Soil Compaction in Sugarcane Fields Induced by Mechanization

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Abstract: Problem statement: Recently in Thailand, the problem of soil compaction, especially associated with more mechanized sugarcane production, has drawn attention from both the government and private sectors. **Approach:** To understand this problem, investigations of soil compaction using cone penetration resistance and bulk density were conducted in 16 sugarcane fields with 10 fields involving mechanized farming and 6 field's mainly manual labor farming. **Results:** It was found that the highest bulk density was 1.78 kg m^{-3} with mechanized farming while the lowest value was 1.24 kg m^{-3} in the fields cultivated using manual labor. The average value of soil bulk density samples under mechanized farming was 12.6% significantly higher than under manual labor. Cone penetration resistance across cane rows could be significantly divided into two layers at a depth of 45 cm, with the lower layer having higher penetration resistance. The average value of penetration resistance under mechanized farming was 23.3% higher than from manual labor. Cone penetration resistance values exceeded 2 MPa, especially for the fields with more years with ratoon canes and in fields subjected to mechanized farming. Under manual labor farming, the soil cone penetration resistance across cane rows showed a pattern of less scattering at depths less than 45 cm. **Conclusion:** Soil compaction induced by mechanization was clarified to some extent.

Key words: Soil compaction, mechanized farming, labor farming, cone penetration, less scattering, important economic, published research

INTRODUCTION

Sugarcane is one of the most important economic crops in Thailand. In 2008, about 73 million tonnes were produced from about one million hectares, which ranked Thailand third among world producers, after Brazil and China (CAI, 2008). Sugarcane serves as both a food and fuel crop. Ethanol production from sugarcane is consistent with the gasohol promotion policy of the Thai government, which aims to increase domestic ethanol demand to three million liters per day by 2011 (Cane and Sugar Industry Policy Bureau, 2006). In the past, the use of manual labor for sugarcane production was popular due to low labor costs. However, nowadays, mechanization in sugarcane farming is becoming more important due to the ever-increasing demand for sugarcane together with the problem of a labor shortage. Grange *et al.* (2005) reported that a high number of machine traffic passes are used in Thailand, with 13 passes being observed in conventional tillage treatments. Heavy equipment and the intensive use of machinery can cause damage to the soil structure, which is of concern as the structure affects the ability of a soil to hold and conduct water, nutrients and air that are necessary for plant root activity, with sustained damage eventually reducing yields. Soil compaction as a result of mechanization must be considered as one of the negative consequences of sugarcane production. Soil compaction has been identified on 4,364,820 hectares or 8.5% of the total area of Thailand (Land Development Department, 2009). Alakukku and Elonen (1995) reported that on average in the first 8 years, compaction of the clay soil with four passes reduced the yields by 4% and nitrogen uptake of the annual crop by 9%. Usaborisut and Niyamapa (2010) reported that the greatest reduction in the yield of sugarcane compared with a control field was 22.9%, which resulted from compaction following 15 tractor passages. Nowadays, the problems of soil compaction are drawing the attention of both the government and private sectors. The Office of Agricultural Economics of Thailand published research work that showed applying subsoiling helped improve the yield of cassava by up to 15%. Mitr Phol Group (2011) which is a group of companies operating businesses in the cane and sugar industry has posted

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information on its websites to encourage farmers to carry out subsoiling in sugarcane fields. In addition, there have also been several campaigns by a number of provincial governments to address soil compaction in crop fields (Udon-City.Com, 2011). Since soil compaction has been recognized as one of the serious problems of sugarcane farming in Thailand, considerable effort has been applied to clarify the behavior and manage the effects of soil compaction. Firstly soil compaction in sugarcane fields needs to be characterized. Therefore, the aim of the present research was to investigate soil compaction induced by mechanization in sugarcane fields and to compare the compaction with that in field's farmed using manual labor.

MATERIALS AND METHODS

Investigation site: The study was conducted in 16 sugarcane fields located in central Thailand, where sugarcane production is undertaken on 326,756 hectares of the total area of 1,042,620 hectares (Office of the Cane and Sugar Board, 2008). The soil properties in the 16 fields are categorized in Table 1.

