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The Longitudinal Tensile Strength Properties of Roots of Sorghum bicolour an important Grain Cereal of Botswana and semi-arid to arid regions of the World

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Abstract

The study was carried out to determine the longitudinal ultimate tensile strength (uprooting force) of the roots of sorghum bicolor, an important staple food in the semi-arid to arid parts of the world. The mean ultimate tensile strength of the sorghum roots was 893N. Different varieties namely Prime silo, Mundy, Mr-Buster-Thiram and Birdgo had varying ultimate root tensile strengths. The ultimate tensile strength of variety Prime silo of 1323N was significantly higher than those of Birdgo and Buster-Thiram at 511N and 725N respectively. Mundy at 1013 N was not significantly different from Prime-Silo or Mr Buster Thiram, however it was significantly stronger than Birdgo. The soil moisture condition has no effect in the ultimate tensile strength of the sorghum roots.

Keywords: Ultimate tensile strength, roots, sorghum and Botswana.

Introduction

Sorghum bicolor is a species of sorghum genus of the Andropogoneae family in the plant kingdom[1], is a monocotyledon originating from Africa[2], and it is related to sugar cane and maize[3]. Sorghum has a well-developed and extensive rooting system[2] with a lateral reach of 1m and a depth of up to 2m[4]. The rooting systems make the plant well-adapted to arid areas with limited soil moisture compared to the other four important cereals, namely wheat, rice, maize and barley, by having a more efficient water usage[5-7]. Water use efficiency enablessorghum to produce more yields than maize[10]in arid areas of the world with limited soil moisture or no irrigation[8,9]. Sorghum is cultivated in areas that are prone to low precipitation[11] where other cereals are not grown unless with supplemental irrigation. Furthermore, sorghum is the main staple cereal crop of semi-arid Botswana[11]. It can also be used to replace maize as beef and poultry feed[12,13] and as fibre and fuel[9].

Information on physical and mechanical properties of crops is important in the successful design of machinery used for various process of the crop. Lack of studies into unique properties of each crop leads to the adaptation and use of machinery developed for other crops which may not be suitable for the crop of interest. So far the available literature indicates does not provide any information on longitudinal tensile properties of the sorghum crop. Most studies on biomechanical properties concentrated on shear, compression and bending which are important for forage harvesting[14]. This lack of information can hinder the proper development of machinery needed for process like harvesting of field crops. Therefore availability and understanding of biomechanical properties of crops is important to engineers for various reasons, like in developing and operating harvesting and processing systems.

During the process of stripping grains from the head of the sorghum plant, the whole plant is subjected to pulling effect or longitudinal tensile forces acting along the longitudinal axis of the plant. The upward motion of the stripping fingers at the panicle exerts an upwards force at the panicle and the roots/soil bond will transfer the force to the ground and providing opposite and equal force to the stripping force. This opposite and equal force system is maintained until part of the plant fails. Since tensile strength is the capability of the given material to support a pulling force along its longitudinal axis. Therefore, by extension the maximum tensile strength is the ability to support the maximum pulling load possible, and it is obtained at yield or breaking point. The findings can be used to aid in the decision making in the use of stripping harvesting mechanism in harvesting sorghum. The objectives of this study were therefore to determine the magnitude of the longitudinal ultimate tensile strengths (UTS) of the sorghum roots.

Material and Methods

Crop availability: Seeds of the four sorghum varieties used in this experiment were sourced from the UK seed suppliers. These varieties were Birdgo, Mr Buster-Thiram, Mundy and Prime Silo, and were the only that were available from the suppliers in the UK. A pot experiment was conducted inside the glasshouses at Harper Adams University. The experiment was laid out in a completely randomised block design. The plants were grown in four blocks of twenty plants each. Each variety had five plants grown in sandy loam (80%) mixed with commercial compost (20%) volume basis per block. The use of compost was to alleviate the collapse of the sandy loam during the growing period. A total of 80 plants were used in this study. The crops were harvested at full maturity. The laboratory studies were carried out at Harper Adams University, Shropshire, UK.

