Plastic Responses of Sweet Potato (*Ipomeabatatas L.*) Root Anatomy in Compacted Soil Conditions

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Abstract-The response of crops to abiotic stress largely depends on its root system architecture since the root is the first to sense abiotic stress prevailing in the soil media. This study was conducted to investigate the effect of soil compaction on the anatomy of sweet potato roots. A field experiment was conducted in March 2017. The treatments used consisted of three compaction levels (no-till, tilled once and tilled twice) and three varieties (Gendut, Kedudut, and Vitato). The treatments were in factorial combination; arranged in a split-plot design and replicated four times. Sampled roots were viewed under a binocular microscope (Olympus BCH) for anatomical studies. The collected data were subjected to analysis of variance (ANOVA) to determine the effect of the treatments and their interactions; using the general linear model; SAS software version 9.4. Differences among treatment means were compared using the least significant difference (LSD) at $p \leq 0.05$. Results obtained, indicated cortex and root xylem diameters, root proliferation was decreased with increased compaction but root lignification was increased. Root structure was also influenced by varietal variation. However, the effect was not constant with varieties. In all the observed characters Kedudut and Gendut had the least and the highest mean values respectively. Gendut variety showed the highest ability to adapt to compacted soil. The decrease in anatomical features could lead to a decrease in yield as a result of possible restrictions in the uptake of soil water and nutrients.

Keywords - Root anatomy, Root development, Soil compaction, Sweet potato.

I. INTRODUCTION

The root is a plant organ that differs in structure and functions; and is found in close contact with growth media [1]. Root ensures plant productivity through the uptake of soil resources. Growing roots are capable of sensing and responding to the particular stimulus which is in most cases induced by physical, chemical, and biological factors in the soil media [2]. The resultant response varies with time, environment, and genotype. The resource use efficiency of most crops including sweet potato could be improved through the understanding of root development[3]. Root varies greatly between species and between individuals of any particular genotypes [2] [4] and has high plasticity response to environmental conditions such as soil compaction, nutrient, water, and oxygen availability [5] [6] [7] [8] [9]. Sweet potato root consists of structural features. These features show great modifications when encountered with environmental stress. This will lead to reduced water and nutrient uptake [10]. As the result, the plant nutrient utilization efficiency is reduced and consequent to this; is the lowering of the plant productivity.

Soil compaction is a structural degradation of the soils where the sizes and shapes of the soil pores are altered thereby leading to a decrease in soil macropores and an increase in both soil bulk density and soil strength [11] [3]. Root growth, development, and extension are inhibited in compacted soils [12]. Thereby resulting in poor root penetration and the emergence of a shallow root system. Plants when confronted with hard surfaces; also have to expend more energy for root growth [13], thereby; the available energy needed for other growth and developmental processes becomes altered. Consequent to these effects, moisture, and nutrients might be in short supply and thus the plants become stressed and stunted.

Compacted soils with high strength may limit root growth through a large mechanical resistance to root growth and development. The roots in turn respond to mechanical impedance by slowing down the process of root extension per given time and increasing the diameter rates at a location behind the root tip [14]. In potato, the roots were found restricted at a shallower depth and were unable to penetrate deeply with an increased degree of soil compaction [15].
The production of sweet potato *(Ipomoea batatas*) covers all major regions of the world (tropics and subtropics). Sweet potato is important in the human diet in terms of its contribution to body nutritional requirements. It also contributes to industrial sustainability and in livestock production. It ranks 5th as the most important food crop after wheat, rice maize, and cassava [16] and 2nd after cassava among root and tuber crops [17]. Malaysia is ranked 56th among sweet potato producers worldwide this is because the crop is considered as a minor in the country, however, it is one of the popular cash crops grown by the small-scale peasant farmers for the fresh market [18]. There exist over 20 different varieties of sweet potato in Malaysia [19] both local and improved.

