Heliyon 10 (2024) e32082

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Organic amendment composition and sowing depth in coffee Arabica: Effects on seedling growth biometrics

Dargie Tsegay Berhe

Dilla University, College of Agriculture and Natural Resources, Dilla, Ethiopia

ARTICLE INFO

Keywords:
Organic amendment
Coffee seedling
Sowing depth
Soil fertility
Environment

ABSTRACT

There is a significant production of coffee in the Gedeo zone, southern Ethiopia, which has could generate a huge amount of coffee husk wastes that have polluted the environment. However, organically enriching the soil is an effective method to enhance the development and productivity of coffee. Thus, this study aims to understand the effects of the interaction between sowing depth and organic amending practices. Three sowing depths and sixteen different organic amendment compositions were tested in a complete randomized design with three replications. Coffee seedling growth biometrics was measured, and R-program was used to calculate the statistical difference at a 5 % significance level. The organic amendment composition with 3:2:1 (topsoil: forest soil: sand) sown at a depth of 2 cm had statistically higher values of seedling stem height, leaf length, and taproot length by 82.82 %, 93.35 %, and 85.41 % than in the topsoil at a depth of 3 cm. Likewise, the main effect of organic amendment with 3:2:1 (topsoil: forest soil: sand) in internode length, number of nodes per seedling stem, number of true leaves per seedling, and leaf width were also higher by 70.42 %, 63.16 %, 92.23 % and 91.80 % than seedlings grown in topsoil solely. Interestingly, the days of 50 % emergence in 3:2:1 (ratio of topsoil: forest soil: sand) organic amendment composition were earlier by 62.11 days than using topsoil. This could be because of the accessibility of a significant quantity of organic carbon, primary macronutrients, alkaline nature of the growth media in addition to having low bulk and particle densities in the forest soil that could increase coffee seedling growth biometrics by improving soil porosity, aeration and nutrient uptake capacity, producing important soil microbes and neutralizing organic acids in comparison with the topsoil.

1. Introduction

Coffee is cultivated in more than 60 countries located in tropical and subtropical regions of the world [1]. Its agro-ecosystems support millions of farmers through income-generating and offering environmental services [2–6]. Coffee is one of the main crops grown in countries such as Brazil, Vietnam, Colombia, Indonesia, and Ethiopia [7,8]. In Ethiopia, the area dedicated to coffee farms in 2017 was approximately 700,475 ha from which 496,091 tons were produced. Oromia Region and Southern Region accounted for 64 and 30 % of the national production share respectively. Gedeo is the second major coffee producer zone in Southern Regional State, after Sidama Zone in Ethiopia ([9]; CSA, 2017). According to Kuma et al. [10] and USAID [11], livelihood in Gedeo Zone is divided into Coffee livelihood areas and Enset livelihood areas where the former is the dominant one.

Coffee seedlings can be grown on raised beds (15 cm height) or in polythene tubes (16 cm diameter and 22 cm height) filled with

E-mail address: tsegadar@yahoo.com.

https://doi.org/10.1016/j.heliyon.2024.e32082
Received 4 February 2024; Received in revised form 26 May 2024; Accepted 28 May 2024
Available online 30 May 2024

forest soil collected from the top 5–10 cm depth. Forest soil is the best organic amendment for quality seedling production [12]. However, in the absence of forest soil (FS), a mixture of decomposed coffee husk, topsoil, and sand soil can be used. According to EIAR [12], the use of topsoil, decomposed coffee husk, and sand in ratios of 3:1:0, 2:1:1, 2:1:0, and 6:3:2 resulted in maximum germination percent and early seedling vigor in diminishing order. Nevertheless, if these media blends are expected to be low in plant nutrients, the addition of 2 g DAP/seedling after the seedling attains two pairs of true leaves would improve seedling growth [13]. Sowing depth could also affect the germination and seedling growth of coffee. According to EIAR [12], for maximum coffee germination and quality seedling production, coffee seeds should be sown at a depth of 1 cm with a grooved side of the seed down. In the Yirgacheffee district, experts use a combination of topsoil, decomposed coffee husk, and sand in a ratio of 4:2:1 and a sowing depth of about 2–3 cm.

The lack of soil fertility in Yirgacheffee, which is closely linked to the low organic matter content, is one of the factors limiting coffee yield in the entire area [14]. Yirgacheffee speciality coffee faces substantial risks in the event of climate change, and adaptation strategies are required to address this issue. The EIAR [12] highlights organic fertilization of soil as one of the key strategies because organic matter improves the physical, chemical, and biological properties of soils and sustains fertility, which is important for long-term soil conservation and/or restoration [15–19]. Among the techniques to increase the amount of organic matter in the soil are crop rotations, no-tillage farming, and the removal of pruning wood from the plant-soil [20]. But applying organic waste, which typically contains high levels of organic matter and significant amounts of nutrients, can also improve soil fertility. Moreover, using organic waste in agriculture can help close natural ecological cycles [21,22].

The supply of organic fertilizers made from alternative leftovers has increased, making up for the decline in soil organic matter replacement caused by the scarcity of animal manures. There is a particular interest in forest soil, coffee husk compost, and farmyard manure, due to their huge availability in the study area. Sowing depth appears to be an interesting strategy to increase seed germination and seedling growth. Conversely, organic amendments tend to boost productivity and enhance soil fertility. However, the interaction between a sowing depth and an organic amendment was not previously studied, to the best of my knowledge. In this context, the main objective of this study is to evaluate the response of coffee seedling growth biometrics to the interactive effects of different organic amendment compositions and sowing depths.

2. Materials and method

2.1. Study area description

The experiment was carried out in Dumerso kebele of Yirgacheffe district (Fig. 1) which is located at 6° 12′ 49″ N latitude and 38° 12′ 21″ E longitudes from January 2020 to February 2021. Dumerso has an altitude of 1859 m above sea level and the area is highly suitable for quality coffee production. There are about twenty coffee-processing businesses in the area that process coffee both wet and dry and have the potential to generate enormous amounts of discarded coffee pulp. Due to possible animal production in the area, there was also a huge amount of animal dung waste available. The climate in Yirgacheffe is warm and tropical climate with moderate wet and dry seasons. The soil type is a red brown, well drainage clay soil. Yirgacheffe has the ideal topography, elevation, and water sources to produce and process exceptional specialty organic coffees.

2.2. Experimental design and treatments

A total of 48 treatments consisting of sixteen organic amendment compositions and three sowing depths were evaluated using Complete Randomized Design (CRD) with three replications in a factorial arrangement (Table 1). Organic amendments were collected, sieved, mixed thoroughly to formulate treatments, and filled in a polythene tube (with 16 cm diameter and 22 cm height). Each plot was accommodated 30 polythene tubes and hence a total of 4320 (16 organic amendment compositions x 3 sowing depth x 3

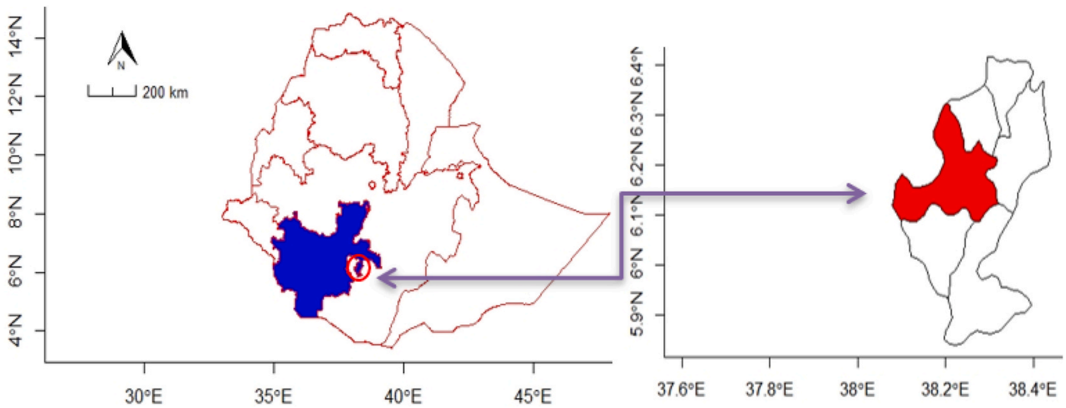

Fig. 1. The experimental research area (blue color = SNNPRS; Red color=Yirgacheffe). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Treatment combinations of organic amendments and sowing depths.

