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Full Length Research Paper

Development and description of soil compaction on orchard soils in the Mekong Delta (Vietnam)

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The study conducted in the Vietnamese Mekong Delta (VMD) was to examine soil degradation and soil compaction in fruit tree plantations due to the impact of agricultural activities. The specific objective was to elucidate the impact of soil compaction on current and future production. Fruit trees are one of the most important components for the development of the delta. The plantation areas have increased rapidly over the recent years (from 117,000 ha in 1996 to 300,000 ha by the year 2006). Fruit trees in this region are usually grown on raised beds to avoid submergence due to annual flood. Most of the soils of raised beds are alluvial and perturbed from the natural soils. Studies on the raised beds have recognized trends of soil compaction during ageing of the raised beds. However, there are many uncertainties and consequently a need for further investigations exists, to improve the knowledge and understanding of soil processes in the region.

Key word: Citrus orchards, soil compaction, soil degradation, Mekong delta.

INTRODUCTION

The Vietnamese Mekong Delta (VMD) is the region in South-east Vietnam belonging to the most downstream of the Mekong River basin with an area of 39.7 million ha (12% compared to Vietnam), in which there are 2.97 million ha using for agricultural cultivation (31.7% compared to that of the whole country). The population is estimated to be 17.3 million people (21% compared to Vietnam). Population density averages 435 persons per square kilometer over the whole delta (General Statistics Office, 2006).

The delta has a monsoon tropical climate, specified with two distinct seasons – dry and wet season. The dry season is from December to April and the wet season is from May to November. The average rainfall ranges from less than 1500 to over 2500 mm. The mean temperature is from 23 to 25°C during the coldest months and is from 32 to 33°C during the warmest months.

The hydraulic regime within the delta is complex with three characteristics – (1) fresh water and annually regular flooding (combination of annual rainfall coupled with the high level of the Mekong River) in the wet season carrying alluvial sediment, ephemeras and larvae; (2) acid water in the sulphate soil areas; and (3) inland intruded by salt water in the dry season. According to the Ministry of Water Resources of the Socialist Republic of Vietnam (1994) the salt water-covered inland extends to an area of 2.1 million ha in the coastal area (especially in April and early May).

The VMD is a young landmass formed and developed in the Holocene era by transgression and regression of the sea (Chiem, 1993). The soils are mainly formed by the deposit of sediment from the rivers (Mekong and Bassac rivers) and the sea. Sediment is carried by flood water deposited along the banks of the Mekong and Bassac rivers. It tends to form ridge-shaped natural levées with relatively large particles of sediment parallel to the river banks (Hori, 2000; Funabiki et al., 2007; Tamura et al., 2007). This effect caused the different distribution of soil texture over the different areas; the further from the river banks, the finer the soil texture. There are seven soil types and these are summarised in Table 1 (Ve and Anh, 1990), and five land form units involving (1) flood plains including natural levées along the main arms of the rivers; (2) a coastal complex of

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Table 1. Major soil groups in the Mekong Delta (Ve and Anh, 1990).

Soil type	Area (km^2)
Alluvial	10,943
Acid sulphate	10,543
Saline	8903
Saline acid sulphate	6214
Old alluvial	1090
Peat	341
Mountainous	347

Table 2. Area and yield of some fruit tree in the Mekong Delta by 2005.

Fruit type	Area (ha)	Yield (ton)
Citrus	55,802	452,977
Pomelo	19,505	144,564
Longan	45,220	406,420
Mango	36,918	234,926
Pineapple	20,760	227,673
Rambutan	5647	85,586
Durian	9196	64,087
Banana	16,304	215,225
Total	209,352	1,831,458

Source: General Statistics Office, 2006.

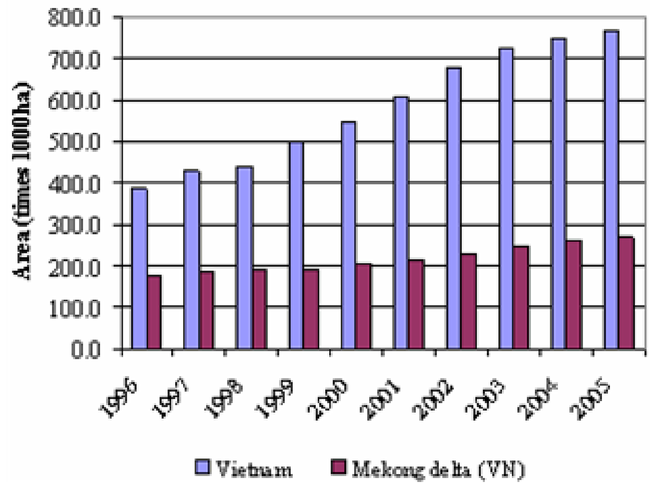

Figure 1. Fruit tree area of Vietnam and Mekong delta, Vietnam from 1996 to 2005. Source: General Statistics Office, 2006.