The first 10 fields in Table 1 were subjected to mechanized farming while the remaining 6 fields were cultivated by manual labor, with the exception of tillage that was done by a tractor with a disk plow. Typically, the machinery used in the mechanization cultivation was: a tractor (weighing about 4 t) with a tillage tool attached for soil preparation; a tractor (4 t) with a sugarcane planter (0.5 t); and a harvester (15 t) and truck with total weight about 30 t. The sugarcane is replanted about every three years and five years for the mechanized and manual labor farming systems, respectively. The sugarcane crops in the study fields

included plants to the 5th ratoon. In the mechanized farming fields, there were 2, 3, 3 and 2 fields containing planted, 1st, 2nd and 3rd ratoon crops, respectively. In the manual labor fields, there were 1, 3, 1 and 1 fields containing planted, 1st, 3rd and 5th ratoon crops, respectively. Three-digit field codes were allocated to each treatment, with the first letter specifying the farming method (M = mechanized farming; L = manual labor farming), followed by a number giving the crop type and the last number identifying the field number.

Data measurement: A cone penetrometer was used to measure the soil resistance in all fields with four samples from each field. Measurements were taken 10 cm apart across a row of cane for 200 cm and extended into soil to a depth of 90 cm. The middle of the row was set at the 100 cm sampling point (Fig. 1). The soil surface profile was also recorded. Samples for bulk density were taken at depths of 20 cm and 40 cm using a core soil sampler.

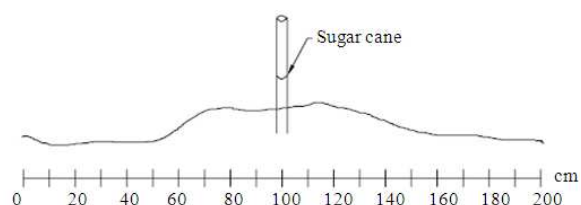Statistical differences were tested using Duncan's multiple Range Test (DMRT) at the 95% level.

Fig. 1: Location of soil resistance samples in sugarcane row

Table 1: Field specifications and soil properties of study area

			Soil Texture			
Field code[*]	Farming method	Crop	Sand (%)	Silt (%)	Clay (%)	Soil type
M1-1	Mechanized	Planted	47.51	34.42	18.07	Loam
M1-2	Mechanized	Planted	67.40	22.60	10.00	Sandy loam
M2-1	Mechanized	1st ratoon	36.37	40.67	22.96	Loam
M2-2	Mechanized	1st ratoon	27.16	36.42	36.42	Clay loam
M2-3	Mechanized	1st ratoon	44.96	33.65	21.39	Loam
M3-1	Mechanized	2nd ratoon	54.51	27.32	18.17	Sandy loam
M3-2	Mechanized	2nd ratoon	21.25	51.97	26.78	Silt loam
M3-3	Mechanized	2nd ratoon	62.72	24.32	12.96	Sandy loam
M4-1	Mechanized	3rd ratoon	42.74	37.58	19.68	Loam
M4-2	Mechanized	3rd ratoon	21.39	50.52	28.09	Clay loam
L1-1	Labor	planted	17.72	42.11	40.17	Silt clay loam
L2-1	Labor	1st ratoon	25.78	35.30	38.92	Clay loam
L2-2	Labor	1st ratoon	45.41	33.53	21.05	Loam
L2-3	Labor	1st ratoon	25.80	50.84	23.36	Silt loam
L4-1	Labor	3rd ratoon	23.89	39.81	36.29	Clay loam
L6-1	Labor	5th ratoon	43.86	33.88	22.26	Loam

[*] M = mechanized; L = manual labor

RESULTS

Soil bulk density: Soil bulk densities varied from 1.24 to 1.78 kg m^{-3}. As expected, the mechanized fields had higher values for soil bulk density. The highest value of 1.78 kg m^{-3} was found in a mechanized farming field with a 2nd ratoon crop (M3-3), while the lowest value was recorded in a manual labor farming field with a planted crop (L1^{-1}) with 1.24 kg m^{-3}.

Cone penetration resistance: To obtain a clearer picture of soil compaction in the field, soil penetration resistance values were plotted as contour lines throughout the soil profile. A natural neighbor model was applied since it shows the boundaries of the surface lines and resulted in a low standard deviation of 0.0496.

Figure 2 shows the penetration resistance contour lines of the sample in field M4-2 after four years of sugar cane cultivation under mechanized farming. The x-axis distance indicates the horizontal distance measured across a sugarcane row with the sugarcane located at a distance of 100 cm. The lightest color represents the area with the highest value of penetration resistance of the soil (2.8 MPa in Fig. 2). The penetration resistance values reduce as the color in the contour plot increase, with the lowest value in the black areas being 0.2 MPa. The general characteristics of soil compaction can be observed from the plot of the soil penetration resistance contours. As shown in Fig. 2, soil penetration resistance was higher below a depth of about 45 cm. The highest penetration resistance in this study was 4.8 MPa found in field M1-1 at a distance of 70 cm and depth of 90 cm. For soil within 45 cm of the surface, the highest penetration resistance was 4.2 MPa in field M1-1 at a distance of 120 cm and depth of 32.5 cm and there were also compacted soil pockets with penetration resistance higher than 2 MPa scattered throughout the soil profiles, especially near the sugarcane row. Figure 2 shows the maximum penetration resistance of 2.8 MPa at position 80 cm or a 20 cm distance from the sugarcane row.