Treatments	Organic amendment Composition	Sowing Depth (cm)
T_1-T_3	Topsoil only (Control)	1, 2, 3
T_4-T_6	3 Topsoil: 1 Coffee Husk Compost: 0 Sand	1, 2, 3
T_7-T_9	2 Topsoil: 1 Coffee Husk Compos: 1 Sand	1, 2, 3
T_{10}-T_{12}	2 Topsoil: 1 Coffee Husk Compos: 0 Sand	1, 2, 3
T_{13}-T_{15}	4 Topsoil: 2 Coffee Husk Compos: 1 Sand	1, 2, 3
T_{16}-T_{18}	3 Topsoil: 2 Coffee Husk Compos: 1 Sand	1, 2, 3
T_{19}-T_{21}	3 Topsoil: 1 Forest Soil: 0 Sand	1, 2, 3
T_{22}-T_{24}	2 Topsoil: 1 Forest Soil: 1 Sand	1, 2, 3
T_{25}-T_{27}	2 Topsoil: 1 Forest Soil: 0 Sand	1, 2, 3
T_{28}-T_{30}	4 Topsoil: 2 Forest Soil: 1 Sand	1, 2, 3
T_{31}-T_{33}	3 Topsoil: 2 Forest Soil: 1 Sand	1, 2, 3
T_{34}-T_{36}	3 Topsoil: 1 Farmyard Manure: 0 Sand	1, 2, 3
T_{37}-T_{39}	2 Topsoil: 1 Farmyard Manure: 1 Sand	1, 2, 3
T_{40}-T_{42}	2 Topsoil: 1 Farmyard Manure: 0 Sand	1, 2, 3
T_{43}-T_{45}	4 Topsoil: 2 Farmyard Manure: 1 Sand	1, 2, 3
T_{46}-T_{48}	3 Topsoil: 2 Farmyard Manure: 1 Sand	1, 2, 3

replications x 30 polythene per plot) was used for the study. Coffee seeds (variety, 74112) were sown at different depths in a field. Watering, weeding, and other agronomic practices were applied to all treatments uniformly.

2.3. *Data collection procedures*

Days to 50 % emergence were registered by counting the average days from sowing to 50 % seedling emergence at the first true leaves growth stage. Plant height is recorded by holding the ruler close to the stem of the seedling. The height was measured from the ground level to the tip of the seedling with a ruler in centimeters. At the matured stage, the number of reproductive nodes was determined by counting all nodes along the main seedling stem. Besides, the internode length of the stem was recorded by dividing plant height by the number of internodes. The number of true leaves per plant at a maximum stage of seedling growth was counted. Leaf length and leaf width of normal leaves (excluding 3 nodes from the terminal bud) was measured from petiole end to apex of a leaf and at the widest part using a ruler respectively. Additionally, the roots were carefully excavated, cleaned with water and measured the length of the taproot using a ruler in centimeters.

2.4. *Organic amendments nutrient analysis*

pH, organic carbon (CO), total nitrogen (N), available phosphorus (P), exchangeable potassium (K), exchangeable calcium (Ca), exchangeable magnesium (Mg), bulk density (BD) and particle density (PD) were determined for four media components namely topsoil, forest soil, coffee husk compost and farmyard manure. Organic carbon was determined by the Walkley-Black dichromate method [23,24] as cited by Landon [25]. The results were quoted as the percentage by weight of organic carbon in the organic amendments according to Bashour and Sayegh [26]. According to Tan [27], the pH of organic amendments was tested using a 1:10 (w/v) water solution of the samples. The total nitrogen content was determined by the micro Kjeldahl digestion and distillation system, which involves the catalytic oxidation of organic and chemically combined N and subsequent alteration to $NH4$, then to $NH3$ [24]. The colorimetric molybdate blue approach was used to measure the available phosphorus [28]. The exchangeable bases, namely, potassium (K), calcium (Ca) and magnesium (Mg) were extracted from the soil media using neutral normal ammonium acetate [29] and measured by titration with Trilon [30]. Particle density (PD) was determined using a graduated cylinder followed by Tan et al. [31] method and the bulk density (BD) was calculated by the following equation:

$$\text{Bulk density} = \frac{\text{Dried weight of the soil}}{\text{Volume of the soil}}$$

2.5. *Statistical data analysis*

Shapiro-Wilk's test was used to check if the data satisfied the assumptions of the analysis of variance (ANOVA), and two-way ANOVA (organic amendment × sowing depth) was then applied in a complete randomized design. The significance level was set at $\alpha = 0.05$ and means were separated using Tukey's honestly significant difference test. The statistical analysis was performed using R-program (version 4.3.3, 2024). To determine the relationship between the variables, correlation analysis was also performed.

3. Results and discussion

3.1. *Physicochemical properties of organic amendments*

There were highly significant ($P < 0.001$) differences among all physical and chemical properties of the organic amendments. The highest percentage of organic carbon was found in the forest soil (39.90 ± 1.20) followed by coffee husk compost (34.82 ± 0.36), while the lowest values were recorded in topsoil (1.21 ± 0.04) and farmyard manure (19.95 ± 0.11). Likewise, the highest percentage of total nitrogen content (2.39 ± 0.06), percentage of available phosphorus (0.41 ± 0.02), and the exchangeable potassium (1.87 ± 0.05 $cmol_{(+)}$/kg of soil), calcium (33.11 ± 0.31 $cmol_{(+)}$/kg) and magnesium (19.69 ± 0.63 $cmol_{(+)}$/kg) were registered in forest soil; in contrast, the topsoil had lower levels of the aforementioned soil chemical characteristics. Furthermore, the pH levels that were higher were observed in forest soil (8.83 ± 0.25) and coffee husk compost (7.93 ± 0.25) while the lower pH values were found in the topsoil (5.87 ± 0.25) and farmyard manure (7.37 ± 0.15) organic amendments (Fig. 2).

Conversely, the maximum bulk density (1.51 ± 0.03 g/cm^3) and particle density (2.69 ± 0.03 g/cm^3) were registered in the topsoil while the minimum bulk density (0.40 ± 0.03 g/cm^3) and particle density (1.26 ± 0.04 g/cm^3) were recorded in the forest soil (Fig. 2).

3.2. Days of 50 % emergence

The main effect of organic amendments on days of 50 % emergence has shown highly significant ($P < 0.001$) variation while its interaction effect with the sowing depth was not significant ($P > 0.05$). The earlier days of 50 % emergence (25.22 ± 1.79) were observed in 3:2:1 (topsoil: forest soil: sand) followed by 3 topsoil: 2 coffee husk: 1 sand (35.44 ± 1.42) and 4 topsoil: 2 forest soil: 1 sand (30.56 ± 2.40) whereas the delayed 50 % emergence days were observed in topsoil (87.33 ± 1.58) followed by the ratio of 3 topsoil: 1 farmyard manure: 0 sand (85.88 ± 1.27) and 3 topsoil: 1 coffee husk: 0 sand (83.89 ± 1.45). The days of 50 % emergence in 3:2:1 (ratio of topsoil: forest soil: sand) proportion emerged earlier by 62.11 days compared with using topsoil exclusively (Fig. 3) perhaps as a result of the notable variation in the physical and chemical properties of the growth media (Fig. 2).

The main effect of a sowing depth on mean days to 50 % emergence was also highly significant ($P < 0.001$). The earlier days of 50 % emergence (59.89 ± 20.71) were observed at a depth of 2 cm whereas the delayed seedling emergence (63.65 ± 20.44) was found at 3 cm sowing depth (Table 3). In line with the current study, some authors describe that forest soil and organic fertilizers improve plant emergence velocity and yield enrichment [32–37]. In addition, seedling emergence in decomposed coffee husk application is more effective compared to using topsoil only [5,33,38–41], probably due to the availability of high organic carbon and the primary macronutrients [15–18] and low pH value, bulk and particle density (Fig. 2) density which improves soil porosity, aeration and nutrient uptake capacity [42] in the organic amendments. The availability of calcium, magnesium, and potassium contents may aid in the neutralization of organic acids and enhance the absorption of other nutrients by roots and their translocation within the coffee plant [40]. The higher pH values in the organic amendments may be related to increased plant growth rate and produce more root exudates as a carbon source available for survival and multiplication of microbes [43].

