Factors Related to Soil Productivity of Orchards and Targets of Soil Improvement

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Orchards are distributed in Japan from Hokkaido in the north to Okinawa in the south. Soils of orchards consist of Brown Forest Soils, Red and Yellow Soils and Volcanic Ash Soils.

In general, mandarin orange is planted in areas of Red and Yellow Soils and apple in areas of Brown Soils. Grape, pear, peach, persimmon and chestnut are planted in both areas.

Since Japan is a chain of volcanic islands, Volcanic Acid Soils are distributed widely, offering locations for various kinds of fruits.

Geological parent materials of the Brown Forest Soils and Red and Yellow Soils are granite, basalt, quartz liparite, quartz prophyry, shale, sandstone, stuff, crystaline schist, chrolite schist and mica schist. Their geological ages are of paleozoic, mesozoic, tertiary and diluvium. Thus the orchard soils have been derived from various parent materials.

Table 1 shows various kinds of orchard soils, acreage and major fruits. It can be found that Volcanic Ash Soils, Tertiary Soils, Granite Soils, Alluvial Soils and Andesite Soils are the principal soils of orchards.

Topography of orchard land is level land (inclination 5°), gentle slope (5–15°) and steep (inclination 15°), and it is related to kinds of plants, i.e., 46% of mandarin orange orchards are located on steep land and 55% of apples are planted on levelled land as shown in Table 2.

Orchard soils, which have been derived from

Table 1. Kinds of soils and cultivation acreage of fruit trees

Kinds of soils	Acreage	Major fruit trees
Granite Soils	13%	Mandarin orange, grape, peach, persimmon, chestnut.
Andesite Soils	9	Mandarin orange, grape, chestnut.
Basalt Soils	3	Mandarin orange
Crystalline Schist Soils	6	Mandarin orange, persimmon, chestnut.
Paleozoic Formation Soils	7	Mandarin orange, apple, persimmon, chestnut.
Mesozoic Strata Soils	5	Mandarin orange, chestnut.
Tertiary Soils	15	Mandarin orange, apple, grape, pear, peach, persimmon, chestnut.
Diluvial Soils	5	Mandarin orange, apple, grape, pear, peach, persimmon.
Alluvial Soils	10	Mandarin orange, apple, grape, pear, peach, persimmon.
Volcanic Ash Soils	21	Mandarin orange, apple, grape, pear, peach, plum, persimmon, chestnut
Other Soils	6	

Note: 1) Statistics of Agriculture, Forestry & Fisheries (1971) Cultitvaion acreage of fruit trees=420, 000 ha
2) Data are derived from "Parent materials and formation of orchard soils and cultivation acreage" in every prefecture.
3) The cultivation acreage of each fruit tree described is more than 1, 000 ha. The fruit underlined with ____ is cultivated more than 10% and that with ==== is more than 20% in each soils.

Table 2. Inclination of land and acreage of orchards (%)

	Total	Levelled land (<5°)	Gentle slope (5°–15°)	Steep (>15°)
Mandarin orange	100	13	41	46
Apple	100	55	34	11
Grape	100	54	34	12
Peach	100	47	40	13
Japanese pear	100	67	22	10

(Data of 1963)

various parent materials through weathering and soil genesis, have strongly been influenced by topographical conditions as well as the chemical and physical characters of the parent materials.

The characters of orchard soils, such as thickness of soil horizon, soil texture, water permeability, water-holding capacity, soil structure, fertility capacity, amount of nutrients and soil acidity, depend greatly on the characteristics of soils and topographical conditions. These characters are intricately interrelated with each other and, as a whole, influence the soil productivity of the orchard.

Factors related to orchard soil productivity

The correlation between soil characters and productivity of fruit trees cannot be easily clarified because of their intricate interrelation. Some physical and chemical characters of soils which are required for the stable yearly production of good fruits will be discussed in this paper.

1) Physical factors of soils

The growth, ages and productivity of fruit trees are greatly influenced by the thickness of soil horizon (available depth) where the root of fruit trees can develop. It can be said, based on the data on the relation between fruit productivity of trees and available soil depth, that the deeper the soil in which rootlets develop, the more stable and higher is yield in many cases.

