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Effect of Soil Types on the Growth of Shoots and Roots and the Grain Yields of Wheat Varieties

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Abstract

Seven wheat varieties were cultivated in four types of soils under the same condition of fertilizer application during the two growing seasons, 1982-1984. Shoot growth was most vigorous in Gray Lowland soil (GLS), which is recognized as the most fertile soil. In Red soil (RS), which is generally short in nitrogen supply, tillering was depressed and leaf color turned pale since the middle of the tillering stage. In the Thick High-humic Andosol (THA) and the Light-colored Andosol (LCA), which are both phosphoric-acid deficient soils, tillering and leaf emergence rates were lower than the case in other soils since the beginning of the tillering stage. Total amount, thickness and distribution of the roots varied among the soil types studied. Elongation of the stems and the spikes started earlier in RS and later in THA and LCA. Grain yields obtained were 649 g/m2 in GLS and 440-493 g/m2 in the other soils. The low yields in RS, THA and LCA were caused by the small number of spikes. These differences in plant growth and yields among the soil types were mainly associated with the soil fertilities and the soil temperature patterns. The wheat varieties producing the highest yields varied among the soil types. The highest yield was achieved by Asakazekomugi in GLS and by Norin 64 in THA and LCA, respectively.

Discipline: Corp production
Additional key words: fertility, soil temperature, tiller, yield components

It is well known that crop yields are greatly influenced by soil types and conditions as well as by climates[6,10,11]. In Japan, there are various types of soils, which are of keen interest for agronomists and plant breeders since the adaptability of crop varieties to soil conditions is a great concern in improving crop productivity[2,4,7,9]. This paper deals with the responses of several winter wheat cultivars to four types of soils predominant in Kanto and Tokai districts, located in the central part of Japan.

Materials and methods

The experiments were carried out in the fields newly opened in 1979. Four kinds of soils brought from different upland areas were installed with a depth of 80 cm in these fields. The soils used were as follows:

1) Red soil (RS) from Tawara, Aichi Pref.;
2) Gray Lowland soil (GLS) from Kawachi and Moriya, Ibaraki Pref.;
3) Thick High-humic Andosol (THA) from Mito, Ibaraki Pref.; and
4) Light-colord Andosol (LCA) from Tsukuba, Ibaraki Pref.

The characteristics of these soils are presented in Table 1.

Prior to the implementation of the present experiments in these fields, two cycles of crop rotation, comprising soybean in summer and barley in winter, had taken place under the same condition of fertilizer application in each soil. The fertilizer was applied

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Table 1. Three-phase distribution and Chemical properties of soil groups

Soil type	Three-phase distribution			pH (H_2O)	Total carbon C(%)	Total nitrogen N(%)	C/N ratio (%)	Available nitrogen (mg/100 g)	Available phosphoric acid (mg/100 g)
	Solid (%)	Liquid (%)	Gaseous (%)						
Red yellow soil	45.3	12.6	42.0	5.6	0.82	0.11	7.5	4.07	32.9
Gray Lowland soil	36.8	24.5	38.8	5.5	1.56	0.13	12.0	5.58	32.6
Thick High-humic Andosol	26.8	34.6	38.6	5.5	7.65	0.39	19.6	5.90	nil
Light-colored Andosol	26.6	35.2	38.2	5.6	4.78	0.34	14.1	3.69	nil

before planting to the topsoil with a depth of approximately 12 cm, at the rate of 64 kg/ha of N, 64 kg/ha of P_2O_5 and 64 kg/ha of K_2O.

Seven varieties, including Asakazekomugi, Fukuhokomugi, Norin 61, Norin 26, Fujimikomugi, Norin 50 and Norin 64, were planted on 31 October both in 1982 and 1983. Plant density was about 110–150/m^2 with a row spacing of 17 cm. The plot size was of 15 m^2 in 1982–83 and 8 m^2 in 1983–84 with two replications in each soil.

Number of shoots per m^2 and number of leaves on the main stem were counted every two weeks during the period 46 days to 184 days after sowing. Leaf color value of the second leaf from the top at the milky stage was measured with a Chlorophyl Meter (GM1, Fuji Film Co.).

At the end of the tillering stage, distribution of the roots from the soil surface to the depth of 25 cm were surveyed by means of the improved Monolith methods.