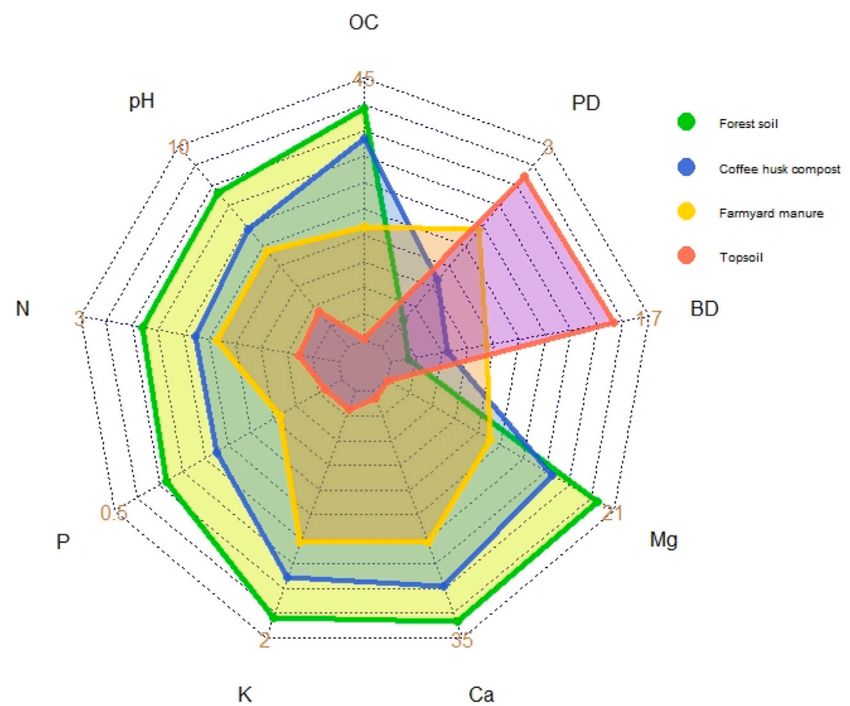

Fig. 2. *Spider plot for soil physicochemical properties of different organic amendments.*

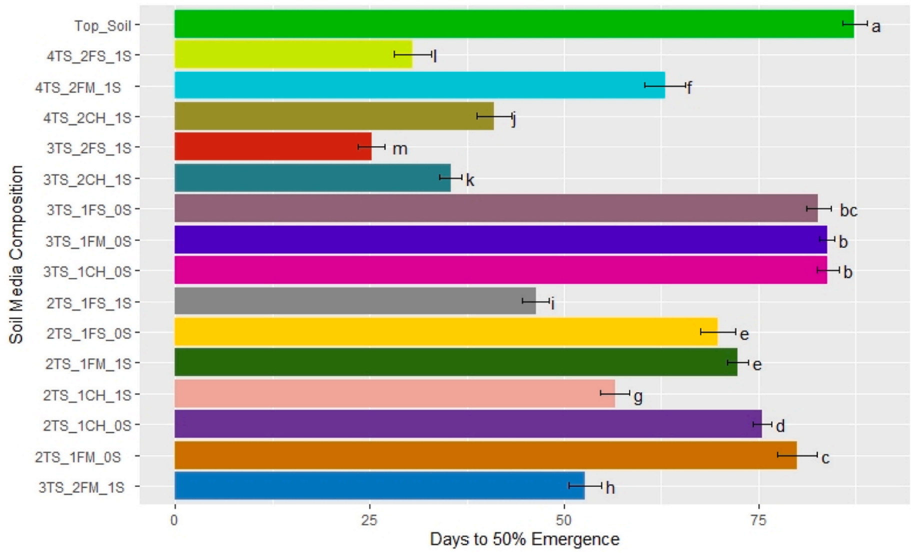

Fig. 3. *Response of days of 50 % coffee seedling emergence to organic amendment composition*; TS = topsoil, FS = forest soil, CH = coffee husk, FM = farmyard manure, S = sand.

3.3. Seedling height (cm)

The interaction effect of growth media and a sowing depth on mean coffee seedling height was a highly significant ($P < 0.001$) difference. Interestingly, the tallest seedling height (57.11 ± 1.37) was recorded in the organic amendment substrate constituting with 3:2:1 (topsoil: forest soil: sand) proportion sown at a depth of 2 cm followed by 4:2:1 (topsoil: forest soil: sand) ratio in 1 cm depth (54.83 ± 1.18) and 3:2:1 (topsoil: forest soil: sand) at a depth of 1 cm (53.63 ± 1.25) while the shortest seedling heights were registered in the topsoil solely in 3 cm (9.81 ± 0.25), 1 cm (10.83 ± 0.49) and 2 cm (11.35 ± 0.68) sowing depths, respectively. Besides, coffee seedling height in 3:2:1 (topsoil: forest soil: sand) ratio sown in 2 cm depth was statistically taller by 82.82 % than seedling height grown using topsoil merely at a depth of 3 cm (Table 2).

As depicted in Fig. 2, forest soil showed higher seedling height compared to coffee husk compost and farmyard manure perhaps as a result of the notable differences in the contents of total nitrogen and organic carbon [15,17] which led to raise plant height by enhancing soil fertility and nutrient uptake capacity. The alkaline nature of forest soil pH is accountable for producing more root exudates and multiplication of soil microbes [43]. Similarly, the low bulk and particle densities in the organic amendments could improve soil porosity, aeration and nutrient uptake capacity as supported by Pham et al. [42]. According to Getachew and Muleta [40], the organic amendments' exchangeable calcium, magnesium, and potassium content may neutralize organic acids and enhance the absorption of other nutrients.

This study's outcome also agreed with several other research outputs [2,4,5,32,34,44–49] who generally and concisely reported that taller plant heights were observed when grown using organic amendments such as forest soil, decomposed coffee husk, farmyard manure, vermicompost, animal and plant biochar etc. This could be because of a huge amount of organic matter and total nitrogen present [15,17,19,50] which enhance the capacity to easily uptake nutrients [42,51], maintain soil moisture and enhance soil fertility [52,53] that ultimately improves growth media porosity, aeration and water retention capacity [54]. Pampuro et al. [55] show evidence that organic amendments act as growth regulators, enabling plants to withstand adverse environmental conditions. Through destructive, antagonism, and inhibitory actions, it also aids in maintaining the biological balance of the soil and inhibits the growth of hazardous microbes [52]. Chemura et al. [56] came to the conclusion that an overabundance of organic amendments might cause more vegetative growth to accumulate than an improvement in crop yield.

3.4. Leaf length (cm)

The combination influence of organic amendment and a sowing depth on average coffee leaf length was a highly significant ($P < 0.05$) difference. The maximum leaf length (23.15 ± 0.32) was recorded in the organic substrate constitutes with 3:2:1 (topsoil: forest soil: sand) proportion sown at a depth of 2 cm followed by 3:2:1 (topsoil: forest soil: sand) in 1 cm depth (22.17 ± 0.35) and 4:2:1 (topsoil: forest soil: sand) sown at a depth of 2 cm (21.96 ± 0.50) while the minimum leaf lengths were registered using topsoil alone in 3 cm (1.54 ± 0.16), 1 cm (1.93 ± 0.15) and 2 cm (1.98 ± 0.24) sowing depths, respectively. The coffee leaf length in the 3:2:1 (topsoil: forest soil: sand) was exceeded by 93.35 % compared to seedling grown using topsoil at a depth of 3 cm (Table 2).

In a more general context, coffee seedling leaf length was higher in soil substrate constitutes of forest soil followed by coffee husk while the shorter leaf lengths were observed in the control treatment using topsoil only and soil composition with farmyard manure. The growth media compositions with forest soil had adequately longer leaves probably due to the high percentages of organic carbon,

Table 2
Interaction effect of growth media and a sowing depth on coffee seedling height, leaf length, taproot length.

