Vol. 14, No. 3 (2025): 1034 - 1039 http://dx.doi.org/10.23960/jtep-l.v14i3.1034-1039

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)

Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

The Use of Organic Fertilizer to Enhance Soil Water Availability and Promote the Growth of Tomatoes in Sandy Loam Soils

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Article History:

Received : 07 January 2025
Revised : 14 Maret 2025
Accepted : 25 Maret 2025

Keywords:

Organic Carbon,
Sandy Soils Texture,
Soil Structure,
Water Retention.

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ABSTRACT

The use of organic fertilizer has been shown to improve soil structure and promote plant root growth, particularly in critical areas with limited water resources for agricultural activities. This study aimed to evaluate the effect of organic fertilizer application on the soil's water holding capacity and the growth performance of tomato. The experiment was conducted using a randomized complete blocs design with six treatments, each replicated three times. The treatments included P0 (0 Mg/ha), P1 (5 Mg/ha), P2 (10 Mg/ha), P3 (15 Mg/ha), P4 (20 Mg/ha), and P5 (25 Mg/ha). The findings revealed that organic fertilizer application significantly influenced soil organic carbon levels, bulk density, hydraulic conductivity, and soil water availability. Additionally, the increased soil organic carbon led to noticeable improvements in shoot dry weight, total root length, and root dry weight of tomatoes. This study found that the availability of organic carbon has very strong correlation with tomatoes growth and soil water availability.

1. INTRODUCTION

Global challenges such as land degradation, poverty, and food insecurity have become pressing concerns in many developing countries. The degradation of natural resources and the environment is largely driven by society's increasing demand for agricultural production, which is often not matches by sufficient inputs (Salvia *et al*., 2019). These issues can be addressed by leveraging local wisdom and enhancing awareness, knowledge, and community perceptions regarding land degradation and desertification (Briassoulis, 2019).

Over time, soil erosion results in deteriorating soil quality. The impact of raindrops disrupts the surface soil structure and reduces soil water conductivity. Organic carbon loss from the surface layer contributes to increased soil compaction and reduced infiltration (Dutal & Reis, 2020). While an increase in organic matter availability may occur, its influence on soil after retention capacity is not always significant (Minasny & McBratney, 2018). However, some studies suggest that applying organic fertilizers can markedly improve soil water availability (Hussain *et al*., 2020; Libohova *et al*., 2018; Zhang & Shangguan, 2016). Disagreements among researchers about the effect of organic fertilizers on oil water availability stem from factors such as 1) varying perspectives on the role of organic acids in binding soil water, and 2) differences in methodologies for evaluating soil water retention (Bonfante *et al*., 2020). Additionally, variations in field capacity measurements, due to differing matrix suction standards, can lead to contrasting conclusions (Eden *et al*., 2017).

Plant-available water is often a limiting factor for agricultural productivity on sandy textured soils. Sandy soil has low water holding capacity and fast to very fast soil water conductivity. The provision of solid organic matter is expected to increase soil water retention through increased soil structure stability and water holding capacity higher than its own weight (Qian *et al*., 2020). To address this, the adoption of good agricultural practices that emphasize the efficient utilization of soil water during critical growth stages is essential, particularly in areas with restricted water resources (Ansar *et al*., 2021). Evaluating various soil physical properties and plant growth parameters can help establish correlations with soil organic carbon availability. This study aims to examine the impact of organic fertilizer application on soil water availability and the growth performance of tomato. This research is expected to explain in more depth the differences in expert opinion regarding the response of increasing soil organic carbon to soil physical properties and plant growth, particularly in relation to the ability to retain soil water and root growth.

2. MATERIALS AND METHODS

The pot experiment was carried out at the experimental farm of the Faculty of Agriculture, Tadulako University, located in central Sulawesi. Sandy loam soil sample were collected from the surface layer in Sidera, Sigi-Biromaru. The study employed a randomized complete block design with six levels of organic fertilizer application (in Mg/ha), namely: 0 (P0), 5 (P1), 10 (P2), 15 (P3), 20 (P4), and 25 (P5). Each treatment was replicated three times.

Solid organic fertilizer was made using a mixture of 10 kg of cow dung, 2 kg of rice bran, 0.05 kg of urea, 0.05 kg of sugar, and effective microorganisms (EM4) according to standard recommendations. The composting process took place in 20 days. The soil physical properties included bulk density (measured from whole soil samples), saturated hydraulic conductivity (using a constant head permeameter), soil water content at field capacity and permanent wilting point (determined using a pressure plate (at -33 k Pa and – 1500 k Pa, respectively), and organic carbon content (analyzed using the Walkley-Black method). The chemical properties of the soil and organic fertilizer used in this experiment were presented in Table 1.