sand ridges, flats and mangroves; (3) a broad depression; (4) an old alluvial terrace; and (5) hills and mountains (Chiem, 1993).

According to the statistics collected and classified from 1996 to 2005 by the General Statistics Office of Vietnam, the Office of Agriculture and Rural Development, and the Agricultural Service of the provinces on the fruit tree areas, the area and production of fruit trees in Vietnam have continuously increased over recent years (Figure 1). This area increased from 346,400 ha in 1996 to 766,100 ha in 2005 (annual average growth rate of 8.9%).

Statistics from the Ministry of Agriculture and Rural Development, the fruit tree areas in the Mekong delta covered approximately 300,000 ha by the year 2005 (37% of the fruit tree area of Vietnam) with diversity of fruit types, in which there are many well-known delicious varieties, such as mango, pomelo, star apple, tangerine, orange, durian, etc. (Table 2).

Most of the areas for growing fruit trees in the delta are lowland with alluvial soil. Due to the influence of annual high flooding, farmers have to build up so-called 'raised beds' to avoid submergence. The raised beds are made by excavating and heaping soil materials up from adjacent lateral ditches, to form the long raised strips that are higher than the original ground surface as depicted in Figure 2. Hence, upland crops and fruit crops can be grown all year round.

Known as the largest agricultural zone in Vietnam with diverse cropping systems, the VMD takes an important role to the country economy. In recent years, in appropriate management of agricultural practices have been triggering land degradation.

The objective of this paper is to examine the impacts of agricultural activities on soil degradation and soil compaction for orchard soils in the VMD. Specific objectives are to clarify to what extent soil compaction is a problem for current and future production. The available literature from the VMD is reviewed to reach the objectives.

MATERIALS AND METHODS

Research on intensive rice farming areas in the Mekong delta has indicated soil degradation in both soil compaction and in soil structure. Due to mechanisation and agglomeration, clay particles move down to lower layers, causing soil compaction. Reduction of organic matter and soil prepared in unsuitable moisture conditions led to the negative impact on the soil structure. The research also obviously found a decrease in rice yield on these areas, although more chemical fertilizer was applied (Khoa, 2002). A recent study by (Guong et al. 2005) on the citrus plantations selected an age range of 7, 9, 16, 26 and 33-year-old raised beds at Cantho province, VMD.

The methodology of this study was based on the hypotheses that the soil on the older raised beds could become tighter and harder, soil nutrients would decline and the soil microorganism activity decrease. These lead to decreased root growth and reduced yield. The addition of organic matter into the soil may help in improving soil nutrient decline, physical conditions and soil biology. The experiments were carried out on the citrus plantations of: (1) 33-year-old raised bed at Phuoc Thoi hamlet, Thoi Long commune, O Mon district; (2) 26-year-old raised bed at Long An hamlet, Tan Phu Thanh commune, Chau Thanh district; (3) 16-year-old raised bed at Tan Thanh Tay hamlet, Tan Phu Thanh commune, Chau Thanh district; (4) 9-year-old raised bed at Tan Thanh Tay hamlet, Tan Phu Thanh commune, Chau Thanh district; and (5) 7-year-old raised bed at Tan Thanh Tay hamlet, Tan Phu Thanh commune, Chau Thanh district. Peculiarly, the 33-year-old raised bed is in a

