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Soil physical properties during different development stage of fruit orchards

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In the Mekong Delta (MD), fruit trees are usually grown on raised-beds to avoid submergence due to annual flooding. The soils are mostly alluvial and disarranged from the natural soils. The soil may be adversely impacted temporally, particularly with its physical properties. The study was conducted on 10 citrus plantations in Hau Giang province, MD, to illustrate if the covariance between clay content and age can be separated from the impact of soil ageing on compaction; we further discuss the design of how to make an investigation where only age is the analyzed event that age has a covariance with the spatial scale. Soil sampling was done in the dry season 2010 at two soil depths for each raised-bed to analyze soil physical properties. Soil texture can be classified as silty-clay soil. The bulk density of topsoils ranged from 0.76 to 1.18 g cm^{-3} and slightly lower than subsoils; 0.85 to 1.24 g cm^{-3}. Saturated hydraulic conductivity spanned the range from 2.04 to 5.43 m day^{-1} for topsoils and significantly higher than in subsoils; 1.4 to 5.5 m day^{-1}. Organic matter was in the range of 4.4 to 12.2% for topsoils and significantly higher than in subsoils; 3.0 to 9.6%. A significant tendency of soil degradation with aging was found. Clay content showed a covariance with age of raised-beds counteracting the compaction processes. The high clay content for the aged raised-bed may have been hiding some of the compaction process. The relation between age and soil degradation was seen for the larger pore sizes within the water retention curve.

Key words: Soil physical properties, soil texture, soil compaction, Mekong delta.

INTRODUCTION

The Mekong delta (MD) is the main area of fruit production that covered approximately 285,300 ha by the year 2009, accounting for about 38% of the fruit tree area of Vietnam (General Statistics Office, 2010). Most of the fruit tree areas are lowland with alluvial soils. Due to the influence of frequent flooding, raised beds are built up to avoid annual submergence. The raised beds are made 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. There are common methods of raised bed construction used by farmers of which soil layers in the raised beds can be arranged in reverse or in the same order as the original soil, or top soil placed in the center of the beds. The ages of raised beds are also widely different. Many of them have lasted for more than 30 years. The size of the raised bed varies depending on the type of crop grown and the highest flooding level (Phong and Ve, 2001). Table 1 shows some common sizes of raised beds for citrus plantations in the MD. Although farmers try to make the raised bed higher than the highest flooding level, submergence still occurs throughout the MD during the flood peak period in September or October. The percentage of citrus plantation submerged is shown in

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Table 1. Size of citrus raised beds in the Mekong Delta, Vietnam (Phong and Ve, 2001).

Type of plants	Top width (m)	Base width (m)	Height (m)	Ratio of base and top
Pomelo	5.8 - 7.0	6.8 - 9.0	0.3 - 0.4	1.2 - 1.3
Sweet Orange (Cam mat)	5.7 - 7.1	7.1 - 8.7	0.0 - 0.3	1.1 - 1.2
King Orange (Cam sanh)	5.3 - 9.0	6.2 - 10	0.0 - 0.3	1.2 - 1.3
Tangerine (Quyt tieu)	5.0 - 6.9	6.3 - 7.9	-0.1 - 0.5	1.1 - 1.3
Tangerine (Quyt xiem)	5.1 - 6.5	6.3 - 8.1	0.2	1.1 - 1.2
Lime	6.6 - 7.4	8.0 - 8.5	-0.2 - 0.3	1.1 - 1.2

Table 2. Ratio of citrus raised beds flooded in the Mekong Delta, Vietnam (Phong and Ve, 2001).

Type of plants	Percentage (%)
Sweet Orange (Cam mat)	27.7
King Orange (Cam sanh)	15.1
Tangerine (Quyt tieu)	38.4
Tangerine (Quyt xiem)	6.5
Lime	38.5

Table 2. Soils in the MD are mainly formed by the deposition of sediment from the rivers (Mekong and Bassac rivers) and the sea in the Holocene period (Hori, 2000; Lap Nguyen et al., 2000; Ta et al., 2001, 2002a, b). The soil minerals are predominated by muscovite in the clay fraction with abundance of dioctahedral mica, and contain dominantly quartz next to other minerals such as feldspars, kaolinite and chlorite in the silt fraction (Khoa, 2002). Soil minerals not only drastically influence on soil physical properties, but also on chemical phenomenon (Khoa, 2002; Lal and Shukla, 2004). Soil degradation is a serious impediment to agricultural sustainability and environmental quality (Lal, 1993). Major reasons of soil degradation are compaction, soil erosion, loss of organic matter, salinization, nutrient depletion and pollution (Oldeman, 1994; Syers, 1997). Degradation of top soils may be easily mitigated, whereas that of subsoils is much more difficult to restore, and the degradation may even be permanent (Dexter and Zoebisch, 2005). There have been warnings of soil degradation in the MD in recent years, not only in the rice farming areas but also in fruit-growing areas and especially in intensive cropping areas (Khoa, 2002). In addition, the fertilization habits of growers in the MD often use a single rather than compound fertilizer, which stress the use of nitrogen while phosphorus, potassium, lime, micronutrients and organic fertilizer are less appropriately considered (Siem, 1997).The alternate drying and wetting cycles of the raised bed soils in the MD are in combination with the fine soil texture. This may contribute to the phenomenon of coalescence, a hardening process by cementing aggregates so that lead to increased soil strength (Cockroft and Olsson, 2000). Different textures cause different pore sizes and thus influence the rooting pattern. Compaction results in loss of soil aggregates, destroyed aeration pore spaces, crushed or collapsed pore spaces (Assouline et al., 1997; Coder, 2000; Richard et al., 2001). In fact, there are many factors which may cause the decreases in soil productivity such as natural conditions and soil tillage. In addition, soil physical properties are not only depending on spatial variability but also on the local and temporal conditions (Lal and Shukla, 2004). On the other hand, cracks on the raised beds are normally formed during the dry season, this significantly facilitates infiltration of stormwater into soils, but dispersive processes of soil are also expedited when the soil becomes wet; therefore, the soil particles may be detached from a soil mass and carried off by flowing water. Soil erosion is a naturally occurring process on all land (Lal and Shukla, 2004). It is evident that the soils in the raised beds have subjected to overtopping and internal erosion processes. Internal erosion occurs when water flows through a cavity, crack, and/or other continuous void within the embankment (Fell et al., 2003; Jantzer, 2009). These openings may be a result of soil block arrangement during construction, differential settlement, desiccation, and/or decay of woody vegetation roots. The loss of soil can affect soil quality, structure, stability and texture (Paustian et al., 2000). The failure of aggregates and the elimination of finer particles or entire layers of soil or organic matter can weaken the structure and even change the texture (Packer et al., 1992). Textural changes can subsequently affect the water-holding capacity of the soil (Arshad and Coen, 1992).

