Growth Retardation of Satsuma Mandarin (*Citrus unshiu* Marc.) in Acid Soils and Preventive Measures

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Introduction

Soils in Japanese citrus growing areas are characterized by high soil acidity because of frequent rainfalls and heavy application of chemical fertilizers. Growth retardation of satsuma mandarin trees in such highly acid soils has been a serious problem in Japanese citrus industry. Therefore, proper fertilization practices without lowering soil pH of citrus orchards has so far been discussed. Low rates of fertilizer application, especially nitrogen fertilizers, may not lower the soil pH, but results in poor yields. On the other hand, high nitrogen application may increase yields but it lowers the soil pH and produces poor quality fruit.

Analysis of the growth retardation of satsuma mandarin caused by acid soils, and fertilizer application practices for higher yields and better quality fruit are presented in this paper.

Yields of satsuma mandarin orange as affected by different cultural conditions

1) *Interrelationship among soil pH, rate of N application and yield*

The author gathered information concerning yields, soil pH and the amount of N annually applied per 10 a from 720 satsuma mandarin orchards in Shizuoka Prefecture. As indicated in Fig. 1, there was a positive correlation ($r = +0.427^{**}$) between the rates of N application and yields. The heavier the rate of nitrogen, the higher the yield over the range of 10–80 kg of N per 10 a.

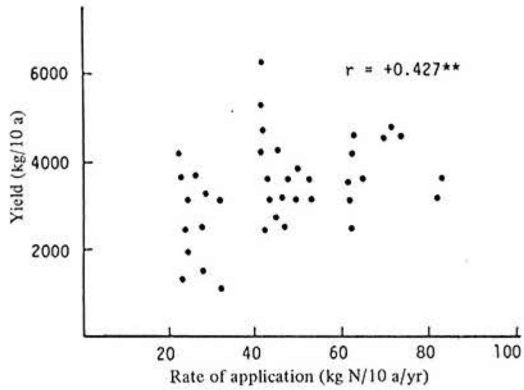

Fig. 1. Correlation between rate of N application and yield[2]
** Significant at 1% level.

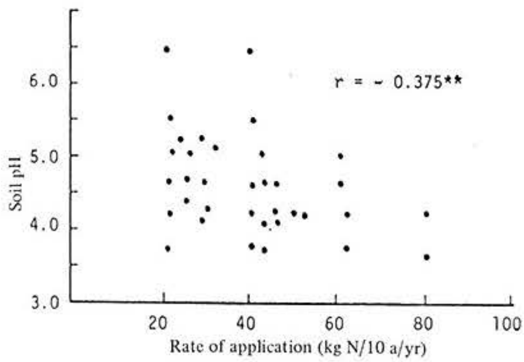

Fig. 2. Correlation between rate of N application and soil pH[2]
** Significant at 1% level.

However, heavy application of N fertilizers, especially in the form of ammonium sulfate considerably lowers the soil pH as evidenced by a significant negative correlation ($r = -0.375^{**}$) between the rate of N application and soil pH (Fig. 2), whereas the amounts of P and K fertilization seemed to have less influence on soil pH.

Naturally, soil pH exerts an influence on yields as shown in Fig. 3. The lower the soil pH, the lower the yields over the pH range of 3.0–7.0. The correlation coefficient was significant at 1% level ($r = +0.245^{**}$), although the value was rather lower because of a high variability.

Lower yields at lower soil pH might be attributable to the reduced tree canopy. The canopy at around pH 4 was about 1/2 as small as that around pH 5 (Fig. 4).