Sorghum roots tensile strength: A sorghum stump of 200mm in height was necessary for attaching the plant roots to the machine. The tests were conducted on sandy loam soils at field capacity (17% moisture content (m.c.)) and at dry soil (2% m.c.) wet basis. The testing of soil at dry soil moisture level was because these are the normal soil conditions during harvesting in Botswana. Testing of roots strength at field capacity was to anticipate conditions where harvesting is carried out at high soil moisture content after a recent rain or higher ground water level causing unfavourable high soil moisture conditions. Samples were left to air dry for five weeks while other experiments (stripping and stem break) were being conducted. At the end of a five week period samples for field capacity testing were watered and left to drain freely for 48 hours to stabilise to an approximate field capacity moisture content level. The soil moisture content was determined using the oven method.

An Avery tensile strength testing machine (of Type A806/1474, Machine number-E43258-212, patent number 537933) was used. However the resolution of the Avery machine mentioned above was not sufficiently accurate to determine the root tensile strength. Hence a load cell from a strain gauged Wheat-stone bridge circuit (Figure-1) was made. The Wheatstone bridge circuit voltage signal output was used to determine the force required to uproot the sorghum roots. The wheat-stone bridge was made and calibrated by hanging steel weights of known mass on the copper tube with strain gauges attached in series. The voltage signal outputs corresponding to the known mass were obtained through computer software and used to plot the calibration curve of mass as independent variable. The signal conditioning was provided by a measurements group 2120A amplifier. The bridge excitation setting was 5V and a gain of 1000.

The voltage obtained was plotted against the weight to get the relationship (Figure-2) The relation obtained was later used to convert the voltage output of the Wheat-stone bridge into the force required to uproot the sorghum stump termed uprooting force or "ultimate tensile strength of the roots" by the following equation**:** $y = 0.0032\ x + 0.0015$ where y is the signal output in volts and x is the force applied to the Wheatstone bridge system in N. The $R^2 = 0.9979$ ($R = 0.9989$) shows that the relationship is close to linear and can be used to give accurate results.