Understanding of dynamic soil physical properties on

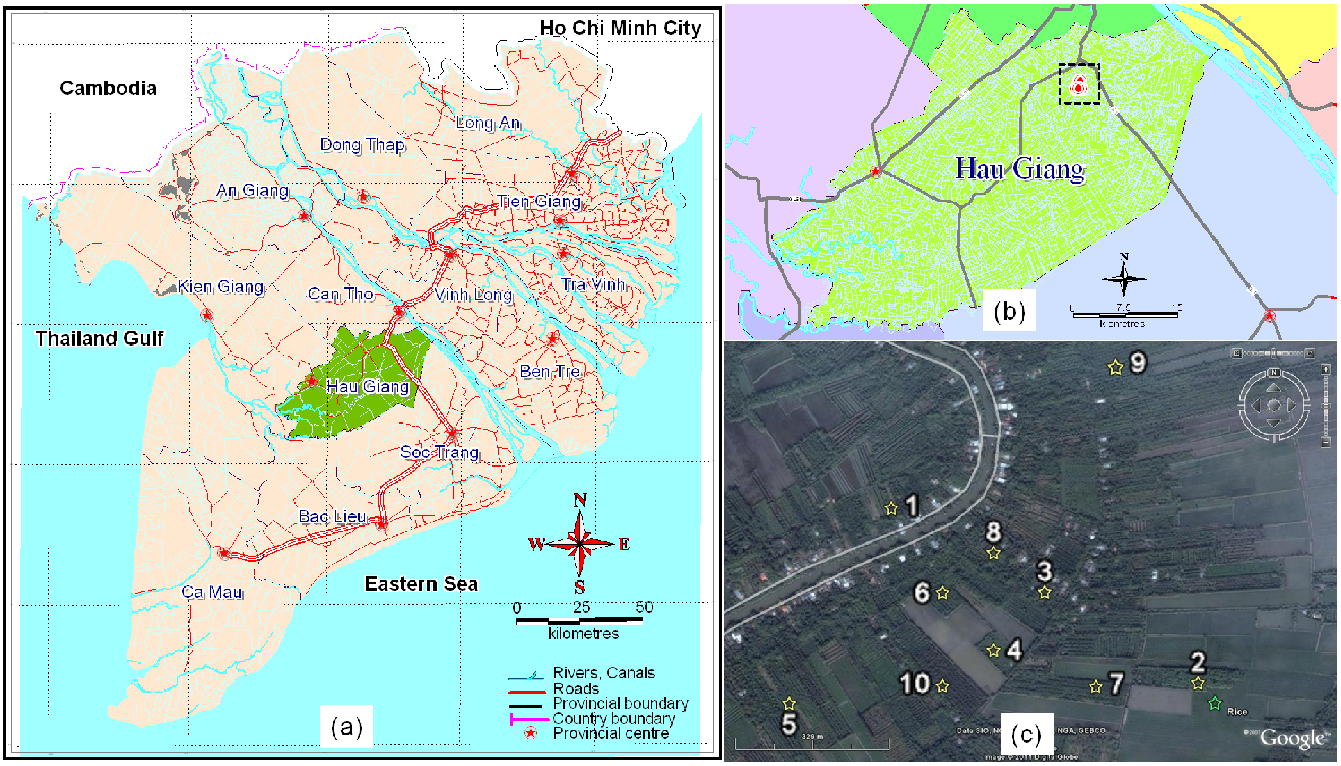

Figure 1. (a) Provincial Administrative Boundary Map of the Mekong Delta, (b) Map of Hau Giang Province, (c) Studied Sites Map – Extracted from Google Earth.

raised bed is important to assess the soil productivity and this can contribute to promoting of better management practices. In a previous unpublished report of the Can Tho University, 60 currently used raised beds were investigated. However, from those it was difficult to find out the raised beds with different age representing the same type of fruit trees and soil origin within the area.

Many sites were available and they have represented a mixture of soil physical properties and management of the soils. Based on available time and on the assumptions that the soil was similar within one region, therefore, ten different orchards were randomly selected to examine soil physical properties. The selected sites were then reinvestigated to record the year of construction exactly. Unfortunately only a small number of sites were selected for detailed investigation which makes it tricky to find significant changes if differences are small and possible systematic differences in other factors than age of the raised beds are important. A tendency to have lower clay content in sites that has been cultivated during longer time was a problem since we do not know if it is the results of a dynamic process or if it is a difference from the start of the construction of the raised bed. The objective has to be formulated to clarify to which extent it is possible to make conclusions on the effect of the age of raised beds on important soil properties like pore size distributions bulk density and hydraulic properties that are not explained as results of the clay content differences.

Another problem with such investigations is the all samplings are made at the same time point. One assumption is that there are minor differences because of the time in itself and that the ageing process is only the results of the management of the raised beds. This is to say that the starting conditions for all the soils should have been the same when cultivation started even that cultivation started during different years.

The main objective was to find out if a small number of samples could be used to make conclusions about the rate of soil compaction on the soil physical properties. Specific objectives were (i) to illustrate the effects of ageing of the raised beds on selected soil physical properties, (ii) to examine if the covariance between clay content and age can be separated from the impact of soil ageing on compaction, (iii) to give guidelines for how future investigations should be designed to overcome the problems with small number of samples and systematic deviations in the soil conditions.

