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Research article

Effects of Adding Coconut Charcoal on Soil Physical Properties and Maize Performance

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Abstract Tonga is a tropical nation that faces susceptibility to the effects of climate change, with one of the primary challenges for its agricultural sector being the impact of El-Nino leading to prolonged periods of drought. The resulting economic crisis in the region was notable during the 2015-2016 drought season, leading to food shortages and a subsequent increase in food prices. This necessitated the importation of more expensive perishable goods to supplement locally produced items. This study aimed to investigate the use of coconut charcoal as a soil water amendment to mitigate water scarcity during drought periods. The findings demonstrated that incorporating 10 % of coconut charcoal with particle sizes of less than 1 mm into the soil can enhance soil physical properties, particularly in terms of maintaining optimal soil water levels of 50 kPa to 100 kPa for plant vegetative growth and grain growth 100 kPa to 1200 kPa. This amendment was found to alleviate plant water stress by prolonging the period before soil dryness occurs, benefiting vegetative growth and grain development stages. In conclusion, the incorporation of coconut charcoal as a soil amendment showed significant improvement in overall plant performance, such as an average increase in leaf area from 33.7 cm^2 to 93.9 cm^2. This suggests that coconut charcoal can be a viable recommendation as a soil amendment, aiding in the conservation of water resources and reducing irrigation costs and other expenses for small-scale farmers. This approach could enhance the resilience of Tonga's agricultural sector and small farmers in coping with drought conditions attributed to El-Nino. Consequently, this strategy could help diminish the need for importing perishable agricultural products from abroad during drought periods.

Keywords El-Nino, drought, coconut charcoal, optimal soil water levels, soil water amendment

INTRODUCTION

Tonga, situated within the Pacific Island Countries, encompasses a collection of 172 coral and volcanic islands positioned between latitudes 15° to 24° degrees South and longitudes 173° to 177° degrees West. The country experiences a tropical climate characterized by an average annual rainfall of 1,728 mm, and an annual mean humidity of 77%, with temperatures ranging from a minimum of 8.7°C to a maximum of 33.1°C. This region faces agricultural challenges during El-Nino, leading to prolonged periods of drought. The El-Nino event from 2015 to 2016 resulted in a significant reduction in annual precipitation, adversely affecting agricultural production in Tonga. The consequent lack of rainfall during this period led to water scarcity for irrigation, prompting an economic crisis that escalated food prices and jeopardized food security in the region.

The food deficit in Tonga has necessitated the importation of perishable goods, leading to higher prices compared to local produce. For instance, the cost of 1 kg of local tomatoes at USD 0.60 was notably cheaper than imported tomatoes at USD 6.00, resulting in market inflation (Finau, 2015). Despite this, only a few commercial farmers have made substantial investments in installing effective irrigation systems relying on underground water sources (Waterloo and Ijzermans, 2017). This study aimed to address these challenges by focusing on preserving water in the soil, making it more accessible for agricultural use. The predominant soil type on the main island of Tongatapu is andosol clay soil, covering 90% of the land due to volcanic eruptions (Gibbs, 1976). Tongatapu's coconut production accounts for approximately 99 million nuts annually (Manu, 2018). It is noted that charcoal can influence soil water retention and aggregate stability, thereby improving crop water availability (Piccolo et al., 1996).

Tryon (1948) examined the impact of charcoal additions on soil moisture availability in soils with different textures. The experiment utilized coconut charcoal from Sri Lanka on Japanese andosol clay soil, similar to the texture of Tongatapu's andosol clay soil. Coconut charcoal, readily available in Tonga and other tropical regions, has the potential to enhance agricultural practices. In Tonga, many households have coconut charcoal residue from their underground ovens (ngoto ‘umu), primarily used for cooking rather than agricultural purposes. This research aimed to demonstrate the beneficial effects of coconut charcoal residue on soil physical properties and plant performance. It highlighted that coconut charcoal residue is not a waste product but a valuable resource that can be utilized by the agricultural sector, particularly during drought seasons, as a soil water amendment.

OBJECTIVE

The main objective of this study was to evaluate the effects of adding coconut charcoal on soil physical properties and plant performance.

METHODOLOGY

Preparation of Coconut Charcoal

The process of preparing coconut charcoal involves heating the coconut residue raw materials to a temperature that increases gradually until it reaches 350°C within 15 minutes. The ratio of raw materials used is 2.5:1.0 for coconut charcoal production (Perera et al., 2013). The charcoal is then pounded and crushed into small particles, which are sieved to obtain different particle sizes of 3 mm, 2 mm, 1 mm, and less than 1 mm.