Growth Media	Sowing Depth	Seedling Height	Leaf Length	Taproot Length
Top Soil only	1 cm	10.83 ± 0.49^{KL}	1.93 ± 0.15^{yz}	6.87 ± 0.32^{G}
2 TS_1CH_0S	1 cm	22.17 ± 0.40^{yz}	5.23 ± 0.15^{opqr}	16.79 ± 0.68^{vw}
2 TS_1CH_1S	1 cm	29.93 ± 0.15^{pq}	10.60 ± 0.82^{k}	23.93 ± 0.15^{no}
3 TS_1CH_0S	1 cm	14.87 ± 0.42^{GH}	3.56 ± 0.25^{uvwx}	11.60 ± 0.11^{CD}
3 TS_2CH_1S	1 cm	45.66 ± 0.75^{g}	20.67 ± 1.32^{c}	30.53 ± 0.82^{g}
4 TS_2CH_1S	1 cm	41.94 ± 0.79^{i}	18.03 ± 1.16^{efg}	27.47 ± 0.60^{ij}
2 TS_1FS_0S	1 cm	27.33 ± 0.36^{tu}	6.63 ± 0.45^{mn}	19.68 ± 0.75^{s}
2 TS_1FS_1S	1 cm	39.16 ± 0.85^{k}	17.40 ± 0.73^{fgh}	26.13 ± 0.69^{kl}
3 TS_1FS_0S	1 cm	17.67 ± 0.38^{E}	3.83 ± 0.31^{tuvw}	13.72 ± 0.36^{zA}
3 TS_2FS_1S	1 cm	53.63 ± 1.25^{c}	22.17 ± 0.35^{b}	40.67 ± 1.68^{b}
4 TS_2FS_1S	1 cm	51.74 ± 0.82^{d}	20.90 ± 0.79^{c}	34.19 ± 0.90^{e}
2 TS_1FM_0S	1 cm	19.81 ± 0.40^{BC}	4.33 ± 0.51^{rstu}	$15.63{+}{\pm}0.32^{xy}$
2 TS_1FM_1S	1 cm	24.32 ± 1.00^{vw}	5.67 ± 0.15^{nopq}	18.22 ± 0.40^{u}
3 TS_1FM_0S	1 cm	12.36 ± 0.64^{IJ}	2.80 ± 0.26^{xy}	10.27 ± 0.35^{E}
3 TS_2FM_1S	1 cm	34.62 ± 0.65^{m}	13.10 ± 1.08^{j}	25.64 ± 0.44^{lm}
4 TS_2FM_1S	1 cm	29.03 ± 0.31^{qrs}	7.53 ± 0.67^{m}	21.87 ± 0.31^{qr}
Top Soil only	2 cm	11.35 ± 0.68^{JK}	1.98 ± 0.24^{yz}	8.31 ± 0.34^{F}
2 TS_1CH_0S	2 cm	22.96 ± 0.21^{xy}	6.10 ± 0.36^{no}	17.74 ± 0.42^{uv}
2 TS_1CH_1S	2 cm	31.15 ± 0.35^{o}	11.33 ± 0.50^{k}	24.33 ± 0.44^{no}
3 TS_1CH_0S	2 cm	15.60 ± 0.62^{FG}	4.03 ± 0.14^{stuv}	12.25 ± 0.38^{BC}
3 TS_2CH_1S	2 cm	47.91 ± 0.36^{f}	21.40 ± 0.62^{bc}	32.71 ± 1.64^{f}
4 TS_2CH_1S	2 cm	42.69 ± 1.15^{hi}	18.60 ± 1.39^{de}	28.57 ± 1.35^{g}
2 TS_1FS_0S	2 cm	27.98 ± 0.15^{st}	7.23 ± 0.38^{m}	20.83 ± 0.55^{r}
2 TS_1FS_1S	2 cm	39.74 ± 0.40^{jk}	17.97 ± 0.49^{efg}	26.96 ± 0.93^{jk}
3 TS_1FS_0S	2 cm	18.69 ± 0.36^{DE}	4.27 ± 0.21^{rstu}	14.18 ± 0.23^{z}
3 TS_2FS_1S	2 cm	57.11 ± 1.37^{a}	23.15 ± 0.32^{a}	43.53 ± 1.12^{a}
4 TS_2FS_1S	2 cm	54.83 ± 1.18^{b}	21.96 ± 0.50^{b}	35.64 ± 0.75^{d}
2 TS_1FM_0S	2 cm	20.51 ± 0.74^{AB}	4.77 ± 0.35^{qrst}	15.80 ± 0.36^{wxy}
2 TS_1FM_1S	2 cm	25.17 ± 1.23^{v}	6.64 ± 0.55^{mn}	19.55 ± 0.70^{st}
3 TS_1FM_0S	2 cm	13.02 ± 0.31^{I}	3.11 ± 0.32^{vwx}	11.13 ± 0.31^{DE}
3 TS_2FM_1S	2 cm	35.62 ± 0.76^{m}	14.52 ± 1.01^{i}	25.97 ± 0.25^{kl}
4 TS_2FM_1S	2 cm	29.74 ± 0.31^{pqr}	8.55 ± 0.76^{l}	22.88 ± 0.24^{pq}
Top Soil only	3 cm	9.81 ± 0.25^{L}	1.54 ± 0.16^{z}	6.35 ± 0.26^{G}
2 TS_1CH_0S	3 cm	21.15 ± 0.25^{zA}	4.95 ± 0.15^{pqrs}	16.14 ± 0.17^{wx}
2 TS_1CH_1S	3 cm	30.31 ± 0.46^{op}	8.72 ± 0.98^{l}	23.32 ± 0.28^{op}
3 TS_1CH_0S	3 cm	14.31 ± 0.72^{H}	3.02 ± 0.36^{wx}	10.80 ± 0.26^{DE}
3 TS_2CH_1S	3 cm	43.60 ± 0.92^{h}	18.34 ± 0.45^{def}	28.29 ± 0.61^{hi}
4 TS_2CH_1S	3 cm	40.52 ± 0.51^{j}	17.35 ± 0.40^{gh}	26.54 ± 0.44^{jkl}
2 TS_1FS_0S	3 cm	26.66 ± 0.86^{u}	5.91 ± 0.36^{nop}	18.58 ± 0.38^{tu}
2 TS_1FS_1S	3 cm	37.93 ± 0.15^{l}	16.61 ± 0.82^{h}	25.50 ± 0.36^{lm}
3 TS_1FS_0S	3 cm	16.40 ± 0.57^{F}	3.24 ± 0.26^{vwx}	12.87 ± 0.43^{AB}
3 TS_2FS_1S	3 cm	51.87 ± 0.31^{d}	20.76 ± 0.47^{c}	39.03 ± 1.83^{c}
4 TS_2FS_1S	3 cm	49.46 ± 0.60^{e}	19.13 ± 0.73^{d}	33.41 ± 0.62^{ef}
2 TS_1FM_0S	3 cm	19.00 ± 0.10^{CD}	3.81 ± 0.15^{tuvw}	14.73 ± 0.31^{yz}
2 TS_1FM_1S	3 cm	23.57 ± 0.76^{wx}	5.53 ± 0.26^{opq}	17.87 ± 0.39^{u}
3 TS_1FM_0S	3 cm	11.70 ± 0.46^{JK}	1.98 ± 0.22^{yz}	8.96 ± 0.25^{F}
3 TS_2FM_1S	3 cm	32.50 ± 0.87^{n}	11.22 ± 0.46^{k}	24.78 ± 0.27^{mn}
4 TS_2FM_1S	3 cm	28.80 ± 0.30^{rs}	7.45 ± 1.16^{m}	21.23 ± 0.57^{r}
Mean		29.72	10.19	21.49
CV		2.23	5.97	3.13
LSD		1.08	0.99	1.09
P-value		***	**	**

Means within a column followed by the same letter(s) are not significantly different at a 5 % LSD test; TS = topsoil, FS = forest soil, CH = coffee husk, FM = farmyard manure, S = sand.

total nitrogen content, exchangeable potassium, calcium, magnesium and pH but low in bulk and particle density (Fig. 2). Likewise, seedling leaf lengths were declined when the ratios of organic amendments reduced in the media compositions.

In this regard, Takala [46] and Hirpa [47] explored similar findings that the organic amendments produce longer leaves, possibly due to the presence of high organic carbon [15–18], total nitrogen content [19], which plays a massive role in light interception [57], vegetative growth and development rates [19], photosynthetic efficiency [58], evapotranspiration [57] and the use of nutrients [42] and water (Adrinal et al., 2021). In this sense, Castillo and Andrade [5] confirmed that the leaves of Arabica coffee patterns significantly varied in various fertilizers types and rates.