Root growth and performance have been extensively studied in: maize [20] [11] [21], sugarcane[21] barley [24] and carrot [25] [26]. However, studies related to this issue are scarce in sweet potato [27]. [28] and [29] provided statistical evidence showing none existence of literature relating to sweet potato root anatomy. The few studies so far conducted on sweet potato roots were mostly done in pots.For a more realistic approach, there is a need to carry out such experiments on the field; to depict the real situation prevailing within the soil environment. The usage of heavy agricultural implements and chemical fertilizers in farm operations coupled with heavy rainfall and the practice of continuous cropping makes the soil in peninsular Malaysia prone to degradation and increased compaction and hence the need to study this environmental menace. It is therefore the objective of this study was to investigate the anatomical responses of sweet potato roots, under compacted soil conditions.

II. MATERIALS AND METHODS

A field experiment was conducted at Ladang 15; Teaching and Research Farm of University Putra Malaysia (UPM). The site is approximately located at $2^{0}99'13.16''N$ and $101^{0}73'34.55''E$ and 32m above sea level. The climate of the area is equatorial, being hot and humid throughout the year. The average annual temperature, relative humidity and rainfall are: 27^{0}C, 90%, and 250cm respectively. The prevailing wind patterns are southeast monsoon and the northeast monsoon that blow from May-September and November-March and these influence light and heavy rainfall in the area respectively [30].

Before the setup of the experiment, soil samples were taken randomly from the experimental plots, with a tubular auger at the depth of 0-30cm. The collected samples were; bulked, air-dried, sieved (using 2 mm mesh), and analyzed for composite (type) and physicochemical properties using the standard procedure as described by [31]. Penetration resistance and soil moisture content at 10 cm depth were measured using a chart recording Eijkelkamp Stiboka penetrograph with a 1-cm^2 cone ('Cone 1' 60° top angle, and 8-mm-diameter shaft) used by the manufacturer's (Eijkkelkamp Agricserch Equipment, 6987 EM Giesbee, Netherland) recommendations. The penetrometer was inserted to 30 cm.

Three sweet potato varieties (Gendut, Vitato, and Kedudut) that varied genetically and are popularly produced amongst the sweet potato farmers in the study area were used. The treatments tested were in factorial combination of three levels of soil compaction (untilled = NT, tilled once = T1 and tilled twice = T2) and three varieties (Gendut, Vitato, and Kedudut). The treatments were arranged in a split-plot design with tillage as the main plot and variety in subplot and replicated four times. In each of the experimental plots ($15m^2$), three plants were randomly tagged and picked to record observations. Root samples were obtained destructively by the excavation of soil cores using Shovelomics technic as described by [32] and [33] using hand trowel and spades. After thorough washing of the sampled roots using a bucket, sieve mesh, and hosepipe; each plant sample was dissected into roots, stems, and leaves. The washed roots were then stored in a refrigerator at 3^oC to reduce root respiration before the commencement of anatomical and morphological analysis.

Sampled roots for anatomical studies were placed in distilled water and sectioned. Transverse sections of about 15µm were done with a razor blade. The sectioned samples were stained with toluidine blue solution for about a minute as described by [34]. To reduce the excesses of the colorant, the samples were rinsed in water. The stained samples were then put on glass slides and viewed under a binocular microscope (Olympus BCH). Data on the following variables were observed and recorded: protoxylem element number, the diameter of the xylem vessels, the thickness of the cortex, and the presence of lignin.

The collected data were subjected to analysis of variance (ANOVA) to determine the effect of the treatments and their interactions; using the general linear model SAS software version 9.4. Differences among treatment means were compared using the least significant difference (LSD) at $p \leq 0.05$.