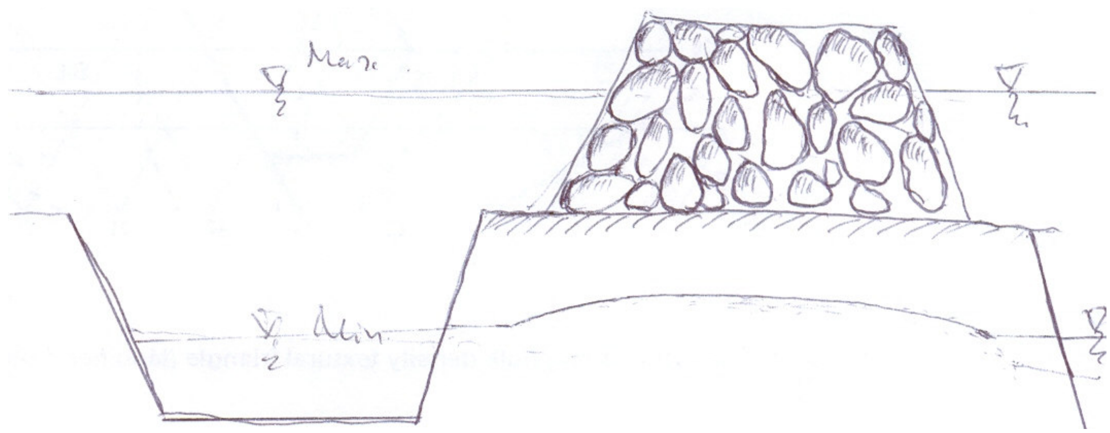

Figure 2. Cross-section of raised bed building.

Table 3. Soil chemical properties of citrus plantations of layers 0–15 cm with different construction years of the raised beds at Cantho province, Vietnam (Guong et al., 2005).

Age of raised beds (year)	pH-H_2O (1:2.5)	Organic matter (%)	N-total (%)	N-av (mg/kg)
7	5.28 a	5.36 a	0.23 a	25.42 a
9	5.33 a	4.00 ab	0.20 b	10.01 c
16	4.67 b	4.93 ab	0.22 ab	19.54 b
26	4.60 b	4.74 ab	0.22 ab	19.13 b
33	2.34	3.34	0.16	16.01
CV (%)	2.34	16.17	6.53	15.60
LSD (5%)	0.22	1.39	0.02	4.61

Within a column, numbers are followed with the same letter show no significant difference.
CV: Coefficient of variation; LSD: least significant difference.

rather low area of the ecological zone of O Mon, although of the same alluvial type, but there were differences in soil texture. Thus, this raised bed was considered as the reference site for those greater than 30 years old and the results were restricted in statistical analysis to compare the differences to the other raised beds belonging to the Chau Thanh ecology. Soil samples were taken at the beginning of the dry season and analysed for physical, chemical and biological components.

The effect of using organic fertilizer and vegetable manure (green manure) was carried out on 33-year-old, 26-year-old and 7-year-old raised beds and the experiments in each raised bed was designed by randomized complete block in triplicate with experimental factors as (1) control, (2) planting Vetiver grass, (3) planting Binh Linh (*Vitex pubescens*), (4) planting mung bean and (5) applying organic fertilizer. There were 15 treatments on each raised bed with the area of 30 m^2 for each treatment. Vetiver grass was planted with two crops a year; Binh Linh (*Vitex pubescens*) was grown with four crops a year (three months each crop); mung bean was grown at five crops a year (two months each crop); and organic fertilizer was applied 10 tons/ha. The dry biomass was recorded and analysed the amount of N, P and K. Stems and leaves of Binh Linh (*Vitex pubescens*) and mung bean were buried into soil. For Vetiver grass, the stems were removed stems and only the roots kept in the soil.

RESULTS

The experimental results showed that there was a tendency of gradual decrease of soil pH according to the ages of the raised beds at 0 – 15 cm soil depth. The pH value of soil was about 5.3 for 7 and 9-year-old raised beds, and was significantly high compared to 16 and 26-year-old raised beds with the pH in a range of 4.6 to 4.7. The 33-year-old raised beds had the lowest soil pH value of 3.5. A similar result of soil pH was also found for the soil layer of 15–30 cm (Table 3). Total nitrogen on all raised beds was at a medium level and varied in the range of 0.16 to 0.23% at 0–15 cm soil depth, with no significant differences between the raised beds from 7 to 26 years old. The amount of total nitrogen in the soil layer of 15 – 30 cm was at a poor level on the raised beds of 16 and 26 years old. The 33-year-old raised beds were at a poor level of total nitrogen at 0 – 30 cm soil depth. The available nitrogen varied from 10.0 to 25.4 mg kg^{-1} for both layers of 0 – 15 and 15 – 30 cm soil depth (Table 3). There was a significant decrease in soil microorganism population on the 26 and 33-year-old raised beds. Soil organic matter varied in the range from 3.5 to 4.9% at 0 – 15 and 15 – 30 cm soil depth (Table 3). Soil texture was classified as clay soil, except the 33-year-old raised bed which was silty clay soil. The bulk density measured in different layers varied between 0.9 and 1.3 $g.cm^{-3}$. The highest bulk densities were observed in the 26 and 33-year-old raised beds. The soil penetration resistance

Table 4. Soil penetration resistance of citrus plantations of layers 0–45 cm with different construction years of the raised beds at Cantho province, Vietnam (Guong et al., 2005).

