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Note

Field performance and effect of SHAKTI and KUBOTA power tillers on physical properties of soil under Sawah rice production in Nigeria

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A b s t r a c t. In the study the authors investigated the field performance of two types of power tillers, which are increasingly popular among farmers adopting sawah rice production technology, and compared their effect on the physical properties of soil. Data were collected for the field performance parameters and for the physical properties of soil. Mean values of soil properties and performance data of power tillers were summarized and subjected to t-test statistics at p = 0.05. The results show that significant differences exist for field efficiency (t = -3.29, p < 0.05), fuel consumption (t = 9.21, p < 0.05) and slippage (t = -25.48, p < 0.05). At 0-7 cm depth, significant differences exist for soil moisture content (t = 15.46, p < 0.05) in soils where SHAKTI was used, while at 7-14 cm depth significant differences exist for all the physical properties of soils covered in the experiment - bulk density (t = -13.89, p < 0.05), cone index (t = -63.97, p < 0.05), soil moisture (t = 46.07, p < 0.05) and shear strength (t = -2.67, p < 0.05). It is important that farmers using these models should not only focus on the cost of purchase but also on their overall efficiency in order to achieve the desired high level of yield.

K e y w o r d s: power tillers, field capacity, field efficiency, soil moisture, bulk density, cone index

INTRODUCTION

Sawah rice production technology was introduced into Nigeria by Japanese institutions such as Japan International Cooperation Agency (JICA), Shimane and Kinki Universities (Nakashima *et al*., 2007). Wakatsuki and Masunaga (2005) reported that the potential of Sawah based rice farming is enormous in West Africa in order to stimulate the long awaited green revolution. This is predicated on the fact that the agro-ecological conditions of the core region of West Africa are quite similar to those of north-eastern Thailand which is one of the rice centres in the country. Ten to twenty million hectares of sawah can produce additional food for more than 300 million people in future. The sawah based rice farming can overcome soil fertility problems through enhancement of the geological fertilization process, conservation of water resources, and the high performance multifunctionality of the sawah type wetlands. The term sawah refers to levelled and bunded rice fields with inlet and outlet connecting irrigation and drainage. An important component of the sawah technology is the use of power tillers.

The power tiller is a multipurpose hand tractor designed primarily for rotary tilling and other operations on small farms. While in operation, an operator walks behind to manoeuvre it. Two-wheel tractors are sometimes referred to as single axle tractor, hand tractor, walking tractor, walk-behind tractor. Two-wheel tractor with different attachments (implements) can accomplish many kinds of farm work like tillage, planting, harvesting and transportation. When a tillage implement is attached to a two-wheel tractor, it is called power-tiller. There are many types of two-wheel tractors such as: mini tiller type (1.5-2.2 kW), traction-type (2.9-4.4 kW), dual type (3.7-5.2 kW), drive type (5.2-10.3 kW) and Thai type (5.9-8.8 kW). The demand, production and concentration of two-wheel tractors have been of particular significance in certain countries of Asia, especially those in which low-land rice is a major crop (Kathirvel *et al*., 2000).

Intensive use of agricultural machines without moisture control has been reportedly causing soil compaction as trafficking by wheeled farm machines is common in most agri-

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cultural operations. Wheel traffic can increase penetrometer resistance to a depth of 30 cm, and as deep as 45 cm below wheel tracks (Young and Voorhees, 1982). Compaction decreases the total porosity of the soil (Blackwell *et al*., 1986), and increases bulk density in wheel traffic areas (Allen and Musick, 1997). Soil compaction by wheels is characterized by a decrease in soil porosity localized in the zone beneath the wheel and rut formation at the soil surface. The degree of compaction depends on soil mechanical strength which is influenced by intrinsic soil properties, such as texture, and soil organic matter content (Larson *et al*., 1980), structure of the tilled layer at wheeling (Horn *et al*., 2000), water status (Guérif, 1984) and loading, which depends on axle load, tyre dimensions and velocity, as well as soil-tyre interaction (Lebert *et al*., 1998). The depth of the compaction varies widely from 10 to 60 cm, but it is more obvious on topsoil (around 10 cm). However, cone index (penetrometer reading) increments of between 16 and 76% can occur in the first 40 cm of the surface layer, and bulk density can also increase, but increases were limited to a 15 cm depth in a study (Bouwman *et al*., 2000). Bulk density is considered to be a measure of soil quality due to its relationships with other properties such as porosity, soil moisture, and hydraulic conductivity, among others.