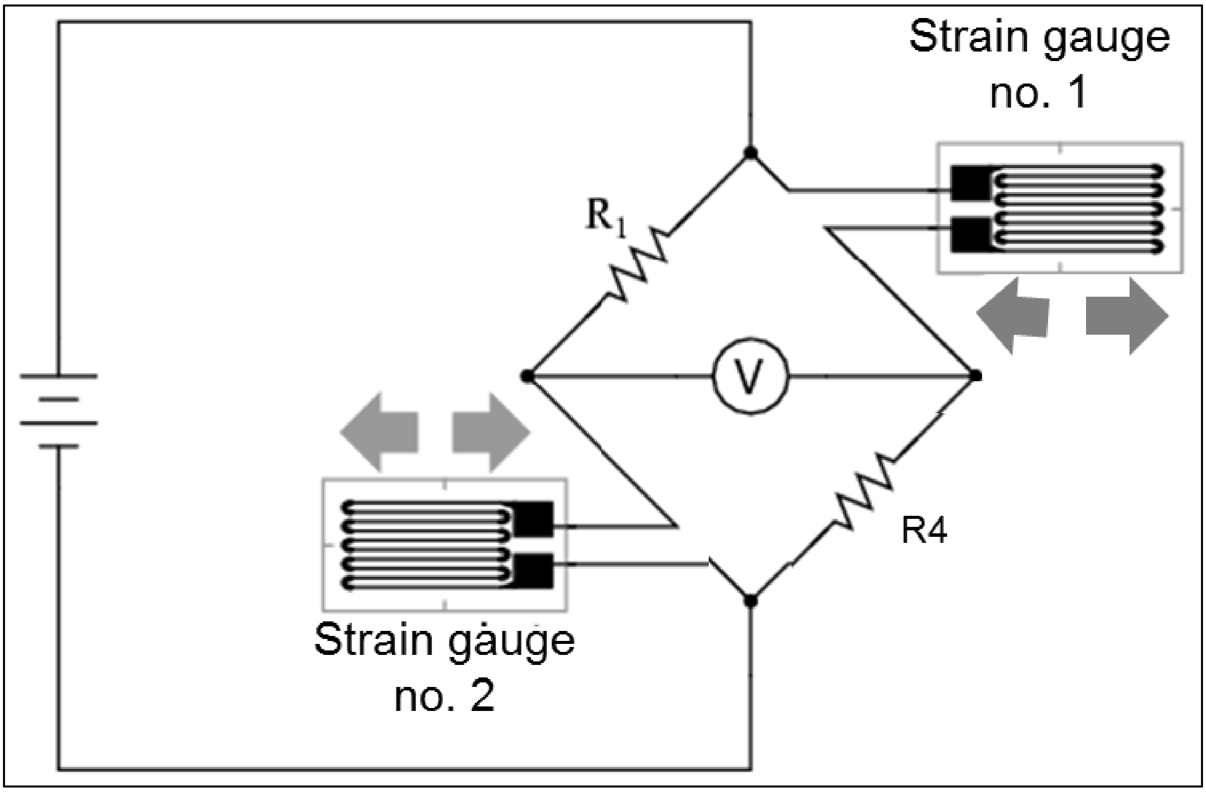

Figure-1
Half-bridge strain gauge used to obtain voltage signals for uprooting force

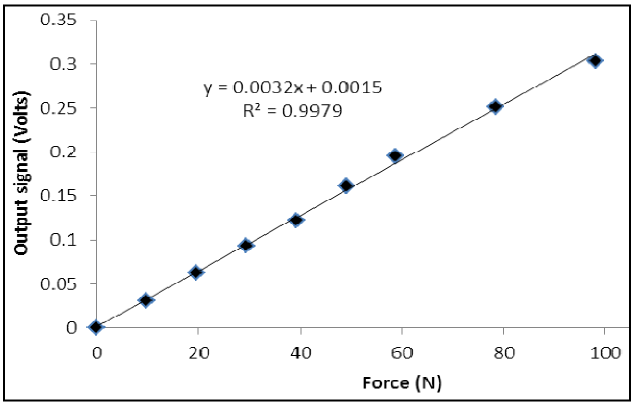

Figure-2
Calibration curve for relation between force/weight(N) and output voltage signal of the wheat-stone bridge

The sorghum stump in the potted soil was attached to the sample gripper. The sample gripper was attached to the sorghum stump on one end and on to the strain-gauge on the other end by means of pin joints (figure-3). The strain gauge was then pin joint connected to the tensile strength machine to supply the pulling power needed to uproot the stem out of the soil.

After the roots reached breaking/yielding points (figure-5) the machine was stopped and the failure characteristics data obtained. Due to the lightweight of the potted soil used to grow each plant the whole soil had a tendency to be uplifted. To avoid the uplifting of the roots together with the soil and pot a wooden collar was used to hold down the soil around the stem during the pulling as in figure-4, with care taken to avoid intrusion into the root zone.

Data analysis: Data were checked for normality and transformed when required and then subjected to analysis of variance (ANOVA) in Genst at using Tukey's multiple range test. A single factor ANOVA set at asignificance of P=0.05 was used to compare the ultimate tensile strength of the roots. Differences in ultimate tensile strength of the roots were indicated using standard errors of means.

Results and Discussion

Effect of Sorghum varieties on the mean roots tensile strength: The overall effect of the sorghum variety on the anchorage strength of the sorghum roots was highly significant ($p < 0.001$) (figure-6). This is because root characteristics tend to be variety specific[15]. The magnitude of the root ultimate tensile strength of the Prime Silo variety recorded at 1323 N was significantly greater than those of Birdgo (511 N) and Mr Buster Thiram (725 N), showing that the Prime-Silo variety has the strongest rooting system compared to other varieties. The mean ultimate root tensile strengths of varieties Prime-Silo and Mundy (1013 N) were not significantly different. Also the root strength of Mr Buster Thiram and Mundy were not significantly different. Finally the root tensile strength of Birdgo variety was not significantly lower than that of Mr-Buster-Thiram; However Birdgo has the root system with the lowest strength as compared to the other varieties whilst the other two varieties namel MBT and Mundy can be said to have intermediate root strength.