MATERIALS AND METHODS

Site description

This study was carried out on 10 selected raised beds at different ages in Hau Giang province, MD (Table 3 and Figure 1). Citrus trees have been grown since raised bed construction. The soil is classified as alluvial soil (Soil Science Department, CTU 1985 to

Table 3. 10 study locations selected in Hau Giang province, Mekong delta, Vietnam.

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

1996; Soil Survey Staff, 1996). The climate is characterized by two distinct seasons, a dry season (January to April) and a rainy season (May to December). The annual rainfall ranges from between 1000 and 1300 mm, of which 90% occur in the rainy season. The mean temperature ranges from 23 to 25°C during the coldest months and from 32 to 33°C during the warmest months. Humidity is high in the rainy season (highest in September, 91%). It is low in the dry season, ranging from 79 to 82%.

Sampling and analysis

Data collection started at the beginning of the dry season (January 2010) after the flooding level had receded and the ground water was below the surface of the raised beds. Soil samples were randomly taken on each of the selected raised beds at 0 to 20 cm (topsoil) and 20 to 50 cm (subsoil) depths with four replications including undisturbed core samples (5 cm long and 5 cm in diameter - approximately 100 cm^3 in volume) and disturbed soil samples of about 4 kg for each layer. All undisturbed core samples were taken by augering to desired depth using a bulk density auger. Disturbed samples were collected by digging using a shovel. Soil physical analysis includes bulk density, saturated conductivity, water retention, soil texture and organic matter. Provincial Administrative Boundary Map of the Mekong Delta, Map of Hau Giang Province, and Studied Sites Map respectively are given in Figure 1a, b and c are extracted from Google Earth.

Bulk density

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).

Saturated hydraulic conductivity

Saturated hydraulic conductivity K_s (m day^{-1}) was measured with undisturbed cores and using the constant head permeameter from Eijkelkamp Agrisearch Equipment, the Netherlands based on Darcy's law.

Soil water retention

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 48 h, 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 to 2) and from 0.3 to 15 bar (pF: 2.5 to 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). Soil pore fractions were categorized according to the soil water retention data in: Non-available water pores (pF > 4.2); available water pores (pF between 2.5 and 4.2); slow drainage pores (pF between 1.8 and 2.5) and fast drainage pores (pF < 1.8).

Soil texture

Soil texture was obtained based upon Stock's law following Robinson pipette method (Gee and Bauder, 1986). Soil samples were air dried and passed through a 2-mm mesh sieve. Soil organic matter was destructed by hydrogen peroxide (H_2O_2).

The percent of soil organic matter was calculated by multiplying the percent organic carbon by a factor of 1.7, following the standard practice that organic matter was composed of 58% carbon (Brady, 1985). Organic carbon was determined by the Walkley and Black method (1934) with the correction factor of 1.33 (recovery of 75%).

Statistical analyses

Data were analyzed using the SPSS statistical package (version 16). A two-way ANOVA with the two factors (age of raised beds and soil depths) was performed to evaluate the soil physical properties. In case no interaction effect between age and soil depths on soil properties was detected, a one-way ANOVA with "age" factor was applied for each of the depths individually. Differences in the mean soil physical properties were determined using the least significance difference (LSD) at 0.05 significant levels. A Pearson's correlation analysis was applied to estimate the relationship among soil properties and age of raised beds. Principal component analysis (PCA) was used to elucidate the main relationships between variables based on the correlation matrix. The final component structure was included only principal components with eigenvalues greater than unity. The purpose of the PCA was to discriminate between clay content and age from the impact of soil ageing on compaction.

RESULTS AND DISCUSSION

There was no significant interaction between age and

Table 4. Topsoil properties of different raised beds.

Age	BD (g cm^{-3})	Ksat (m day^{-1})	Clay (%)	Silt (%)	Sand (%)	OM (%)
15	0.76^{a}	5.4^{a}	51.2^{a}	42.5^{a}	6.2^{ab}	12.2^{a}
17	1.02^{b}	4.1^{bc}	51.7^{a}	40.7^{a}	7.5^{a}	5.2^{c}
19	1.02^{b}	3.0^{bc}	51.7^{a}	44.0^{a}	4.2^{b}	6.6^{bc}
28	1.16^{b}	2.6^{d}	50.5^{a}	43.2^{a}	6.2^{ab}	4.6^{c}
30	1.09^{b}	3.1^{dc}	50.7^{a}	40.5^{a}	8.7^{a}	4.5^{c}
31	1.17^{b}	2.1^{d}	50.2^{a}	42.2^{a}	7.5^{a}	4.4^{c}
32	1.11^{b}	2.5^{d}	50.5^{a}	43.0^{a}	6.5^{ab}	5.5^{bc}
33	1.18^{b}	2.61^{d}	49.7^{a}	42.2^{a}	8.0^{a}	4.4^{c}
35	1.02^{b}	2.0^{d}	46.5^{a}	45.2^{a}	8.2^{a}	4.5^{c}
37	1.14^{b}	4.8^{ab}	48.0^{a}	44.7^{a}	7.2^{ab}	8.8^{ab}
LSD (5%)	0.17	1.18	5.40	6.79	3.18	3.49

BD, Bulk density; Ksat, hydraulic conductivity; OM, organic matter. Within a column, numbers are followed with the same letter show no significant difference at 5%. LSD, least significant difference.

Table 5. Subsoil properties of different raised beds.

