



Enhancing Soil Productivity for Sustainable Agriculture in Afghanistan: The Impact of Organic Amendments on Soil Water Holding Capacity and Grapevine Growth in Kabul, Afghanistan

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Abstract Afghanistan's sandy loam soils hold significant agricultural potential; however, they face challenges such as low water-holding capacity, poor organic matter content, and high infiltration rates, which hinder plant growth and productivity. This study aimed to evaluate the effects of organic amendments on soil volumetric water content, water-holding capacity, and grapevine performance. A controlled pot experiment was conducted in a glasshouse at Tokyo University of Agriculture, using five different treatments (T), each applied at a rate of 7.5%: T0 (control), T1 (sawdust), T2 (compost), T3 (chicken manure), and T4 (a combined treatment). Delaware grapevine seedlings were planted in each pot, and volumetric water content and matric potential data loggers were connected to sensors to monitor soil moisture and water suction. Additionally, leaf area index and chlorophyll content were measured using ImageJ software and a chlorophyll-measuring device. The results showed that organic amendments sawdust, compost, chicken manure, and the mixed treatment significantly improved soil water-holding capacity, and overall soil productivity, all of which are essential for sustainable agriculture in water-scarce regions like Afghanistan. Chicken manure and the mixed treatment demonstrated the highest volumetric water content, while sawdust and compost provided the greatest water-holding capacity. Moreover, these amendments enhanced grapevine growth, as indicated by increased leaf area and chlorophyll content. The findings suggest that incorporating organic amendments into sandy loam soils can improve water efficiency, plant growth, and soil sustainability, contributing to the long-term viability of Afghanistan's agricultural sector.

Keywords organic amendments, soil productivity, water holding, plant growth

INTRODUCTION

In Afghanistan, agriculture is the backbone of the economy, with most of the population relying on it for food, income, and livelihood. Even though only 12% of Afghanistan's total land is arable and only about 6% is currently cultivated (Yousufi, 2016). Among all fresh fruits, grapes hold the highest economic importance, covering 50% of the total horticulture crops (Yusufi and Yamada, 2017), with a production volume of 993,382 tons in 2020 (MAIL, 2020). Despite the 87,593 hectares (ha) of vineyards cultivated across the country, less than 1% of the vineyards are located in highly suitable areas, while another 22% of suitable land remains available for potential expansion of grape farm (Arab and Ahamed, 2022). Water scarcity is a primary barrier for agriculture in Afghanistan's arid and semi-arid regions, with irrigation accounting for 85% of water use to sustain the country's agriculture (Aini, 2007). However, the prevalent sandy loam soils in the region are limited by low water-holding capacity, high infiltration and evapotranspiration rates, and

minimal organic matter content with a range from only 0.02 to 2.1 percent, factors that collectively restrict soil moisture and productivity for plant growth. These base problems are especially challenging during frequent droughts impacting overall agricultural productivity (FAO, 2020). The challenges of low water retention, poor organic matter content, and rapid infiltration limit soil productivity and its ability to support plant growth (Yusufi and Yamada, 2019).

OBJECTIVES

To evaluate the effectiveness of organic amendments in improving soil water-holding capacity, enhancing soil productivity, and assessing their impact on grapevine cultivation, with the goal of developing sustainable agricultural practices for arid regions of Afghanistan.

STUDY AREAS AND METHODOLOGY

The study areas are Shakardara, Kalakaan and Mir Bacha Kot districts of Kabul, Afghanistan, have a semi-arid to arid climate, characterized by low precipitation, hot summers, and cold winters. The soil in these regions is generally sandy loam to loam, with low organic matter, poor water retention capacity, and limited fertility. One of the major challenges for agriculture in these areas is the scarcity of irrigation water, as precipitation is insufficient to support reliable crop production. Additionally, climate variability, high temperatures, and soil degradation further reduce productivity. My study focuses on improving soil water-holding capacity and fertility using compost, chicken manure, sawdust, and their combinations as potential amendments to enhance sustainable agriculture in these water-limited environments.

