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Soil Penetration Resistance and Its Dependence on Soil Moisture and Age of the Raised-Beds in the Mekong Delta, Vietnam

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Abstract:—The research was conducted on 10 citrus plantations at Hau Giang province in the Mekong delta, Vietnam during one year with a portable electronic penetrometer to understand the impact of moisture on the soil compaction. Soil penetration resistance (PR) was measured in the depth of 0-80 cm depth and soil samples also taken at each 10 cm depth from the soil surface to the water level for soil moisture measurement. The results showed that PR increased as a function of raised-bed's age and it could be reached to a high degree by soil moisture variability during the season. The sensitivity of PR to soil moisture decreases with the age of raised-beds while the soil moisture represented an increasing tendency with the age of raised-beds. Relationship between PR and soil moisture are explained better by the volumetric water content than the corresponding soil water potential expressed as pF values. The measurements of soil PR determined by the previous results, which are obtained from soil, core samples with the dry bulk density and water retention curves were calculated and analyzed. Using the PR data will be very useful; it is a complementary and important information for identification the soil structure and soil moisture content. Without such processing of PR measurements, the values of the PR measurements will be limited and not indicated for soil compaction. To minify soil compaction on the raised-beds, all the pressure and mechanical activities should not be done in the soil surface, specially in the wet condition. Organic fertilizers and Biochar can be considered as soil conditioners and recommended to applied in orchard for improving soil properties.

Keywords:—Citrus orchard, soil strength, soil compaction, Mekong delta

I. INTRODUCTION

Soil-water-plant relationship is a dynamic system that it interacts mutually. Soil plays a vital important role as a crucial foundation, on which the plant can coexist harmoniously with surrounding environments. Under natural conditions, soil has a resilient capacity. However, soils are prone to the deteriorative processes, which have subjected to the soil formation and cultural practices.

There are many soil physical properties affecting to the plant growth such as texture, structure, water retention, hydraulic conductivity, heat capacity, thermal conductivity and soil strength. For good plant growth, it is essential that the soil must provide a favorable physical environment for root development. Since plant root system is mostly growing in porous media, it must therefore overcome mechanical soil resistance. Penetration resistance (PR) of soils is an important parameter that influences to the root growth and water movement. The most common method to evaluate soil strength is by using a penetrometer, which is characterized by the force required to advance a cone of specific base size into the soil (Bradford, 1986). Cone penetrometers have been extensively used in agriculture and horticulture to study tillage system (Unger and Jones, 1998), soil compaction and soil crust formation (Baumhardt et al., 2004; Jung et al., 2010; Mosaddeghi et al., 2000; Smith et al., 1997). Studies done by Laboski et al. (1998), Lampurlanes and Cantero-Martinez (2003), Pabin et al. (1998) and Stelluti et al. (1998) revealed strong correlations between PR and root elongation, between PR and crop yield. A few studies related to soil science were carried out by using cone penetrometers in the Mekong delta, Vietnam (MD). Such studies were also researched on rice-field cultivation to identify the natural and compacted layers (Khoa, 2002), and on citrus plantations to recognize soil physical and chemical degradation with the different ages of the raised beds (Guong et al., 2005).

Soil penetration resistance mainly depends on soil type, bulk density and soil water content (Ayers and Perumpral, 1982; Gliński and Lipiec , 1990; Henderson et al., 1988). Compaction leads to the changes in soil porosity (Alaoui and Helbling, 2006), and consequence in variability of the pore-size distribution (Hayashi et al., 2009). Wet and dry cycles naturally influence to the soil moisture content that affects cohesion, angle of internal fiction, compressibility and adhesion. In the saturated soi1 condition, cohesion is at its minimum because of the presence of free water in soil pores. When soil moisture decreases, negative water potentials develop and water held by soil particles takes action as a bonding agent, therefore increasing cohesion. PR increases as the soil dries and decreases as the soil becomes wetter or any soil at a given bulk density (Bar-Yosef and Lambert, 1981). In addition, bulk density may not have large changes over relatively short periods; therefore, PR is mostly associated with soil moisture changes. To allow comparison of PR taken at the different soil moisture contents, it is necessary to normalize PR readings to common soil moisture. A penetrometer measurement of 2 MPa generally concerned as sufficient to impede the growth and development of plants (Taylor and Gardner, 1963). At PR larger than 2.5 MPa, root elongation is significantly restricted (Whalley et al., 2007). However, some studies showed significantly the higher PR values due to the influence of the soil moisture content at the time of the penetrometer readings with visually healthy plants (Smith et al., 1997; Sojka et al., 2001; Whalley et al., 2007).

In this study, penetration resistance was used to obtain a general description of soil strength under 10 raised beds with the different ages in the MD. Major objective was to investigate if measurements of penetration resistance can be used to understand how soil degradation will develop during cultivations in the raised beds in the MD. The specific objectives were (i) to describe how the relationship between PR and soil moisture that may be affected by soil compaction, (ii) to describe the seasonality of simultaneous dynamics of PR and soil moisture, (iii) to discuss the additional value of soil PR compared with conventional information on soil physical properties, and (iv) to provide some general guidelines for how to counteract with soil degradation in the MD.