Age	BD (g cm^{-3})	Ksat (m day^{-1})	Clay (%)	Silt (%)	Sand (%)	OM (%)
15	0.85^{d}	5.5^{a}	53.7^{a}	40.0^{a}	6.2^{abcd}	9.6^{a}
17	1.09^{bc}	2.3^{b}	54.2^{a}	37.7^{a}	8.0^{abcd}	3.5^{c}
19	1.13^{abc}	2.5^{b}	53.7^{a}	42.0^{a}	4.2^{d}	4.3^{bc}
28	1.20^{ab}	1.8^{b}	51.7^{a}	42.5^{a}	5.7^{cd}	3.2^{c}
30	1.15^{abc}	1.9^{b}	53.7^{a}	36.0^{a}	10.2^{a}	3.1^{c}
31	1.12^{abc}	1.8^{b}	52.5^{a}	38.5^{a}	9.0^{abc}	3.4^{c}
32	1.17^{abc}	2.4^{b}	53.5^{a}	40.5^{a}	6.0^{bcd}	4.4^{bc}
33	1.16^{abc}	1.4^{b}	51.7^{a}	39.0^{a}	9.2^{abc}	3.0^{c}
35	1.24^{a}	1.9^{b}	50.2^{a}	39.7^{a}	10.0^{ab}	3.6^{c}
37	1.03^{c}	1.9^{b}	50.5^{a}	42.5^{a}	7.0^{abcd}	6.5^{b}
LSD(5%)	0.15	2.20	5.39	6.69	4.10	2.43

BD, Bulk density; Ksat, hydraulic conductivity; OM, organic matter. Within a column, numbers are followed with the same letter show no significant difference at 5%. LSD, least significant difference.

depths on soil properties at the 0.05 level of significance, suggesting that changes in soil properties at different depths were independent on age. Therefore, the main effects of age and depths were investigated separately.

Soil texture was classified as silty-clay soil. Clay, silt and sand fraction (%) were in the range of 46.50 to 51.75, 40.50 to 45.25 and 4.25 to 8.75 respectively for topsoil; and 50.25 to 54.25, 36.00 to 42.50 and 4.25 to 10.25 for subsoil. The bulk density of topsoil ranged from 0.76 to 1.18 g cm^{-3} and it was slightly lower than that in subsoil (0.85 to 1.24 g cm^{-3}). Saturated hydraulic conductivity spanned the range from 2.04 to 5.43 m day^{-1} for topsoil and it was significant higher than that in subsoil (1.42 to 5.47 m day^{-1}). Organic matter was in the range of 4.36 to 12.19% for topsoil and it was significant higher than that in subsoil (2.99 to 9.59%) (Tables 4 and 5).

Soil water retention curves (SWRC) for topsoil and subsoil of the raised beds were shown in Figure 2. The curves had rather gentle shape as the volumetric water content gradually changed with soil pressure heads but different shape among the sites as well as the soil depths within each site were found. The shape of the SWRC is intrinsically related to pore-size distribution. Compaction energy and soil structure influence the shape of the SWRC for fine-grained soils (Vanapalli et al., 1999). Water retention was higher in the wet range but slightly lower in the dry range for topsoil compared to subsoil (Table 6 and Figure 2).

The residual water content, θ_r, remains in soil at very high pressure; it is directly related to micro-pores and considered as unavailable to plants. The θ_r generally tended to increase with age of the raised beds (Table 6). This implies greater soil water retention and greater proportion of micro-pores. An increased proportion of micro-pores is an indicator of soil compaction. The air-entry pressure (1/α) corresponds to the matric suction

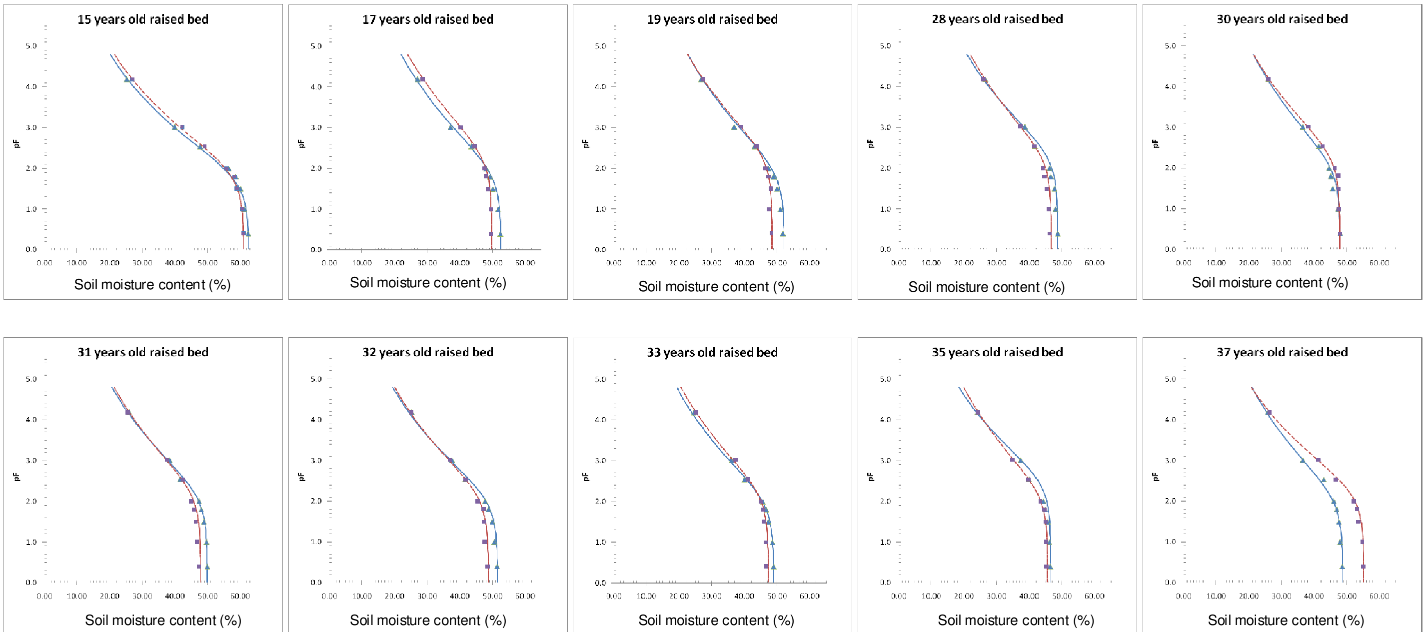

Figure 2. Soil water retention curves of soil profile for different age of raised beds at topsoil (solid blue line) and subsoil (dash red line) corresponding to triangle and square symbols for measured pF points

Table 6. Fitted van Genuchten parameters of soil moisture characteristic for topsoil and subsoil – values in the parenthesis.