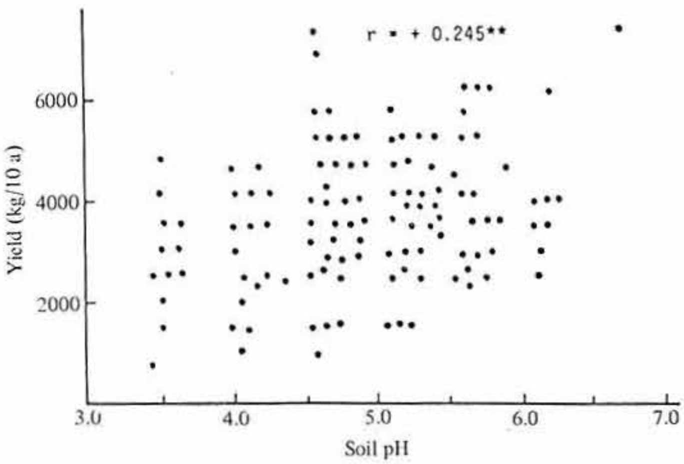

Fig. 3. Correlation between soil pH and yield[2]
** Significant at 1% level.

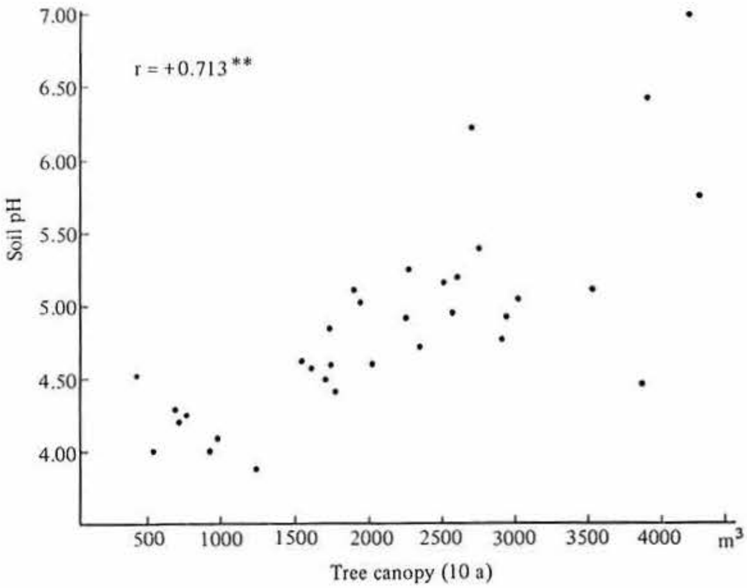

Fig. 4. Correlation between soil pH and tree canopy of satsuma mandarin orange[1]

2) *Factors causing reduced yields at lower soil pH*

(1) Nutrient elements in leaves. Concentrations of nutrient elements in leaves as % on dry weight basis do not mean anything in such elements as N and P unless they are of deficient levels. However, concentrations of nutrient elements fractionated into different forms may be of significance in diagnosing tree activity even without symptoms detectable with the naked eye. In the present study, N and P in satsuma mandarin leaves were determined in acid soluble and insoluble forms. Although the total N and P were not significantly correlated with soil pH, concentrations of insoluble N and P, ratio of insoluble N/soluble N, and that of insoluble P/soluble P were positively correlated with soil pH, whereas concentration of soluble N was negatively correlated with soil pH. These data indicate that the amount of soluble N increased but that of insoluble N decreased at lower soil pH. In other words, the activity of protein synthesis in the leaves might be lowered at lower soil pH. High content of insoluble P at higher soil pH might have favorable influences on physiological activities of the tree.

Total K_2O and CaO in leaves were positively correlated ($r = +0.476^*$, $+0.540^{**}$) and Mn was negatively correlated ($r = -0.571^{**}$) with soil pH (Table 1).

(2) Mineral elements in soils. Total N, available P (Truog), exchangeable K, Ca, Mg, Mn, Al and Fe in the soil of citrus orchards in Shizuoka Prefecture were determined. A positive correlation ($r = +0.50^*$) between soil pH and available P content in the soil was observed. It suggests that P availability in the soil must have been reduced at lower pH. One of the reasons why the canopy of satsuma mandarin trees became small at lower soil pH might be explained by the reduced P availability in such soils.