III. RESULTS AND DISCUSSION

3.1 Effect of tillage

Results on Table 1 showed that soil compaction had a significant effect on root xylem diameter, the thickness of the root cortex, and the number of lignified roots. However, it had no significant effect on the number of protoxylem elements having five or more xylem poles. The smallest xylem (4.74%) and root cortex diameter (0.68%) values were obtained from NT treatment. But, the highest number of lignified roots (42.93%) was obtained from NT treated plots. The largest xylem (39.42%) and root cortex diameter (27.82%) values and the least number of lignified roots (17.44) were, however, obtained with T1 treatment. NT treatment did not differ significantly with T2 treatments in all the observed parameters (Table 1). Correlation studies showed that; an increase in soil compaction index (bulk density) resulted in a significant increase (0.94) in the number of lignified roots. However, soil compaction had a negative but weak correlation with root xylem diameter and thickness of the root cortex (-0.15 and -0.18 respectively) (Table 2). The decrease in the sizes of these anatomical features may probably lead to a corresponding decrease in hydraulic conductivity of the xylem vessels and also, reduced carbohydrate storage capacity of the cortex. This may probably lead to; reduced plant growth as the result of hindrances in hydraulic conductivity and possibly, poor yield; owing to the low storage capacity of the cortex. In agreement with this finding, [35] reported a decrease in the cortex and root xylem diameter in more compacted soils when working with *Fraxinus Angustifolia (*Vahl) seedlings. An increase in soil compaction led to a significant increase in the number of lignified roots. The lignification process in root renders the root unable to develop into a storage root [36] and therefore, this is an indicator that the more the roots become lignified, the more the yield potential is reduced. The influence of soil compaction on the protoxylem element number was however not significant (Table 1). This trait could probably remain unaffected by an external stimulus; or possibly, the degree of compaction within the soil is quite insufficient to introduce changes, in growth and developmental pattern of protoxylem element number.

3.2 Effect of variety

Variety had a significant effect on root xylem diameter, the thickness of the root cortex, protoxylem element with five or more xylem pole numbers, and the number of lignified roots (Table 1). Gendut had the highest mean xylem diameter (31.33%), the thickness of the cortex (49.22%), and protoxylem element number (39%). However, it had the least number of lignified roots (29.17%). In contrast, Kedudut had the least means for xylem diameter (16.69%), the thickness of the root cortex (27.62%), and protoxylem element number (8.12) having five or more poles but it had the highest number (50.93%) of lignified roots. Vitato on the other hand differed significantly with both Gendut and Kedudut in all characters except the number of lignified roots: where it was at par with Kedudut. The largest mean diameters of root cortex and root xylem observed in the Gendut variety signified that Gendut may probably have better hydraulic conductivity and larger storage capacity and hence, may have greater yield potentials than Kedudut which had the least mean thickness of both cortex and xylem. Roots having five or more protoxylem element numbers are often associated with the possibilities of developing into storage roots [23] [36] and hence a variety (such as Gendut) having a higher number of roots with five or more protoxylem element is expected to give a higher yield than Kedudut. The lignification process in roots, tends to prevent the roots from developing into storage roots [36] and thus a variety such as Kedudut that had a higher number of lignified roots may tend to promote lower yield production. This confirmed earlier findings [23] [36] that reported the significant influence of variety on protoxylem element number and presence and distribution of lignified roots in different varieties of the sweet potato crop.

Table 1. Effect of soil compaction and variety on: Root xylem diameter, Protoxylem element number, Thickness of the cortex, and Number of lignified roots on sweet potato at UPM

Treatment	**Xylem diameter**	**Protoxylem element number**	**Thickness of the cortex**	**Number of lignified roots**
Tillage (T)				
No-till (NT)	**119.76b**	**2.58**	**152.34b**	**1.98a**
Tilled once (T1)	**196.35a**	**2.55**	**210.54a**	**1.13b**
Tilled twice (T2)	**18.95b**	**2.59**	**154.11b**	**1.81a**
LSD	**9.32**	**NS**	**1.78**	**0.44**
P-value	**≤0.0001**	**0.0082**	**≤0.0001**	**0.0305**
Variety (V)				
Gendut	**162.02a**	**3.00a**	**191.65a**	**1.58b**
Kedudut	**124.09c**	**1.83c**	**140.17c**	**3.24a**
Vitato	**148.92b**	**2.75b**	**185.17b**	**3.09a**
LSD	**5.54**	**0.21**	**1.75**	**0.54**
P-value	**≤0.0001**	**≤0.0001**	**≤0.0001**	**0.0424**
T*V	**1042.35**	**0.03**	**361.45**	**0.51**
LSD	**NS**	**NS**	**1.76**	**NS**
P-value	**≤0.0001**	**0.8551**	**≤0.0001**	**0.6463**
CV (%)	**4.45**	**16.59**	**1.18**	**11.23**

Table 2. The correlation coefficient between soil compaction and anatomical characteristics of sweet potato root

	SBD	***RXD***	***TRCOT***	***LIG. ROOT***
SBD	**1**			
RXD	**-0.11ns**	**1**		
TRCOT	**-0.15ns**	**0.99****	**1**	
LIG. ROOT	**0.95****	**0.20ns**	**0.15ns**	**1**