Table 3
The effect of a sowing depth on days to 50 % emergence, internode length, number of nodes, number of true leaves and leaf width.

Sowing Depth	Days to 50 % Emergence	Internode length	Number of nodes	Number of true leaves	Leaf width
1 cm	61.73 ± 20.67[b]	3.31 ± 1.01[b]	6.52 ± 2.25[ab]	26.00 ± 16.02[b]	6.75 ± 4.08[b]
2 cm	59.89 ± 20.71[c]	3.40 ± 1.05[a]	6.68 ± 2.24[a]	27.60 ± 16.63[a]	7.06 ± 4.24[a]
3 cm	63.65 ± 20.44[a]	3.27 ± 1.04[b]	6.29 ± 2.15[b]	24.42 ± 15.44[c]	6.39 ± 4.02[c]
Mean	61.76	3.33	6.49	26.01	6.73
CV	1.56	3.59	8.80	5.82	4.47
LSD	0.39	0.05	0.23	0.61	0.12
P-value	***	***	**	***	***

Means within a column followed by the same letter(s) are not significantly different at a 5 % LSD test.

3.5. Taproot length (cm)

The combination effect of organic amendment and a sowing depth on average coffee taproot length was substantially significant (P < 0.05). The longest taproot (43.53 ± 1.12) was recorded in the organic matter and available phosphorus-rich forest soil substrate constitutes with 3:2:1 (topsoil: forest soil: sand) proportion sown at a depth of 2 cm followed by 3:2:1 (topsoil: forest soil: sand) at a depth of 1 cm (40.67 ± 1.68) and 3 cm (39.03 ± 1.83) while the shortest taproot lengths were registered in the poor in phosphorus and organic carbon topsoil in 3 cm (6.35 ± 0.26), 1 cm (6.87 ± 0.32) and 2 cm (8.31 ± 0.34) sowing depths, respectively. Accordingly, coffee taproot length in the 3:2:1 (topsoil: forest soil: sand) ratio in 2 cm depth was statistically longer by 85.41 % than grown in topsoil at a depth of 3 cm (Table 2).

The taproot length was higher in soil substrate constitutes of forest soil followed by coffee husk compost while the shorter taproots were observed using topsoil only and soil composition with farmyard manure possibly due to the amount of growth media physical and chemical properties (Fig. 2). The available phosphorus in the organic amendments mainly in forest soil may improve cell division and development of new tissue, associate with energy transformations in the plant, promote root growth and stimulate root penetration, and often hastens maturity as supported by Anteneh and Heluf [13]. On other hand, the topsoil had low bulk and particle densities (Fig. 2) which could be used as indicators for problems in root growth and poor soil aeration.

The current findings are also in agreement with Poncet et al. (2024), Bracken et al. [3], Castillo and Andrade [5], Wegari and Amin [59], Bohórquez et al. [60], Silva et al. [61], Defrenet et al. [62], who reported that top root length exhibits significant variation in different plant growth media compositions. This might be chiefly due to the fertility variation of the organic amendment compositions [63] and growing condition difference [64] that enabled the seedling taproot to penetrate deeply and store assimilates from source to sink. Likewise, Ribeirinho et al. [50] explored that taproot length in soil with enough organic matter and available phosphorus is longer and stabilized on soil minerals more efficiently. Roots are thus major contributors to stable soil organic matter build-up, especially in deep soil layers as substantiated by Yenani et al. [17].

3.6. Number of nodes

The main effect of organic amendments on the mean number of nodes was highly significant (P < 0.001) whereas the interaction

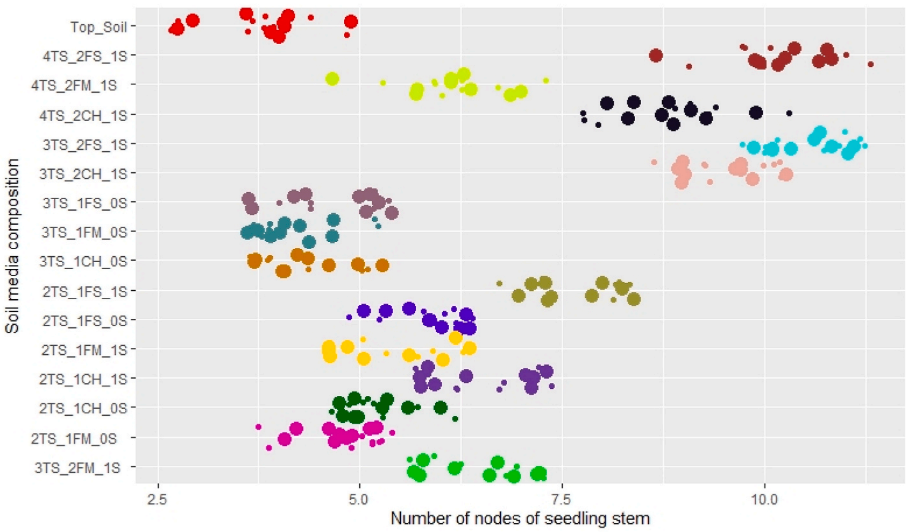

Fig. 4. *Influence of organic amendment composition in the number of nodes.*

effect with a sowing depth was not significant ($P > 0.05$). The highest numbers of nodes (10.56 ± 0.53) were found in 3 topsoil: 2 forest soil: 1 sand and in the growth media composition of 4 topsoil: 2 forest soil: 1 sand (10.21 ± 0.66) while the lowest number of nodes was observed in topsoil (3.89 ± 0.60) followed by in the soil substrates constitutes with 3 topsoil: 1 farmyard manure: 0 sand (4.22 ± 0.44). The number of nodes in 3:2:1 (ratio of topsoil: forest soil: sand) organic amendment proportion was elevated by 63.16 % compared with the number of nodes in the topsoil alone (Fig. 4) possibly due to the high percentage of organic carbon, the primary macronutrients, alkaline nature of the growth media and low in bulk and particle density of forest soil (Fig. 2).

The finding of this study was in agreement with some research results [2,5,65–69] who reported that higher number of nodes were observed when coffee seedlings grown using organic amendments possibly due to the availability of rich organic carbon [15–19] that eventually improves growth media porosity, aeration, nutrient uptake and water retention capacity (Adrinal et al., 2021).

The average number of nodes was significantly influenced ($P < 0.05$) by the main effect of a sowing depth. Likewise, the maximum number of coffee seedling nodes (6.68 ± 2.24) was scored at a depth of 2 cm while the minimum numbers of nodes were recorded in 3 cm (6.29 ± 2.15) and 1 cm (6.52 ± 2.25) sowing depths, respectively (Table 3). In contrast, Netsere and Kufa [69] reported that coffee seed germination and seedling growth was higher at a depth of 1 cm and had declined tendency with increasing a sowing depth. This might be due to the variation in the physicochemical properties of the growth media and other abiotic factors [62] particularly high temperature and light [70].

3.7. *Internode length (cm)*

The interaction effect of organic amendment composition and a sowing depth on mean internode length was not significant ($P > 0.05$) however there was a highly significant ($P < 0.001$) difference in the main effect of sowing media. Generally, the maximum internode length (5.68 ± 0.34) was recorded in the soil substrate constitutes with 3:2:1 (topsoil: forest soil: sand) proportion followed by a ratio of 4 topsoil: 2 forest soil: 1 sand (4.89 ± 0.22) and 3 topsoil: 2 coffee husk: 1 sand (4.31 ± 0.12) while the minimum seedling internode lengths were registered in the topsoil (1.68 ± 0.14) and 3 topsoil: 1 farmyard manure: 0 sand (2.14 ± 0.06) proportion. Concisely, coffee seedling internode length in the soil substrate constitutes with 3:2:1 (topsoil: forest soil: sand) was statistically longer by 70.42 % than seedling internode length grown using solely topsoil (Fig. 5) probably due to the high percentage of organic carbon, the primary macronutrients content, alkaline nature of the growth media and low bulk and particle density of forest soil (Fig. 2).

The current findings concur with Teixeira et al. [65], Muvunyi et al. [66], Rodrigues et al. [67] and Netsere and Kufa [69] who reported that internode lengths of coffee seedlings significantly varied in different plant growth media compositions, probably due to the fertility variation of the organic amendment [68] and the variation in growing condition [64]. Besides, DaMatta et al. [71] and Ribeirinho et al. [50] supported that the internode length of coffee seedlings in soil with enough organic matter is longer compared with seedlings grown merely in topsoil.

