal phosphorus requirement of the tuber. As a result, sweet potato was able to maintain higher phosphorus content in leaves than that of potato especially in low phosphorus soils.

d) Phosphorus efficiency expressed by the amount of harvested organ produced by 1 g phosphorus absorbed by potato was higher than that of sweet potato in the +P treatment. The higher phosphorus efficiency in potato rather than in sweet potato was caused by (1) the capacity of potato to destroy shoot and to translocate most of the photosynthate to tuber rapidly after maximum shoot growth stage and (2) the ability of sweet potato to maintain a high content of phosphorus in the leaves until harvest.

e) Under low phosphorus conditions, phosphorus efficiency of sweet potato increased more strongly than potato.

f) The stronger tolerance of sweet potato to low phosphorus soils than potato was considered to be mainly due to (1) maintenance of higher phosphorus content in the leaves for the longer growth duration and (2) increased phosphorus efficiency under low phosphorus soil conditions which was caused by (1).

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