However, the introduction of two-wheel tractors (power-tillers) in many countries is proving to be a better and more appropriate intermediate technology for power supply on farms. In the past three to four years, there has been an influx of two-wheel tractors into Nigeria, and the demand has particularly been increasing due to their use for the cultivation of low-land rice. In order to determine their suitability to local conditions, field evaluation of performance has to be carried out, and also their effect on the physical soil properties should be ascertained. The objective of this study was to determine the field performance and effect of SHAKTI and KUBOTA power tillers on the physical properties of soil under Sawah rice production in Nigeria.

MATERIALS AND METHOD

The field performance evaluation of an Indian model (VST-SHAKTI 130 DI) and a Japanese model (K120) (newly acquired) was carried out in rice fields located at Ejeti village near Bida, on a clayey loamy, sandy soil, under the guinea savannah ecology. Bida is 137 m above sea level and lies on longitude 6°01’E and latitude 9°06’N in Niger State of Nigeria. Also the effects of power tiller on physical properties of soil were determined. The Indian model power-tiller is a single-axle (two-wheel) tractor with 10 kW (13 hp) rated power, diesel engine of 2400 r.p.m. rated crankshaft speed. The engine is single cylinder horizontal 4-stroke, water cooled and hand-cranking type. While the Japanese model is of type K120 with a mounted engine model RK125, with rated power of 7.83 (10.5 hp) for the RK125 diesel engine and having 2200rpm rated crankshaft speed. The engine is single cylinder horizontal 4-stroke, water-cooled and double speed handle manual-cranking type. The 600 mm tine cultivator was attached to each of the power tillers and it was used for puddling of rice field.

Data collected for field performance evaluation covered parameters such as average time of operation, effective field capacity, theoretical field capacity, field efficiency, working speed, average draught, fuel consumption, fuel consumption, and slippage, while the soil physical properties monitored included soil moisture content, bulk density, cone index and shear strength. Based on the types of power tillers, two treatments for VST-SHAKTI 130 DI and K120 were replicated three times and completely randomised.

Particle size analysis was determined by the hydrometer method in air-dried 2 mm sieved soil samples collected from 0-7, 7-14 and 14-21 cm depths of the 18 plots before the start of the experiment. Samples were collected for the above depth intervals using a core sampler (5 cm diameter, 5 cm high) and were put in an oven set at 105°C for 24 h for determination of bulk density. Before and after tillage operations using the two models of power tillers, three core samples per plot were collected at 0-21 cm depth for bulk density. The core samples were collected from the centre of each plot at random. Soil samples were collected randomly at 0-21 cm depth and analysed for physical properties. Mass of wet samples was taken and the samples were placed in oven for 24 h at the temperature of 105°C. Thereafter, the mass of dry samples was taken and soil moisture calculated. A cone penetrometer was used to measure penetration resistance in the field at the surface and at 21 cm depth. Mean values of soil properties and performance data of power tillers were summarized and subjected to t-test statistics at $p = 0.05$.

RESULTS

The field performance evaluation was carried out on 3 different plots at Ejeti, and the average values of the parameters are employed in the analytical comparison given in Table 1. For the KUBOTA power tiller, the average time of operation on the field is 28.36 which, when compared to the estimated to theoretical time of operation, gives a difference of 0.05 (h).

Table 2 shows the differences in the parameters used for field evaluation of the two power tillers. Of the nine parameters covered, significant difference exists only for three parameters. These are field efficiency ($t = -3.29$, $p < 0.05$) having the fuel consumption ($t = 9.21$, $p < 0.05$) and slippage ($t = -25.48$, $p < 0.05$).