The main effect of a sowing depth on mean internode length was a highly significant difference ($P < 0.001$). The longer internode (3.40 ± 1.05) was recorded at a depth of 2 cm while the shorter internodes were registered in 3 cm (3.27 ± 1.04) and 1 cm (3.31 ± 1.01) sowing depths, respectively (Table 3) probably due to the variation in the physicochemical properties of the growth media (Fig. 2) and other abiotic factors [62] particularly temperature and light [70].

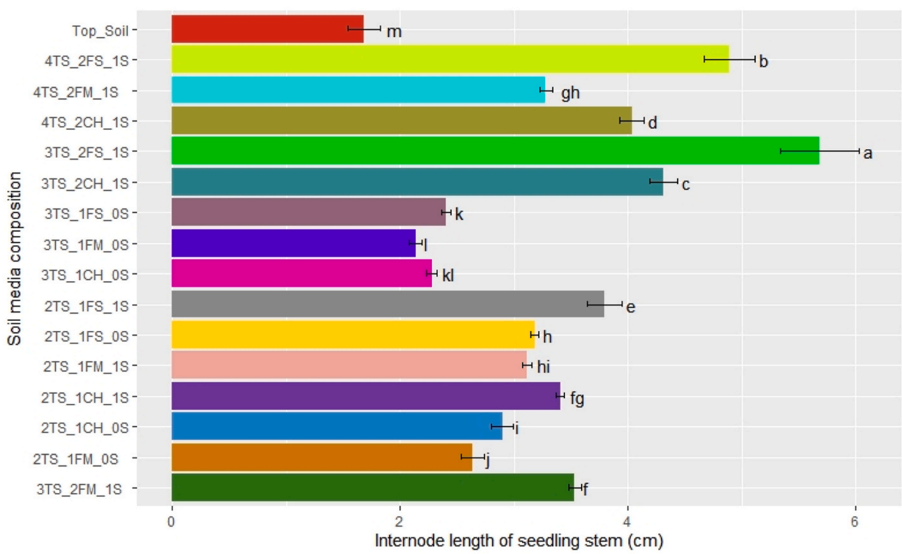

Fig. 5. *The effect of organic amendment composition in the internode length of seedling stem.*

3.8. Number of true leaves

The main effect of organic amendment on the average number of true leaves has shown a highly significant difference ($P < 0.001$) whereas the interaction effect of organic amendment and a sowing depth was non-significance ($P > 0.05$). The maximum number of true leaves (55.32 ± 3.24) was observed in 3 topsoil: 2 forest soil: 1 sand proportion followed by in the ratios of 4 topsoil: 2 forest soil: 1 sand (50.03 ± 2.74) and 3 topsoil: 2 coffee husk: 1 sand (46.01 ± 2.45) while the minimum number of true leaves was found in topsoil (4.30 ± 0.71) followed by the ratios of 3 topsoil: 1 farmyard manure: 0 sand (5.46 ± 1.22) and 3 topsoil: 1 coffee husk: 0 sand (8.19 ± 1.87). The number of true leaves in 3:2:1 (ratio of topsoil: forest soil: sand) organic amendment proportion was higher by 92.23 % than with using topsoil exclusively (Fig. 6).

Generally, the true number of leaves in coffee seedling was higher in soil substrate constitutes of forest soil followed by coffee husk compost while the lower true leaf numbers were observed in the control treatment using topsoil followed by the farmyard manure probably due to high percentages of organic carbon, calcium, magnesium, exchangeable potassium, total nitrogen content, and alkaline nature of the pH but low in bulk and particle density (Fig. 2). Likewise, the number of true leaves was declined when the ratios of organic amendments reduced in the growth media compositions supported by Castillo and Andrade [5], Letort et al. [72], Fernandes et al. [45] and Hirpa [47]. This could be also due to the photosynthetically active radiation and solar brightness [3,5,73] as the leaf is responsible for evapotranspiration, nutrient and water use, carbon assimilation, development rate, and photosynthetic efficiency [74].

The main effect of a sowing depth on the average number of true leaves was a highly significant difference ($P < 0.001$). The higher (27.60 ± 16.63) and lower (24.42 ± 15.44) number of true leaves were explored at a depth of 2 cm and 3 cm respectively (Table 3) possibly due to various abiotic factors [62] mainly the influence of temperature and light [70].

3.9. Leaf width (cm)

The principal influence of organic amendment on mean leaf width was a highly significant difference ($P < 0.001$) whereas the interaction effect of organic amendment and a sowing depth was non-significance ($P > 0.05$). The highest value of leaf width (14.02 ± 0.50) was found in 3 topsoil: 2 forest soil: 1 sand growth media proportion followed by the ratios of 4 topsoil: 2 forest soil: 1 sand (13.11 ± 0.37) and 3 topsoil: 2 coffee husk: 1 sand (12.19 ± 0.62) while the lowest leaf width was observed in topsoil (1.15 ± 0.24) followed by the ratios of 3 topsoil: 1 farmyard manure: 0 sand (1.94 ± 0.18) and 3 topsoil: 1 coffee husk: 0 sand (2.43 ± 0.15). The leaf width in 3:2:1 (ratio of topsoil: forest soil: sand) organic amendment proportion was higher by 91.80 % than with using topsoil alone (Fig. 7).

Interestingly, forest soil had statistically longer leaf width compared to the control treatment (topsoil) probably because of the substantial difference in total nitrogen and organic carbon [16–18] which led to increate leaf width by improving soil fertility. Likewise, the alkaline nature of forest soil pH could be accountable for the multiplication of important soil microbes [43]. Similarly, the low bulk and particle densities in the organic amendments could improve soil porosity, aeration and nutrient uptake capacity as supported by Pham et al. [42]. The availability of potassium, magnesium and exchangeable calcium in the organic amendments could neutralize organic acids and improve the absorption of other nutrients [40].

This is in coherence with several research findings [32,33,37–40,46,47] who reported that leaf dimension increases when grown using forest soil and various composts, possibly due to the availability of organic matter [15–18] and easily nutrient uptake [42]. Leaf width variation might be also depend on light interception [57], photosynthetic efficiency [58], and evapotranspiration [57].

The main effect of a sowing depth on mean leaf width was a highly significant difference ($P < 0.001$). The larger leaf width (7.06 ±

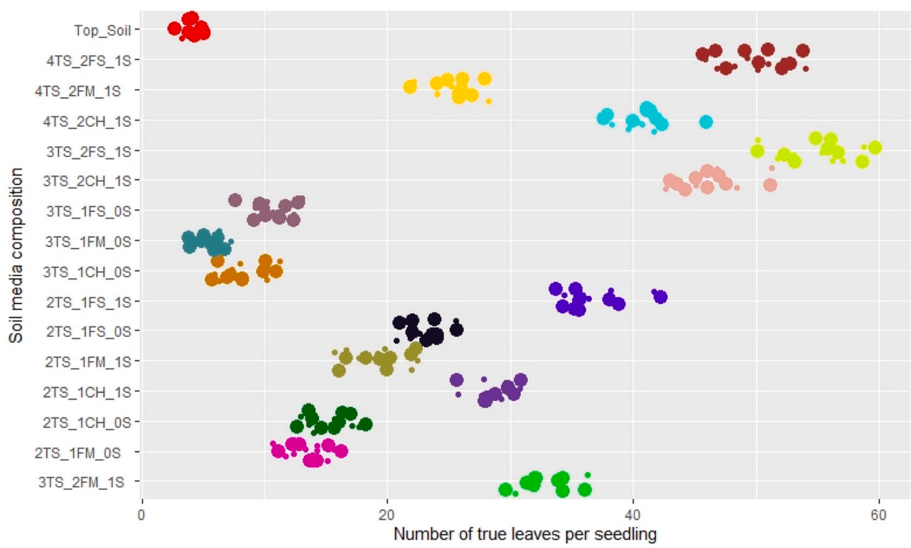

Fig. 6. *Response of number of true leaves of coffee seedling to organic amendment composition.*

