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Impact of Soil Compaction on Soil Physical Properties and Physiological Performance of Sweet Potato (*Ipomea batatas* L.)

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ABSTRACT

Sweet potato is the most important food crop after wheat, rice, maize and cassava. Soil compaction degrades soil by altering its structure and aggregate, thereby causing poor plant-water relationship. This study aimed to determine the effect of soil compaction on some soil physical properties and eco-physiological characteristics of sweet potato. Prior to planting and after harvest, soil bulk density and moisture content were determined. For the eco-physiological measurements, the treatments tested were assembled in a factorial combination of three levels of soil compaction as main plots and three varieties in the sub-plots. The treatments were arranged in a split plot design and replicated four times. Gas exchange parameters, leaf area index and chlorophyll content were subsequently determined. The results showed that soil compaction significantly decreased plant chlorophyll content, leaf area index and gas exchange parameters. On tropical sandy loam soils, tilling the soil once was sufficient for optimum emergence and establishment of a sweet potato. Gendut proved to be a tolerant variety, suitable to be planted in environments prone to compaction stress.

Keyword: Bulk density, compaction, physiology, soil and sweet potato.

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is a root crop grown in the tropics and subtropical regions. The crop does best in well-drained sandy loam or loamy soils and does poorly on clay soils especially when flooded (Neduchezhiyan and Raya, 2010). Under water logged conditions, the roots might rot and problems of aeration may

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arise thereby leading to poor plant growth and a significant reduction in yield. Considering the environmental requirements of the crop, Peninsular Malaysia is suitable for the commercial production of this commodity; surprisingly however, sweet potato is being considered among the minor crops in the area (Tan *et al*., 2007).

An ideal soil has sufficient water content, adequate aeration, easy root penetration, good anchorage and is rich enough to provide sufficient nutrients to the plant. Soil is said to be compacted when it undergoes changes owing to alteration of soil structure and soil aggregate. Soil compaction is an abiotic stress that restricts plant growth and is a serious menace globally (Ramazan *et al*., 2012). When soil experiences compression from external forces (farm machinery, farm workers, animals etc.) the distance/volume of the pore spaces becomes reduced (Grzesiak *et al*. 2013). The exerted force then causes an increase in soil density, a phenomenon referred to as soil compaction (Abu-Hamdeh 2003). Advancements in mechanisation and increased usage of chemical fertilisers coupled with heavy rains and intensive cropping practices are the main causes of soil compaction. The consequence is alteration in soil structure, thereby leading to increased soil bulk density, penetration resistance and decreased total porosity, all of which are suggested indices of soil compaction (Håkansson and Lipiec 2000; Abu-Hamdeh 2003; Huang *et al*. 2012).

Soil bulk density (SBD) is a basic physico-chemical characteristic of the soil and this includes soil texture and structure, presence of organic matter etc. Chaudhari *et al*. (2013) reported normal ranges of soil bulk density as 1.0 to 1.6 mg/m^3 and 1.2 to 1.8 mg/m^3 for clay and sand soil particles, respectively and $\geq$ 1.4 mg/m^3 and $\geq$ 1.6 mg/m^3 as potential values capable of restricting root growth in the respective mediums. Sand has been reported to significantly and positively correlate with soil bulk density while clay negatively (Chaudhari *et al*. 2013). Consequent to high levels of compaction, slow seed emergence, poor seedling establishment, thin stands, uneven growth and poor yield in terms of quantity and quality occur in plants (Grzesiak *et al*. 2013).

Limitations in plant growth and physiological performance mainly occur owing to retardation of plant root growth by compaction. Restriction in root growth and penetration and subsequent retarded physiological activities of the plant is attributed to poor plant-water relationship and shoot development. Changes in root architecture under varying levels of compaction are always accompanied by changes in physiological parameters. Leaf water potential (LWP) of maize and triticale has been reported to decrease with increased soil compaction. Water deficit in leaf owing to compaction inhibits various physiological processes. Soil compaction is also responsible for low stomatal conductance and consequently reduced carbon supply. Several studies shown that changes in LWP in response to stress prompt stomatal closure and results in rising LWP and slower transpiration (Cornic and Massacci, 1991; Chen and Weil, 2011; Grzesiak *et al*., 2013). Stomatal closure is responsible for water content in leaf tissue in a short stress period.