Table 1. Analysis of soil properties and organic fertilizer

Criteria	Soil	Organic Fertilizer
Soil Texture: Sand (%)	62.84	--
Silt (%)	17.36	--
Clay (%)	19.50	--
Bulk Density (g/cm^3)	1.34	--
C-organic (%)	1.18	28.42
N-total (%)	0.13	0.90
P-total (%)	--	0.032
K2O (%)	--	0.28
pH H_2O (1 : 2.5)	6.94	6.70

Air-dried soil samples, sieved through a 2 mm mesh, were used as the experimental material, with 10 kg of soil placed in each pot. Prior to planting, NPK fertilizer was applied to all pots at the recommended dosage (15 g/pot). Tomato seedlings were transplanted at the three-leaf stage, and watering was done every three days. Pest and disease management was performed using pesticides applied at recommended rates.

Plant growth parameters observed included shoot and root dry weights (determined by oven-drying at 80°C for 24 hours), root length (measured from the base to the tip by straightening curled roots), and total root length following the method of Atkinson (2000). Data from the experiment were analyzed using analysis of variance. When significant differences among treatments were detected, a Tukey test at a significance of $\alpha = 0.05$ was applied to compare means. The green house experiment ended when the plants were 50 days old after planting. Measurements of root length and the top of the plant were carried out when the tomatoes were 55 days old after planting.

3. RESULTS AND DISCUSSION

Soil quality capable of ensuring the availability of water, oxygen, and mechanical support is a critical factor for achieving optimal agricultural productivity. Soil water availability is determined by factors such as soil texture, structure, mineralogical composition, and organic carbon. Sandy loam soils with low organic carbon typically exhibit a reduced capacity to retain and provide soil water. The findings of this study indicate that organic fertilizer application significantly influenced several physical properties of the soil water. However, the soil water content at the permanent wilting point did not show any significant differences (α = 0.05) among treatments (Table 2).

Table 2. The effect of organic fertilizer treatment on several physical soil properties

Treatment	Soil Organic Carbon (%)	Bulk Density (g/cm^3)	Hydraulic Conductivity (cm/h)	Field Capacity (%)	Wilting Point (%)	Available Soil Water (%)
P0	3.35 ± 0.44 c	1.36 ± 0.02 a	2.58 ± 0.13 d	16.59 ± 1.37 d	4.19 ± 0.08	12.41 ± 1.45 c
P1	3.72 ± 0,11 c	1.34 ± 0.03 ab	3.01 ± 0.68 d	17.30 ± 1.81 cd	4.20 ± 0.05	13.10 ± 1.83 bc
P2	4.11 ± 0.23 bc	1.32 ± 0.04 ab	3.24 ± 0.12 cd	18.75 ± 2.15 bc	4.26 ± 0.09	14.49 ± 2.23 ab
P3	5.10 ± 0.74 b	1.30 ± 0.04 abc	3.71 ± 0.64 c	19.96 ± 1.56 ab	4.29 ± 0.05	15.68 ± 1.53 a
P4	6.56 ± 0.05 a	1.23 ± 0.07 bc	6.73 ± 1.04 b	20.40 ± 1.14 ab	4.33 ± 0.07	16.10 ± 1.07 a
P5	7.06 ± 0.49 a	1.20 ± 0.07 c	9.24 ± 0.92 a	20.97 ± 1.82 a	4.35 ± 0.08	16.62 ± 1.77 a

Note: Mean ± standard deviation (*n* = 3). Different letters in the same column are declared significantly different in the Tukey test (α = 0.05)

Increasing the dose of organic matter did not cause significant differences (α = 0.05) in observations of soil organic carbon, bulk density, and hydraulic conductivity in treatments P0, P1, and P2. These treatments showed significant effects on observations of field capacity water content and soil water availability. In contrast, the administration of organic matter at higher doses (treatments P3, P4, and P5) showed significant differences in observations of soil organic carbon, hydraulic conductivity, field capacity water content and soil water availability. The decreasing bulk density indicated that the soil was increasingly loose and porous. Increasing total soil porosity can cause increasing hydraulic conductivity, field capacity and soil water availability. Changes in permanent wilting point water content were not affected by changes in soil structure.