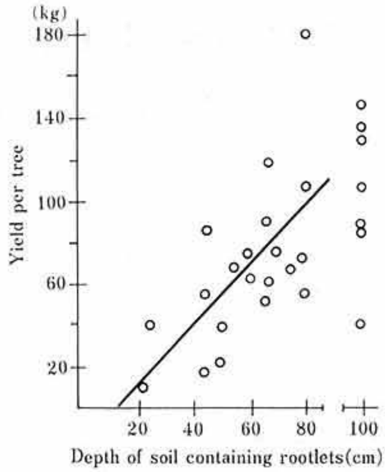


Fig. 1. Distribution depth of rootlets and fruit yield (Chugoku Agr. Expt. Sta.)

Fig. 1 shows the relation between the depth of soil horizon where rootlets were found and the fruit yield per tree in orange orchards of the coastal regions of the Seto Inland Sea. It shows a close relationship between the depth of available soil and fruit productivity.

The solid phase rate, gaseous phase rate, soil compactness, water permeability and porosity are the physical factors which relate to the structure of soils in which rootlets can develop. Many data have manifested that the proportion of the solid, liquid and gaseous phases in soils determines the development of rootlets of fruit trees. Fig. 2 shows the relation between the adequate and inadequate proportion of these three phases and the extent of rootlet distribution. Quantitatively, the critical point for stable and high yields of fruit seems to be 40 to 55% with solid phase, 20 to 40% with liquid phase and 15 to 37%

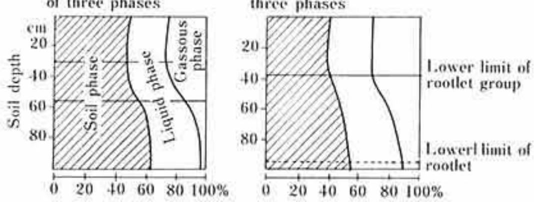


Fig. 2. Distribution of three phases and distribution depth of rootlets

with gaseous phase.

However, even with the same percentage of the solid phase, the conditions of the liquid and gaseous phases are different with soil structure, fine or coarse. Therefore, the critical percentage of the solid phase for rootlet development depends on the kind of soils; 45 to 55% with Granite Soil and 40 to 45% with Andesite Soil. It is generally known that Granite Soil is apt to be of coarse texture, whereas soils derived from basalt, andesite and quartz liparite are liable to become fine texture.

The orchard soils produced by the weathering of various parent materials are greatly influenced by the physical characters of the parent materials. This influence can be found apparently in subsoil horizon. Root development is greatly influenced by the presence of rocky beds, water-impermeable layer made of alternated clay and gravel layers, or a layer of weatherable breccia at the soil depth of 50 to 80 cm.

Soil hardness (or compactness) is one of the physical factors which influence root development. The hardness is determined with a hardness meter. When the reading of this meter indicates 18 to 20, the hardness of soils is at the critical point permitting easy development of ramified rootlets group. Rootlets scarcely distribute in the soils of which hardness is more than 25 in the reading. The reading is high when soils are dry, and is low when soils contain an excess of moisture. Therefore, the determination of the soil compactness should be carried out with soils of optimum moisture content. The value thus determined is used as a common index to show the compactness of soils in relation to root development notwithstanding the kinds of soils.

The water permeability of soils is also one of important physical characters determining the soil productivity of orchards. Low permeability keeps water in the soils for a long time after a heavy rainfall, resulting in a decreased air in soils and root damage.

Water permeability is expressed by coefficient of permeability. Soils with the coefficient of $\times 10^{-5}$ to $\times 10^{-6}$ cm/sec are of poor drainage, causing retarded root development and root decay in the upper horizon of that soils. If the coefficient is $\times 10^{-3}$ to $\times 10^{-4}$ cm/sec, no stagnation of water takes place. Air can easily penetrate into soils, causing good root development.

Porosity of soils is a factor related to water and air permeability. Volume of soil porosity is the difference between the total soil volume and the volume of solid phase. Therefore the porosity consists of liquid and gaseous phases, when the liquid phase increases, the gaseous phase decreases naturally.

Water of soils is held in innumerable pores of various sizes. Water in the pores larger than a certain dimension moves downward due to gravity. Air quantity in soils at the time when such downward movement of water is finished is referred to macropore, and the water condition at that stage is about 1.5 to 1.8 of pF value. In some respects, the volume of macropore can be regarded as indicating the quantity of large pores which relate to water permeability of soils as well as the quantity of air in soils required for root development. Volume of macropores is used as an index for assessing possibility of root growth; when the macropore is less than 10%, root development is usually retarded.

2) Chemical factors of soils

Soil chemical factors influencing growth of fruit trees and production of fruit are fertilizer-holding capacity, amount of nutrients, status of bases and acidity. Productivity studies in the past showed that excellent orchards have lower soil horizon with good base status while that of poor orchards shows high exchange acidity in many cases.