However, when stress is prolonged, changes in chlorophyll, chloroplast and in the accumulation and distribution of assimilates occur (Medrano *et al*. 2002).

Advancements in mechanization and increased usage of chemical fertilizers, not only by the large but also small scale farmers, coupled with year-round rains and practice of intensive cropping makes Malaysia more prone to soil compaction problems. This problem therefore indicates the need for continuous soil compaction studies in the area. The effect of soil compaction on bulk density and water content of the soil has been studied but only a few were found in relation to sweet potato production. In Malaysia, there exists, however, quite a few field studies on response of physiological performance of sweet potato varieties to abiotic stress of soil compaction. As research in the management of soil physical properties in sweet potato field is lacking, this study therefore aimed to compare the temporal variation of soil bulk density, and soil moisture content with varying levels of soil compaction and its subsequent influence on physiological performance of sweet potato.

MATERIALS AND METHODS

Experimental Site

An experiment was conducted at Field 15 (L15) and University Agriculture Park (TPU), Universiti Putra Malaysia (UPM). The climate of the area is equatorial in nature, being hot and humid throughout the year. The average annual temperature, relative humidity and rainfall are 27°C, 90% and 250 cm respectively. The prevailing wind patterns are South-east monsoon and North-east monsoon that blow from May to September and November to March and these influence light and heavy rainfall in the areas respectively (Malaysian Meteorology Department, 2016).

Prior to the set-up of the experiment, soil samples were taken from both experimental sites at a depth of 0 to 30 cm before and after land preparation (according to the dictates of the experimental design). A tubular auger was driven manually into the soil by using a hammer. Samples collected were wrapped in plastic bags and taken to the laboratory for analysis. In the laboratory the samples were bulked, air dried, sieved (using 2-mm mesh) and analyzed for its composite (type) and physical and chemical properties using standard procedures as described by Carter (1993).

Prior to sample collection, a tractor (Massey Ferguson 5340 MODEL) was run four times so as to increase the compaction intensity in the experimental sites. Three levels of soil compaction (no till, tilled once and tilled twice) as dictated by the experimental design were performed during land preparation. For purposes of this study, soil bulk density was used as soil compaction index; this was arrived at by decreasing soil mass for the same volume. Hence, tillage was used in modifying and varying the degree of compactness. The treatments were arranged in a completely randomised design with four replications. A total of nine samples were taken at depths of 0-15cm and 15-30 cm per replication i.e. three samples per plot. Unit plot size was 4.8 m x 3 m (14.4 m^2). The samples collected were used in the determination of soil bulk density by using gravimetric method (Materechera *et al*., 1991). The same procedure was repeated after harvest. Soil moisture content was determined by using soil moisture sensor attached to (Eijkelkamp penetrometer 06.15.31) Eielkamp Agricserch Equipment, 6987EM Giesbee. Moisture values were automatically generated from a chart recording on the Eijkelkamp Stiboka penetrograph when the penetrometer was held in a vertical position and pressure was manually applied to the penetrometer handle.

For the eco-physiological measurements, the treatments tested were assembled in a factorial combination of three levels of soil compaction (untilled, tilled once and tilled twice) on three varieties of sweet potatoes (Gendut, Vitato and Kedudut). The treatments were arranged in a split plot design and replicated four times. In these experiments, tillage was used in modifying and varying the degrees of compactness. Photosynthesis, gas exchange rate (carbon dioxide and oxygen) and stomata resistance and conductance were determined using a portable photosynthesis system (LI-6400XT Li-cor, Nebraska, USA). This was done at 9 WAP at a day when the sky was cloud clear. Leaf area index (LAI) was determined by using a plant canopy analyser (LI-COR 2200) that has a probe connected to a meter. For each sampled plant, the probe was held at four locations around it and measurements taken. At same period the chlorophyll content of the leaf was measured using a portable chlorophyll meter (SPAD 502-MINOLTA Inc.). From the sampled plants, two mature leaves were selected and clamped into a hand held probe that gave the estimated values of chlorophyll presence in the plant. The mean values of the physiological measurements were calculated and recorded.