Effect of Soil moisture condition on the mean roots tensile strength: The overall effect of soil moisture content was found to have an insignificant effect on the mean root strength ($p = 0.394$) (figure-7). The samples in soil with high moisture content with a mean ultimate tensile strength of 846 N were not significantly lower than those in dry soil (2% m.c.) at 939 N.The different soil moisture contents did not significantly affect the mean ultimate roots tensile strength; this is not surprising because soil is weak in tension and shear when wet or dry. In comparison the shear strength of the sorghum fibres is reported to be 4.68 to 9.02 MPa[14] at grain stage which is higher than the shear strength of loam soil at 2.21 Pa[15], this difference in strength may result in the soil structure shearing well before the sorghum roots breaks[17]and thus rendering the effect of soil insignificant in influencing the ultimate tensile strength of sorghum roots.

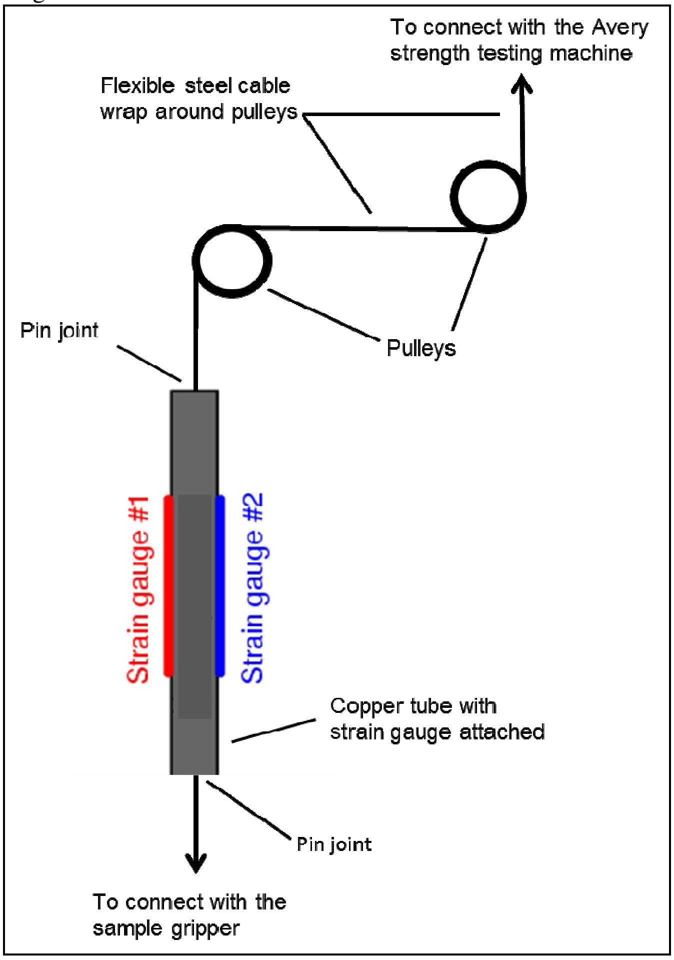

Figure-3
Illustration of the set up to determine the uprooting forces of sorghum, showing the positioning of the strain gauges in the system