Exchangeable Mn and Al were negatively correlated with soil pH as shown in Table 2 ($r = -0.54^{**}$ and -0.71^{**}, respectively). Higher Al content in highly acid soils must have reduced P availability, because soluble P and Al chemically combined each other in the soil to produce non-available forms of P.

Extremely high Mn content usually occurred in the soil where soil pH was very low. This

Table 1. Correlation coefficients(r) between soil pH and nutrient elements in leaves of satsuma mandarin orange[1)]

	T-N	Ins-N	S-N	Ins-N/S-N	T-P	Ins-P	S-P
pH (H_2O) 0–30cm	+0.149	+0.601**	−0.672**	+0.620**	+0.306	+0.663**	+0.410
	Ins-P/S-P	K_2O	CaO	MgO	Fe	Mn	Al
pH (H_2O) 0–30cm	+0.467*	+0.476*	+0.540**	+0.073	−0.143	−0.571**	−0.359

T-N = Total N, Ins-N = Insoluble N, S-N = Soluble N, Ins-P = Insoluble P, S-P = Soluble P,
* Significant at 5% level, ** Significant at 1% level.

Table 2. Correlation coefficients(r) between soil pH and mineral elements in soils of satsuma mandarin orchards[1)]

	Total	Ava.	Exchangeable					
	N	P	K	Ca	Mg	Fe	Mn	Al
pH (H_2O) 0–30cm	+0.20	+0.50*	+0.31	+0.52*	+0.46*	−0.35	−0.54**	−0.71**

Ava. = Available, * Significant at 5% level, ** Significant at 1% level.

Table 3. Effect of pH and presence of Mn in the culture solution on respiratory rate and TTC reaction of satsuma mandarin roots growing in sand culture[1]

Treatmet	Respiration rate (O_2 μl/g/hr) pH 4	pH 6	TTC reaction pH 4	pH 6
+Mn	80.2	113.2	+	++
−Mn (Cont.)	245.5	248.6	+++++	+++++

is one of the main cause of growth inhibition of satsuma mandarin trees. As shown in Table 3, respiration rate and TTC (triphenyl tetrazolium chloride) reduction in fine roots of satsuma mandarin trees growing in sand culture were markedly lowered in the presence of Mn, especially at lower pH of the culture solution. This result indicates that the fine roots, which play an important role in absorbing water and mineral nutrients were damaged by excessive Mn in strongly acid soils, resulting in water stress of the tree.

(3) Water stress. Growth inhibition by Mn excess was observed with 2 year-old satsuma mandarin trees grown in wooden boxes (50 cm × 50 cm × 40 cm). The soil used for the experiment was a mineral acid soil (red clay) taken at Mikkabicho, Shizuoka Prefecture, and its pH was adjusted to 4 levels from about 7.2 to 3.9 with slaked lime and sublimed sulfur. Growth of the trees was extremely reduced at lower soil pH, where both fine roots (ϕ1–2 mm) and especially fibrous (ϕ less than 1 mm) roots absorbed extremely large amounts of Mn. Reduced ratio of dried fibrous roots/dried fine roots might have been caused by extremely high Mn content in the fibrous roots (Table 4).

Damaged fine and fibrous roots naturally induced water stress in the tree. As shown in Fig. 5, water potential was very low at low

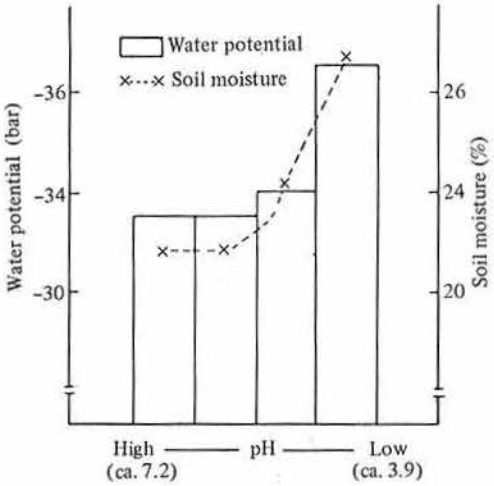

Fig. 5. Leaf water potential of young satsuma mandarin trees growing in soils of different pH
Note: Watering was equally done to each box. The measurement was conducted on a fine day in winter 18 months after planting.[1]