Data Analysis

The generated data from this experiment were subjected to Analysis of Variance (ANOVA) using SAS version 9.4. The mean values were compared using the Least Significant Difference (LSD) test of mean separation at 95% significance level (Gomez and Gomez, 1984). Linear correlations were calculated to determine the existing relationships between the variables.

RESULTS AND DISCUSSION

Soil Compaction and Temporal Variation of Soil Bulk Density (SBD) and Moisture Content

At both sampling periods (before planting and after harvesting) and both locations, the results showed that soil compaction had a significant effect on SBD (Table and 2). It is pertinent to note that there was an increase in SBD with time. Locations subjected to treatments of one and two tilling saw 15.4% and 24.2% decrease in bulk density. The low SBD values (ranging from 1.49 to 1.59 g/cm^3) observed at L15 could be the result of formation of good soil aggregation caused by relatively high (1.85%) organic matter content and a high (80.15%) silt proportion. The higher values of SBD at TPU could possibly be attributed to filling up of pore spaces by migrating clay particles in the soil horizon. The decreased soil bulk density in tilled treated plots as observed in this experiment could be as the result of loosening effect of tillage. This observation is in conformity with Otto *et al.* (2011) and Huang *et al.* (2012) who reported decreased soil bulk density with varying compaction treatments using tillage practices. The increased SBD (ranging from 1.59 to 1.62 g/cm^3) at/after harvest could be the result of frequent rains impacting the soil surface and the movement of the farm workers. The increased compaction was quite obvious as earlier reported by several researchers that a force as low as 1.81 kg/m^2 and trampling of soil by grazing animals in the course of movement can cause significant soil compaction (Maciej, 2009; Adekiya *et al.*, 2011; Ramazan *et al*., 2013).

Soil compaction treatment had a significant effect on soil moisture content (SMC) (Table 2). The SMC at L15 was significantly higher (8.66% and 12.12% before and after planting respectively) than that at TPU. At both locations, it was observed that the SMC of the first sampling period was higher than that of the second sampling period (Table 2). The no till treatments had the highest SMC (ranging from 13.64% to 63.64%) before planting which, however, declined (in the range of 59.46% to 68.35%) at harvest. However, the SMC of tilled once and tilled twice treatments were at par after harvest. The presence of higher soil moisture content prior to planting in no till plots could possibly be due to the protective covering it received from the topmost layer of the soil surface. The upper layer in most cases is dry soil with low conductivity and hence, capable of reducing evaporation losses (Adekiya *et al.*, 2011). Unlike the tilled soils which were exposed to evaporation losses, the no till plots had their organic matter intact on the soil surface and thus acted as mulch by reducing evaporation losses. However, the decrease in soil moisture content values in no till plots, at/after harvest could be due to moisture uptake by the growing crop, coupled with slow infiltration of water into the soil to replace the quantity already absorbed by the

TABLE 1
Pysico-chemical properties of the experimental sites at UPM, Serdang, Selangor, Malaysia

	Location	
Location	Ladang 15	TPU
Properties		
Sand (%)	34.5 ± 0.42b	71.1 ± 1.06a
Silt (%)	15.23 ± 0.38b	17.83 ± 0.34a
Clay (%)	50.54 ± 1.03a	10.03 ± 0.03b
PH	4.67 ± 0.02a	5.20 ± 0.02a
Organic matter content	1.51 ± 0.02a	1.50 ± 0.02a
Carbon (%)	1.38 ± 0.02a	1.40 ± 0.01a
Nitrogen (%)	0.13 ± 0.06a	0.10 ± 0.04b
Phosphorus (µg/g)	8.3a ± 0.19	18.13 ± 0.07b
Potassium (µg/g)	41.27 ± 1.62a	28.74 ± 0.94b
Calcium (µg/g)	26.82 ± 1.12b	62.52 ± 0.88a