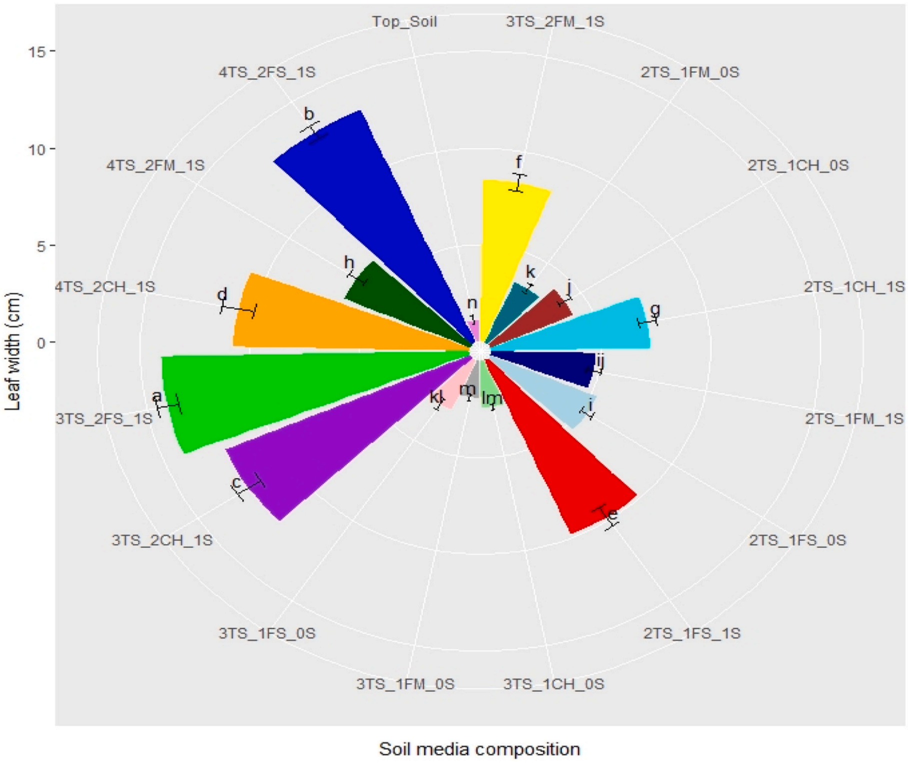

Fig. 7. *Effect of organic amendment on the coffee seedling leaf width.*

4.24) was recorded at a depth of 2 cm while the narrower leaf widths were registered in 3 cm (6.39 ± 4.02) and 1 cm (6.75 ± 4.08) sowing depths, respectively (Table 3). Conversely, Netsere and Kufa [69] observed higher leaf width was found at a depth of 1 cm possibly due to the variation in the physicochemical properties of the growth media (Fig. 2) and other abiotic factors [62] mainly the soil temperature [70].

4. Conclusion

Coffee husk and farmyard wastes generated from various processing industries were the primary ecological confronts in Yirgacheffee, Southern Ethiopia. On other hand, soil fertility is the primary factor of coffee productivity challenge in the study area. However, these wastes are vital if there is proper management and use as an organic fertilizer to replace the expensive chemical fertilizers. In this study, the taller seedling height, elongated leaf, longest taproot, larger internode, the higher number of nodes per seedling stem, maximum number of true leaves per seedling, wider leaves and earlier days of 50 % emergence were recorded in the organic amendment constitutes with 3:2:1 (topsoil: forest soil: sand) at a depth of 2 cm while lowest values of the aforementioned variables were registered in coffee seedlings grown in the topsoil solely at a depth of 3 cm. Potential coffee seedling growth biometrics were also scored in the soils amended by coffee husk and farmyard manure, possibly due to high amount of organic carbon and primary macronutrients. Hence, reusing farmyard manure wastes and coffee husk or switching them into reusable organic fertilizers could be a master key to opening dual doors of high-yielded quality coffee and a clean environment.

Data availability

The data that support the findings of this study are available upon request.

CRediT authorship contribution statement

Dargie Tsegay Berhe: Funding acquisition.

Declaration of competing interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The author earnestly acknowledges Dilla University for financial support.