Table 4. Effect of soil pH on growth of satsuma mandarin trees and Mn contents in leaves and roots[1]

		Aver. pH	Fr. increment	Dr. leaf weight	Leaf no.	D.l.w./Leaf	Dr. Frt weight	Dr. Fbr weight	F/Fb	Mn content Leaf	F-root	Fb-root
			g	g		g	g	g		ppm	ppm	ppm
		7.17	2,577	146.9	484	0.30	80.3	138.7	173	11.7	107	733
		5.29	2,289	95.0	378	0.25	83.7	132.7	160	51.7	490	1,513
		4.33	1,816	74.6	404	0.19	109.7	102.3	93	133.3	883	3,050
		3.87	759	3.2	21	0.15	51.7	39.0	75	150.0	1,200	3,152
LSD	1%	—	—	18.26	—	—	23.08	32.05	—	—	—	—
	5%		89.9	26.57	162.4	0.097	33.58	46.63	—	72.50	369.4	1,349.7

* Fr = Fresh, Dr = Dry, D.l.w. = Dry leaf weight, F = fine, Fb = Fibrous, Frt = Fine root, Fbr = Fibrous root.

soil pH, in spite of the fact that soil moisture content was high. The water stress reduced fresh weight increment, leaf dry weight and leaf number. Water stress of ca. −36 bar in water potential associated with lower soil pH (around 3.9) caused severe defoliation. Such defoliation accompanied by Mn excess was often called 'Ijorakuyo'—abnormal defoliation. In fact Mn content in leaves of satsuma mandarin trees growing at lower soil pH (3.9) was 150 ppm which is a toxic range.

Prevention of growth inhibition of satsuma mandarin trees induced by lower soil pH

1) Cultural practices for higher yields

(1) Correction of soil pH. The most important cultural practice in citrus orchards showing low yields due to very low soil pH is to correct soil pH by applying liming materials. Data obtained from field surveys and a series of pot experiments showed that soil pH should be raised to around 6 from the viewpoint of growth of trees and yields. Recommended liming materials to be applied to commercial citrus orchards are calcium carbonate or 'Phosphate rock-magnesium silicate glass' (fused phosphate).

(2) Importance of organic matters. As shown in Fig. 6, the content of soil humus formed from organic matters was positively correlated with cation exchange capacity (CEC) of citrus roots ($r = +0.676^{**}$). On the other hand, as the CEC was positively correlated with soil pH ($r = +0.718^{**}$), application of liming materials together with organic matters is a significant cultural practice in acid soils. Growth of tree canopy as related to soil humus content is shown in Fig. 7.

(3) Kinds of N fertilizer. There are two main types of N fertilizers; NH_4-N and NO_3-N. In acid soils with pH lower than 5, activities of nitrate and nitrite bacteria are lowered, so that nitrification of NH_4-N does not readily occur. In general citrus trees absorb NO_3-N more readily rather than NH_4-N. Therefore, it is not recommendable to use NH_4-N, such as ammonium sulfate, in citrus orchards with soil pH lower than 5.

On the other hand NO_3-N fertilizers are effective in a wide range of soil pH, but have the nature of deliquescence, and are readily washed away by heavy rainfalls. In addition, the comparison of shoot growth between young satsuma mandarin trees receiving NH_4-N and these receiving NO_3-N, indicated that the former was much greater than the latter (Fig. 8). Therefore application of NH_4-N to citrus orchards in Japan is advisable when a care is taken not to markedly lower soil pH.