Note: Means with similar letters are not significantly different (p<0.05);
NS = not significant at p (0.005)

TABLE 2
Temporal variation of soil bulk density and moisture content with compaction at L15 and TPU, UPM, Sri Serdang, Selangor, Malaysia

		Location					
Parameter	Treatment	Ladang 15		TPU		Combined	
		Before planting	After harvest	Before planting	After harvest	Before planting	After harvest
Soil bulk density	Location(L)						
	Ladang 15					1.30b	1.39b
	TPU					1.35a	1.44a
	P-value					0.0246	0.0001
	No till	1.49a	1.59a	1.50a	1.62a	1.50a	1.61a
	Tilled once	1.28b	1.34b	1.33b	1.44b	1.31b	1.39b
	Tilled twice	1.14c	1.23c	1.21c	1.25c	1.17c	1.24c
	P-value	≤0.0001	≤0.0001	≤0.0001	≤0.0001	≤0.0001	0.0137
	SE	±0.10	±0.11	±0.08	±0.11	±0.10	±0.11
	(L*T)					0.2978	0.1447
	CV (%)	3.01	2.20	3.68	2.52	3.27	3.005
Soil moisture content							
	Ladang 15					31.75a	33a
	TPU					29.00b	29b
	P-value					0.0482	0.0123
	No till	44.00a	15.50b	39.00a	12.50c	42.00a	14.0b
	Tilled once	38.00b	37.00a	32.00b	34.75b	35.00b	35.88a
	Tilled twice	16.00c	42.75a	15.00c	39.5a	16.00c	14.25b
	P-value	≤0.0001	0.0001	≤0.0001	0.0001	≤0.0001	0.0001
	SE	±8.51	±8.29	±7.13	±8.32	±7.77	±7.25
	(L*T)					0.5216	0.9628
	CV (%)	11.19	12.59	8.41	8.488	10.31	9.63

Note: Means with similar letters are not significantly different ($p<0.05$); NS = not significant at p (0.005)

plant owing to compaction pressure. The reduction in soil moisture content on tilled plots before planting could possibly be attributed to exposure of the soil to evaporation activities. The rapid moisture loss could be due to the resultant increase in turbulent movement of atmospheric air into the soil (Ojeniyi and Dexter, 1979).

Effect of Soil Compaction and Variety on Physiological Characteristics of Sweet Potato

This study showed that soil compaction had a significant effect on the entire observed physiological characters of sweet potato. At TPU, the net photosynthetic rate (NPR) and chlorophyll content were significantly reduced, ranging from 6.52%

to 16.31% and 30.29% to 57.45% with increased soil compaction respectively; whereas transpiration rate increased (Table 3). Water vapour potential decreased significantly (ranging from 35.58% to 36.79%) owing to an increased level of compaction; however, this was only at L15 (Table 4). At both locations, soil compaction had a significant effect on stomata conductance and LAI (Tables 3 and 4 respectively). These were reduced in the range of 12.50% to 36.79% and 22.93% to 24.34% respectively. Transpiration rate was however, significantly decreased (from 5.50% to 12.67%) with increased soil compaction. The decrease in NPR could be associated with reduced carbon supply due to a decrease in stomata conductance and decreased transpiration (Tun and Tan,1988). Reduced moisture supply affects LAI negatively and this could be another reason for lower NPR. The lower chlorophyll content observed could be due to lower uptake of nitrogen in the soil horizon by the restricted roots. Decreased chlorophyll might be one of the factors responsible for the observed decrease in NPR. Insufficient chlorophyll has been earlier reported (Liu, 2011; Kobaissi *et al*., 2013) to limit the photosynthetic potentials of a plant. From the correlation studies, it was observed that soil compaction had a strong but negative relationship with leaf area index (-0.92), chlorophyll content (-0.95), water vapour potential (-0.90), NPR (-0.46) and stomata conductance (-0.45) (Table 5). The observed decrease in these parameters could subsequently affect plant productivity negatively. However, soil compaction and transpiration rate correlated positively (Table 5). This implies that transpiration rate tends to increase with increased soil compaction. Despite the fact that photosynthesis and stomatal conductance declined with increased soil compaction, they had no significant relationship with compaction in the soil (Table 5). Contrary to this finding, Kobaissi *et al.* (2013) observed a strong relationship between soil compaction on one hand and photosynthesis and stomatal conductance on the other. However, this was in crops other than sweet potato and on soils with higher values of SBD than our experimental sites.