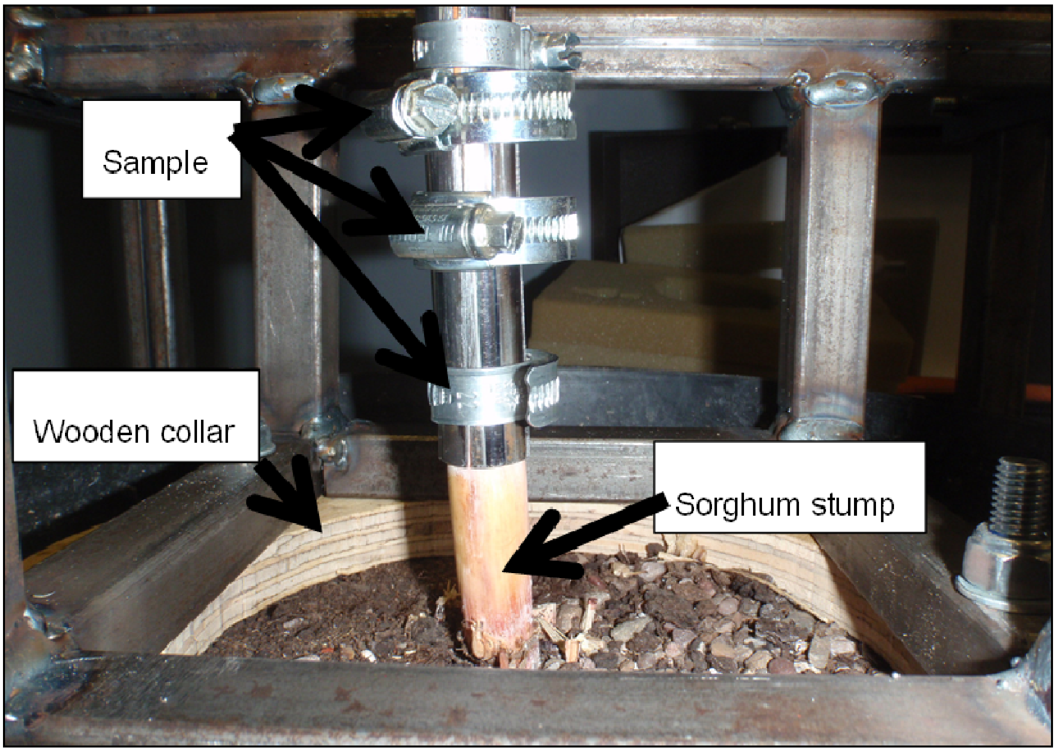

Figure-4
Sorghum uprooting test equipment with wooden collar to hold down soil block, and clamps attached before the process of uprooting commence

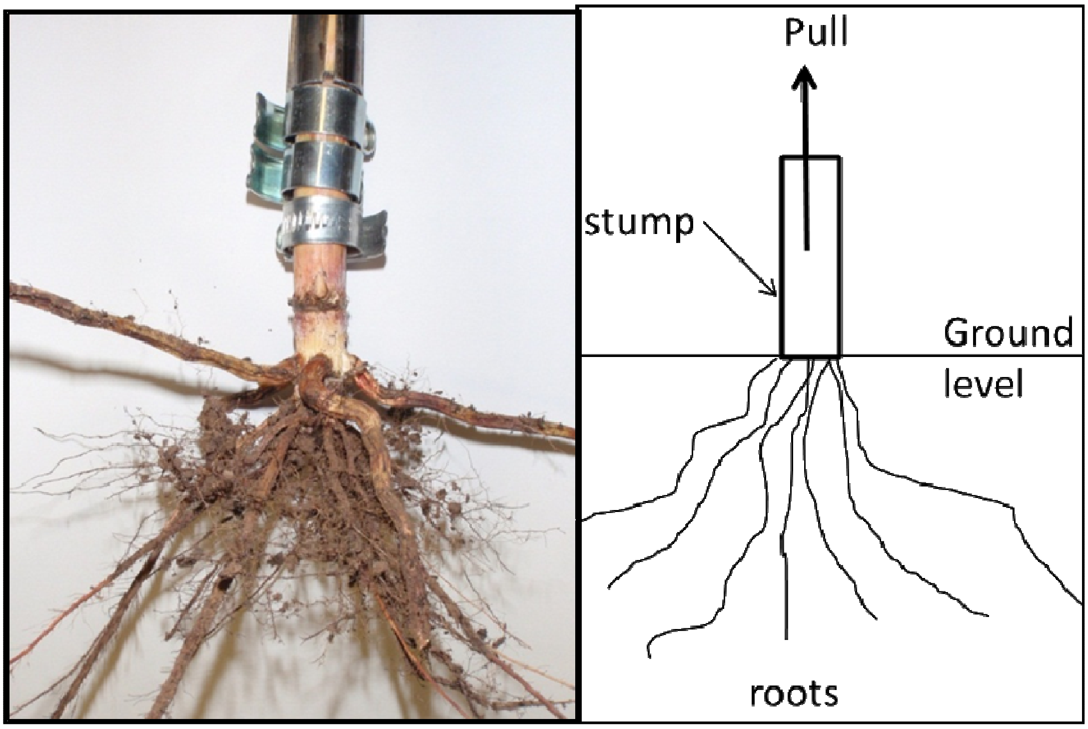

Figure-5
An uprooted sorghum stump with roots, and simplified figure showing the uprooting force