Preparation of Pot Plants

In the preparation of pot plants for the current study, the same andosol soil was added to each pot, along with crushed coconut charcoal in varying particle sizes of 3 mm, 2 mm, 1 mm, and less than 1 mm. Different application rates of coconut charcoal, such as 2.5%, 5.0%, 7.5%, and 10%, were mixed into the soil in each pot. One pot served as the control group, containing only andosol soil without any added coconut charcoal.

Direct Sowing the Corn Seeds

Corn seeds were directly sown in each pot, with three seeds planted to ensure germination. Thinning was done subsequently, leaving one seedling to grow for visual observation purposes throughout the study. This experimental setup aimed to assess the impact of different particle sizes and application rates of coconut charcoal on plant growth and soil physical properties in comparison to the control group without charcoal amendment.

Irrigation

As part of the irrigation process used in the experiment, hand irrigation was conducted using a spring can with an amount of 500 ml of water per pot plant, totaling 10 L for the 20 pot plants. Irrigation was applied as needed for optimal plant growth. When the soil indicated dryness below the comfort range, irrigation was applied to maintain soil moisture for the plants.

Experimental Layout

The experimental layout followed the Random Complete Block Design (RCBD) methodology proposed by Clewer and Scarisbrick (2001). The design involved five treatments that were replicated four times, with the coconut charcoal mixtures applied at a depth of 10 cm in the pots. The experiment was carried out in a glasshouse at the Tokyo University of Agriculture, as indicated in Fig. 1, below, to ensure controlled environmental conditions and accurate data collection. This experimental layout allows for the systematic comparison of the different treatments and their effects on plant growth and soil physical properties.

Treatment 1 (T1) :	Soil (97.5%)	+ Charcoal (2.5%, 3 mm)
Treatment 2 (T2) :	Soil (95.0%)	+ Charcoal (5.0%, 2 mm)
Treatment 3 (T3) :	Soil (92.5%)	+ Charcoal (7.5%, 1 mm)
Treatment 4 (T4) :	Soil (90.0%)	+ Charcoal (10.0%, <1 mm)
Treatment 5 (T5) :	Soil (100.0%)	Control (without charcoal)

Fig. 1 Experimental layout

Installation of Sensor

In the experiment, soil water content was monitored using TEROS 21 sensors to provide a more comprehensive understanding of soil moisture dynamics. Unlike traditional sensors that measure water content alone, the TEROS 21 sensor measures water potential, indicating the availability of water to plants and its movement within the soil (Campbell et al., 2010). Additionally, S-SDM-M005 sensors were used to measure water content percentages in the soil.

Five TEROS 21 sensors were installed at a depth of 5 cm, while S-SDM-M005 sensors were placed at a depth of 10 cm in each pot of the five treatments. This setup allows for detailed monitoring of soil and water conditions at different depths. Data collection was done using Zentra Utility and HOBO Ware software for accurate and reliable measurements throughout the experiment.

Measuring Leaf Area

Leaf area measurements were taken using a measuring tape to determine the length and width of the leaves in centimeters, following the method described by Chanda and Singh (2002). These measurements were recorded to compare the leaf area among the different treatments and analyze any significant differences that may indicate the impact of coconut charcoal on plant growth and development. The leaf area calculated was given by the following Eq. (1).

$$\text{Leaf area (LA)} = \text{leaf width (W)} \times \text{leaf length (L)} \tag{1}$$

RESULTS AND DISCUSSION

Statistical analysis was conducted using ANOVA Single Factor, as displayed in Table 1 below, revealing that treatment 4 (T4) has the highest average leaf area of 93.9 cm^2. This indicates that the addition of coconut charcoal has positively contributed to increasing the size of the leaves, ultimately enhancing plant performance in terms of leaf development.

On the other hand, the control treatment, or treatment 5 (T5), which did not involve the addition of coconut charcoal, exhibited the lowest average leaf area of 33.7 cm^2. This suggests that plants in this treatment had smaller leaves compared to those treated with coconut charcoal, emphasizing the potential beneficial effect of coconut charcoal on leaf size and, by extension, plant growth and performance.