Plant variety had a significant effect on NPR, LAI (Table 3), WVP and chlorophyll content (Table 4). The highest and the lowest mean values of NPR and LAI were observed in Gendut and Kedudut respectively. Gendut could possibly perform better than Kedudut due to higher values of LAI and NPR. Vitato, however, had the highest mean chlorophyll content. The effects of variety on stomatal conductance and TR were, however, not significant at both locations (Table 4). This indicates that the ability of carbon uptake and maintenance of the leaf water potential of the tested varieties are similar. However, there was no significant interaction effect between soil compaction and variety on chlorophyll content, stomatal conductance and transpiration rate (Tables 3 and 4 respectively). On the other hand, there was a significant interaction effect between soil compaction and variety on NPR and LAI at only TPU (Table 3 and 4, respectively). At L15, however, soil compaction and variety had a significant interaction effect on water vapour potential (Table 4). This means that the performance of the observed characteristics were a result of the combined effect between soil compaction and varietal treatments.

TABLE 3
Effect of soil compaction and variety on photosynthesis, stomatal conductance and transpiration rate of three varieties of sweet potato at L15 and TPU, UPM, Sri Serdang, Selangor, Malaysia

Parameters	Photosynthesis			Stomatal conductance			Transpiration rate		
Location	L15	TPU	Combined	L15	TPU	Combined	L15	TPU	Combined
L15			24.28a			0.93			4.70
TPU			15.71b			1.26			5.64
P-value			0.0020			0.2520			0.1150
LSD			0.403			NS			NS
SE			±4.29			±0.93			±0.47
Tillage(T)									
No till	23.73	14.34c	19.07b	0.67b	0.98b	1.09	4.73	6.00a	5.20
Tilled once	25.64	17.14a	20.49a	1.06a	1.38a	1.17	4.83	5.67a	5.14
Tilled twice	23.47	15.34b	20.44a	1.04a	1.12a	1.03	4.54	5.24b	5.17
P-Value	0.1225	≤0.0001	0.0126	≤.0001	0.0535	0.6393	0.6132	0.0516	0.9786
LSD	NS	0.03	1.04	0.05	0.09	NS	NS	0.57	NS
SE	±0.68	±0.82	±0.47	±0.13	±0.12	±0.04	±0.09	±0.22	±0.02
Variety (V)									
Gendut	23.18b	16.97a	20.08a	1.23	0.89	1.13ab	5.47	4.58	5.20
Kedudut	26.36a	15.62b	20.99a	1.11	0.86	1.27a	5.76	4.93	5.41
Vitato	23.30b	14.54c	18.92b	1.22	0.93	0.88b	5.69	4.58	4.89
P-Value	0.0088	≤.0001	0.0011	0.0569	0.4234	0.0312	0.1672	0.3211	0.2458
SE	±1.06	±0.70	±0.33	±0.04	±0.02	±0.04	±0.09	±0.12	±0.15
LSD	2.15	0.03	1.04	NS	NS	0.32	NS	NS	NS
T*V									
p-value	0.1598	≤0.0001	≤0.0001	0.3605	0.3489	0.0997	0.2542	0.1762	0.6830
LSD	NS	*	NS	NS	NS	NS	NS	NS	NS
CV (%)	10.32	0.20	8.86	16.87	17.74	45.44	12.51	52.90	20.44

Note: Means with similar letters are not significantly different (p<0.05); NS = not significant at p (0.005)