(4) Rate of N application. As previously discussed, heavy application of N surely increases yields, but too heavy application lowers soil pH. Therefore, the annual application rate of 15–25 kg of N/10 a is generally accepted in satsuma mandarin culture in Japan.

(5) Kinds and rate of application of P fertilizer. P fertilizers are not readily absorbed by citrus trees even at an extremely high P fertilization (e.g. 10 times of customary use). 'Phosphate rock-magnesium silicate glass' is recommended as a promising P fertilizer, because it contains a high percentage of basic agents, which are advantageous for raising soil pH.

As for kinds and rate of application of K fertilizers, no marked differences in growth of satsuma mandarin trees were observed with different kinds and rates within the customary range.

2) Fertilization for better quality fruit

(1) N fertilization. As N fertilization has been believed to have negative influences on quality of citrus fruit, the amount of N fertilization, especially in satsuma mandarin orchards located on flat land areas has been minimized for producing better quality fruit and for keeping their soil pH at a favorable range as well. However, such a reduced N fertilization as 0–10 kg/10 a/yr sometimes produces very poor quality fruit especially in storage quality.

(2) Methods of efficient P fertilization.

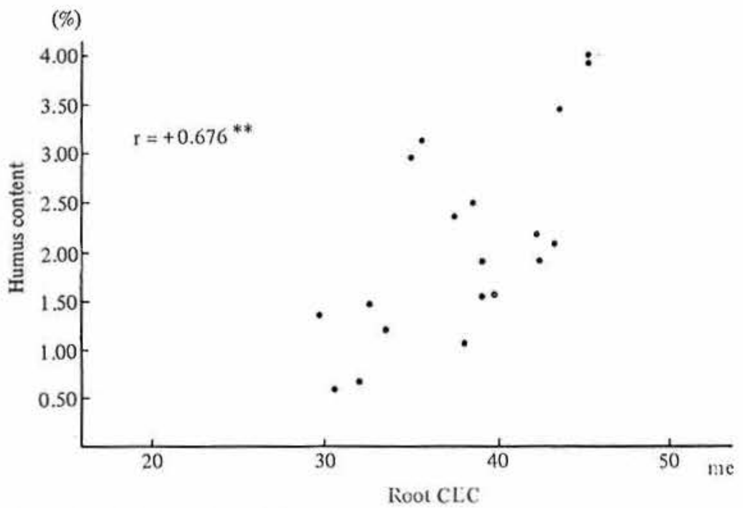

Fig. 6. Correlation between humus content in the soils and root CEC of satsuma mandarin oranges[1]

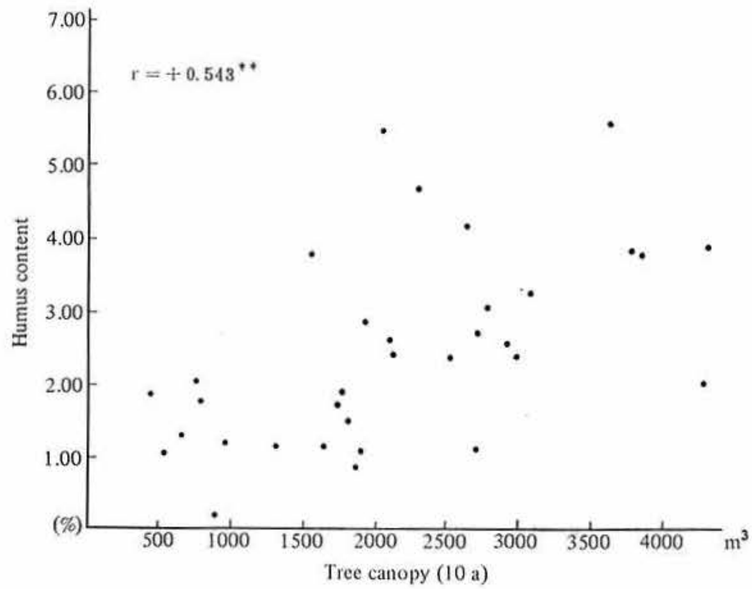

Fig. 7. Correlation between humus content of soils and canopy of satsuma mandarin trees[1]

To know whether or not P fertilizer improve fruit quality of satsuma mandarin, a number of studies have been conducted by using matured trees in fields or potted young trees. Some results showed disappointedly poor response to P fertilizers, while other results showed good responses, especially when P fertilizers were applied after soil pH correction or to deep soil layers.