Age of raised bed	Fitted parameters[a]			
(year)	θ_s	θ_r	α	n
15	62.34 (61.01)	0.017 (0.004)	0.010 (0.009)	1.18 (1.17)
17	52.14 (49.20)	0.040 (0.052)	0.011 (0.004)	1.13 (1.13)
19	51.66 (48.15)	0.037 (0.040)	0.011 (0.004)	1.13 (1.14)
28	48.32 (45.93)	0.040 (0.045)	0.005 (0.004)	1.13 (1.14)
30	47.18 (47.97)	0.046 (0.040)	0.006 (0.004)	1.13 (1.15)
31	49.91 (46.95)	0.049 (0.043)	0.008 (0.004)	1.13 (1.14)
32	51.13 (48.23)	0.040 (0.042)	0.009 (0.005)	1.14 (1.15)
33	48.87 (46.71)	0.071 (0.073)	0.009 (0.004)	1.14 (1.15)
35	46.08 (45.54)	0.099 (0.095)	0.006 (0.005)	1.12 (1.14)
37	48.38 (54.79)	0.063 (0.074)	0.005 (0.005)	1.14 (1.16)

[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.

required to remove water from the largest pores, which is also related to soil pores forming a continuous network of flow paths within the soil (Assouline et al., 1998). Air entry values tended to increase with age (Table 6). Root respiration may decrease when soils have a volume of macro-pores lower than 10% (Greenland, 1981). In addition, fast and slow drainage pores showed a decrease tendency with age of the raised beds (Figure 3). This revealed a decreased-level of soil macroporosity and it may therefore affect soil aeration and growth of plant roots.

The variability for some properties within each site was low compared to that between the sites. However, the soil texture indicated a high variability within sites and relatively low variability between sites for both the topsoil and the subsoil. This was indicated as non-significant values for the one-way anova (Table 7 and 8). Also the pF 4.2 value of the topsoil showed non-significant values. All the remaining properties had large variability between sites compared to the variability within the sites.

The differences of the low pF among the sites were also reflected by the differences of saturated conductivity

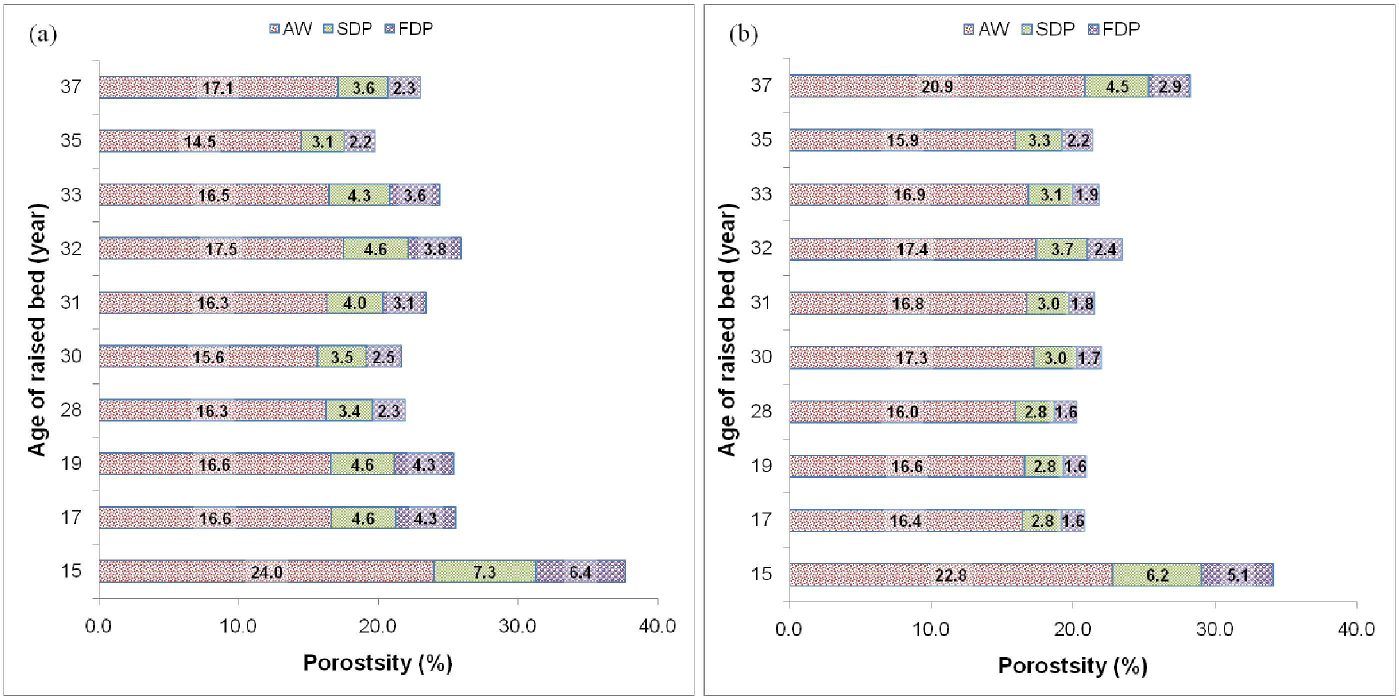

Figure 3. Pores (% of total soil volume) size distribution for topsoil (a) and subsoil (b). AW: pores of available water for the crop, SDP: slow drainage pores; FDP: fast drainage pores.

Table 7. One-way ANOVA on soil properties for topsoil.