Soil temperatures at the depth of 5 cm were measured with thermo-couples at the selected four points in each soil.

Results

1) Weather condition and the growth of shoots and roots

In the 1982–83 season, the early development of spike and stem elongation took place due to the high temperature in winter. The heading of Norin 61 started in 175 days after sowing, which was about 8 days earlier than the standard year. On the other hand, in the 1983–84 season, the temperature in winter was low with frequent snowfalls. The heading of Norin 61 started in 191 days after sowing, which was about 8 days later than the standard year.

More leaves on the main stem were counted in RS and GLS than those in the two Andosol plots, THA and LCA (Fig. 1).

The seasonal patterns of the shoot number varied to a great extent among the soils and cultivars, as shown in Fig. 1. In Asakazekomugi and Norin 61, the number of shoots increased faster in GLS and RS than in THA and LCA during the beginning of the tillering stage. In RS, however, the increase in the shoot number became slower since the middle of the tillering stage than that in GLS. The maximum number of the shoots was about 1,300/m^2 in GLS and 1,000/m^2 in RS. On the contrary, the shoot number in THA and LCA increased very slowly but continuously, reaching 600/m^2 at the end of the tillering stage. In the following stage, the weak shoots faded away; thus their number decreased. Much more shoots survived in GLS than in other soil types. In Norin 64, the shoots increased until the beginning of March 1983 and the maximum number of the shoots was larger than that in Norin 61 and Asakazekomugi.

In THA and LCA, the wheat leaves had thinner blades with a darker green color compared with those in RS and GLS. In RS, the leaf color became light since the middle of the tillering stage and the leaf color value at the milky stage, being 0.99, was smaller than that of 1.32–1.35 in other soils (Table 2).

The distribution, the diameter and the total amount of the roots were also quite different among the soils, as shown in Plate 1. In THA and LCA, a small amount of thin roots developed, whereas in RS and GLS, a large amount of thick roots grew. The roots in RS distributed in the whole layer of the soils, reaching the depth of 25 cm, while a majority of the roots in GLS distributed in the topsoil layer rather than in the subsoil.

The seasonal patterns of the stem and spike length

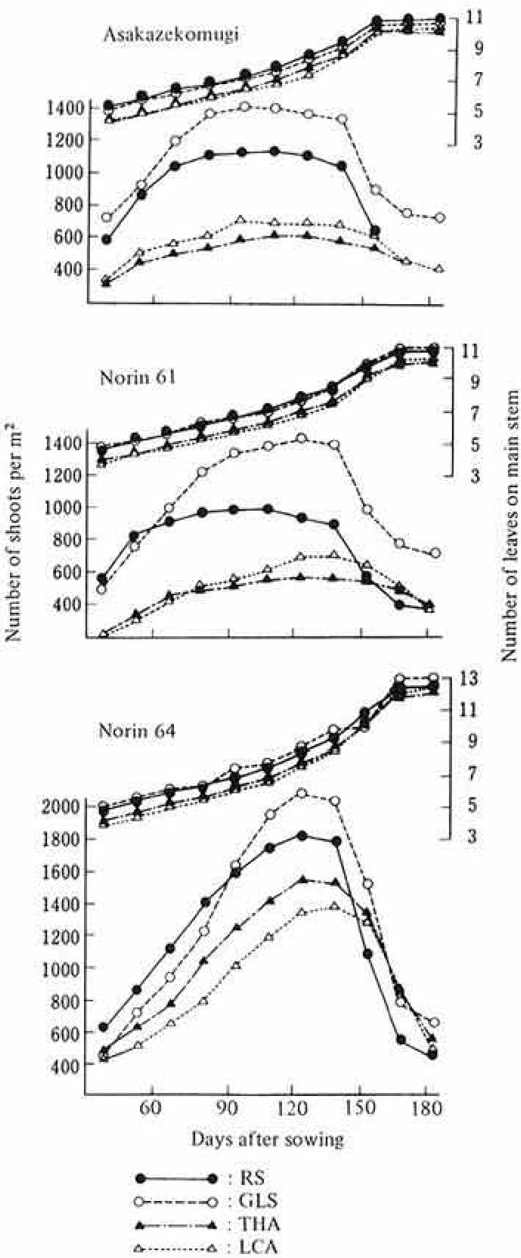

Fig. 1. Seasonal changes in number of shoots and leaves on main stem in 1982–83

were shown in Fig. 2. The elongation of stems and spikes in Asakazekomugi started earlier in RS than in the other soils. In all varieties, the elongation of stems and spikes were slower in both of the Andosols plots, especially in LCA.