On the other hand, the penetration resistance contour lines after labor farming had lower values and were fairly uniform to a depth from the surface of about 45 cm. Furthermore, there were no resistance values higher than 2 MPa (Fig. 3).

In order to characterize soil penetration resistance throughout the soil profiles among the sugarcane fields, each soil profile was divided into 10 sections (Zone1-Zone10) as shown in Fig. 4. Zone boundaries were set

at a depth of 45 cm and a width of 40 cm. Average values of penetration resistance in each zone in all samples were calculated and analyzed statistically. The results indicated that there were two different groups of penetration resistance-Zone1 to Zone5 had significantly lower resistance than Zone6 to Zone10 (Table 3). The cone penetration resistance in the sugarcane crops was highest in field M3-1 with a value of 1.86 MPa while field L2-3 recorded the lowest value of 0.51 MPa (Table 4). Sugarcane crops where manual labor had been used had lower cone penetration resistance, with average values not exceeding 1.59 MPa.
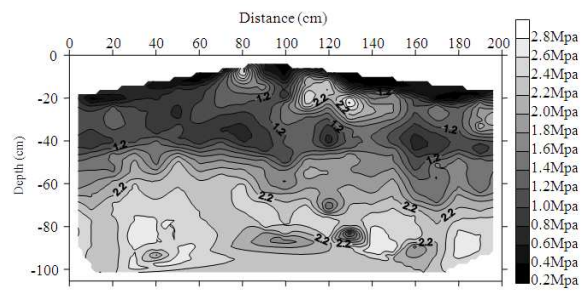

Fig. 2: Soil penetration resistance contour lines after mechanized farming in field M4-2
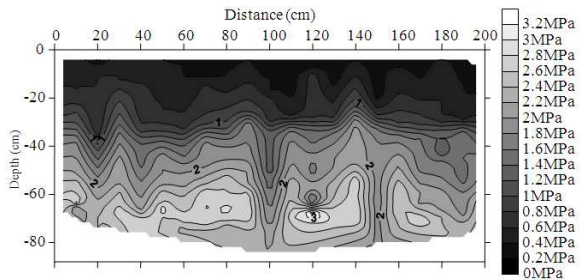

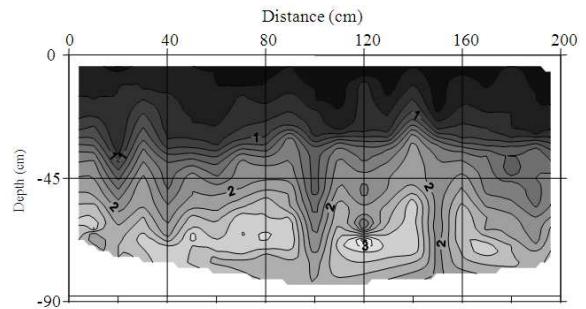Fig. 3: Soil penetration resistance contour lines after manual labor farming in field L6-1

Fig. 4 Division of soil profile into zones

Table 2: Soil bulk density results

Field code[*]	Average bulk density at 20 cm (kg m^{-3})	Average bulk density at 40 cm (kg m^{-3})	Average bulk density (kg m^{-3})
L1-1	1.24a	1.24a	1.24a
L2-1	1.24a	1.24a	1.24a
L4-1	1.26a	1.28a	1.27a
M3-2	1.37b	1.38b	1.38b
M4-2	1.39bc	1.38b	1.39b
M2-3	1.40bcd	1.44bc	1.42bc
L6-1	1.42bcd	1.42bc	1.42bc
M2-2	1.45cde	1.43bc	1.44c
L2-2	1.46cde	1.42bc	1.44c
L2-3	1.47de	1.47cd	1.47c
M1-1	1.51ef	1.52de	1.51d
M4-1	1.54fg	1.51de	1.52d
M2-1	1.54fg	1.54e	1.54de
M1-2	1.58gh	1.58ef	1.58ef
M3-1	1.62h	1.61f	1.62f
M3-3	1.78i	1.78g	1.78g

[*]: M = mechanized; L = manual labor. Remark: Figures in the same column with the same lower case letter are not significantly different by Duncan's multiple range test at 95% significance level

DISCUSSION

Bulk density is dependent on soil texture. Sandy soils have relatively high bulk density since the total pore space in sand is less than that of silt or clay. NRCS Soil Quality Institute (2003) reported that bulk densities that may affect root growth are 1.63, 1.60 and 1.55 kg/m^3 for sandy loam, silt loam and silt clay loam, respectively. Based on these data and the list of soil types in Table 1, most of the mechanized fields in Table 2 have severely affected root growth.