II. MATERIALS AND METHODS

Site description

The study was initiated in 2010 on 10 selected citrus plantations in Hau Giang province, Mekong delta, Vietnam with the different ages as shown in Table 1 and Fig. 1. The climate is characterized by two distinct seasons, a dry season from December to April and a rainy season from May to November. The annual rainfall ranges from less than 1000 mm to over 1300 mm, however most of 90% rainfall concentrates in the rainy season. The mean temperature is from 23-25 ^{o}C during the coldest months and from 32-33 ^{o}C during the warmest months. The humidity is high in the rainy season, the highest in September (91%), and the lowest in the dry season (79 – 82%). The soil is classified as the alluvial soils (Soil Science Department, CTU 1985-1996; Soil Survey Staff, 1996). Texture is classified as silty clay. The raised beds were constructed by excavating and heaping up soil materials from adjacent lateral ditches to form the long raised strips that are higher than the original ground surface. Soil layers on the raised beds were commonly arranged in the reverse order compared to the sequence of soil master horizon in natural soils.

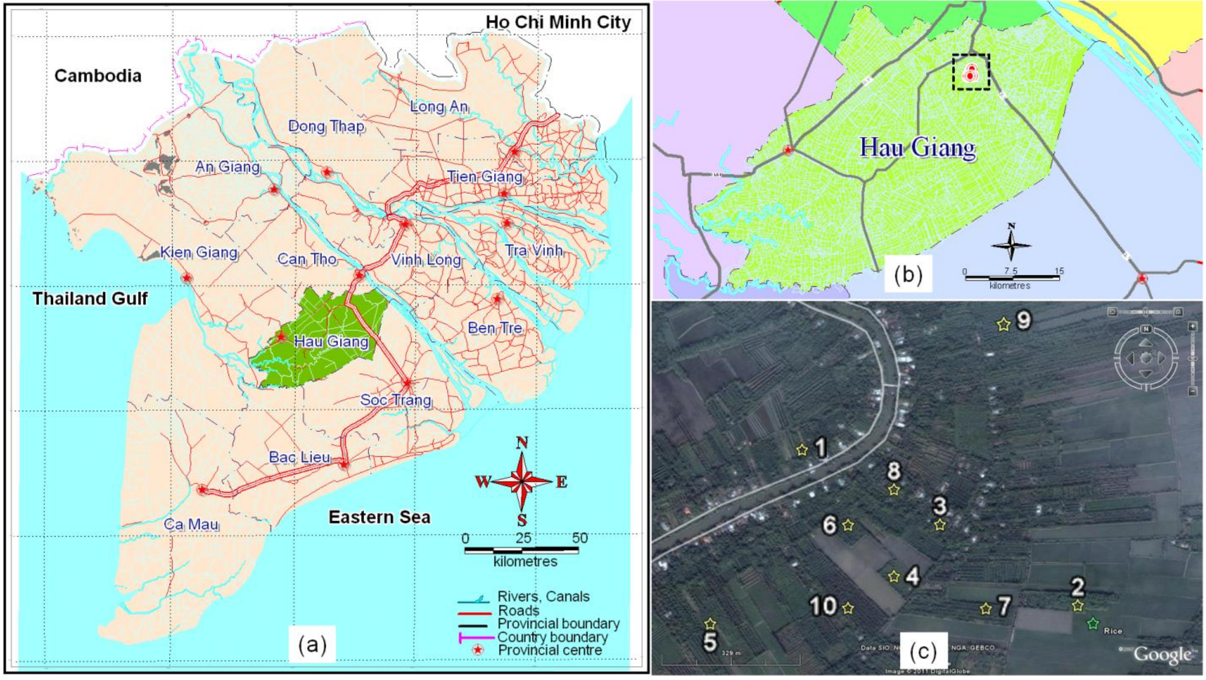

Figure 1. *(a) Administrative map of the Mekong Delta, Vietnam (b) Map of Hau Giang Province, (c) Map showing the study location, extracted from Google Earth.*

The data collections started at the beginning of the dry season, January 2010. Soil samples were taken from each of the raised bed for soil physical analyses at the layers of 0-20 cm and 20-50 cm depth with four replications at each study site. Laboratory tests were also done to determine the soil physical properties; it consisted of bulk density and water retention. Bulk density, ρ_b (g cm^{-3}) was determined from oven-dry weight of 5 cm in diameter and 5 cm long undisturbed core samples (Blake and Hartge, 1986). Soil water retention (pF curve) was experimentally determined using soil sample procedures (Cassel and Nielsen, 1986; Klute, 1986). Undisturbed and disturbed samples were saturated with water in 48h, subsequently using the sand box apparatus and pressure membrane apparatus (*Eijkelkamp* Agrisearch Equipment, the Netherlands) for a range of suction pressures from 0 to 0.1 bar (pF: 0 - 2) and from 0.3 to 15 bar (pF: 2.5 - 4.2) respectively. Soil water retention was determined in the laboratory with 8 pF values. Soil water retention curves were established by fitting the pressure-soil moisture content data to the model of van Genuchten (1980).

Table 1. Ten study locations selected in Hau Giang province, Mekong delta, Vietnam

Locations	Latitude	Longitude	Age range (years)
1	9^{o} 53' 44.38"	105^{o} 43' 41.09"	15
2	9^{o} 53' 28"	105^{o} 43' 57.14"	17
3	9^{o} 53' 35.74"	105^{o} 43' 47.75"	19
4	9^{o} 53' 31.7"	105^{o} 43' 42.78"	28
5	9^{o} 53' 28"	105^{o} 43' 29.46"	30
6	9^{o} 53' 35.7"	105^{o} 43' 41.27"	31
7	9^{o} 53' 29.18"	105^{o} 43' 50.7"	32
8	9^{o} 53' 38.47"	105^{o} 43' 45.34"	33
9	9^{o} 54' 2.7"	105^{o} 43' 49.4"	35
10	9^{o} 53' 29.22"	105^{o} 43' 41.16"	37

This study used a portable electronic penetrometer, with a built-in data logger for storage and processing of a great number of measuring data (500 measurements), developed by the *Eijkelkamp* Agrisearch Equipment, the Netherlands. The penetrologger method had a measuring range of 1000 N (10 MPa). PR was measured by a load cell connected to a cone screwed onto the bottom end of a bipartite probing rod. The cone used in this study has 60° angle and the base area of 1 cm^2. An internal ultrasonic sensor accurately registers the vertical distance above the soil surface and load cell was used to calculate the PR at each centimeter and the device stored data up to the depth of 80 cm in the profile. Speed penetration was set at 1 cm s^{-1}.