Table 2. Leaf color value of the 2nd leaf from the top at milky stage[1)]

Variety	Soil type			
	RS	GLS	THA	LCA
Asakazekomugi	0.86	1.35	1.34	1.44
Fukuhokomugi	1.03	1.33	1.36	1.37
Norin 61	1.04	1.24	1.35	1.31
Norin 26	0.95	1.25	1.33	1.32
Fujimikomugi	1.05	1.37	1.46	1.42
Norin 50	1.00	1.31	1.29	1.25
Norin 64	0.98	1.39	1.31	1.32
Average	0.99[2)]	1.32	1.35	1.35

1): Average of 10 leaves, sampled at 192 days after sowing in 1982–83.
2): Significant at 0.001.

2) *Grain yields and yield components*

Grain yields and yield components are summarized in Table 3. The average grain yield in GLS was 649 g/m^2, which was approximately 50% higher than those in the other soils; i.e. 440 g/m^2 in RS, 493 g/m^2 in THA and 463 g/m^2 in LCA. No significant difference was observed among the yields in RS, THA and LCA.

Comparison of the yield components indicated that the higher grain yield in GLS was attributed mainly to the larger number of spikes. The rate of survived shoots was low in RS and high in THA and LCA. The small number of spikes in RS was mainly caused by a low rate of survived shoots. On the other hand, in both Andosols, the small number of spikes was mainly due to a low level of the maximum number of shoots.

The interaction between soils and varieties was significant in grain yields, spike number, weight per grain and degree of lodging. Asakazekomugi, a high yielding variety with a semi-dwarf type, showed the highest grain yield of 748 g/m^2 in GLS, which was the most productive soil (Fig. 3). Asakazekomugi in GLS demonstrated a higher rate of survived shoots (approximately 50%, Fig. 1), a large number of spikes and less lodging which contributed to reducing the loss of the grain weight. The other varieties in GLS had a smaller number of spikes due to the lower rates of survived shoots or decreased grain weight per spike due to severe lodging.

In both of the Andosols plots, Norin 64 showed about 550 g/m^2 of grain yield, which was 20% higher than those of the other tested varieties (Fig. 3).