Age of raised beds (years)	Soil penetration resistance		
	0–15 cm	15–30 cm	30–45 cm
7	2.8 d	1.7 b	1.3 b
9	3.5 c	1.9 b	1.3 b
16	4.3 b	1.5 b	1.2 a
26	5.8 a	6.8 a	4.7 a
33	5.6	4.4	2.96
CV (%)	10.40	10.76	24.84
LSD (5%)	0.26	0.19	0.33

Within a column, numbers are followed with the same letter show no significant difference.
CV: Coefficient of variation; LSD: least significant difference.

values varied in the range of 2.8 to 5.8 MPa at 0–15 cm; from 1.5 to 6.8 MPa at 15–30 cm; and from 1.2 to 4.7 MPa at 30–45 cm soil depth. The highest value of soil penetration resistance was found on the 26-year-old raised bed. There was a significant increase in agreement with the ages of the raised beds (Table 4). According to Materechera et al. (1992) as cited by Guong et al. (2005), the soil layers is considered as compacted and give an impact to the root growth when the soil penetration resistance is higher than 3 MPa or 300 $N.cm^{-2}$. Surface compaction (0–15 cm) consequently occurred on all of the raised beds in the dry season, except the 7-year-old raised beds. Higher soil penetration resistance and enhancement to the deeper layer of root growth occurred on the 26 and 33-year-old raised beds.

The experiments on the effect of using organic fertilizer and vegetable manure left in the soil showed the amount of dry biomass from 2.7 to 3.3 tons/ha for the stems and leaves of mung beans; from 4.4 to 6.0 tons/ha for the stems and leaves of Binh Linh (*Vitex pubescens*). For the treatment of planting Vetiver grass, there was more root growth within layers from 0 to 15 cm than layers from 15 to 30 cm soil depth and the least root growth on the 33-year-old raised bed. In 15–30 cm soil depth, the root density showed very little growth, the amount of biomass was of from 2.4 to 12.1 percent compared to that in the surface layer. It was observed that in the layer deeper than 30 cm soil depth, root growth was not worth considering. Applying green manure, burying stems and leaves of Binh Linh and mung bean helped to improve the organic matter content on the 26 and 33-year-old raised beds, while Vetiver grass treatment was not significant compared to control.

The results of another study conducted by Minh (1996) to determine water flow for new, 1 and 2-year-old raised beds for yam and pineapple cultivation showed that the area and perimeter of soil pores in 2-year-old pineapple beds decreased to about one third, and bypass flow rates decreased to about 80% of those in newly constructed beds.

DISCUSSION

Soil degradation is known as a major constraint to the plant yield and soil production, in which soil compaction as a physical process is one problem that needs attention. The process takes a long time and depends on many factors such as soil type, climate condition and management practices. But when the soil becomes compacted it is difficult to correct, thus attempts should be made in an early stage to prevent compaction. This may be the best way to maintain soil quality and to reach sustainable agriculture.

Aggregate stability also needs to be paid attention on. It refers to the ability of aggregates to resist soil degradation. Soils with stable aggregates are more resistant to water erosion and thus it may prevent the movement of soil particles downward sublayers (Le Bissonnais, 1996; Barthcs and Roose, 2002).

Compacted soil commonly has many constraints to plant growth and a great deal of negative impact on the physical environment and therefore it will be a hazard for soil production. The expanding area of fruit trees and with specific conditions of the delta, soil compaction is a difficulty to avoid if one has no comprehensive measures and thorough understanding about mechanism of the process. The studies by Minh (1996) and Guong et al. (2005) identified soil on the raised beds as potentially compacted because of the ageing of the raised beds. However, the mechanism of compaction has not been demonstrated for the field conditions in the VMD.

Further study has to address the settlement rate, aggregate stability and water storage capacity during the ageing of raised beds. Simulation approaches based upon hypotheses and measurement of field experimental data in the VMD will be of high interest.

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