Effect of Hand Tractor Implements on Soil Physical Properties in Upland Conditions

R. R. Pechon[*1], N. Ito[*2], K. Kito[*1] and H. Jinyama[*1]
[1] Department of Environmental Science and Technology
Faculty of Bioresources, Mie University

1577 Kurimamachiya-cho, Tsu-shi, Mie-ken, 514-8507 Japan
[2] Faculty of Engineering, Mie University, 1577 Kurimamachiya-cho,
Tsu-shi, Mie-ken, 514-8507 Japan
repech_99@yahoo.com, itonobu@eng.mie-u.ac.jp

ABSTRACT

Low efficiency and substandard machines are common problems in agricultural mechanization in most developing countries. In this paper, a prototype non-power rotary tiller implement (NPRT) was developed to pulverize soils after first plowing for seedbed preparation. Field performance of NPRT, power rotary tiller (PRT) and traditional comb tooth harrow (CTH) were compared. Results showed that highest pulverization was attained by PRT due to higher power transmitted directly from the engine to the rotary blades. Soil water content and bulk density were inversely proportional with tillage passes in all tested implements. PRT attained highest temperature diurnal wave than NPRT and CTH on soil surface and highly affected as the ambient temperature changes due to porous and looseness of the soil. Pulverization and mixing of clods had maximized the exposure of the lower layers to solar radiation and evaporation process and reducing soil moisture and bulk density.

Keywords: Developing country, land preparation, mechanization, tillage implements

1. INTRODUCTION

Mechanization was started from the development of the animal drawn implements such as plow, weeder, harrows and other farming tools. These are essential and major inputs to agriculture; it can be argued that they are one of the most important. The term "*Mechanization*" is generally used as an overall description of the application of these inputs (Clarke, 2000). Asian farmers commonly have small-scale and narrow fields of less than 0.3 ha in traditional farming district and hilly areas. In such cases, hand tractor are quite handy to use and can attain higher working efficiency and accuracy than four-wheel tractors (Sakai, 1999).

Effective tillage systems create an ideal seedbed soil condition (i.e. soil moisture, temperature, bulk density, and soil aggregates) for plant emergence and plant development. Most researches had often used bulk density, soil structure, compaction, particle size distribution, porosity and moisture content for characterizing soil tillage (Fragin, 1986; Hakansson, 1990; Steyn and

Tolmay, 1995). Lal (1985) suggested a system for rating of soil and climatic characteristics to facilitate the identification of tillage requirements. However, his analysis was limited to no-till, minimum tillage, chiseling and both primary and secondary tillage systems without consideration of the implements, depth and frequency of operations. Kaspar et al. (1990) found that soil moisture and soil temperature within the seedbed zone (top 5 cm) can promote or delay seed germination and plant emergence. On the other hand, Natsis et al. (2002) investigated the influence of the fore ploughshare and disk coulter on the tillage quality found that the best tillage quality was obtained when both the disc coulter and foreploughshare were used. He found that the plant residue left on the soil surface was considerably reduced and clods size category larger than 15 cm did not appear at all. Reduced soil disturbance of disc harrowing gave better water storage unlike the chisel and particularly the moldboard plough where the soil disturbance subjected deeper wet layers to rapid desiccation (Aboudrare et al. 2006). Although a number of studies (Aboudrare et al. 2006; Licht and Al-Kaisi, 2005; Natsis et al. 2002) have been carried out to quantify seedbed condition after tillage operation, yet it has not been possible to identify the appropriate soil physical property for determining an optimum till.

In this paper, a prototype non-power rotary tiller implement is introduced. It is designed and constructed as an alternative attachment for hand tractor for harrowing operation intended for developing countries. The objective is to evaluate and compare the effects of three different tiller implements (Fig. 1) on soil water content, bulk density, penetration resistance and soil temperature in upland soil conditions.

a) Power rotary tiller b) Prototype non-power rotary tiller c) Traditional comb tooth harrow

Figure 1. Three different implements for hand tractor

Table 1. Machine implements specification and description

	PRT [1]	NPRT [2]	CTH [3]
Length	700 mm	600 mm	400 mm
Width of cut	450 mm	1000 mm	1000 mm
Height	800 mm	550 mm	500 mm
No. of blades/tooth*	12 (c-shape type)	8 (disc type)	10 *
Spacing of blades	50 mm	120 mm (adjustable)	100 mm