Table 1 Average leaf area for each treatment

Groups	Count	Sum	Average (cm^2)	Variance
T1	4	251.8	62.950	84.94
T2	4	246.6	61.650	199.53
T3	4	162.9	40.725	113.96
T4	4	375.6	93.900	128.04
T5	4	134.8	33.700	306.81

ANOVA single factor average leaf area

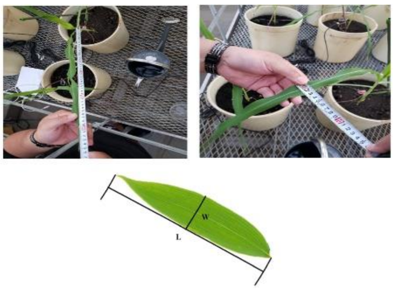

Fig. 2 Measuring of leaf area

Table 2 displays the comparison of the P-values for the average leaf area among the different treatments. The results indicated that there was a significant difference in leaf area among the treatments, except for the comparisons between T1-T2, T2-T3, and T3-T4, where no significant difference was observed. This suggests that the impact of treatments on leaf area varied, with specific treatments showing distinct effects on leaf development and size. Further analysis of the data can provide insights into the specific effects of each treatment on plant performance and growth.

Table 2 Compared P-value of average leaf area for each treatment

Treatment	P-value	Highly significant (H.S) Significant (S) Non-significant (N.S)	Escalation / Abbreviation
T1 vs T2	0.535256248	N.S $\geq$ 0.05 (5 %)	d (N.S)
T1 vs T3	0.019770135	S $\leq$ 0.05 (5 %)	b* (S)
T1 vs T4	0.011535978	S $\leq$ 0.05 (5 %)	b* (S)
T1 vs T5	0.025427129	S $\leq$ 0.05 (5 %)	b* (S)
T2 vs T3	0.054299548	N.S $\geq$ 0.05 (5 %)	e (N.S)
T2 vs T4	0.014394010	S $\leq$ 0.05 (5 %)	c* (S)
T2 vs T5	0.047533118	S $\leq$ 0.05 (5 %)	c* (S)
T3 vs T4	0.000566231	H.S $\leq$ 0.001 (.1 %)	a** (H.S)
T3 vs T5	0.518949725	N.S $\geq$ 0.05 (5 %)	f (N.S)
T4 vs T5	0.000493836	H.S $\leq$ 0.001 (.1 %)	a** (H.S)

ANOVA single factor P-value comparison

The bar graph in Fig. 3 demonstrates an evident and statistically significant difference in the average leaf area between treatment groups T3-T4 and T4-T5, with a P-value of less than or equal to 0.001 (0.1%). Furthermore, the confidence interval for this difference is 99.99%. Additionally, comparisons between treatment groups T1-T3, T1-T4, T1-T5, T2-T4, and T2-T5 also revealed statistically significant differences, with a P-value of less than or equal to 0.05 (5%) and a confidence interval of 95%.

Table 3 shows that Treatment 4 (T4) exhibited a notably high average soil water matric potential, making it a suitable option for farmers looking to use soil water amendments (Fig. 4). This range aligned with the favorable/comfort range of soil water matric potential conducive to maize growth, typically falling between 50 - 1200 kPa (Campbell et al., 2010).

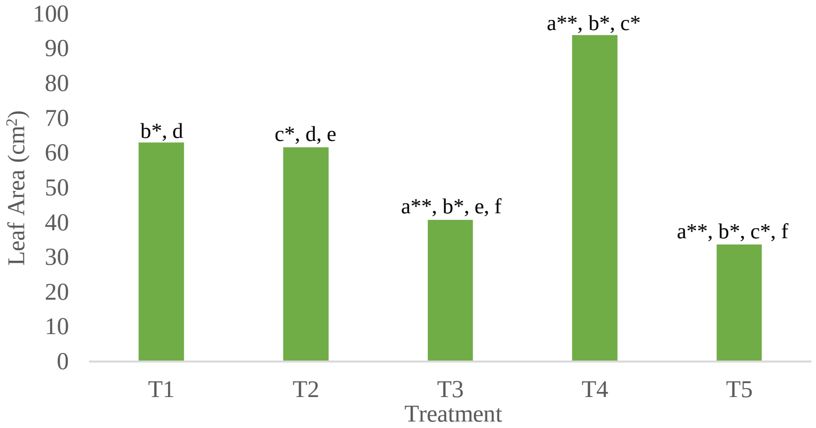

Fig. 3 Average leaf area for each treatment

Table 3 Average soil water matric potential for each treatment

Groups	Count	Sum	Average (kPa)	Variance
T1	228	-760074.51	-3333.66013	9570332.2
T2	228	-703200.3	-3084.21186	9548436
T3	228	-439837.87	-1929.11346	6001146.4
T4	228	-148724.54	-652.300595	1117680
T5	228	-732918.35	-3214.55417	7508437.7

ANOVA single factor average soil water matric potential

The ANOVA single factor statistical analysis comparing T1-T2 and T1-T5, as well as T2-T5, revealed no significant differences with a p-value greater than or equal to 0.05. However, contrasts between T1-T3, T2-T3, T3-T5, T1-T4, T2-T4, T3-T4, and T4-T5 exhibited highly significant differences with a p-value of less than or equal to 0.001 in terms of soil water matric potential kPa.