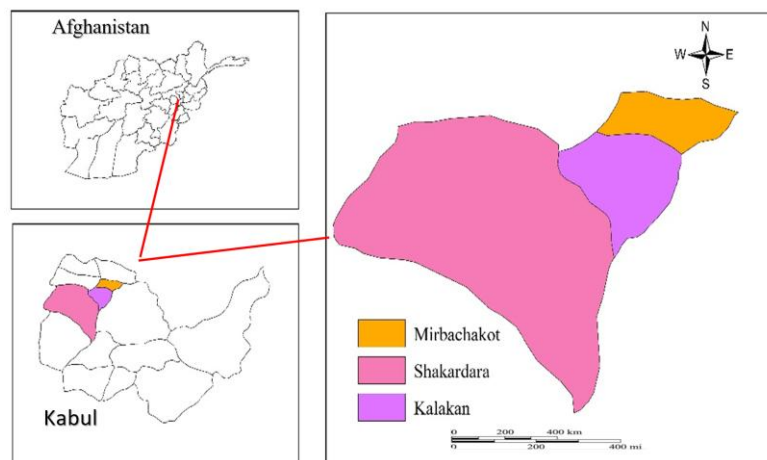


Fig. 1 Map of the study area

Materials

A pot experiment was conducted in a controlled environment at the Tokyo University of Agriculture from August 2023 to December 2024. After the preparation of 15 pots, two-year-old Delaware grapevine seedlings were transplanted into each pot. Irrigation was provided during the growing season as necessary. Weed control and other management procedures were regularly undertaken by standard protocols, especially at the early stages of seedling growth. Plant growth parameters such as the chlorophyll content of leaves and leaves areas of grapevine were assisted. Testing five organic amendments to assess their effects on soil water holding and grapevine growth.

Experimental Layout

The study tested under five treatments and three replications as shown in Table 1.

Table 1 Experimental layout with five treatments

Number	Treatments
(i) T0	Control/no amendment: sandy loam soil 9,000 g (100% of soil weight)
(ii) T1	Sandy loam soil 8,325 g (92.5%) + sawdust 675 g 1 mm (7.5%) (8325 + 675 = 9000 and % figures would be 92.5% and 7.5%)
(iii) T2	Sandy loam soil 8,775 g (92.5%) + compost 675 g (7.5%) (8775 + 675 = 9450 and % would be 92.5% and 7.5%)
(iv) T3	Sandy loam soil 8,775 g (92.5%) + chicken manure 675 g (7.5%) (8775 + 675 = 9450 and % figures would be 92.5% and 7.5%)
(v) T4	Sandy soil 8,775 g (92.5%) + mixed 675 g (7.5%) (8775 + 675 = 9450 and % figures would be 92.5% and 7.5%)

The selection of a specific ratio (7.5%) of organic soil amendments was based on several scientific and practical criteria (Bot and Benites, 2005). This ratio falls within a range commonly used in agricultural research, where moderate amendments are tested to evaluate their impact on soil properties without causing nutrient imbalances. Further, higher rates may be more costly and labor-intensive.

Installation of Sensors

Matric potential and volumetric water content sensors were placed in each pot at a depth of 10 cm because it provides the most valid and representative data and many plants have a significant portion of their root system within the top 10-15 cm of soil, where they absorb most of the water and nutrients. Additionally, two software tools, Zentra Utility and HOBO Ware, were used for automated data collection. For measuring chlorophyll, we used SPAD-502Plus, a portable device used to measure leaf chlorophyll content. For leaf areas index, we used ImageJ software.

RESULTS AND DISCUSSION

The soil moisture-irrigation relationship relies on balancing the timing and amount of water application to maintain soil moisture within an optimal range for plant uptake. After irrigation or rainfall, the soil reaches its field capacity. At this point, the soil has enough moisture for plants to absorb easily. If soil moisture falls below the permanent wilting point, plants are unable to extract adequate water, leading to wilting and, ultimately, death in the absence of irrigation. In an experimental context, sandy loam soil treated with chicken manure and mixed at a ratio of 7.5% by total mass demonstrated a significantly higher volumetric water content compared to other treatments.

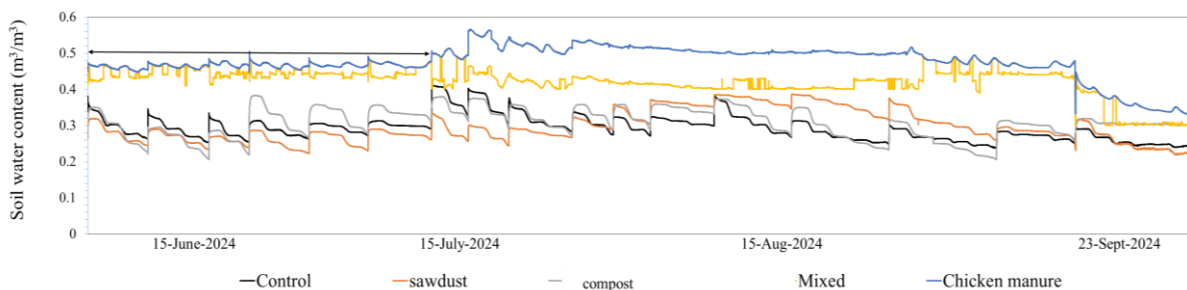


Fig. 2 Effects of organic amendments on soil volumetric water content

The data, as shown in Fig. 2, reveal that the moisture content of this treatment (represented by the blue and yellow lines) remained higher than that of untreated soils. This improvement in water-holding capacity may be attributed to increased cohesive forces, which enhance soil structure by

attracting water particles. Consequently, the water-holding capacity of the treated soil exceeds that of untreated soil, indicating improved soil moisture availability for plant growth.