Blade Diameter/tooth length*	380 mm	380 mm	200 mm*
Total weight	45 kg	27 kg	10 kg
Shaft diameter	35 mm	20 mm	-
Blade power	engine drive	self propelled	-

[1] Power rotary tiller
[2] Prototype non-power rotary tiller
[3] Comb tooth harrow

2. MATERIALS AND METHODS

2.1 Experimental Approach

Three implements were tested and compared. These are the powered rotary tiller (PRT), a prototype non-powered rotary tiller (NPRT) and the comb tooth harrow (CTH). The PRT had a horizontal shaft with rotary slasher blades that cut and stir the soil. These machines are well suited to work in paddy fields for stirring the soil and incorporating trash. They were not suitable for hard soil conditions, except perhaps the very large type fitted to a four-wheel tractor as they have severe vibration and wear problem under these conditions. The prototype NPRT had petal like shape rotary disk blades arranged such that they rotate as they are pulled through the land. They are used to cut up the clods after primary cultivation and they had good stirring and mixing characteristics. The traditional CTH was an implement consisting of teeth welded on crossbars and staggered so that each tooth works on a strip. Straight and pointed teeth were used. The tooth bars were adjustable to change the tooth angle from vertical to nearly horizontal to control the depth of penetration.

The field was tilled by four-wheel tractor using rotary plow two weeks before the test. It was conducted in December 2005. The field condition was flat, free of weeds and totally exposed to the sun from sunrise to sunset. Three replications were conducted at every implements test. The field was divided into three plots. Each plot was intended for each tillage implement and a separate plot for no seedbed preparation or no tillage (NT). NT refers to the soil condition without seedbed preparation. The plowing depth was maintained at 12 cm through a marker on the guide wheel at the rear portion both of the rotary tillers. In the case of the comb tooth harrow, a marker on the tooth was placed for the hand tractor operator to maintain the penetration depth. A guide marker was placed in maintaining straight tillage direction to avoid overlapping.

2.2 Location and Climatic Condition

The field experiment was conducted in the upland research field of Mie University. The soil is sandy loam that develops medium to moderately coarse texture soil aggregates. During the test, the field was almost completely free from roots and other plant material that could have interfered with the break up of the soil.

The University is located in Tsu City, Mie Prefecture, Japan. Mie Prefecture has a long narrow shape. Stretching 170 km from north to south and spanning 80 km from east to west. It has varied landscape that includes mountains, plains and coastlines. It has a moderate climate with an annual average temperature and rainfall of 15.5 ^{0}C and 137.41 mm respectively as shown in Fig.

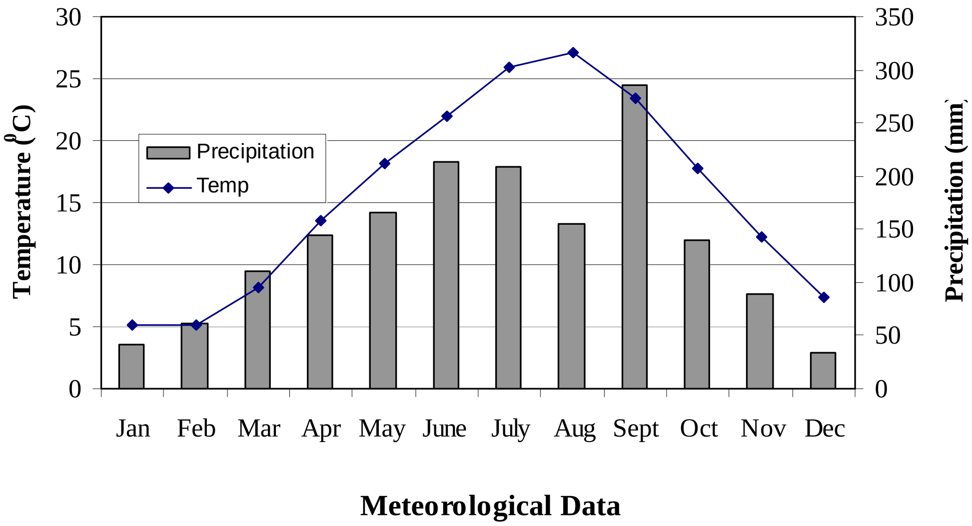

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Figure 2. Average rainfall and temperature of the study site (Year 1971-2000)

2.3 Soil Textural Profile

Three samples were collected at different location of the test field for the analysis of soil textural profile. Soil auger was used to collect sample from the surface up to 50 cm. Textural analysis was conducted using hydrometer method. Figure 3 below show the textural profile of the soil.