Data were periodically taken on 10 raised beds with once a week, started from 22-01-2010 to 02-06-2010 (a data series of ten points). On each raised bed, penetrometer measurements were designed into three plots and three ‘penetrations’ were carried out to obtain a representative average result per plot automatically. At the same time as PR measurements, soil samples were also taken from a distance within 0.1 m from the PR measurement points. Sampling depths were selected in the following intervals, 0 to 10 cm; 10 to 20 cm; and so on down to water level. Soil samples were then taken to determine the soil moisture by dried method at 105°C in the laboratory. The measured soil water retention characteristic curves were used to convert the volumetric moisture content data to water potential (pF). The volumetric moisture content was calculated from the mass moisture content and bulk density.

A subset of PR data series was extracted from the PR measurements. At the depth of 5, 15, and 25 cm from the soil surface were considered as a representative for layer of 0-10, 10-20, and 20-30 cm respectively. Based on the PR data series and according to the soil moisture data set, the relationship between PR and soil moisture was analyzed by using linear regression method. The same procedure was also applied to determine the relationship between PR and pF values. On the bases of these regression equations, PR was recalculated from the soil moisture and/or pF values for further analyses. Comparisons of the differences between the raised beds were determined by using the t-test with 0.05 significant levels.

III. RESULTS

Bulk density varied in the range of 0.76 - 1.18 g cm^{-3} and 0.85 - 1.24 g cm^{-3} for topsoil and subsoil respectively (Table 2). Bulk density value of the subsoil was slightly higher than that of topsoil. There are the differences significantly at 0.05 level between the raised beds and the increasing trend with the age of raised beds was found for the subsoil. The similar trend was also seen for the topsoil. However, there are no the differences significantly at 0.05 level exception for the 15-year-old raised bed.

Table 2: Bulk density and fitted van Genuchten parameters of soil moisture characteristic for topsoil and subsoil – values in the parenthesis

Age of raised bed (year)	Bulk density (g cm^{-3})	Fitted parameters[a]			
		θ_s	θ_r	α	n
15	0.76 a (0.85 d)	62.3 (61.0)	0.017 (0.004)	0.010 (0.009)	1.18 (1.17)
17	1.02 b (1.09 bc)	52.1 (49.2)	0.040 (0.052)	0.011 (0.004)	1.13 (1.13)
19	1.02 b (1.13 abc)	51.7 (48.1)	0.037 (0.040)	0.011 (0.004)	1.13 (1.14)
28	1.16 b (1.20 ab)	48.3 (45.9)	0.040 (0.045)	0.005 (0.004)	1.13 (1.14)
30	1.09 b (1.15 abc)	47.2 (48.0)	0.046 (0.040)	0.006 (0.004)	1.13 (1.15)
31	1.17 b (1.12 abc)	49.9 (46.9)	0.049 (0.043)	0.008 (0.004)	1.13 (1.14)
32	1.11 b (1.17 abc)	51.1 (48.2)	0.040 (0.042)	0.009 (0.005)	1.14 (1.15)
33	1.18 b (1.16 abc)	48.9 (46.7)	0.071 (0.073)	0.009 (0.004)	1.14 (1.15)
35	1.02 b (1.24 a)	46.1 (45.5)	0.099 (0.095)	0.006 (0.005)	1.12 (1.14)
37	1.14 b (1.03 c)	48.4 (54.8)	0.063 (0.074)	0.005 (0.005)	1.14 (1.16)

Within a data column, numbers are followed with the same letter show no significant difference at 5%; [a] *Units of parameters:* θ_r*, residual water content (*cm^3 cm^{-3}*);* θ_s*, saturated water content (*cm^3 cm^{-3}*);* α*, inverse of the air entry potential (*cm^{-1}*); n, empirical constant affecting the shape of the retention curve.*

Soil water retention curves (SWRC) of the topsoil and subsoil in the raised beds are shown in Fig. 2. The curves had rather gentle shape as the volumetric water content gradually changed with soil pressure heads but the different shape of curve among the sites as well as at the different soil depths within each site are found. The shape of the SWRC is intrinsically related to the pore-size distribution. Compaction energy and soil structure influenced the shape of the SWRC for fine-textured soils (Vanapalli et al., 1999). Water retention is higher in the wet range but slightly lower in the dry range for topsoil compared to subsoil (Table 2, Fig 2).

The residual water content, θ_r, remains at a very high pressure. It is directly related to micro-pores and is considered as unavailable to the plants. The θ_r generally tended to increase with age of the raised beds (Table 2). This implied that the greater soil water retention, the greater proportion of micro-pores are. The increasing of micro-pore proportion can be used as an indicator of soil compaction. The air-entry pressure ($1/\alpha$) corresponded to the matric suction required to remove water from the largest pores, which is also related to soil pores forming the continuous network of the flow paths within the soil (Assouline et al., 1998).