Soil physical properties prior to experimentation are shown in Table 3. At 0-21 cm depth, where roots are mainly formed, bulk density was high and increased with depth. The results of the significance difference in the effect of SHAKTI and KUBOTA power tillers on soil physical properties across the three depth levels where the experiment was conducted are shown in Table 4.

T a b l e 1. Field performance test for VST SHAKTI 130D1 and KUBOTA power tillers

Parameters	SHAKTI				KUBOTA			
	I	II	III	Average	I	II	III	Average
Average time of operation (h ha^{-1})	25.45	21.74	17.92	21.7	28.49	23.46	33.65	28.36
Effective field capacity (ha h^{-1})	0.0393	0.046	0.0558	0.047	0.0359	0.0426	0.0297	0.0353
Theoretical field capacity (ha h^{-1})	0.0416	0.0492	0.0605	0.0504	0.0419	0.0480	0.0371	0.0406
Field efficiency (%)	94.44	93.55	92.13	93.37	85.23	88.80	80.00	86.90
Working speed (km h^{-1})	2.66	24139	2.66	2.66	0.90	0.90	0.90	0.90
Average draught (kN)	1.73	1.73	1.73	1.73	5.04	5.04	5.04	5.04
Fuel consumption (l ha^{-1})	9.35	10.94	13.28	11.19	21.71	21.78	21.63	21.72
Fuel consumption (l h^{-1})	0.367	0.503	0.741	0.537	0.78	0.93	0.64	0.77
Slippage (%)	10.53	10.53	10.53	10.53	2.04	2.03	2.04	2.05

I, II, III - replicates.

T a b l e 2. Differences in field performance of SHAKTI and KUBOTA power tillers on sawah rice plots in Nigeria

Parameters		N	Mean	Standard deviation	Standard error mean	t	df	p
Average time of operations (h ha^{-1})	KUBOTA	3	28.53	5.0951	2.9417	1.86	4	0.13
	SHAKTI	3	21.70	3.7651	2.1738			
Effective field capacity (ha h^{-1})	KUBOTA	3	3.6E-02	6.452E-03	3.725E-03	-1.81	4	0.14
	SHAKTI	3	4.7E-02	8.298E-03	4.791E-03			
Theoretical field capacity (ha h^{-1})	KUBOTA	3	4.2E-02	5.463E-03	3.154E-03	-1.28	4	0.27
	SHAKTI	3	5.0E-02	9.510E-03	5.491E-03			
Field efficiency (%)	KUBOTA	3	84.67	4.4260	2.5554	-3.29	4	0.03
	SHAKTI	3	93.37	1.1651	0.6727			
Working speed (km h^{-1})	KUBOTA	3	0.90	0.0000	0.0000	-1.00	4	0.37
	SHAKTI	3	8048.10	13935.1224	8045.4467			
Avergae draught (kN)	KUBOTA	3	1.67	0.27	0.15	- 0.35	4	0.73
	SHAKTI	3	1.73	3.51E-02	2.02E-02			
Fuel consumption (l ha^{-1})	KUBOTA	3	21.79	7.506E-02	4.333E-02	9.21	4	0.001
	SHAKTI	3	11.19	1.9769	1.14			
Fuel consumption (l h^{-1})	KUBOTA	3	0.78	0.1450	8.3E-02	1.79	4	0.14
	SHAKTI	3	0.53	0.1893	0.1093			
Slippage (%)	KUBOTA	3	2.03	5.774E-03	3.3E-03	-25.48	4	0.00
	SHAKTI	3	10.53	0.0000	0.0000			

T a b l e 3. Average soil properties before tillage operations

Depth (cm)	Soil moisture (MC) (%)	Bulk density (BD) (g cm^{-3})
0-7	35.10	1.29
7-14	18.42	1.59
14-21	17.92	1.67

DISCUSSION

The differences justify the percentage field efficiency of operation of the KUBOTA, estimated to be 86.87%. The average theoretical field capacity of the KUBOTA, which was estimated as 0.0419 ha h^{-1}, when compared with the effective field capacity which consists of the average turning time (or unproductive time) of 12.78 s, working speed of 1.08 km h^{-1}, time of operation of 0.377 h, and estimated as 0.0359 ha h^{-1}, also justifies the efficiency of operation of KUBOTA with reduced tractive power loss during field