Note: SBD = Soil bulk density, RXD = Root xylem diameter, TRCOT = Thickness of root cortex, LIG.ROOT = Lignified roots

3.3 Interaction effect between tillage and variety

Interaction between soil compaction and variety on the root cortex was also significant (p=0.05) (Table 1). All varieties showed thicker and thinner root cortexes with T1 and NT treatments respectively. The thickest root cortex was obtained from the combination of Gendut and T1 treatments. In contrast, Kedudut when combined with NT treatment produced the thinnest root cortexes. It is interesting to note that both Vitato and Kedudut at T1 treatment had larger root cortexes than Gendut under T2 treatment; even though, the variety Gendut had the thickest root cortex as shown on (Figure 1).

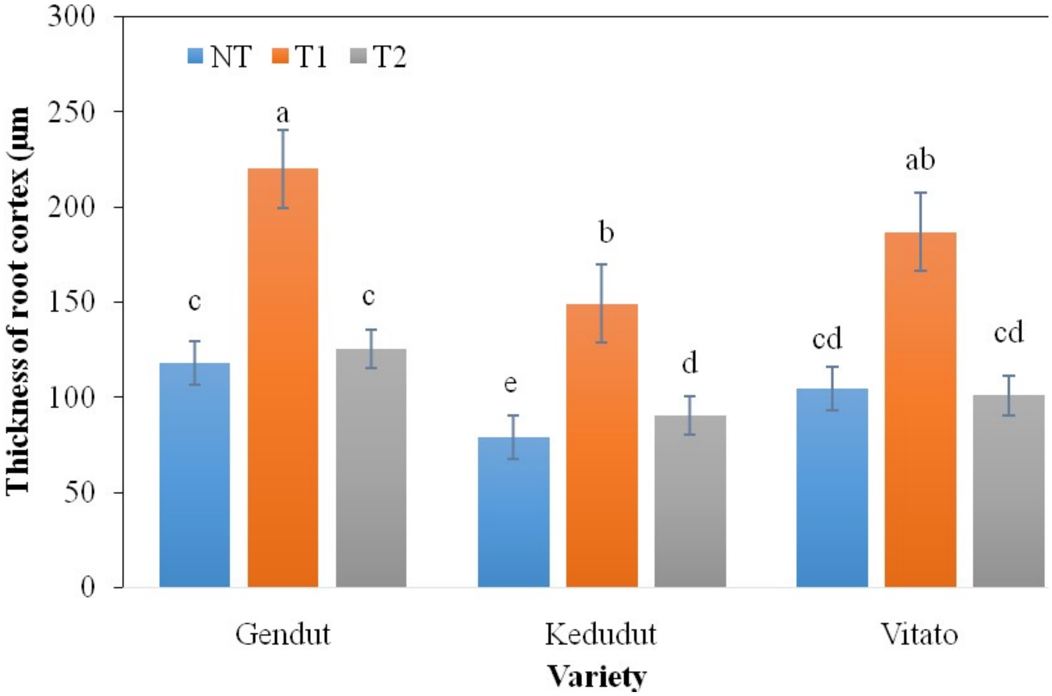

Figure 1. Interaction between soil compaction and variety on the thickness of sweet potato root cortex. Note: NT= No Tilled, T1 = Tilled Once and T2 = Tilled Twice.

IV. CONCLUSION / RECOMMENDATION

Environmental stress resulting from soil compaction adversely influenced the structural performance of sweet potato roots; by decreasing resource capture potentiality of the crop. However, the intensity of the effect varied with the type of variety and the degree of soil compaction. The more the soil becomes impended, the more the root traits underwent diminishing changes in growth patterns and development. In this study, however, moderately compacted soil (T1) tends to promote better root development than the high and less compacted treatments. Gendut variety had the highest potentials to adapt to compacted soils; having the highest mean xylem diameter, the thickness of the cortex, protoxylem element number, and the least number of lignified roots. A single tillage operation is adequate; to overcome soil compaction menace and Gendut exhibited promising traits for better performance in the study area. However, there is a need for further research to vindicate this assertion.

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