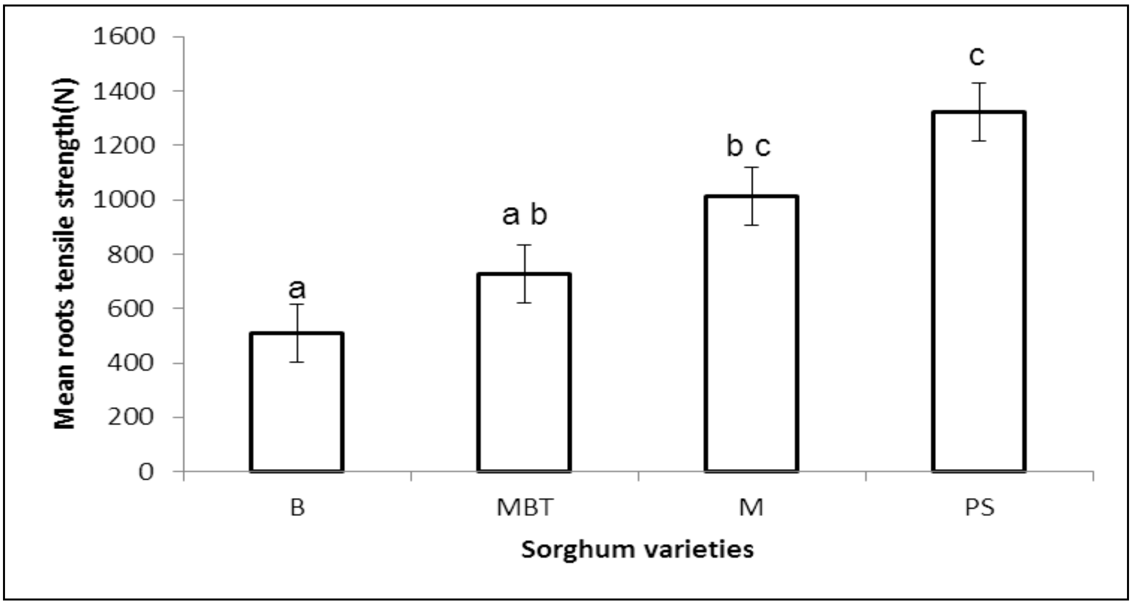

Figure-6

Mean roots tensile strength of different sorghum varieties. Treatments not accompanied by the same letter are significantly different at P = 0.05 according to Tukey's multiple range test, p = 0.001, LSD at 5% level = 318.7N, DF = 16 and CV = 29.2%). B- Birdgo, MBT – Mr Buster Thiram, M - Mundy and PS – Prime Silo