T a b l e 4. Differences in the effect of SHAKTI and KUBOTA power tillers on soil physical properties

Depth (cm)	Soil characteristics	Power tiller	N	Mean	Standard deviation	t	df	p
0≤7	Bulk density (g cm^{-3})	SHAKTI	3	1.3600	1.000E-02	0.32	4	0.76
		KUBOTA	3	1.3533	3.512E-02			
	Cone index (N m^{-2})	SHAKTI	3	6.667E-04	5.774E-04	2.00	4	0.11
		KUBOTA	3	0.0000	0.0000			
	Moisture content (%)	SHAKTI	3	39.2733	0.3055	15.46	4	0.00
		KUBOTA	3	36.3267	0.1250			
	Shear strength (MPa)	SHAKTI	3	3.333E-04	5.774E-04	-2.18	4	0.09
		KUBOTA	3	1.800E-02	1.400E-02			
>7≤14	Bulk density (g cm^{-3})	SHAKTI	3	1.5467	1.528E-02	-13.8	4	0.00
		KUBOTA	3	1.8933	4.041E-02			
	Cone index (N m^{-2})	SHAKTI	3	3.4500	1.000E-02	-63.9	4	0.00
		KUBOTA	3	40.0167	0.9900			
	Moisture content (%)	SHAKTI	3	29.5633	5.508E-02	46.07	4	0.00
		KUBOTA	3	14.6233	0.5590			
	Shear strength (MPa)	SHAKTI	3	6.000E-03	0.0000	-2.67	4	0.06
		KUBOTA	3	3.633E-02	1.966E-02			
>14≤21	Bulk density (g cm^{-3})	SHAKTI	3	1.6767	2.082E-02	-3.81	4	0.01
		KUBOTA	3	1.7767	4.041E-02			
	Cone index (N m^{-2})	SHAKTI	3	15.2200	7.211E-02	-14.14	4	0.00
		KUBOTA	3	19.0500	0.4636			
	Moisture content (%)	SHAKTI	3	19.5000	0.1000	9.73	4	0.001
		KUBOTA	3	15.9533	0.6231			
	Shear strength (MPa)	SHAKTI	3	1.000E-02	0.0000	-9.23	4	0.001
		KUBOTA	3	6.467E-02	1.026E-02			

operation. The percentage slippage of 2.04%, which is the proportional measure by which the actual travel speed of the KUBOTA exceeds the zero slip speed, also justifies its effective speed field capacity. For the SHAKTI power tiller, the average time of operation on the field is 21.7, with a theoretical field capacity of 0.0504 ha h^{-1}. This value, when compared with the estimated effective field capacity of 0.0504 ha h^{-1}, gives a difference of 0.0034 ha h^{-1}. The difference justifies the field efficiency which was estimated to be equal to 93.37%, considering the effects of turning time (or unproductive time), working speed of 2.66 km h^{-1}, and average time of operation of 21.7h ha^{-1}.

Comparing the evaluation performance parameters of the KUBOTA and the VSPT, the average draught force required for the SHAKTI is 1.73 (kN), while that required for the KUBOTA equals 0.88 (kN). This force difference implies that more force is required to pull the SHAKTI than the KUBOTA. This fact is also reflected in the percentage slippage of both the SHAKTI and the KUBOTA which indicates a travel reduction difference of 8.49%. The fuel consumption in litres per hectare of the KUBOTA equals 21.71 l ha^{-1}, while that of the SHAKTI equals 11.91 l ha^{-1}. Although the area of land used for both performance evaluations was different, the ratio of average area of field (0.0139/0.035= 0.397) and the ratio of fuel consumed per hectare, which equals 1.823 (21.71/11.91= 1.823), justifies the fact that more fuel is consumed by the KUBOTA than the SHAKTI for field operations on the same area of land. This supports the findings of Mohanty *et al.* (2004).