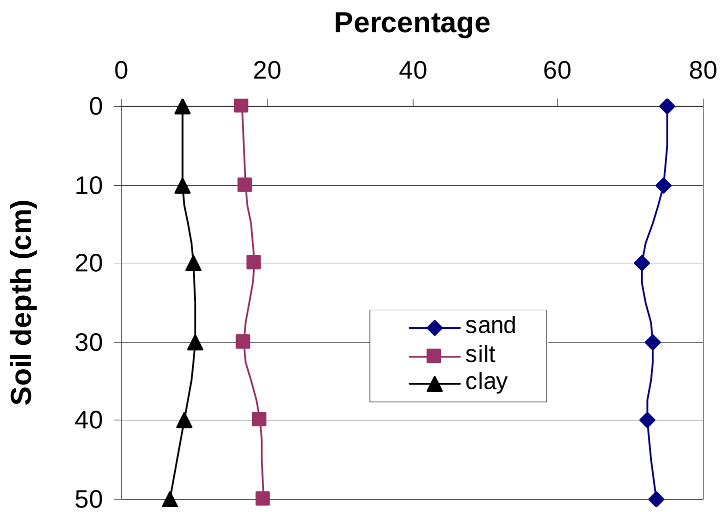

Figure 3. Textural profile of the soil

2.4 Soil Water Content

The need to determine the amount of water content present in the soil arises frequently for understanding the soil's mechanical behavior such as the results of tillage operation and the response of plants growth. Gravimetric water content was measured before starting and after the harrowing operation. Five samples at every tillage passes of test implements were taken after the field was plowed by four-wheel tractor for data analysis. Gravimetric water content may be expressed by weight as the ratio of the mass of water to the dry weight of the soil sample, or by volume as the ratio of volume of water to the total volume of the soil sample. The water mass must be determine by drying the soil to constant weight and measuring the sample mass before and after drying. The traditional method of measurement consists of removing a sample by soil auger and place the sample in an oven at 105^0C for 24 hours (ASAE Standards, 2002. EP419.1; Hillel, 1980; Dirksen, 1999). The water content in dry weight basis can be calculated using the following formula:

$$\theta_g = \frac{(\rho_{ws} + \rho_{ec}) - (\rho_{ds} + \rho_{ec})}{(\rho_{ds} + \rho_{ec}) - (\rho_{ec})} \qquad (1)$$

where θ_g the gravimetric water content dry basis, ρ_{ws} is the weight of wet soil sample, ρ_{ds} is the weight of oven dried soil sample and ρ_{ec} is the weight of empty can

2.5 Soil Aggregate

Since soil particle differ in shape, size and orientation, and can be variously associated and interlinked, the mass of them can form complex and irregular configurations which are in general extremely difficult if not impossible to characterize in exact geometric terms. Soil aggregate properties are usually different from bulk soil properties (Horn, 1990). Aggregate size and density are identified as two of the most important properties of soil aggregates. The aggregates were measured by using sieves with different mess diameter. The particles were separated by passing the sample through a set of sieves and weighing the fraction retained on each sieve.

2.6 Soil Dry Bulk Density

Measurement of bulk density requires separate measurement of both the mass of dry soil and the volume the soil occupied prior to measurement. It is expresses as the ratio of the mass of dried sample to the total volume of the soil including the particles as well as the pores (Hillel, 1971). Dry soil defines operationally as the state of soil sample after 24 hours of drying in an oven at 105^0C. Before and after the test, bulk density was measured by random sampling at 7 different sites in each implements test passes using by core method. It can be calculated as follows:

$$\rho_b = \frac{M_s}{V_t} = \frac{M_s}{V_s + V_a + V_w} \qquad (2)$$

where ρ_b is the dry bulk density, M_s is the mass of solid, V_a is the volume of air, V_w is the volume of water, V_s is the volume of solid, V_f is the volume of pores and the total volume V_t of soil; and

$$\rho_s = \frac{M_s}{V_s} \qquad (3)$$

where ρ_s is the density of solids

2.7 Soil Penetration Resistance

Penetration resistance of the soil was measured randomly within the plot. Five measurements were recorded for every treatment plot. A 30-degree circular stainless steel cone with 15.88 mm driving shaft and having a cross sectional area of 323 mm^2 soil cone penetrometer was used. It was manually pushed into the soil at approximately 30 mm/s penetration rate (ASAE Standards, 2002, EP542). The surface reading was obtained after the cone has sunk into the soil, while depth is being recorded simultaneously by the marking on the shaft of the cone penetrometer. Maruto penetrometer model SH-36 was used in measurement.