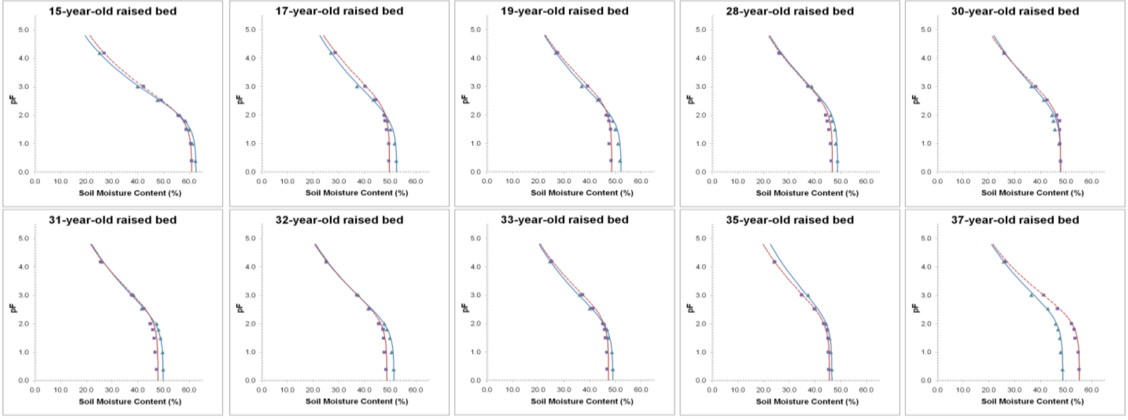

Figure 2*. Soil water retention curves of soil profile at the different ages of raised beds at topsoil (solid blue line) and subsoil (dash red line) corresponding to the triangle and square symbols for measured pF points*

Soil penetration resistance (PR), which plotted against soil depth under the different raised beds, is shown in Fig. 3. The results showed the average values which are taken overall the observed period of 22-01 to 2-06-2010. In general, the variability of the PR regularly increased from the soil surface and reached maximum value at 10 cm within the depth of 25 cm then it decreased in the depth of 25 – 40 cm and again PR increased below 40 cm. The PR values changed in the range of 0.13 - 3.05 MPa with the confident intervals from 0.03 to 0.52 MPa in 60 cm the soil depth of profile (Fig. 3).

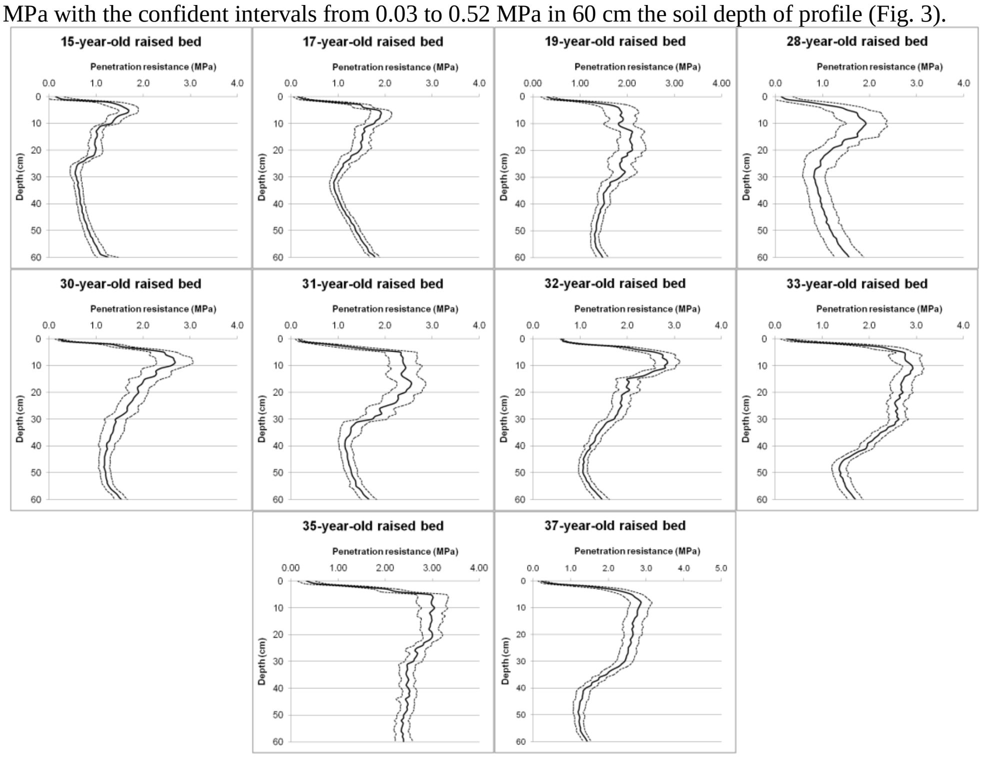

Figure 3: *Penetration resistance plotted against soil depth at all the observed period of 22-01-2010 to 02-06-2010. Solid-line: average value and dot-line: confident intervals at 95%.*

Figure 4 showed the general variation of soil water content and PR over the observed period of 22-01 to 02-06-2010. These values are the average ones, they are obtained from the data set of 10 raised beds, on soil water content and PR at three soil depths. The lowest water content of 30.7% found in the top 10 cm depth and the highest of 41.7% determined in the layer of 20-30 cm depth corresponding to PR of 2.5 MPa and 1.7 MPa respectively. The variation for both soil water content and PR value is higher in the top layers compared to that of the deeper layers.