An increase in micro-pore volume and aggregate stability, resulting from higher organic carbon, is evident in sandy loam soils. The addition of organic material to dense sandy soils enhances total pore space and improves soil micro structure (Bouajila & Sanâa, 2011). Soil organic matter with a high carbon-to-nitrogen (C/N) ratio contributes on macro-pores increases with higher organic carbon availability, whereas sandy-clay soils, it tends to decrease (Brar *et al*., 2015). The application of 25 Mg/ha (P5) of organic fertilizer reduced soil bulk density by 14.2 % compared to the control treatment (P0). Organic material inputs can expand total pore space and increase the proportion of micro-sized pores. Improved soil water content at field capacity enhances water availability for plat growth (Blanco-Canqui *et al*., 2017; Vogelmann *et al*., 2013). The primary benefit of applying organic materials to soil lies in their ability to retain higher levels of water compared to mineral soils. Organic materials can absorb water exceeding their own weight (Liu *et al*., 2014; Ramos, 2017).

The application of fertilizer at rate of 25 Mg/ha (P5) increased organic carbon by 3.71 % and available soil water 4.21 % compared to the control (P0). A strong positive correlation between soil organic carbon and available soil water is presented in Figure 1. This study revealed that for every 1% increase in organic carbon, the available soil water

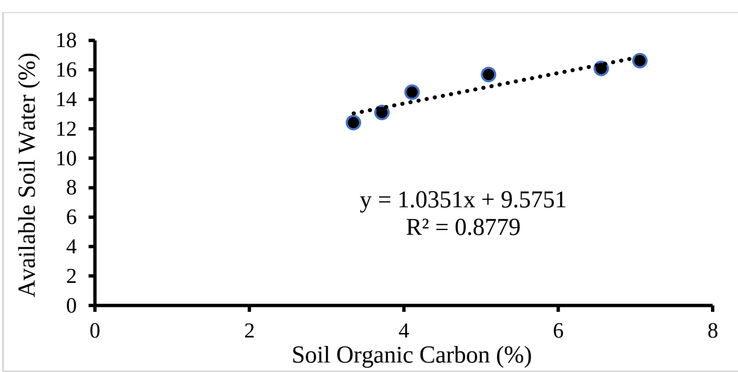

Figure 1. Relationship between soil organic carbon and available soil water

water rose by 1.14 %. The enhancement of soil organic matter significantly improved available soil water in sandy soils. Conversely, in clay-textured soils, the application of organic carbon did not result in a significantly different effect (Ankenbauer & Loheide, 2016).

The application of fertilizer increases soil pore space with diameter less than 50 µm. This enhancement in soil water availability is closely linked to the expansion of micro pore volume (Głąb *et al*., 2018; Leelamanie & Karube, 2010; Ramos, 2017). Additionally, organic fertilizer application significantly influenced shoot dry weight, root length, total root length, and the dry weight of tomato roots (Table 3).

Table 3. Effect of organic fertilizer on tomato growth

Treatment	Dry Weight of Shoot (g/plant)	Root Length (cm)	Dry Weight of Root (g/plant)	Total Root Length (cm/cm^{-3})
P0	2.49 ± 0.09 c	23.98 ± 2.59 c	0.73 ± 0.05 b	0.1980 ± 0.04 d
P1	2.57 ± 0.17 c	25.47 ± 2.69 bc	0.74 ± 0.03 b	0.2225 ± 0.02 c
P2	2.67 ± 0.16 b	26.58 ± 2.72 b	0.79 ± 0.06 b	0.2444 ± 0.02 b
P3	3.14 ± 0.32 a	29.58 ± 2.95 a	0.93 ± 0.13 a	0.2554 ± 0.02 b
P4	3.34 ± 0,21 a	29.66 ± 1.79 a	1.10 ± 0.26 a	0.2676 ± 0.01 a
P5	3.43 ± 0.31 a	29.78 ± 1.65 a	1.14 ± 0.22 a	0.2745 ± 0.01 a

Note: Mean ± standard deviation (n = 3). Different letters in the same column declared significantly different in the Tukey test (α = 0.05).

The dispersion of clay particles within the soil micro structure (<250 µm) can be minimized through the formation of bonds between clay particles and organic acids secreted by plant roots (Kobierski *et al*., 2018). Meanwhile, the development of macro soil structures is influenced by the penetration capability and growth volume of plant roots. Soil micro structure plays a crucial role in sustaining water content at field capacity (Chen *et al*., 2021; Grunwald *et al*., 2016). The relationship between soil organic carbon and plant growth is illustrated in Figures 2 and 3.