2.8 Soil Temperature

Soil temperature monitoring and recording was conducted regularly right after the harrowing. Analysis has been focused on the top soil layer surface temperature (representative of the first 10 cm below ground surface). A soil temperature probe was utilized per treatment plot of the test implement attachment. Temperature was recorded after the cultivation of PRT, NPRT, CTH and NT. The probe buried at specific depth parallel to the soil surface and data was then monitored and recorded using resistance temperature detectors probe (RTDs) through a data logger. The probe is 100 mm long and 4.5 mm diameter. Temperature was measured directly and recorded to the data logger. Data collection was configured at specific interval of 30 minutes for automatic scanning. All reading was automatically time-stamped and stored in the data logger. Enough memory to hold more than a week's data (20 channels scanned). It is then downloaded to a personal computer on a spreadsheet for data analysis.

3. RESULTS AND DISCUSSION

3.1 Water Content and Soil Aggregates

The soil water content had dramatically decreased due to tillage operation. PRT attained higher water content reduction in every pass compared to NPRT and CTH. PRT achieved high soil pulverization even in one pass due to the power transmitted directly from the engine to the rotary blades compared to the other attachments. Average water content reduction of 2.24% on CTH, 2.42% on NPRT and 2.92% on PRT were obtained on three passes from NT. Tillage passes affects the soil water content and it is inversely related (Fig. 4). This was the results of soil disturbance and loosening that caused the pulverization of clods thus maximized the exposure to the solar radiation and enhanced evaporation process.

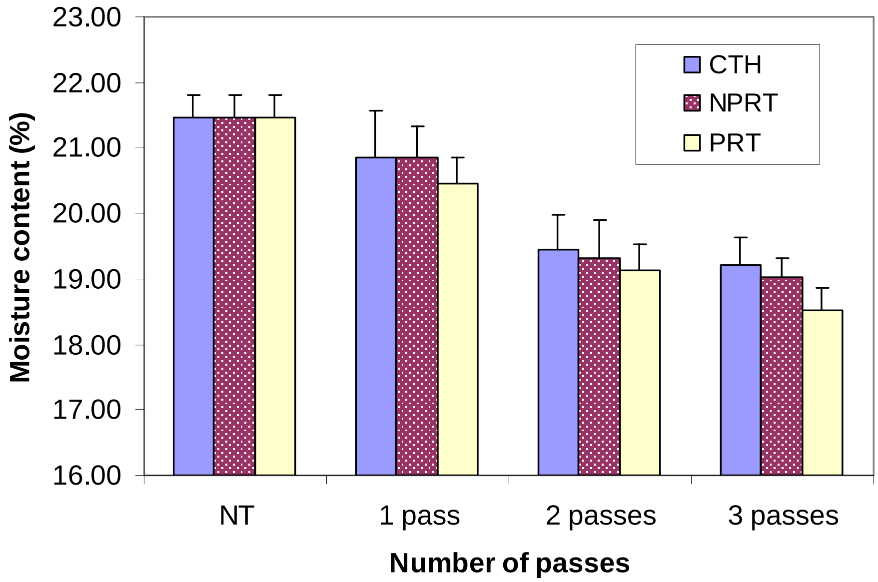

Figure 4. Average water content on soil surface (0 - 10 cm depth) influence by tillage passes. Error bars represent the standard error.

Composition of soil aggregates is an indicator of tillage implement performance. Aggregation was influenced by agricultural practices such as tillage and disrupts mechanically and changes the soil condition (temperature, moisture, aeration) (Balesdent et al., 2000). Table 2 shows the percentage size distribution of aggregates obtained after the passage of three different attached implement. The aggregates are broken up during tillage. Data shows that in the 7.27 mm diameter sieves, 38.44%, 34.35% and 18.51% soil aggregates were retained after three passes by CTH, NPRT and PRT respectively. Between 7.27 to 2.00mm diameter sieves, NPRT achieved the highest percentage of soil fraction. PRT exhibits the highest mean aggregates passes through 2mm diameter sieves. The number of tillage passes reduced the soil particle size as a result of fragmentation and soil particle are sorted. Sorting occurs with a small particles tending to sink to the bottom of the tilled layer and the larger aggregates tending to rise at the surface. This result had agreed with Ojeniyi and Dexter (1979).