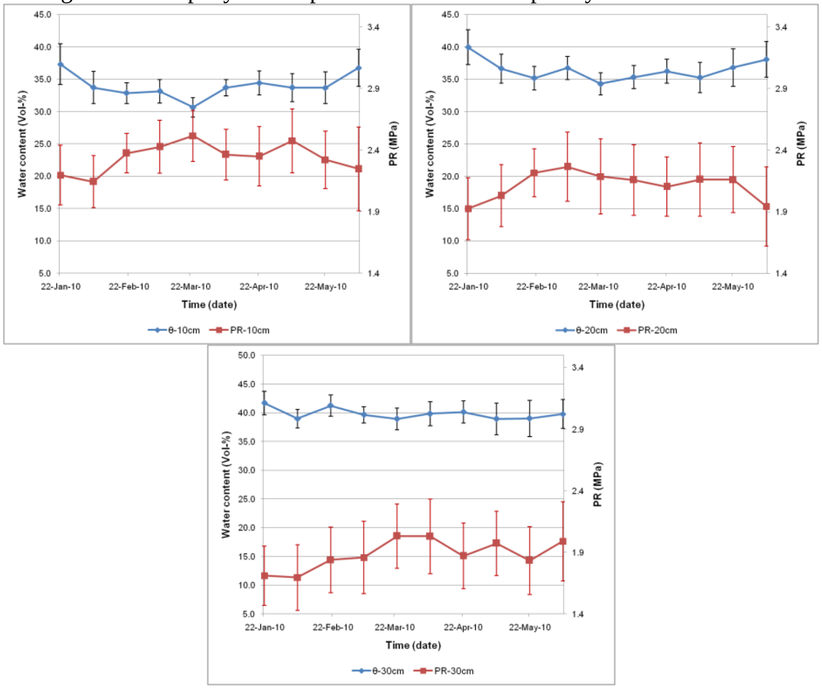

Figure 4: *Average soil water content (θ, vol-%) and penetration resistance (PR, MPa) at 10 raised beds over the observed period of 22-01 to 02-06-2010 for three soil layers.*

Average PR calculated from the PR measurements at the soil layers of 0-10 cm (layer 1), 10-20 cm (layer 2) and 20-30 cm (layer 3) for the period of 22-01 to 02-06-2010 is shown in Figure 5. The highest PR obtained at all three layers is measured on the 35 year old raised bed and the lowest PR is found on 15 year old raised bed, exception for 28 year old raised bed.

The increasing trend with age of the raised beds is revealed, and the changing rate of the PR against age of the raised beds (slope coefficient of the regression equation) increased about 42% for layer 1 compared with layer 2 and 44% for layer 1 compared with layer 3. However, the increase is not significant for layer 2 compared with layer 3 (Fig. 5). PR values decreased with the soil depth; however, there are no statistical significant differences of the mean value. The PR, that is greater than 2.5 MPa, is found at the 30, 31, 32, 33, 35 and 37-year-old raised beds for layer 1, at the 31, 32, 33, 35 and 37-year-old raised beds for layer 2, and at the 33, 35 and 37-year-old raised beds for layer 3 (Fig. 5).

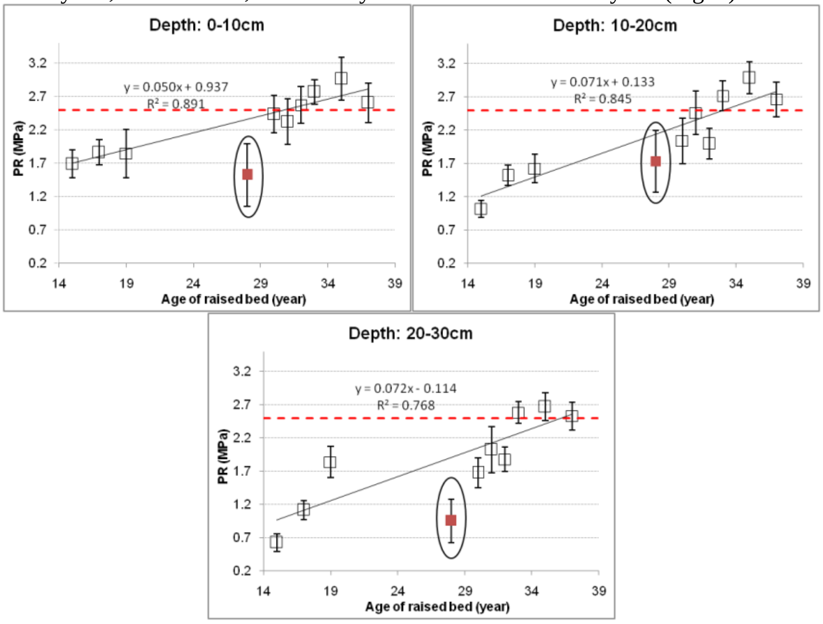

Figure 5: *Average penetration resistance at the different age of the raised beds and soil depths on all the observed period of 22-01-2010 to 02-06-2010. Red-dash-line: critical PR of 2.5 MPa.*

Volumetric water content (%) and pF values of soil layers of 1, 2, and 3 at the different raised beds are presented in Fig. 6 and Fig. 7. Average soil moisture varied from 29.5 to 48.0%, correspondingly to the pF value of 3.7 and 1.9. Soil moisture in layer 1 is significantly ($p < 0.05$) lower than that of the layer 3; but there are not significant differences between layer 1 and layer 2 as well as layer 2 and 3. For soil water retention (pF values), there are not significant differences between layer 1 and layer 2 but there are significant differences between layer 1 and layer 3 as well as layer 2 and layer 3.