Variable	Sum of squares*	df*	Mean square*	F	Significant
Bulk density ($g.cm^{-3}$)	0.56 (0.44)	9 (30)	0.06 (0.01)	4.3	0.00
Saturated conductivity ($m\ day^{-1}$)	49 (20)	9 (30)	5 (1)	8.1	0.00
Clay (%)	100 (423)	9 (30)	11 (14)	0.8	0.63
Silt (%)	87 (662)	9 (30)	10 (22)	0.4	0.90
Sand (%)	60 (145)	9 (30)	7 (5)	1.4	0.24
Soil organic matter (%)	236 (175)	9 (30)	26 (6)	4.5	0.00
pF 0.4 (cm	712 (63)	9 (30)	79 (2)	37.8	0.00
pF 1.0	650 (70)	9 (30)	72 (2)	30.9	0.00
pF 1.5	620 (96)	9 (30)	69 (3)	21.5	0.00
pF 1.8	548 (103)	9 (30)	61 (3)	17.7	0.00
pF 2.0	424 (88)	9 (30)	47 (3)	16.1	0.00
pF 2.5	182 (53)	9 (30)	20 (2)	11.4	0.00
pF 3.0	59 (74)	9 (30)	6 (2)	2.7	0.02
pF 4.2	32 (92)	9 (30)	3 (3)	1.2	0.35

* The first value stands for "Between Groups" followed by "Within Groups" in the parenthesis

and organic matter. The high pF (for example, pF 4.2) was not significantly influenced by aggregation, structural porosity, and soil organic matter content, but it was primarily influenced by the amount and nature of clay content (Lal and Shukla, 2004).

Some soil physical properties were strongly correlated with each other but others were independent (Table 9 and 10). The correlations are caused by the location of the specific sites, and the correlations may be caused by the time since the site was constructed and firstly cultivated (age of raised beds). These can partly be separated from each others, especially clay content and age of the raised beds. For instance, bulk density, saturated hydraulic conductivity, organic matter and pF below 3.0 were significantly correlated with age, while pF 3.0 and 4.2 were strongly correlated with clay content.

Table 8. One-way ANOVA on soil properties for subsoil.

Variable	Sum of squares	df	Mean square	F	Significant
Bulk density (g.cm^{-3})	0.44 (0.34)	9 (30)	0.05 (0.01)	4.3	0.00
Saturated conductivity (m day^{-1})	48 (70)	9 (30)	5 (2)	2.28	0.04
Clay (%)	75 (418)	9 (30)	8 (14)	0.6	0.78
Silt (%)	164 (643)	9 (30)	18 (21)	0.8	0.58
Sand (%)	148 (242)	9 (30)	16 (8)	2.0	0.07
Soil organic matter (%)	154 (85)	9 (30)	17 (3)	6.0	0.00
pF 0.4 (cm	833 (626)	9 (30)	92 (20)	4.5	0.00
pF 1.0	834 (627)	9 (30)	93 (21)	4.4	0.00
pF 1.5	675 (429)	9 (30)	75 (14)	5.2	0.00
pF 1.8	645 (265)	9 (30)	72 (9)	8.1	0.00
pF 2.0	547 (286)	9 (30)	61 (9)	6.4	0.00
pF 2.5	278 (187)	9 (30)	31 (6)	4.9	0.00
pF 3.0	176 (266)	9 (30)	20 (9)	2.2	0.05
pF 4.2	54 (93)	9 (30)	6 (3)	2.0	0.08

* The first value stands for “Between Groups” followed by “Within Groups” in the parenthesis.

Table 9. Pearson correlation among selected variables for topsoil.

Variable	Age	Db	Ksat	Clay	Silt	Sand	OM	pF0.4	pF1	pF1.5	pF1.8	pF2	pF2.5	pF3
Db	0.54**													
Ksat	-0.41**	-0.33*												
Clay	-0.34*	-0.26	0.08											
Silt	0.13	0.09	-0.09	-0.85**										
Sand	0.29	0.26	0.05	0.03	-0.55**									
OM	-0.33*	-0.79**	0.53**	0.14	0.01	-0.23								
pF0.4	-0.74**	-0.64**	0.54**	0.39*	-0.23	-0.18	0.60**							
pF1.0	-0.73**	-0.59**	0.52**	0.32*	-0.18	-0.16	0.56**	0.98**						
pF1.5	-0.68**	-0.56**	0.50**	0.25	-0.11	-0.19	0.54**	0.97**	0.98**					
pF1.8	-0.67**	-0.56**	0.48**	0.29	-0.16	-0.16	0.54**	0.97**	0.98**	0.98**				
pF2.0	-0.64**	-0.56**	0.46**	0.32*	-0.20	-0.12	0.53**	0.96**	0.97**	0.97**	0.98**			
pF2.5	-0.67**	-0.61**	0.55**	0.39*	-0.25	-0.15	0.63**	0.88**	0.87**	0.85**	0.88**	0.89**		
pF3.0	-0.44**	-0.42**	0.14	0.64**	-0.60**	0.12	0.26	0.59**	0.54**	0.53**	0.57**	0.61**	0.66**	
pF4.2	-0.28	-0.17	0.09	0.77**	-0.68**	0.07	0.10	0.18	0.08	0.05	0.09	0.10	0.32*	0.65**

**Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Soil texture is mainly inherited from the characteristics of parent materials; the clay content has not been expected to change with time. So it was important to find out how this correlation can be interested. On the other hand some other variables like organic matter, bulk density and saturated hydraulic conductivity were not significantly correlated with clay content, while they were significantly correlated with age of the raised beds (Tables 9 and 10).

In case when the double correlation existed both with age and clay content, we noted the different directions of the correlations obtained.

The clay content showed many differences in the correlations compared with the age. For instance the clay content showed strong correlation with high pF values but no strong correlations with the low pF values. The age showed the reverse tendency with high correlations with the low pF values but no strong correlations with the high pF values. For instance, the pF 4.2 value had correlation coefficients of -0.27 and 0.77 (Table 9) for the correlation with age and clay respectively. This tendency was clear for the topsoil but the situation was quite different for the subsoil; -0.45 and 0.77 (Table 10). The strong correlation between clay content and pF 4.2 was the same for the subsoil but the other correlations shifted and showed not the same tendency as for the topsoil (Tables 9 and 10). This indicated that the topsoil was much more affected by age compared to the subsoil. This is also reflected in reality because most of activities are frequently taken

Table 10. Pearson correlation among selected variables for subsoil.