The present author applied P fertilizers by different methods; foliar spray, heavy application to soil and trunk application with pressure. The foliar spray did not show any good effect to fruit. Heavy application was

Table 5. Leaf and fruitlet P_2O_5, and fruit quality of satsuma mandarin as affected by foliar or trunk P application (1975)[4]

Tratment	Leaf P_2O_5(%)		Fruitlet P_2O_5(%)	Coloring*	Pulp (%)	Brix	Acidity (g/100ml)
	July 26	Nov. 28	July 26				
Trunk application	0.41b	0.46b	0.43b	8.5a	71.3a	11.3a	1.21a
Foliar application (Reno)	0.34a	0.36a	0.35a	8.3a	69.1a	10.9a	1.23a
Foliar application (Atlox)	0.35a	0.39ab	0.39ab	8.3a	70.3a	10.8a	1.21a
Control	0.36a	0.37a	0.38ab	8.5a	68.3a	11.6a	1.24a

*: Coloring rate was calculated by the score full orange color 10 and green 0.
Mean separation in columns by Duncan's range test, 5% level.

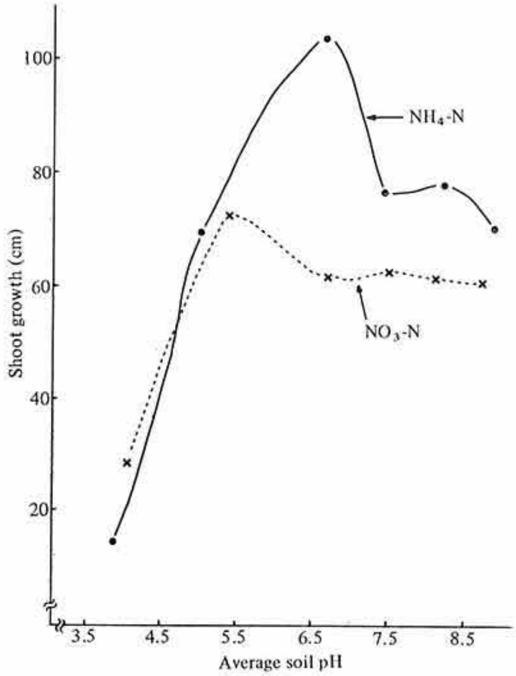

Fig. 8. Shoot growth of young citrus trees as affected by soil pH and different forms of N fertilizer[1]

inconsistent in its effect. When a liquid P fertilizer in a mixture of ammonium di-phosphate and ammonium monophosphate with pH adjusted to 7.0 was introduced into xylem tissues of tree trunk with pressure P_2O_5 contents in both leaves and fruitlets were significantly increased, but fruit quality seemed not improved. Further studies must be done in this respect (Table 5).

Conclusion

A cultural practice for obtaining stable yearly yields of satsuma mandarin is to maintain soil pH at around 6.0, because strong acidification of orchard soils causes growth inhibition of plants. This can be attained by applying a moderate amount of N fertilizer, e.g. 15–25 kg N/10 a/yr, together with liming materials. Application of organic matters is also advisable, as it increases humus content of soils to an adequate level, so that buffer action of the soil, and CEC of both soil and satsuma mandarin roots may be increased. In addition, some efficient P fertilization methods to improve fruit quality must be studied because demand for better quality fruit has been increasing.[3,4]

References

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