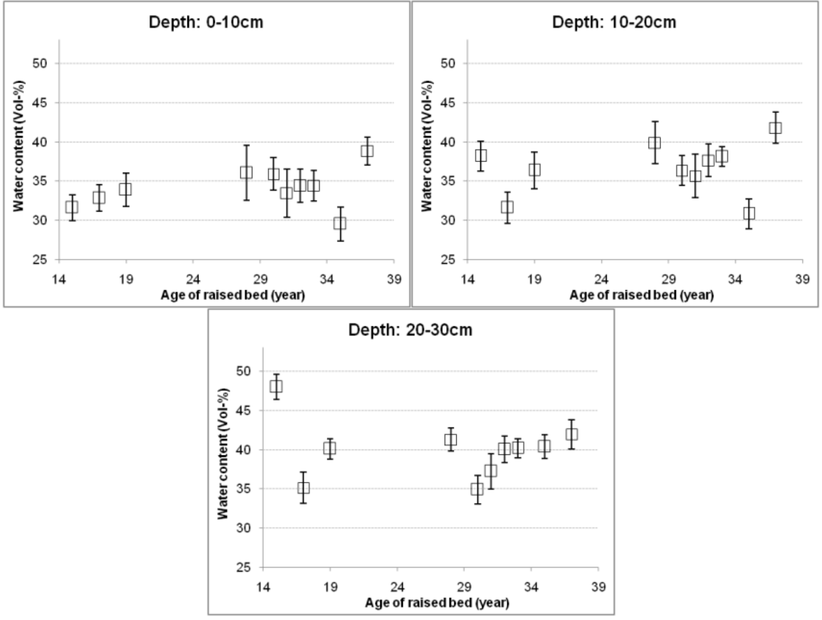

Figure 6: *Volumetric soil water content (%) at the different raised beds for three soil layers.*

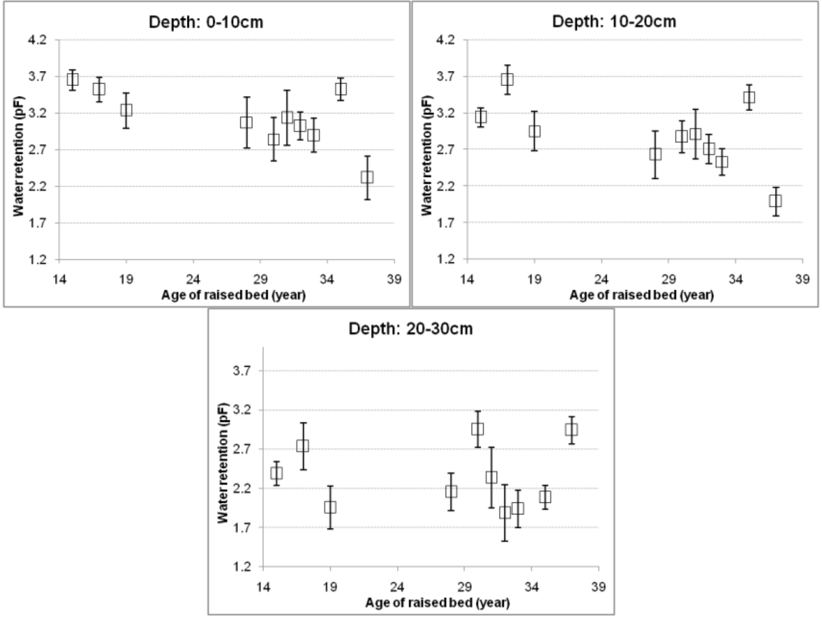

Figure 7: *pF values at the different raised beds for three soil layers.*

The slope coefficients increased with the soil depth as well as with age of the raised beds (Fig.8). The relationship between a_1 (from $PR = a_1\theta + a_0$) and age of the raised beds is significantly consistent with linearity ($R^2 > 0.7$). The plot of a_1 versus age becomes more scattered for deeper layers, this is reflected by the decrease in R^2 (Fig. 8). In contrast to soil moisture, the slope coefficients (from $PR = a_1pF + a_0$) decreased with soil depth as well as with age of the raised beds (Fig. 8); however, the plot of a_1 versus age of the raised beds is more dispersed.