Variable	Age	Db	Ksat	Clay	Silt	Sand	OM	pF0.4	pF1	pF1.5	pF1.8	pF2	pF2.5	pF3
Db	0.42**													
Ksat	-0.44**	-0.49**												
Clay	-0.30	-0.27	0.06											
Silt	0.04	0.02	-0.12	-0.72**										
Sand	0.28	0.28	0.11	-0.09	-0.63**									
OM	-0.31*	-0.55**	0.16	0.11	0.20	-0.42**								
pF0.4	-0.32*	-0.56**	0.51**	-0.03	0.12	-0.14	0.61**							
pF1.0	-0.32*	-0.57**	0.49**	-0.01	0.11	-0.15	0.61**	0.99**						
pF1.5	-0.35*	-0.58**	0.51**	0.09	0.01	-0.11	0.63**	0.97**	0.98**					
pF1.8	-0.35*	-0.62**	0.45**	0.20	-0.08	-0.12	0.69**	0.89**	0.90**	0.96**				
pF2.0	-0.35*	-0.57**	0.44**	0.20	-0.12	-0.06	0.62**	0.84**	0.87**	0.93**	0.97**			
pF2.5	-0.41**	-0.55**	0.38*	0.41**	-0.28	-0.05	0.59**	0.63**	0.64**	0.74**	0.82**	0.85**		
pF3.0	-0.36*	-0.42**	0.34*	0.37*	-0.31*	0.03	0.36*	0.33*	0.35*	0.46**	0.56**	0.69**	0.75**	
pF4.2	-0.45**	-0.26	-0.01	0.77**	-0.47**	-0.20	0.21	0.05	0.06	0.13	0.23	0.25	0.49**	0.49**

**Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

place from the topsoil. Furthermore soil in the raised beds was re-organized by bed construction; therefore, dominance of macro-pores resulted from the excavation process where the soil mass was randomly piled up from the original soil. The decomposition of the root system of the original plants also contributed to an increase in meso-pore percentage after a few years of bed construction. A soil is more unstable when it is wet due to reduced cohesion and softening of cements (Marshall et al., 1996). Shrinkage and dispersion/swell are two processes that destabilize soil structure during wetting condition (Emerson, 1977). Soil particles will be tied together by capillary forces during the shrinkage stage of molded soil resulting in increase in contact points and in a higher bulk density as well as higher penetration resistance (Horn et al., 1994).

Most important is that in the topsoil the bulk density was not significantly correlated with the clay content, however, the correlation was weak negative for both topsoil and subsoil. This is suggesting that the bulk density may decrease with increasing clay content. According to Hillel (1982) soil bulk density generally increases in association with increases sand and silt content in soil texture; Reichert et al. (2009) also reported soil bulk density decreased with increasing content of clay and clay plus silt. The bulk density in itself was positively correlated with the age, while saturated conductivity and soil organic matter were negatively correlated with the age, suggesting that the bulk density increases with age in contrast with saturated conductivity and soil organic matter. The same tendency was found for both the topsoil and the subsoil. Bulk density is expressed as the soil's ability to function for structural support, fluid movement, and soil aeration. High bulk density has been attributed to soil structure degradation as a consequence of low soil porosity and soil compaction. The correlation between age and clay content for the topsoil was significant at the 0.05 level. A possible reason may be internal redistribution of fine particle by the water flow during the period since the raised bed was constructed. During the dry seasons cracks will normally develop and rapid water flow can appear in the beginning of the rainy season. This may be contributed by the amount of finer particles lost as sediment in runoff flow under older raised beds.

A PCA of the 14 selected variables was performed in order to elucidate the main relationships between variables. Figure 4 shows the distribution of the variables in the space formed by two components of the analysis, which explained 76.5% of the variance for the topsoil (70.8% for the subsoil). Three principal components (PC) with an eigenvalue greater than 1 were extracted as shown in Tables 11 and 12. For the topsoil, PC1 explained 57.7% of the observed variance and included the variables low pF values, and age of the raised beds; PC2 explained 18.9% of the observed variance and contained clay, silt, and high pF values. PC3 (organic matter, bulk density, and saturated conductivity) explained 7.5% of the variance. For the subsoil, PC1 explained 51.8% of the observed variance and included the variables low pF values, and organic matter; PC2 explained 19.0% of the observed variance and contained clay, silt, and high pF values. PC3 including age of the raised beds, bulk density, and saturated conductivity explained 7.4% of the variance.

PC1 can be described as a wet range factor, as it contained most of the low pF range. PC2 was related to soil texture and dry range, considered as an influence of the micro-pores proportion. PC3 contained the parameters that affected soil structure. Age variable showed a high negative loading on the first component, and its correlation with soil organic matter, bulk density