According to Figure 3 when soil is wet, the matric potential is near zero because water is easily available. As soil dries, water becomes more tightly bound to the soil, increasing the negative value of the matric potential (e.g., -50 kPa to -800 kPa), indicating that plants need to exert more effort to extract water. In this line graph, matric potential is monitored using sensors to measure soil water suction, which helps determine irrigation needs and optimize water use. Each line corresponds to a different organic amendment treated with soil. The blue, yellow, and orange lines remain higher and less steep than the others, indicating that these soil types retain water better at lower tensions, making it easier for plants to access water. Understanding matric potential helps optimize irrigation by providing a guide to when soil water content is too low and needs to be replenished to ensure plants receive adequate moisture for growth. This information aids in making informed decisions about irrigation practices.

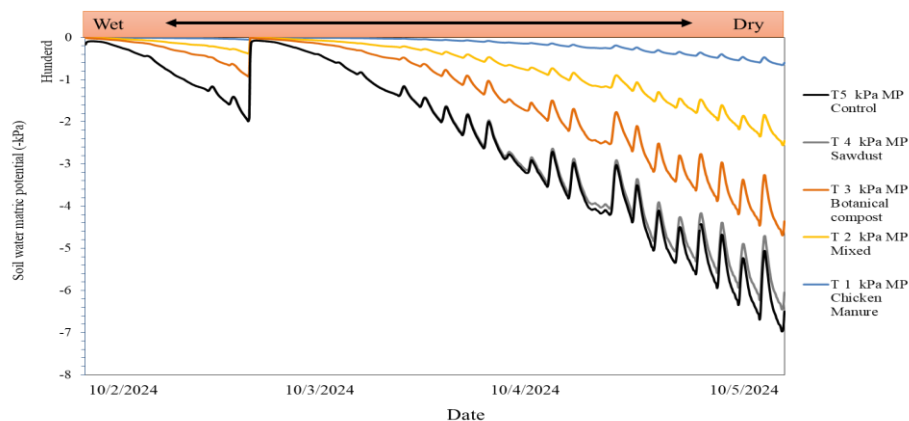
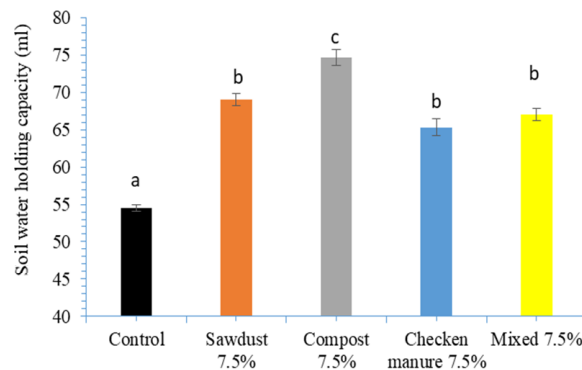


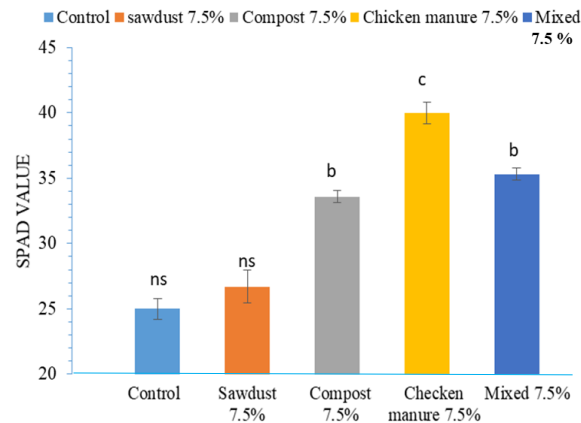
Fig. 3 Effects of organic amendments on soil matric potential

The bar graph suggests that different soil treatments have a significant impact on soil water-holding capacity. Compost at 7.5% has the highest water retention, followed by sawdust Figure 4. When added to soil, sawdust improves soil structure by increasing its porosity, allowing the soil to hold more water and nutrients. Sawdust has relatively low nutrient content and decomposes slowly compared to other organic materials, but it helps improve soil texture by increasing the proportion of finer particles. This creates more micropores that can retain water, unlike the larger macropores typical of sandy loam soils, which allow water to drain quickly. However, the grapevine leaves chlorophyll content significantly increased soil treated with compost, chicken manure and mixed at 7.5% (Fig. 5).