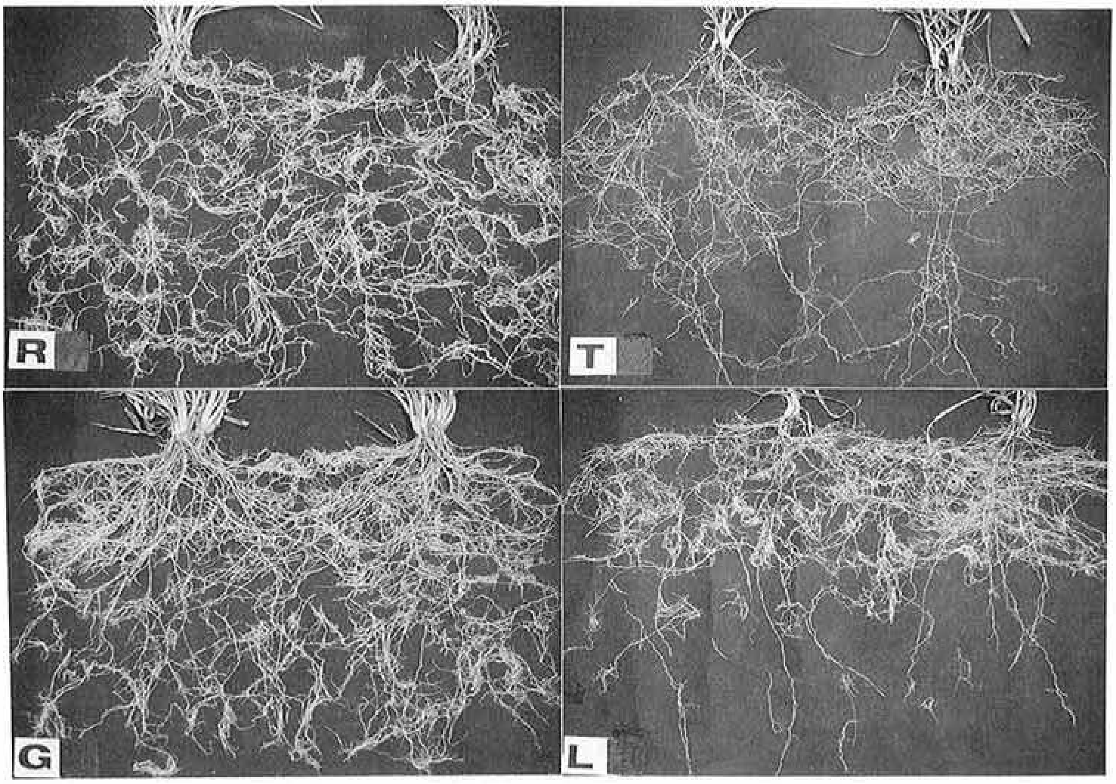

Plate 1. Root development in the depth of 25 cm at the end of the tillering stage (Norin 61)
R: Red soil, G: Gray Lowland soil,
T: Thick High-humic Andosol, L: Light-colored Andosol.

Norin 64 had a large number of shoots (Fig. 1) and spikes (Fig. 3) in the Andosols plots, where the other varieties had a smaller number of shoots and spikes.

No significant difference of yields was found among the varieties in the RS plot.

Discussions

The grain yield in GLS was higher in 1983–84 (the average yield of seven varieties was 703 g/m^2) than in 1982–83 (596 g/m^2). The differences of the grain yields between these two seasons were smaller in the other soils. However, the effect of soil types on the wheat growth and grain yields was similar in the two growing seasons.

The high level of the grain yield in GLS was attributed mainly to large number of spikes. The low yielding level in RS, THA and LCA was due to small number of spikes, which was associated with the low rate of survived shoots in RS and with the low level of maximum number of shoots in the two Andosols plots.

Ogawa[8] reported that nigrogen was a limiting factor for wheat and barley growth in mineral soil of Iwatahara, which was the same soil type with RS. Total carbon (C), total nitrogen (N) and C/N ratio in RS were lowest among all the plots, and available nitrogen in RS was lower than that in GLS and THA (Table 1). In RS, the shoot number increased slowly since the middle of the tillering stage (Fig. 1). The color of leaves in RS became light since the same stage in Janaury; the leaf color value at the milky stage was much lower than the other soils (Table 2). These results indicate that nitrogen deficiency starting at the middle of the tillering stage diminished chlorophyll content in wheat plants in RS and the resulting decrease of photosynthesis reduced the number of spikes and grain weight per spike

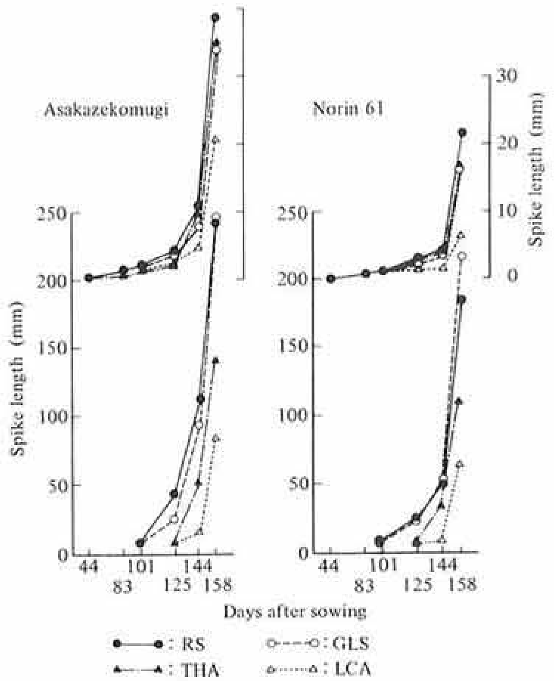

Fig. 2. Seasonal changes in stem length and spike length in 1982–83

as well.