Soil compaction can be caused by natural events such as raindrops, as well as more severely by field operations, such as tillage operations and wheeled traffic. Therefore, compaction may vary depending on the history of operations. As expected, penetration resistance values of soil in the sugarcane fields studied were scattered throughout the soil profile. When considering penetration resistance contours as typically shown in Fig. 2 and 3, a division into two layers can be seen at a depth of about 40-50 cm. Furthermore, statistical analysis confirmed that the value of penetration resistance in the upper layer above 45 cm and the lower layers at or below this depth were significantly different (Table 3). Since, the conventional plowing depth is about 40 cm, the upper soil is loosened periodically by tillage operations. However, the soil below the tillage layer becomes compacted year by year, resulting in subsoil compaction. In the upper layer, there were some areas at a horizontal distance of 80 cm and also at 100-140 cm that showed penetration resistance greater than 2 MPa (Fig. 2). Mari and Changying (2008) stated that the ability of plant roots to penetrate soil is restricted as soil strength increases and Sojka *et al*. (1990) reported that soil penetration resistance of more than 2 MPa made penetration by the roots very difficult.

Table 3: Cone penetration resistance by zone

Zone	Cone penetration resistance (MPa)
zone3	1.11a
zone2	1.11a
zone4	1.12a
zone1	1.13a
zone5	1.16a
zone8	1.95b
zone6	1.96b
zone10	1.96b
zone7	1.98b
zone9	2.00b

Remark: Figures in the same column with the same lower case letter are not significantly different by Duncan's multiple range test at 95% significance level

Table 4: Cone penetration resistance by field

Field code	Cone penetration resistance (MPa)
L2-3	0.51a
M1-2	0.70b
M2-3	1.17c
L2-1	1.32d
L1-1	1.41de
L4-1	1.46e
M1-1	1.51ef
L6-1	1.53ef
L2-2	1.59fg
M4-1	1.60fg
M2-2	1.60fg
M3-2	1.63fg
M3-3	1.69gh
M2-1	1.77hi
M4-2	1.80hi
M3-1	1.86i

Remark: Figures in the same column with the same lower case letter are not significantly different by Duncan's multiple range test at 95% significance level

The greater penetration resistance around 100-140 cm horizontally and at a depth of about 20-30 cm seems to have been caused by forces acting on the ground due to

the continuous or repeated tracking of agricultural machinery. Radcliffe *et al*. (1988) reported that the soil at a depth of 15-30 cm from the surface under tractor wheels will be compressed more than at the same depth with no tractor activity. However, the higher soil penetration resistance in soil near the surface at a horizontal distance of 80 cm may have been due to other causes, perhaps related to changes in soil conditions after flooding and then subsequent drying.

In general, the fields treated using mechanized farming seemed to showed higher values of both bulk density and cone penetration resistance when compared with the fields under manual labor farming. The highest value of bulk density found in a mechanized farming field (M3-3) was 44.4% higher than the lowest value found in a manual labor field (L1-1). In addition, it is of interest that the bulk density in a field farmed using manual labor with a 5th ratoon crop (L6-1), which was the highest ratoon crop used in this research, was 21% lower than the highest value. On average, the bulk densities of soil in mechanized farming fields were 12.6% significantly higher than in manual labor farming fields. The highest value of penetration resistance in a mechanized field (M3-1) was 264.7% higher than the lowest resistance in a manual labor field (L2-3) and the average value for the mechanized field treatments was 23.3% higher than for the manual labor treatments.

CONCLUSION

Based on the results of this research:

- The average bulk density of soil in mechanized farming fields was 12.6% significantly higher than in manual labor farming fields. Moreover, most of mechanized fields were in a state where there was severe impairment to root growth
- Soil penetration resistance contours can provide a useful visual presentation of soil compaction throughout the soil profile
- The average value of soil penetration resistance in mechanized farming field was 23.3% higher than in manual labor farming fields
- The soil penetration resistance in manual labor farming fields at soil depths to about 45 cm was more uniformly distributed than in mechanized farming fields

ACKNOWLEDGEMENT

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