Investigations on root distribution conducted in experimental fields and orchards for a long period showed that degree of lime saturation less than 10%, extremely high acidity [pH(H_2O) less than 4.5] or high exchange acidity (more than 15) have caused retarded rootlet development and decayed roots. Low lime content (less than 10%) of apple orchard soils is liable to cause bitter pit and that in pear orchards may also cause Ishinashi (stone fruit) and black end fruits.

Although the base status of soils is usually indicated by acidity i.e. pH(H_2O), pH(KCl), exchange acidity (Y_1) and degree of lime saturation, the composition of exchangeable cations (calcium, magnesium, and potassium) also influences significantly the growth of trees.

The influence of chemical factors on roots depends on the physical factors of the soils. When the physical factors of soils are in good condition as a whole, they often compensate the lack of good chemical factors and *vice versa*. The former case is rather more often observed.

The fertilizer-holding capacity of soils gives no direct effect on growth of trees when fertilizers are applied abundantly. Its indirect effect, however, takes place in the form of salt damage, rapidity of nitrogen action, run-off of fertilizers and, hence capacity of buffer action against soil acidity and lime saturation. Generally, Granite Soils have low fertilizer-holding capacity (about 10 m.e. of cation-exchange capacity) while soils from andesite, basalt, crystalline schist and the soils of the Chichibu paleozoic formation have medium to large capacity (about 15–25 m.e. of cation-exchange capacity).

The abundance of soil nutrient can be controlled artificially by soil management, including fertilizer application, up to about 30 cm of soil depth where rootlets distribute. Therefore, there is no great problem as to the major nutrients (nitrogen, phosphorus and potash), but quantitative balance between calcium, magnesium and potash as well as micronutrients are of important problem.

In a large scale orchard construction, parent rocks are often brought up to ground surface from the depth of five to six meters, crushed mechanically, and used for cultivation in place of old surface soils. In such case, chemical characteristics of the parent material, especially content of micronutrients, give a direct effect on plants. Deficiency of nutrients is also recognized due to retarded solubility of manganese, copper, zinc, etc. caused by the application of lime and phosphorus for the improvement of soils.

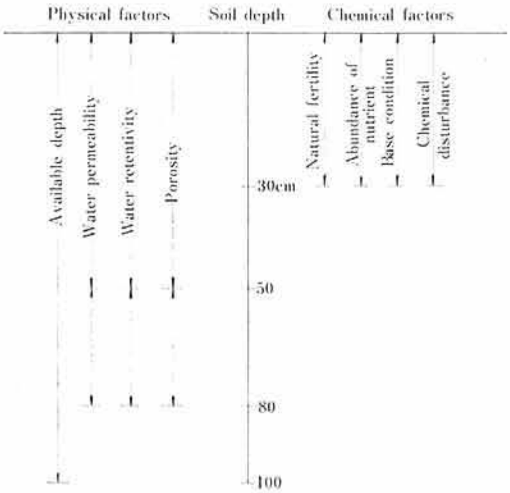
On the contrary, in mature orchards, an excessive fertilization results in high acidity [below 4.5 in pH(H_2O)] of soils, making manganese more soluble. An excessive absorption of manganese appears to be one of the factors of the abnormal leaf fall of mandarin orange and internal bark necrosis of apple.

Though it is not a problem of quantity of soil nutrients, an elimination of chemical obstacles in soils (heavy metals such as nickel, chrome, copper, lead, zinc, cadmium and arsenic) is also necessary to produce good yield of high quality.

Targets of soil improvement

Physical and chemical factors of soils described above can be summarized in terms of an indispensable target for soil improvement.

When a soil horizon having 10% of macropore exists within 50 cm in depth, soil im-



Note: 1) Solid line indicates soil depth mainly concerned with each factor of soil improvement
2) Dotted line indicates soil depth to which attention be paid in soil improvement

Fig. 3. Extent of depth of soil to be improved

provement should be made. In level lands, if an impermeable layer (with coefficient of permeability less than $\times 10^{-5}$ cm/sec) exists in the depth from 50 to 80 cm it should be crushed.

If the degree of lime saturation is less than 10% and pH(H_2O) is below 4.5 in the lower horizon of soils (30 to 50 cm in depth), soil acidity must be amended.

Fig. 3 shows the extent of depth of soils to be improved regarding above-mentioned physical and chemical factors.

Finally, it is needless to say that drainage should be taken into consideration for soil improvement.