It is well known that Andosols show a higher phosphate absorption coefficient, and phosphorus deficiency takes place occasionally in this type of soils. Phosphorus is an important element for energy metabolism in plants and its rapid deficiency seriously suppresses the biological activities of growing points. It was observed that the available phosphoric acid was very limited in THA and LCA (Table 1). The deterioration of wheat growth such as the decrease in number of shoots and leaves (Fig. 1), the poor development of roots (Plate 1), and the slow elongation of young spikes and stems (Fig. 2) in THA and LCA might have been caused by the deficiency of phosphorus in the wheat plants.

Patterns of the diurnal changes of soil temperature at the depth of 5 cm in winter are presented in Fig. 4. In December and January 1982–83, there were several days when the daily maximum soil temperature was 2–4°C higher in RS than that in the other soils, whereas the daily minimum soil temperature in RS was much lower in the night. In LCA, the diurnal changes of soil temperature were

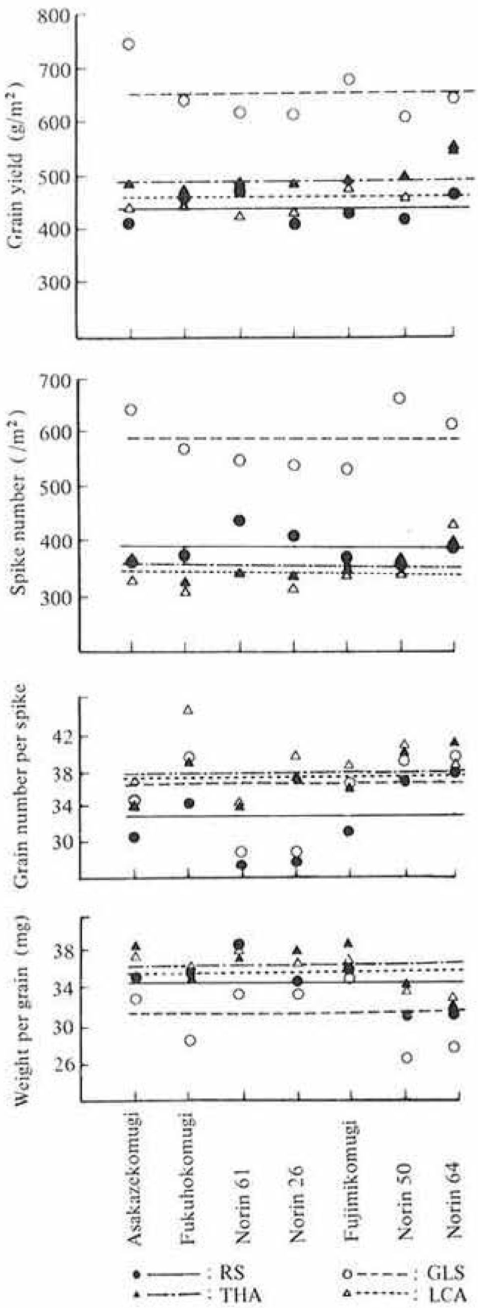

Fig. 3. Grain yields, spike number, grain number per spike and weight per grain of seven varieties in each soil type

The lines in the figure show average yields in each soil.

Table 3. Yields, yield components and analysis of variance

Treatment	Heading date	Grain yield (g/m^2)	Spike number ($/m^2$)	Rate of survived shoots (%)	Grain weight per spike (g)	Grain number per spike	Weight per grain (mg)	Degree of lodging (0–5)
Year								
1982	Apr. 23	492	414	41.6	1.22	34.6	35.1	1.2
1983	May 9	528	431	44.2	1.26	37.6	33.8	0.8
lsd(5%)	1.5***	—	—	—	—	4.5+	—	—
Soil								
RS	Apr. 29	440	392	30.2	1.13	33.4	34.7	0.2
GLS	May 2	649	590	39.4	1.14	36.5	30.9	3.8
THA	Apr. 30	493	360	50.8	1.37	37.5	36.2	0
LCA	May 2	463	348	50.9	1.34	37.3	36.0	0
lsd(5%)	2.1+	111*	38***	15.5+	0.14*	—	—	2.1**
Variety								
Asakazekomugi	Apr. 26	521	426	55.1	1.24	34.2	35.9	0.4
Fukuhokomugi	Apr. 28	504	398	43.6	1.31	38.5	34.0	0.6
Norin 61	May 1	500	424	50.4	1.20	33.3	37.1	1.2
Norin 26	May 3	486	404	43.5	1.24	34.8	35.8	1.0
Fujimikomugi	May 2	521	403	35.3	1.30	35.7	36.8	1.3
Norin 50	May 3	497	439	35.8	1.21	38.0	31.2	1.3
Norin 64	May 4	552	466	35.6	1.22	38.6	30.6	1.3
lsd(5%)	0.8***	34*	30***	8.0+	0.08*	2.0***	1.0***	0.7***
Soil × Variety								
lsd(5%)	—	68*	60**	—	—	—	2.0**	1.4***