TABLE 4

Effect of soil compaction and variety on water vapour potential, leaf area index and chlorophyll of three varieties of sweet potato at L15 and TPU, UPM, Sri Serdang, Selangor, Malaysia

Parameters	Water vapour potential			Leaf Area Index			Chlorophyll content		
Location	L15	TPU	Combined	L15	TPU	Combined	L15	TPU	combined
L15			0.50b			8.33a			24.75
TPU			0.76a			6.49b			25.92
P-value			0.0063			≤0.0001			0.5617
LSD			0.13			0.34			NS
SE			±0.13			±0.92			±0.59
Tillage(T)									
No till	0.67b	1.21	0.67	6.87b	5.41b	6.14b	18.67	16.25b	17.46c
Tilled once	1.06a	1.47	0.56	9.06a	7.03a	8.04a	26.54	23.31b	24.92b
Tilled twice	1.04a	1.09	0.66	9.08a	7.02a	8.05a	29.05	38.19a	33.62a
P-Value	≤.0001	0.3489	0.0717	0.0003	0.0042	≤.0001	0.0722	0.0130	0.0009
LSD	0.05	NS	NS	0.66	0.82	0.47	NS	12.41	6.86
SE	±0.13	±0.11	±0.04	±0.73	±0.54	±0.64	±3.13	±6.47	±4.67
Variety **(V)**									
Gendut	0.98a	1.21	0.66ab	8.72a	7.12a	7.92a	24.40a	28.50a	27.45a
Kedudut	0.93a	1.35	0.56b	7.77b	5.28b	6.53b	20.19b	20.46b	20.33b
Vitato	0.86b	1.21	0.68a	8.50a	7.07a	7.78a	27.67a	28.78a	28.23a
P-Value	0.0424	0.8457	0.0544	0.0023	≤0.0001	≤0.0001	0.0037	≤0.0001	≤0.0001
LSD	0.10	NS	0.11	0.50	0.22	0.26	4.28	3.27	2.60
SE	±0.03	±0.05	±0.04	±0.29	±0.61	±0.44	±2.16	±2.73	±2.51
T*V									
p-value	≤.0001	0.4554	0.3617	0.4407	0.0299	0.2402	0.7868	0.2638	0.3227
LSD	*	NS	NS	NS	*	NS	NS	NS	NS
CV (%)	12.51	52.90	27.05	7.02	3.93	6.09	20.15	14.72	17.53

Note: Means with similar letters are not significantly different ($p<0.05$); NS = not significant at p (0.005)

TABLE 5

Correlation coefficient between soil compaction and physiological characteristics of three varieties of sweet potato at L15 and TPU fields, Universiti Putra Malaysia

	Soil bulk density	Photosynthesis rate	Stomatal conductance	Transpiration Rate	Water vapour potential	Leaf area index	Chlorophyll content
Soil bulk Density	1						
Photosynthesis Rate	-0.457*						
Stomatal Conductance	-0.450*	0.999**	1				
Transpiration rate	0.982**	-0.280NS	-0.273NS	1			
Water vapor potential	-0.899**	0.801**	0.796**	-0.799**	1		
Leaf area index	-0.920**	0.770**	0.765**	-0.828**	0.998**	1	
Chlorophyll content	-0.950**	0.157NS	0.148NS	-0.992**	0.716**	0.750**	1

Note: * and ** correlate at p<0.05 and p< 0.01 respectively

CONCLUSION

As the soil at TPU was more compacted and drier, it had higher mechanical impedance than that of L15. Tilled treated plots did not only reduce soil compaction but also promoted good root penetration and water infiltration rates within the pore particles. The physiological performance of sweet potato was adversely influenced by soil compaction. However, the effect was not consistent with varieties. The Gendut variety had the highest ability to adapt to compacted soils. In order to promote good crop establishment, there is therefore a need to carry out tillage on agricultural lands before planting. On tropical sandy loam soils, tilling the soil once is sufficient for optimum emergence and establishment. Gendut which proved to be a better tolerant variety should be planted in environments prone to compaction stress.

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