The average efficiency values of the KUBOTA and SHAKTI reflect the fact that these power tillers are efficient for field operations in terms of work rate, quality of work done, ease of operations on farmland, and fuel economy, although this varies with their individual efficiencies which may be affected by operator capability and ease of handling.

The results in Table 2 imply that the field efficiency of the SHAKTI is greater than KUBOTA, the mean values being 93.37 and 84.67, respectively. Also the slippage for SHAKTI (10.53%) is higher than for KUBOTA (2.03%). However, fuel consumption is higher in KUBOTA (21.79 l ha^{-1}) than SHAKTI (11.19l ha^{-1}).

After power tiller operations (Fig. 1), bulk density was higher in the plots where KUBOTA was used than in those where SHAKTI was used across the depths. This may be attributed to the mass of the engine and the number of times wheel trafficking was carried out. Mari and Changying (2008) reported that high frequency (four passes) of crawler tractor produced significant increase in dry bulk density in the entire soil profile to 15 cm depth. The shear strength and cone index parameters were higher for both power tillers at

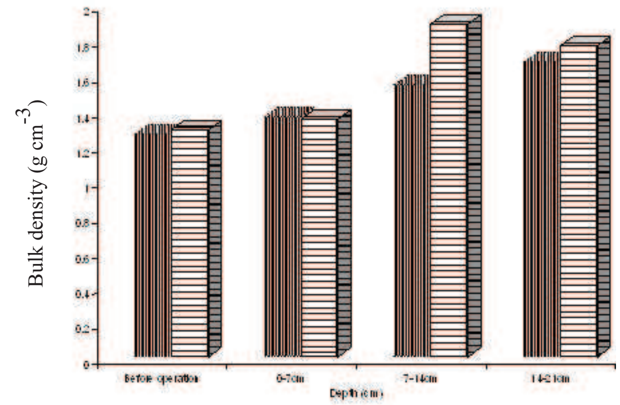

Fig. 1. Bulk density before and after tillage operations., SHAKTI – left, KUBOTA – right.

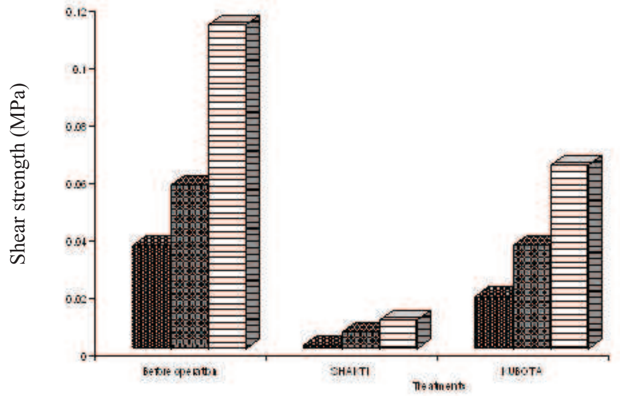

Fig. 2. Shear strength before and after tillage operations for the investigated depths: 0-7, 7-14, and 14-21 cm from left to right.

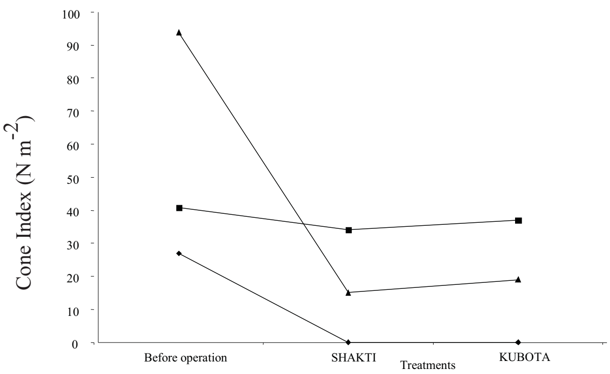

Fig. 3. Cone index before and after tillage operations. ◆ 0-7 cm, ■ 7-14 cm, ▲ 14-21 cm.

7-14 cm depth than for the other depths. This region is very critical for rice roots which always concentrate around this depth (Figs 2 and 3). This aggress with the findings of Mohanty *et al*. (2004).