Notes: Error bars indicate the standard deviation of the mean; $p < 0.01$, ns: not significant compared to the control one way ANOVA.

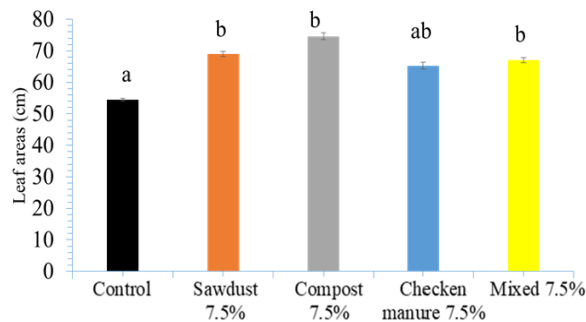
Fig. 4 Changes on soil water holding capacity at saturation with addition of organic amendments in sandy loam soil



Notes: Error bars indicate the standard deviation of the mean; $p < 0.01$, ns: not significant compared to the control one way ANOVA.

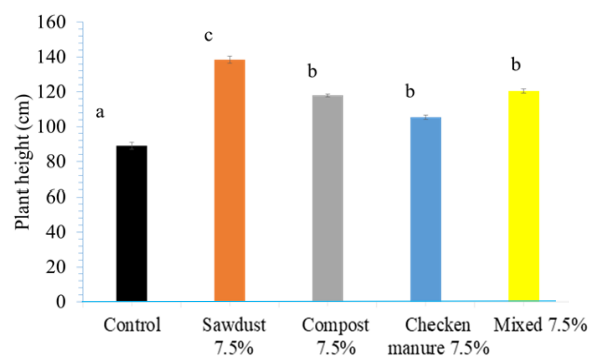
Fig. 5 Changes on grapevine leaves chlorophyll content with addition of organic amendments in sandy loam soil

According to the bar graph in Fig. 4, the nutrients and improved soil properties resulting from organic amendments promote overall plant growth and leaf area expansion. Larger and healthier leaves tend to produce and maintain more chlorophyll, enhancing photosynthesis and boosting vine productivity. According to Fig. 5, the amendments notably enhanced the chlorophyll content in grapevine leaves. Previous studies have also shown that chlorophyll content is a useful indicator for assessing nitrogen uptake in plants (Bojović and Marković, 2009).



Notes: Error bars indicate the standard deviation of the mean; $p < 0.01$, ns: not significant compared to the control one way ANOVA

Fig. 6 Changes on leaf area with addition of organic amendments in sandy loam soil



Notes: Error bars indicate the standard deviation of the mean; $p < 0.01$, ns: not significant compared to the control one way ANOVA

Fig. 7 Changes on plant height with addition of organic amendments in sandy loam soil

Leaves are one of the most important organs that plants have. Leaves enable photosynthesis, the process by which plants produce food using light, carbon dioxide (CO₂), and water. Leaves are essentially responsible for the productivity of a plant. Therefore, understanding the leaf area is important (Trimble, 2020). According to Figure 6, the effects of organic amendments on the leaf area of plants vary depending on the specific type of amendment used, the ratio of soil amendments, and the overall health of the grapevines. The addition of sawdust, compost, and chicken manure, mixed at a ratio of 7.5%, contributed essential nutrients to the soil and promoted healthy grapevine leaf area and growth compared to the control. As shown in Figure 7, adequate nutrient levels are crucial for photosynthesis and overall plant development. Soil amendments can influence factors such as nutrient availability, soil structure, water retention, and microbial activity, all of which can impact grapevine height and growth.

CONCLUSION

The experiment demonstrated that organic amendments significantly enhanced volumetric water content, soil water-holding capacity, and overall soil productivity, all are key factors for sustainable agriculture in water-scarce regions like Afghanistan. Chicken manure and the mixed treatment showed the highest volumetric water content and soil water matric potential, while sawdust and compost contributed the most to water-holding capacity due to their ability to modify pores distribution compared to control and promote with larger pores, which retain more water. Decomposition of organic matter releases essential nutrients in plant-available forms, as reflected in increased leaf area and chlorophyll content both indicators of improved plant health and photosynthetic efficiency as evidenced by increased leaf area and chlorophyll content. Thus, the application of organic amendments to sandy loam soils not only enhances water efficiency and plant growth but also promotes soil sustainability, supporting the long-term viability of Afghanistan's agricultural sector.

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