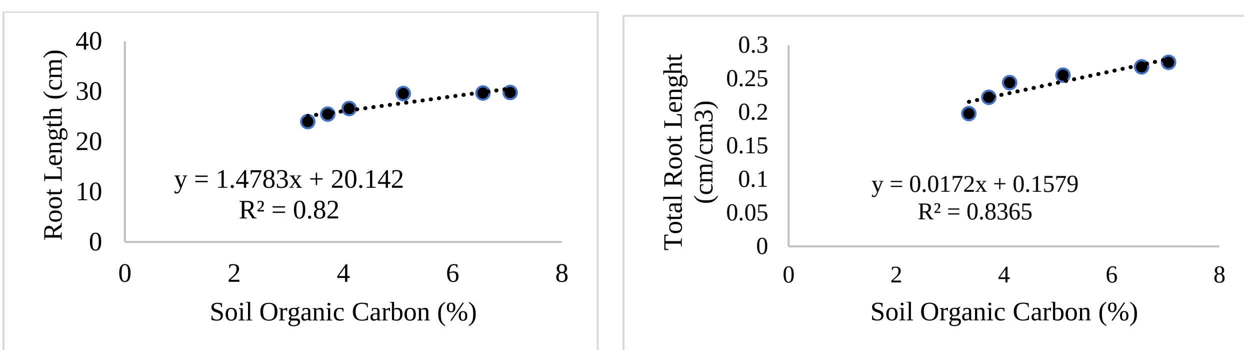

Figure 2. Relationship between organic carbon and root length of plants (a) and total root length of plants (b)

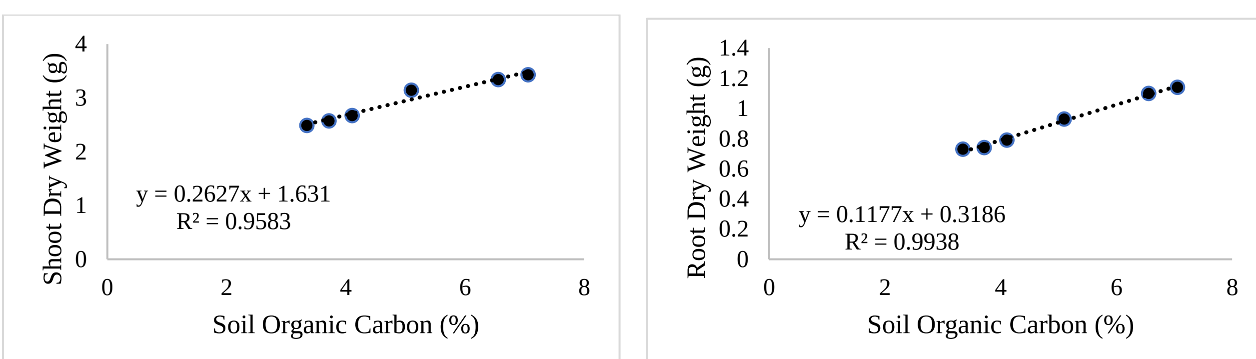

Figure 3. Relationship between soil organic carbon and shoot dry weight (a) and root dry weight (b)

Root growth improves with an increase in soil organic carbon. The application of organic fertilizer enhances soil microorganism activity, particularly in soils with low organic carbon. Additionally, increased nitrogen availability promotes root development and stimulates microbial activity in the soil (Jindo *et al*., 2012).

A noticeable finding in this study was that soil hydraulic conductivity improved with higher soil organic carbon, while water holding at field capacity also showed a significant increase. However, this study could not fully elucidate the relationship between increased soil organic carbon, root growth, and changes in soil structure. The provision of organic fertilizer can increase the volume of macro soil pores in massive intra and inter aggregate soil structures such as in intensive rice fields (Zhou *et al*., 2016). The presence of soil organic carbon tends to move towards the plant's root system so that it can increase the nitrogen content of the soil. Nevertheless, the root growth of plants is not entirely affected by soil organic carbon. Root growth can be enhanced through cyclical assurance and nitrogen availability in the root system (Li *et al*., 2022).

Future research should focus on understanding the changes in soil pore size distribution associated with organic carbon and plant root growth. Investigating organic fertilizer treatments with varying carbon : nitrogen ratio is also crucial to better understand the formation of soil micro structure in sandy soils.

4. CONCLUSION

The study demonstrated that applying organic fertilizer to sandy soils significantly influenced soil water availability, shoot dry weight, and tomato root growth. There was a strong to very strong correlation between increasing soil organic carbon and water holding capacity, root length, and plant dry weight. Future research should explore the effects of applying organic carbon with varying C/N ratio on changes in the pore size distribution of sandy soils.

ACKNOWLEDGEMENT

The author would like to express their gratitude to the parties who made important contributions to the research, such as the Dean of the Agriculture Faculty, Tadulako University as the person in charge of the Soil Science Laboratory of the Agriculture Faculty.

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