Table 2. Percentage size distribution of soil aggregates after three passes of three different attached implements on hand tractor

Soil diameter (mm)	Percentage soil fraction		
	CTH [1]	NPRT [2]	PRT [3]
> 7.27	38.44±4.17	34.35±4.05	18.51±2.70
7.27 - 2.00	24.07±3.74	28.33±3.86	27.46±3.54
< 2.00	37.48±3.83	37.32±3.52	54.03±3.95

[1] Comb tooth harrow
[2] Non-power rotary tiller
[3] Power rotary tiller

3.2 Bulk Density and Penetration Resistance

The bulk density on the top soil layer (0-10 cm) presented significant changes after the tillage operation using the three different implements. Figure 5 indicates that bulk density was inversely proportional to the tillage passes on upland condition. PRT produced the highest reduction compared to NPRT and CTH in three different tillage passes due to the high blade rotation and intensity. A mean reduction of 0.14, 0.17 and 0.25 g-cm^{-3} was attained by CTH, NPRT and PRT respectively after three passes. The undisturbed subsoil, however, was compacted by the weight of the walking-type tractor.

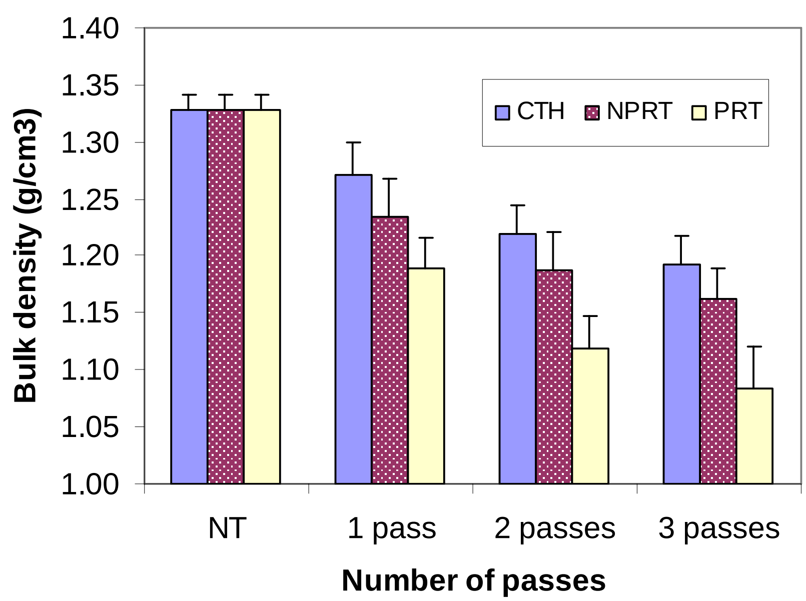

Figure 5. Soil bulk density on soil surface in relation to harrowing of three different attached implements in walking-type tractor. Error bars represent the standard error.

Penetration resistance from 0-10 cm soil layers (Fig. 6) was significantly lowest in PRT compared to NPRT and CTH. At 10 cm depths the recorded value of CTH, NPRT and PRT were 0.944, 0.886 and 0.554 MPa respectively. The cone penetration resistance tended to continually increase with sampling depth.