At the 0-7 cm depth, significant differences exist for soil moisture content ($t = 15.46$, $p < 0.05$), with the soil where SHAKTI was used having a higher mean (39.27%). At 7-14 cm depth significant differences exist for all the physical properties of soils covered in the experiment. These are bulk density ($t = -13.89$, $p < 0.05$); cone index ($t = -63.97$, $p < 0.05$); soil moisture ($t = 46.07$, $p < 0.05$) and shear strength ($t = -2.67$, $p < 0.05$). The SHAKTI power tiller had higher means for all the properties except for bulk density and cone index. A similar trend was recorded for the soil properties at the 14-21 cm depth. All the properties were significantly different for the soils where SHAKTI and KUBOTA power tiller were used. This agrees with the findings of Allen and Musick (1997).

CONCLUSIONS

1. SHAKTI and KUBOTA power tiller models have different efficiency on sawah rice soils in Nigeria.
2. Field efficiency of SHAKTI is greater than KUBOTA.
3. Slippage for SHAKTI is higher than for KUBOTA.
4. Fuel consumption is higher in KUBOTA (21.79 l ha^{-1}) than SHAKTI (11.19 l ha^{-1}).
5. The use of power tiller has a significant impact on the soil physical conditions for improving the soil conditions for a plausible high rice yield and not the usual deterioration effect of soil compaction often associated with the use of farm machinery on farm fields.

REFERENCES

Allen R.R. and Musick J.T., 1997. Furrow irrigation infiltration with multiple traffic and increased axle mass. Appl. Eng. Agric., 13, 49-53.

Blackwell P.S., Graham J.P., Armstrong J.V., Ward M.A., Howse K.R., Dawson C.J., and Butler A.R., 1986. Compaction of a silt loam soil by wheeled agricultural vehicles: Effects upon soil conditions. Soil Till. Res., 7, 97-116.

Bouwman L.A. and Arts W.B.M., 2000. Effects of soil compaction on the relationships between nematodes, grass production and soil physical properties. Appl. Soil Ecol. ,14, 213-222.

Guérif J., 1984. The influence of water-content gradient and structure anisotropy on soil compressibility. J. Agric. Eng. Res., 29, 367-374.

Horn R., van den Akker J.J.H., and Arvidsson J., 2000. Subsoil compaction: distribution, processes and consequences. Advances in Geoecology, 32, 5-462.

Kathirvel K., Job T.V., and Manian R., 2000. Development and evaluation of power tiller operated ladder. Agric. Mech. Asia, Africa and Latin America, 31(1), 22-27.

Larson W.E., Gupta S.C., and Useche R.A., 1980. Compression of agricultural soils. Soil Sci. Soc. Am. J., 44, 450-457.

Lebert M., Burger N., and Horn R., 1998. Effect of dynamic and static loading on compaction of structured soils. In: Mechanics and Related Processes in Structured Agricultural Soils (Eds W.E. Larson, G.R. Blake, R.P. Allmaras, W.B. Voorhees, S. Gupta). Kluwer Academic Press, Dordrecht, the Netherlands.

Mari G.R. and Ji C., 2008. Effect of small wheel tractor and crawler tractor on soil physical properties. J. Food Agric. Environ., 6(1), 190-194.

Mohanty M., Painuli D.K., and Mandal K.G., 2004. Effect of puddling intensity on temporal variation in soil physical conditions and yield of rice in Vertisol of central India. Soil Till. Res., 76(2), 83-94.

Nakashima K., Oladele O.I., Buri M.M., and Wakatsuki T., 2007. Determinants of farmers participation in sawah projects in Ashanti Region. China Agric. Econ. Rev., 5(4), 488-497.

Wakatsuki T. and Masunaga T., 2005. Ecological engineering for sustainable food production and the restoration of degraded watersheds in tropics of low pH soils: Focus on west Africa. Soil Sci. Plant Nutr., 51(5), 629-636.

Young R.A. and Voorhees W.B., 1982. Soil erosion and runoff from planting to canopy development as influenced by tractor wheel-traffic. Trans. ASAE, 25, 708-712.