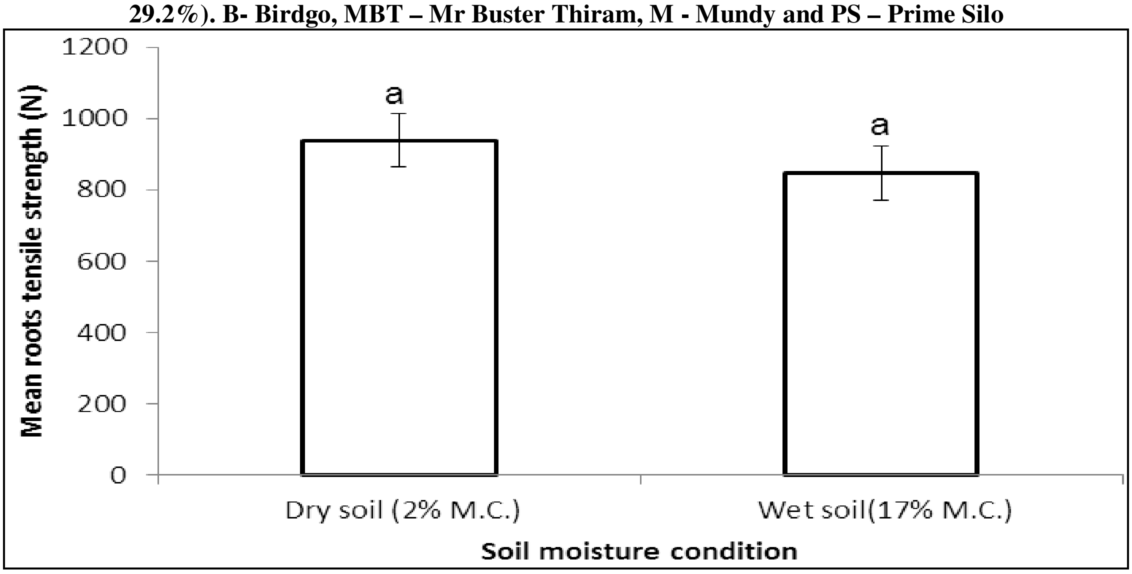

Figure-7

Mean sorghum roots tensile strength in various soil moisture conditions (Treatments not accompanied by the same letter are significantly different) (p = 0.394, LSD at 5% level = 225.3N, DF = 16 and CV = 29.2%)

The combined effect of soil moisture conditions and sorghum varieties on the sorghum roots tensile strength: There was no significant interaction between the variety and the soil moisture content (p = 0.970 as in (Figure-8). All the mean ultimate tensile strength of Birdgo (dry soil (593 N) and wet soil (428 N) and Mr-Buster-Thiram (dry soil (785 N) and wet soil (664 N) treatments were not significantly different from each other. Likewise the mean ultimate tensile strength of Mr-Buster-Thiram was not significantly different from Mundy treatments. The mean ultimate tensile strength of Mundy and Prime-Silo treatments were also not significantly different from each other. The Prime-Silo treatments were significantly higher in ultimate tensile strength than those of Birdgo and Mr-Buster-Thiram. The mean ultimate tensile strength of sorghum variety Birdgo roots at 428 N in wet soil is significantly lower than Mundy in both Dry (1033 N) and wet (993 N) soil and Prime-Silo of both dry (1346 N) and wet (1300 N) soil.

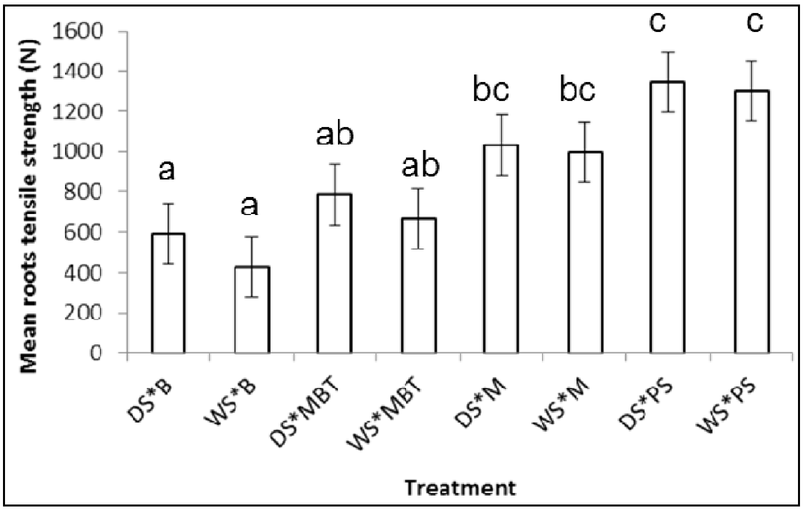

Figure-8
Mean sorghum roots tensile strength due to interaction of various soil moisture conditions and sorghum varieties. Treatments not accompanied by the same letter are significantly different

Conclusion

Sorghum bicolor is hardy a crop. The mean ultimate tensile strength of the sorghum roots was 893N. Different varieties namely Prime silo, Mundy, Mr-Buster-Thiram and Birdgo had varying ultimate root tensile strengths. The ultimate tensile strength of variety Prime silo of 1323N was significantly higher than those of Birdgo and Buster-Thiram at 511N and 725N respectively. Mundy at 1013 N was not significantly different from Prime-Silo or Mr Buster Thiram, However it was significantly stronger than Birdgo. The soil condition has no effect in the ultimate tensile strength of the sorghum roots. Currently, an on-going study will come up with the strength profile of sorghum plant.

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