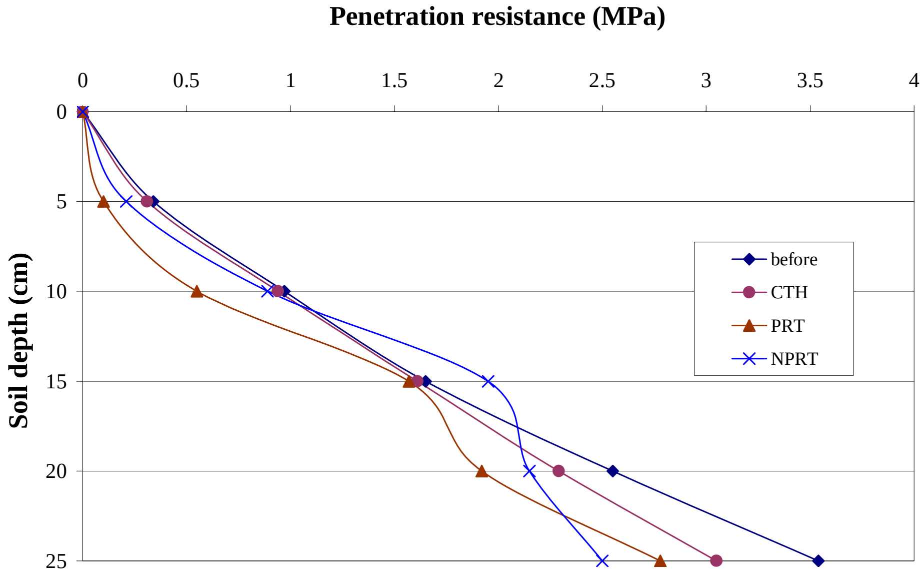

Figure 6. Soil penetration resistance profiles in relation to harrowing of three different implements attachment of walking-type tractor.

3.3 Pre-cultivation Diurnal Temperature

The diurnal variations in temperature were measured at different depths before soil cultivation of the three different hand tractor attachments (Fig. 7). It was observed that before sunrise, the minimum temperature was lowest at the surface and increased with its depth. For instance, at 3:30 am, when the ambient temperature was approximately 4.23 ^{0}C, the temperature at 20 cm depth was 9.99 ^{0}C. Similar result obtained by previous study that heat is leaving the soil at this time because of the time lag associated with soil heat flow when the surface temperature is changing; the lower depths continue to cool for a period of time (Jury et al., 1991; Yukawa 1945). The mean diurnal soil temperature was highest at 20 cm depth. It is 0.57 ^{0}C higher than 15 cm, 1.08 ^{0}C than 10 cm depth and 1.46 ^{0}C than 5 cm depth. On the other hand, the mean diurnal ambient temperature was 0.7 and 0.64 ^{0}C lower compared with 15 and 20 cm soil depth respectively but 0.82 and 0.44 ^{0}C higher than 5 and 10 cm soil depth. It was also found that the soil temperature increases with its soil depth and agreed with Sarkar and Singh (2006).

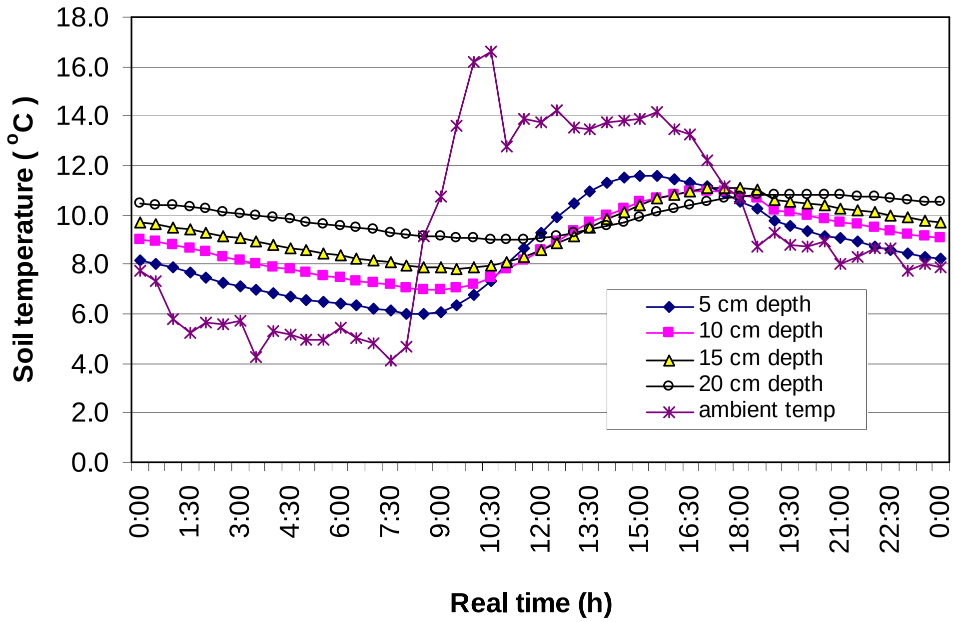

Figure 7. Diurnal variations in temperature measured continuously at different depths in sandy loam soil before tillage operation.