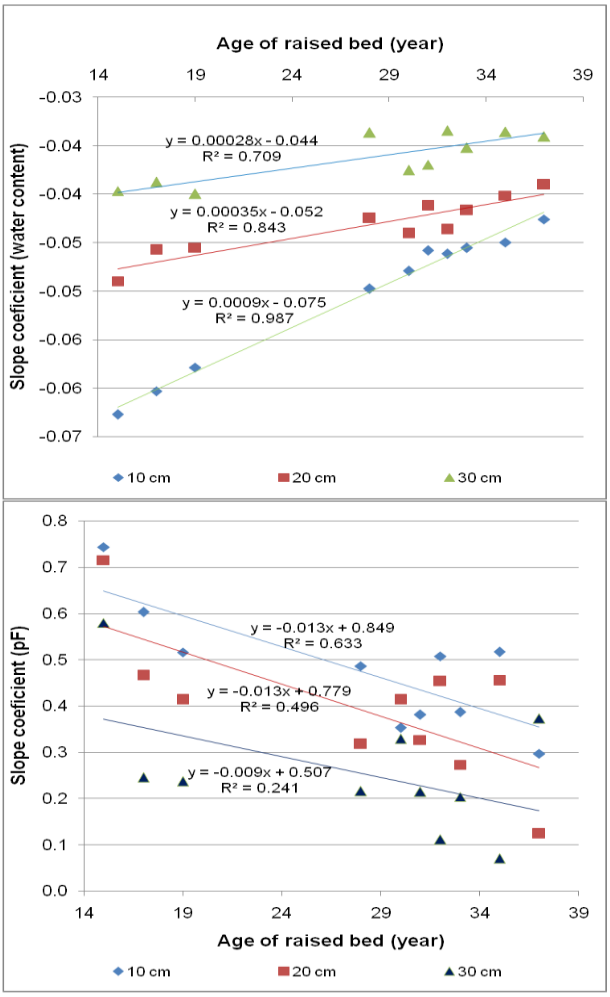

Figure 8: *Slope coefficient plotted versus age of the raised beds on different soil layers.*

The recalculations of PR based on regression equations (PR = $a_1\theta + a_0$) correspondingly using soil moisture values at pF of 2, 2.5, 3 and 4.2 are presented in Fig. 9 for layer 1, 2, and 3. The results showed the increasing trend of PR with age of the raised beds on whole soil profile. PR values are higher corresponding to the lower in soil moisture. Similarly, the results of PR by using PR = $a_1pF + a_0$ with pF value of 2, 2.5, 3 and 4.2 are not significant differences compared to PR = $a_1\theta + a_0$.

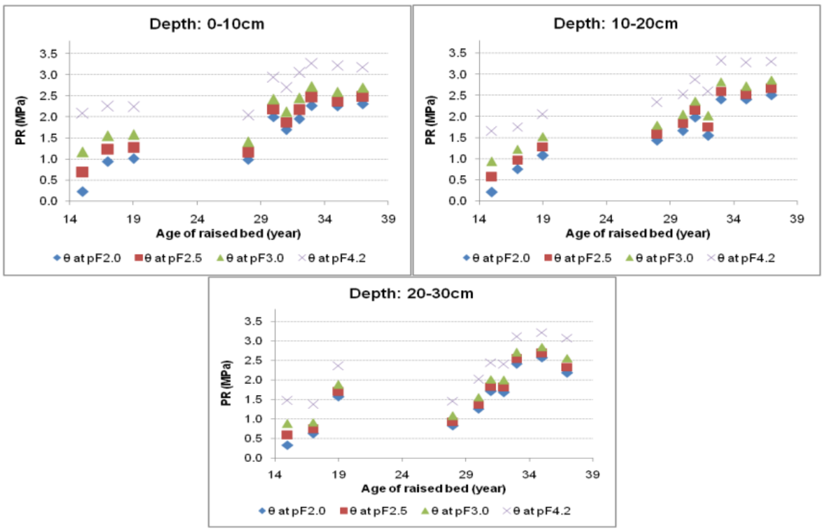

Figure 9: *Soil penetration resistance recalculated by PR = $a_1\theta + a_0$ (θ estimated from water retention curves at pF value of 2, 2.5, 3 and 4.2)*

IV. DISCUSSIONS

The role of soil moisture

The PR-intercept (a_0) can be interpreted as the value predicted for PR if $\theta = 0$ (or $pF = 0$). It is expected to have the average PR for a very dry soil ($\theta = 0$) or fully saturated condition (soil pressure head is 1 cm water). However, this is an extrapolation from the current stage of soil moisture to a complete dry or wet soil condition. If the ultimate dry nor wet soil is never reached, these extrapolations are mostly of theoretical interest. It just anchors the regression line in the right place. In this study case, it is easy to see that ultimate dry condition may never occur in the real field soil conditions and then the intercept has no real interpretation itself. Moreover, the definition of pF value is the base 10-logarithm function of the soil pressure head expressed in cm of water. Therefore, pF value will be infinitive when soil pressure head approaches to 0.

The slope coefficient (a_1) gives the average change in PR with respect to θ (or pF values). The magnitude of a_1 (large or small) indicates the change rate of PR and the sign of a_1 suggest the increase of PR (positive) or the decrease of PR (negative). The greater the a_1 (absolute value), the more influence the θ (or pF value) has on the PR, and the more change of PR associated with a unit change in θ (or pF value). In this study, the negative a_1 for PR versus soil moisture is obtained, while the opposite situation is found for PR versus pF values - representing soil water retention. This suggested the PR decreased with increasing soil moisture and the PR increased with decreasing pF value. The results demonstrated that the less change in PR associated with a change in θ (or pF values) when the raised beds became older. This indicated that the young raised beds have been easier to disturb, while the old ones are in a mode of more inert system with smaller sensitivity. In other words, the soil is more compacted with age of the raised beds. We can see that both of predictors (θ and pF value) showed the same phenomena but in the different ways. Based on the obtained results, PR is predicted by θ and pF value is not significantly different. So, the pF value and either θ can be used to predict PR. However, it will be easier to obtain the θ than pF value. Moreover, it was interesting that slope coefficient plotted against age of the raised beds on the different soil layers, drawn from regression equations $PR = a_1\theta + a_0$ and $PR = a_1pF + a_0$ (Fig. 8). The results showed that the explanations based on θ are better than pF value. This suggested the PR ($a_1\theta + a_0$) could predict the PR more credible than using PR ($a_1pF + a_0$).