Fig. 4 Measuring of soil water matric potential

In Fig. 5, the impact of the various treatments on both soil temperature and soil water matric potential is depicted. The measurements suggested that an increase in soil temperature, particularly within the range of 30 to 40 degrees Celsius, had led to a decrease in the soil water matric potential measured in kilopascals. The average values for T1 were 3333.66 kPa, T2 - 3084.21 kPa, T3 - 1929.11 kPa, T4 - 652.30 kPa, and T5 - 3214.55 kPa over a specific period. It was observed that all treatments experienced rapid drying within a few days, except for T3 and T4, which exhibited a slightly slower drying rate.

Table 4 Compared P-value of soil water matric potential for each treatment

Treatment	P-value	Highly significant (H.S) Significant (S) Non-significant (N.S)
T1 vs T2	0.389458216	N.S ≥ 0.050 (5.0%)
T1 vs T3	1.23E-07	H.S ≤ 0.001 (0.1%)
T1 vs T4	1.50172E-30	H.S ≤ 0.001 (0.1%)
T1 vs T5	0.6636359	N.S ≥ 0.050 (5.0%)
T2 vs T3	1.21916E-05	H.S ≤ 0.001 (0.1%)
T2 vs T4	4.81429E-26	H.S ≤ 0.001 (0.1%)
T2 vs T5	0.63391606	N.S ≥ 0.050 (5.0%)
T3 vs T4	2.12078E-12	H.S ≤ 0.001 (0.1%)
T3 vs T5	1.99896E-07	H.S ≤ 0.001 (0.1%)
T4 vs T5	8.69324E-34	H.S ≤ 0.001 (0.1%)

ANOVA Single Factor P-value Comparison

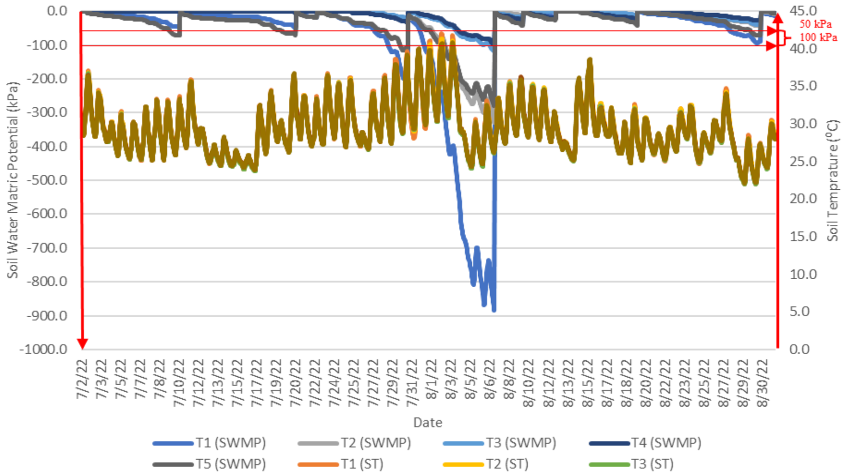

Fig. 5 Soil water matric potential and soil temperature

CONCLUSION

The comprehensive findings suggested that incorporating 10% coconut charcoal with a particle size of less than 1mm as a soil amendment can enhance the soil's physical properties, leading to improved water-holding capacity and a reduction in plant water deficit. Furthermore, the inclusion of coconut charcoal as an amendment can boost overall plant performance, particularly in terms of leaf area, which saw an increase from 33.7 cm^2 to 93.9 cm^2.

As a result, coconut charcoal emerged as a recommended soil amendment that not only aids in conserving water resources but also helps diminish financial burdens related to irrigation and other associated expenses like the installation of irrigation systems, ultimately reducing labor time for small-scale farmers. Additionally, with the agricultural sector in Tonga and small farmers able to provide an ample supply for the local market, the daily basic needs of the populace can be adequately met. This proactive approach can help avoid excessive imports of perishable agricultural products from overseas during periods of drought, particularly those triggered by phenomena such as El-Nino.

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