3.4 Temperature Variation after Tillage

The temperature variation of PRT, NPRT and CTH are presented in fig. 8. The diurnal wave on top soil layer (0-10 cm depth) was decreasing early in the morning and started increasing when the ambient temperature increased due to solar radiation. PRT attained highest diurnal wave and directly affected as the ambient temperature changes compared to NPRT and CTH. The ambient temperature was lowest from 0:00 to sunrise and start increasing between 9:30 to 10:00 am when the sun is above the horizon and top soil layer temperature start increasing when the vertical transport of heat in the soil occurs due to the soil heat flux and solar radiation. The same result was presented by the previous studies (Licht and Kaisi, 2005; Hillel, 1971; Tanner, 1968) that daytime net radiation is much greater than at night. High ambient temperature was significantly affecting the soil surface temperature.

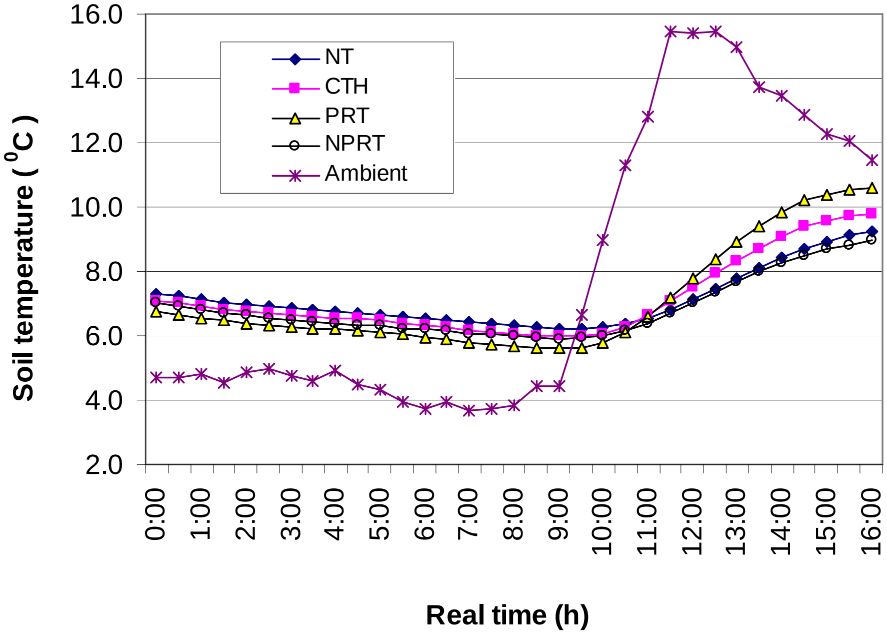

Figure 8. Temperature variation on top soil layer measured continuously (temperature at between 0 to 10 cm soil depth) of three different implements after tillage operation.

The soil surface temperature varies comparatively as result of tillage activity. Descriptive statistics shows the mean soil temperature values from 00:00 to 16:00 were highest in CTH and lowest in NPRT whereas for NT and PRT shows intermediate mean soil temperatures. There is a significant difference at 0:00 to 9:00 A.M. between NT and other tillage treatments (CTH, PRT and PRT) at 95% interval when the ambient temperature was low. The same results obtained at 9:00 to 16:00 P.M. when the ambient temperature increases. In this study, when maximum ambient temperature started to decrease, the soil temperature remained increasing at a certain span of time at 10 cm soil depth. Licht and Al-Kaisi (2005) found that maximum air temperature often resulted in maximum soil temperature at 5 cm soil depth and changes in soil temperature magnitude due to tillage effects were highly dependent on air temperature throughout the day.

4. CONCLUSIONS

A prototype non-power rotary tiller attached implement was designed, constructed and tested. The following conclusions were obtained:

- The rotating motion of blades by PRT and NPRT attained significant advantage in pulverization of soils in secondary tillage compared to the scratching motion of the traditional comb tooth harrow.

- Tillage affects in moisture content reduction of 2.24%, 2.42% and 2.92% by CTH, NPRT and PRT respectively after three passes of the test implements.
- Bulk density was lowest on PRT than NPRT and CTH; moreover PRT attained highest fine soil aggregates smaller than 2mm diameter. Bulk density of CTH at two passes (1.22 g cm^{-3}) is almost equal in one pass (1.23 g cm^{-3}) of NPRT, and three passes of CTH can be attained in two passes of the NPRT.
- The temperature varies considerably at shallow depth but the amplitude of the diurnal wave decreases rapidly as soil depth increases.

Based from the abovementioned results, NPRT is one alternative replacement of the existing CTH used in most small-scale farmers and further study will be conducted in tropical developing country.

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