Soil water content was found to be an important factor affecting to the PR. Compressibility is also closely related to soil water content (Larson et al., 1980). The slower drying is maybe a phenomenon of a poor plant development because it may restrict plant root growing to deeper layer and soil is poor aeration. Nevertheless, it may also be the sign of a very efficient soil that stores high amount of water. Soil water content, which plant growth is at a maximum, is near field capacity condition - soil pressure head at pF of 2.5 or -30 kPa, where the integrated supply of both oxygen and water are the most favorable (Foth, 1990; Lal and Shukla, 2004). Moreover, plant root will be dramatically affected if soil is compacted that means the soil strength exceeds the root penetration capacity (Jarmillo-C et al., 1992). Field measurement of the PR is the indicator to characterize soil compaction. Lutz et al. (1986) studied the relationship between citrus root growth and soil physical conditions documented that 1.5 MPa is the maximum soil strength restricting root growth. As the results showed in Fig. 9, it can be seen that the PR reached to 2 MPa over the top 30 cm depth for starting from 30 year old raised beds at the field capacity condition and PR is able to be higher when soil becomes drier. Since soil water dynamics is seasonally dependent in the MD with 2 major periods – dry and wet. Water acts as a lubricant, so soil particles are easily rearranged and squeezed together more tightly at wet than under dry conditions. These directly have the effect on soil water regime, which is combined with the phenomena of swelling and shrinking limit, may contribute to the process of erosion and compaction. In addition, cracks are normally formed during the dry periods. The desiccation cracks are developed that may cause the increase in the hydraulic conductivity of several orders of the magnitude (Albrecht and Benson, 2001; Boynton and Daniel, 1985; Rayhani et al., 2007). These cracks also create the weak zones in a soil body leading to reduce overall the mechanical strength and bearing capacity and to increase the compressibility and therefore it considerably affects stability of the soils (Bagge, 1985). Soil particles may be detached from a soil mass along the surface of soil cracks and carried off by flowing water because of rainy or irrigation. It depends on the velocity of water flow that the amount of the soil loss manifests itself in various mechanisms such as suffusion, erosion, and clogging. These processes have occurred over long time; whereas suffusion or erosion takes place at an interface between two different materials, clogging is a process that works in the direction of stability. Finer particles position themselves in the soil pores between larger particles and/or in the soil cracks resulting in the increase in soil strength. The clogging process could be considered as one mechanism that could have promoted to the stability of soils, since their deposition and hence increase in soil strength. This could be a possible reason to explain the PR of the old raised beds is higher than the young raised beds as revealed by regressing. The arrangement of the soil particles through erosion over a long time caused the changes in soil aggregates and soil structures with the less of finer particles as an adhesion agent. These actions have made the declination of soil quality.

As discussed above, it represented that the old raised beds having a tendency of soil degradation, which is attributed by the higher values of the PR at the same soil moisture. These results also strengthened the previous studies related to soil compaction which are evidenced by some soil properties such as the increasing of bulk density, the decreasing of hydraulic conductivity and the lowering of soil organic matter. Using the electric penetrometer as a handy tool to keep away from many drawbacks of sampling and laboratory tests, ant it has become a widely accepted means for the in-situ properties. Penetrometer is easy to use and can collect soil information without disturbing the ground like bulk density does (Chacalo and Grabosky, 2000). The PR equipment applied is suitable in the MD under monsoon climate of the tropics. Based on the data recorded by PR measurements and the reasons caused to soil compaction, the solutions for soil restoration can be precisely recommended for soil management. With this study, mechanical impacts during cultivation and the elluvial and illuvial soil process are the main factors creating the compaction in situ. Under the condition, PR equipment can not be purchased, soil porosity is usually used as the principal indicator for soil compaction.

Many factors directly or indirectly affect to the plant growth in which soil compaction is specially interested. As mentioned above, soil compaction is characterized by the PR that has limited to effective rooting depth. If the soil status is too weak, anchor capacity of plant roots will not be adequate to withstand the forces of wind and water. On the other hand, if it is too strong, the plant roots will not have the required strength to penetrate to the soil matrix. The soil of raised bed has annually tolerated to the wet and dry periods. In the flooding period, the roots are not able to penetrate to deeper layers due to the restriction of water level, while soil strength may reach over the critical limit for developing of the roots during the dry season.

With respect to the management practices, soil strength can be moderated by inputting the organic materials such as mulches, composts or covering by crop pattern to improve the stability of soil aggregates and to develop the soil macro-structures. Gypsum can be applied to stabilize the soil aggregates and micro-structure for preventing the clay dispersion. Excessive tillage or soil preparation done under the wet condition can break down or compact both the macro and micro-size of the aggregates leading to hardsetting and crusting at the surface soils. Biochar can be considered as another soil conditioner for improving soil properties.

V. CONCLUSIONS

The increasing of soil penetration resistance with age of the raised beds could not be limited by the higher soil moisture content. The sensitivity of PR equipment to soil moisture decreases with age and simultaneously the soil moisture tended to increase with the age of raised beds. Irrigation will not be the appropriate mitigation method in this case; due to it will also decrease the air space in soil porosity.

The measurements of soil penetration resistance illustrated the picture, which are previously given by determination of dry bulk density and water retention curve. The penetration measurements are however, much easier since it is non-destructive and it can be repeated at many positions within a short period of time.

Soil penetration resistance measurement combined with soil water content can be used to identify the soil quality in term of the constraints for root growth. Based on the results and linear relationship, the highest proportion of the total variation of the PR can be explained by soil water content, it is around 70%, indicating that there are at least 30% of the uncertainties involved. The uncertainties may come from two main sources comprising both of PR and soil water content measurements.

The best results can be obtained if soil water content measurements are simultaneously taken place on the same PR measurement points with the same resolution readings.

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