Degree of lodging: No lodging (0) to severe lodging (5).
+, *, **, ***, —: Significant at 0.1, 0.05, 0.01, 0.001 and non-significant, respectively.

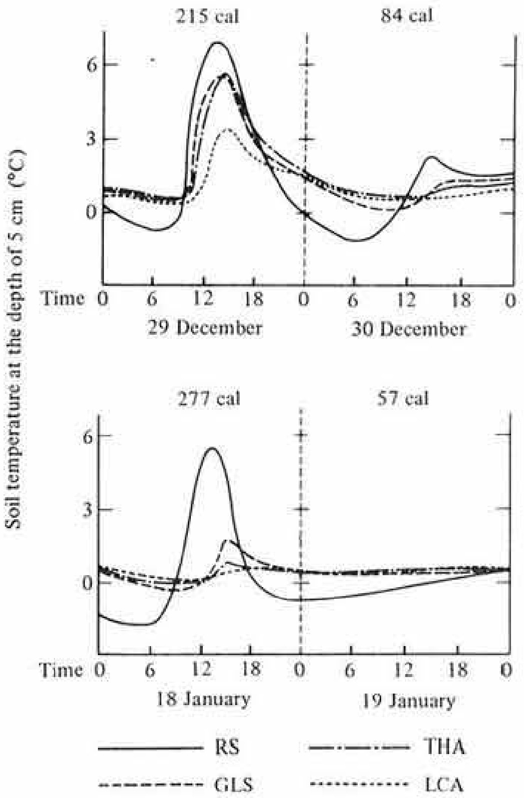

Fig. 4. Diurnal changes of soil temperature at the depth of 5 cm
Average of four points.
Numerics in the figure indicate total radiation per day. The weather on 29 December 1982 and 18 January 1983 was clear, while that on 30 December 1982 was cloudy and 19 January 1983 was snowy.

small with the lowest daily maximum temperature in the above-noted months. The difference of the soil temperatures among the soil types studied was larger in January 1983 than in December 1982, and in the clear days (29 December and 18 January) than in the cloudy day (30 December) or the snowy day (19 January).

Hay & Wilson[3] reported that the rate of leaf appearance and extension was linearly related to the accumulated soil temperature above 0°C and 2.5°C. Aston & Fischer[1] indicated that the early wheat growth was accelerated by higher accumulated soil temperature above 4°C even if the average soil temperature was the same. In the present study, the accumulated soil temperature above 4°C in winter was higher in RS and lower in LCA. Therefore, it is likely that in RS, the higher soil temperature during the day time accelerates the elongation of spikes and stems and that in LCA, the lower soil temperature during the day time accompanied by the deficiency of phosphoric acid slackened the elongation of spikes and stems.

Kasubuchi[5] showed that the difference of the diurnal variations of soil temperature was reflected by the values of thermal conductivity and coefficients of water permeability. The difference in diurnal variation patterns of the soil temperature in this study might possibly be attributed to the difference in physical property of the soil under testing.

The varieties producing the highest yield varied among the soil types. There was no significant difference of grain yields among the varieties in RS. However, the highest yield was performed by Asakazekomugi in GLS and by Norin 64 in the THA and LCA plots, respectively (Fig. 3). In GLS, the most productive soils, the yield of Asakazekomugi was the highest because of the high rate of its survived shoots, the large number of spikes, and the low degree of lodging which otherwise might have reduced the grain weight per spike.

In the phosphoric acid deficient soils such as THA and LCA, Norin 64 had vigorous tillering activity and a large number of spikes. This implies that there is a varietal difference in adaptability to phosphoric acid deficient soils.

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