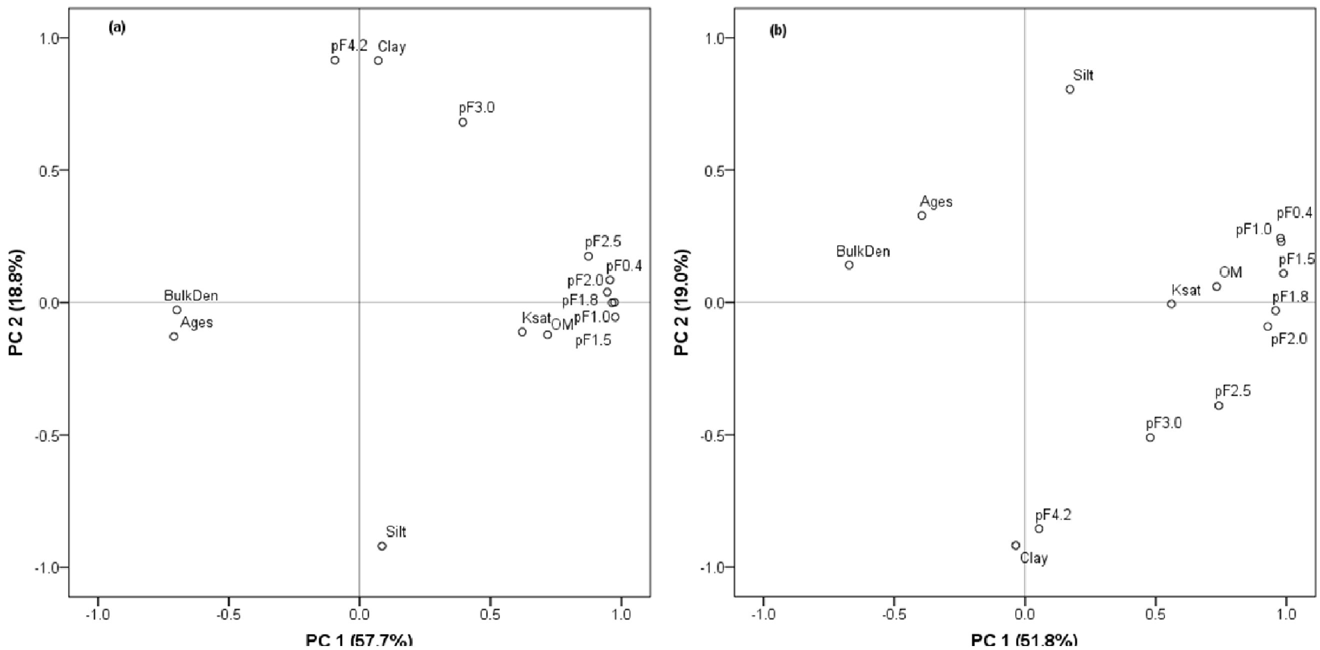

Figure 4. Three-dimensional plot of the PCA performed for the whole data set, including age of the raised beds and soil physical properties; (a) for topsoil, (b) for subsoil.

Table 11. Principal components extracted from a correlation matrix based on selected variables over 10 raised beds for topsoil.

Variable	Components		
	1	2	3
pF 1.0	**0.99**	0.23	**-0.61**
pF 1.8	**0.99**	0.22	**-0.58**
pF 1.5	**0.98**	0.17	**-0.59**
pF 2.0	**0.98**	0.25	**-0.57**
pF 0.4	**0.98**	0.31	**-0.66**
pF 2.5	**0.90**	0.39	**-0.69**
Ages	**-0.75**	-0.29	0.51
Clay	0.33	**0.93**	-0.18
pF 4.2	0.13	**0.90**	-0.16
Silt	-0.19	**-0.90**	0.02
pF 3.0	**0.61**	**0.77**	-0.30
Soil organic matter	0.53	0.09	**-0.95**
Bulk density	**-0.58**	-0.23	**0.87**
Saturated conductivity	0.51	0.06	**-0.66**
Percent variance explained	57.7	18.9	7.5

Values in the table are the correlation of each variable with each principal component. Bold values indicate the strongest associations.

and saturated conductivity under the topsoil, suggesting that age affects on larger pore sizes along with changes of the soil physical properties. The age was replaced by soil organic matter on the first component with a high loading for the subsoil, suggesting that organic matter plays more important role than age of the raised beds affected on larger pore sizes for deeper soil.

PCA was able to discriminate between clay content and age from the impact of soil ageing on compaction. Clay content mostly showed the impact on the range of small pore sizes, while age of the raised beds exhibited the influence on the range of larger pore sizes. It was clear

Table 12. Principal components extracted from a correlation matrix based on selected variables over 10 raised beds for topsoil.

Variable	Components		
	1	2	3
pF 1.8	0.98	-0.21	-0.49
pF 1.5	0.97	-0.06	-0.53
pF 2.0	0.96	-0.26	-0.47
pF 1.0	0.93	0.06	-0.51
pF 0.4	0.92	0.08	-0.52
pF 2.5	0.83	-0.53	-0.45
Soil organic matter	0.76	-0.09	-0.26
Clay	0.13	-0.91	-0.21
pF 4.2	0.21	-0.87	-0.23
Silt	0.02	0.78	0.08
pF 3.0	0.57	-0.60	-0.40
Saturated conductivity	0.43	-0.03	-0.87
Ages	-0.34	0.34	0.79
Bulk density	-0.64	0.23	0.66
Percent variance explained	51.8	19.0	7.4

Values in the table are the correlation of each variable with each principal component. Bold values indicate the strongest associations.

for the upper most layers where soil was directly exposed to the air. This result was also consistent with correlation analysis in previous section.

Conclusions

Clay content showed a covariance with age and it may have influenced the results of the other soil properties and how they are affected by the ageing. However, the clay counteracted on the compaction processes. The high clay content for the aged raised bed may have been hiding some of the compaction process. The strong impact on clay was on the wilting point and the water holding within the dry range. However, this domain of the pore distributions was less affected by the ageing. Effects of age on soil degradation were mainly on the larger pore sizes, while clay content affect on the small pore sizes.

The raised beds with high age have exhibited a tendency to soil degradation based on physical features. This is evidenced by soil properties such as increase in bulk density, decrease in hydraulic conductivity and lower organic matter. If low infiltration capacity and low organic matter are combined with high clay fraction, the soil may easily be subjected to surface erosion, compaction and surface sealing. To improve the design for a more precise future investigation we recommend a much larger material where no covariance of basic soil properties like texture and age exist. However, by using a complete statistical evaluation on all the possible correlations it was possible to clarify that the soil bulk density increased during the stage of developments of raised beds of Orchards. Nevertheless, large uncertainties on the rate of degradation and to what extent it was caused by the differences in the management of the raised beds.

However, we cannot exclude that the ageing of the raised beds have an impact on the clay content. It should be possible to study the mechanism for such phenomena in the laboratory or in the field scale. Obviously, the current type of investigation is only useful to describe possible changes but to find explanation we need also dynamic studies to follow the ageing process of raised beds.

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