References

[1] International Coffee Organization – ICO, Historical data on the global coffee trade. The international coffee organization. http://www.ico.org/new_historical.asp, 2020. (Accessed 10 November 2021).
[2] V. Poncet, P.V. Asten, C.P. Millet, P. Vaast, C. Allinne, Which diversification trajectories make coffee farming more sustainable? Curr. Opin. Environ. Sustain. 68 (2024) 101432 https://doi.org/10.1016/j.cosust.2024.101432.
[3] P. Bracken, P.J. Burgess, N.T. Girkin, Opportunities for enhancing the climate resilience of coffee production through improved crop, soil and water management, Agroecol. Sustain. Syst. 47 (8) (2023) 1125–1157, https://doi.org/10.1080/21683565.2023.2225438.
[4] K. Wienhold, L.F. Goula, The embedded agroecology of coffee agroforestry: a contextualized review of smallholder farmers' adoption and resistance, Sustainability 15 (8) (2023) 6827, https://doi.org/10.3390/su15086827.
[5] J.A. Castillo, D. Andrade, Coffee (Coffea arabica L,var. Castillo) seedling growth in Nariño, Colombia, Revista de Ciencias Agrícolas 38 (1) (2021) 62–74, https://doi.org/10.22267/rcia.213801.145.
[6] S. Castro-Tanzi, M. Flores, N. Wanner, T.V. Dietsch, J. Banks, N. Ureña-Retana, M. Chandler, Evaluation of a non-destructive sampling method and a statistical model for predicting fruit load on individual coffee (Coffea arabica) trees, Sci. Hortic. 167 (2014) 117–126, https://doi.org/10.1016/j.scienta.2013.12.013.
[7] A. Deshmukh, Which Country Produced the Most Coffee in 2020? The world Economic Forum, 2021. https://www.weforum.org/agenda/2021/10.
[8] L. Hein, F. Gatzweiler, The economic value of coffee (Coffea arabica) genetic resources, Ecol. Econ. 60 (2006) 176–185, https://doi.org/10.1016/j.ecolecon.2005.11.022.
[9] A. Mebrate, N. Zeray, T. Kippie, G. Hailea, Determinants of soil fertility management practices in Gedeo Zone, Southern Ethiopia: logistic regression approach, Heliyon 8 (1) (2022) e08820, https://doi.org/10.1016/j.heliyon.2022.e08820.
[10] T. Kuma, M. Dereje, K. Hirvonen, B. Minten, Cash crops and food security: evidence from Ethiopian smallholder coffee producers, J. Dev. Stud. 55 (6) (2019) 1267–1284, https://doi.org/10.1080/00220388.2018.1425396.
[11] USAID, United States agency for international development, in: Ethiopia Southern Nations, Nationalities, Peoples Region (SNNPR) Livelihood Zone Reports Contract No. 663-C-00-05-00446-00, 2005.
[12] EIAR, Ethiopian institute of agricultural research, in: Crop Research Technology Recommendations. Addis Ababa, Ethiopia, 2015.
[13] N. Anteneh, G. Heluf, Response of Arabica coffee seedling to lime and phosphorus: II. Dry matter production and distribution. 1095-1100, in: International Conference on Coffee Science, 2007, 21st, Montpellier, 11th -15th September, ASIC, France.
[14] Central Statistical Agency (CSA), Report on area and production of major crops, 1, in: Addis Ababa, Ethiopia, 2017, p. 118.
[15] S. Mosier, S.C. Córdova, G.P. Robertson, Restoring soil fertility on degraded lands to meet food, fuel, and climate security needs via perennialization, Front. Sustain. Food Syst. 5 (2021) 706142, https://doi.org/10.3389/fsufs.2021.706142.
[16] M. Aytenew, Effects of organic amendments on soil fertility and environmental quality: a review, J. Plant Sci. 8 (5) (2020) 112–119, https://doi.org/10.11648/j.jps.20200805.12.
[17] E. Yenani, H. Santoso, A. Sutanto, Muhfahroyin, Organic fertilizer of coffee peel with PUMAKKAL starter formula for sustainable plantation cultivation, J. Phys. Conf. 1796 (2021), https://doi.org/10.1088/1742-6596/1796/1/012038.
[18] J. Urra, I. Alkorta, C. Garbisu, Potential benefits and risks for soil health derived from the use of amendments in agriculture, Agronomy 9 (9) (2019) 542, https://doi.org/10.3390/agronomy9090542.
[19] G.H. Lense, R.S. Moreirai, F.A. Bocoli, T.C. Parreiras, A.E. Teodoro, V. Spalevic, R.L. Mincato, Soil organic matter loss by water erosion in a coffee organic farm, Agric. For. 66 (2) (2020) 45–50, https://doi.org/10.17707/AgricultForest.66.2.04.
[20] F. Gaiotti, P. Marcuzzo, N. Belfiore, L. Lovat, F. Fornasier, D. Tomasi, Influence of compost addition on soil properties, root growth and vine performances of Vitis vinifera cv Cabernet sauvignon, Sci. Hortic. 225 (2017) 88–95.
[21] D. Fangueiro, H.M. Ribeiro, R. Vasconcelos, J. Coutinho, F. Cabral, Influence of animal slurries composition and relative particle size fractions on the C and N mineralization following soil incorporation, Biomass Bioenergy 47 (2012) 50–61.
[22] M. Diacono, F. Montemurro, Long-term effects of organic amendments on soil fertility. A review, Agron. Sustain. Dev. 30 (2010) 401–422.
[23] A. Walkley, A critical examination of a rapid method for determining organic carbon in soil. Effect of variations in digestion conditions and inorganic soil constituents, Soil Sci. 63 (1947) 251–263.
[24] P.R. Hesse, A Textbook of Soil Chemical Analysis, London, UK, 1971.
[25] J.R. Landon, Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics, Longman, UK Limited, Essex, UK, 1991, p. 474.
[26] I.I. Bashour, A.H. Sayegh, Methods of Analysis for Soils of Arid and Semi-arid Regions, FAO, Rome, 2007, p. 119.
[27] K.H. Tan, Principles of Soil Chemistry, fourth ed., CRC press. Taylor & Francis Group, 2011, p. 362.
[28] S.R. Olsen, L.E. Sommers, Phosphorus, in: A.L. Page, R.H. Miller, D.R. Keeny (Eds.), Method of Soil Analysis, Part 2, American Society of Agronomy, Madison, 1982, pp. 403–430.
[29] C. Schollenberger, R. Simon, Determination of exchange capacity and exchangeable bases in soil-ammonium acetate method, Soil Sci. 59 (1945) 13–24.
[30] G.W. Thomas, Exchangeable cations, in: A.L. Page, R.H. Miller, D.R. Keeney (Eds.), Method of Soil Analysis, Part 2, Agronomy Series No. 9. Am. Soc. Agronomy and Soil Sci. Soc. Am., Inc., Publ., Madison, WI, 1982, pp. 159–165.
[31] K.H. Tan, Basic Soils Laboratory, Alpha edition, Burgess Publ.Co., Minneapolis, Minnesota, 1990.
[32] R. Li, J. Cheng, X. Liu, Z. Wang, H. Li, J. Guo, H. Wang, N. Cui, L. Zhao, Optimizing drip fertigation at different periods to improve yield, volatile compounds and cup quality of Arabica coffee, Front. Plant Sci. 14 (2023) 1148616, https://doi.org/10.3389/fpls.2023.1148616.
[33] T.L. Souza, D.P. Oliveira, C.F. Santos, T.H. Reis, J.P. Cabral, Nitrogen fertilizer technologies: opportunities to improve nutrient use efficiency towards sustainable coffee production systems, Agric. Ecosyst. Environ. 345 (2023) 108317, https://doi.org/10.1016/j.agee.2022.108317.
[34] D.M. Rahmah, A.S. Putra, R. Ishizaki, R. Noguchi, T. Ahamed, A life cycle assessment of organic and chemical fertilizers for coffee production to evaluate sustainability toward the energy–environment–economic nexus in Indonesia, Sustainability 14 (7) (2022) 3912, https://doi.org/10.3390/su14073912.
[35] B. Takala, T. Kufa, A. Regassa, Effects of lime and coffee husk compost on the growth of coffee seedlings on acidic soil of Haru in Western Ethiopia, J. Degraded and Mining Lands Manag. 8 (1) (2020), https://doi.org/10.15243/jdmlm.2020.081.2391, 2502-2458.
[36] V. Sofiatti, E.F. Araujo, R.F. Araujo, A. Cargnin, S.M. Reis, L.V. Silva, 1, Use of sodium hypochlorite to hasten the emergence and development of coffee seedlings Bragantia, 68, 2009, pp. 233–240, https://doi.org/10.1590/S0006-87052009000100025.
[37] B.C. Ferreira, S.F. Lima, C.A. Simon, M.G. Andrade, J. Ávila, R.C. Alvarez, Effect of biostimulant and micronutrient on emergence, growth and quality of arabica coffee seedlings, Coffee Science 13 (3) (2018) 324–332.
[38] B. Takala, Dry matter yield and nutrient uptakes of arabica coffee seedlings as influenced by lime and coffee husk compost amendments at western Ethiopia, Pelita Perkebunan 37 (2) (2021) 97–106, https://doi.org/10.22302/iccri.jur.pelitaperkebunan.v37i2.468, 2021.
[39] G. Chali, Abera T. Tolera, T. Wakgari, Effect of coffee husk compost and NPS fertilizer rates on growth and yield of coffee (*Coffea arabica L.*) at Haru research sub-canter, Western Ethiopia, Am. J. Biosci. Bioeng. 9 (3) (2021) 81–87, https://doi.org/10.11648/j.bio.20210903.14.
[40] G. Getachew, D. Muleta, Optimization of compost maturity of coffee waste mixed with agricultural wastes and evaluation of their effect on growth of lettuce (Lactuca Sativa), J. Nat. Sci. Res. 7 (8) (2017) 82–92.

[41] N.A. Dzung, T.T. Dzung, V.T.P. Khanh, Evaluation of coffee husk compost for improving soil fertility and sustainable coffee production in rural central highland of Vietnam, Resour. Environ. 3 (4) (2013) 77–82, https://doi.org/10.5923/j.re.20130304.03.

[42] T.T. Pham, N.H. Nguyen, P.N. Yen, T.D. Lam, N.T. Le, Proposed techniques to supplement the loss in nutrient cycling for replanted coffee plantations in Vietnam, Agronomy 10 (2020) 905, https://doi.org/10.3390/agronomy10060905.

[43] L.A. Msimbira, D.L. Smith, The roles of plant growth-promoting microbes in enhancing plant tolerance to acidity and alkalinity stresses, Front. Sustain. Food Syst. 4 (2020) 106, https://doi.org/10.3389/fsufs.2020.00106.

[44] S.N. Mkhabela, C.S. Mavuso, M.T. Masarirambi, P.K. Wahome, The effects of different organic fertilizers on the vegetative growth and fruit yield of baby marrow (*Cucurbita pepo* L.) in Luyengo, Eswatini, Int. J. Dev. Sustain. 9 (2020) 49–67, https://doi.org/10.3329/jbcbm.v6i1.51329.

[45] A.L. Fernandes, E.F. Júnior, M.J. Santana, R.O. Silva, M.M. Dia, Use of organic fertilization with irrigation in coffee production in brazilian cerrado, Rev. Ambient. Água 15 (5) (2020) e2578, https://doi.org/10.4136/ambi-agua.2578.

[46] B. Takala, Ameliorative effects of coffee husk compost and lime amendment on acidic soil of Haru, Western Ethiopia, J. Soil and Water Sci. 4 (1) (2020) 141–150, https://doi.org/10.36959/624/439.

[47] G.Y. Hirpa, Evaluation of some physicochemical parameters of compost produced from coffee pulp and locally available organic matter at dale district, southern Ethiopia, Am. J. Biosci. Bioeng. 8 (2) (2020) 17–26, https://doi.org/10.11648/j.bio.20200802.11.

[48] B. Chemura, The growth response of coffee (Coffea arabica L) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply levels, Int. J. Recycl. Org. Waste Agric. 3 (2014) 59, https://doi.org/10.1007/s40093-014-0059-x.

[49] B.W. Murphy, in: Soil Organic Matter and Soil Function- Review of the Literature and Underlying Data: Effects of Soil Organic Matter on Functional Soil Properties. Canberra, Australia, 2014. http://nla.gov.au/nla.arc-147907.

[50] V.S. Ribeirinho, C.S. Carvalho, N.P. Nilza Patrícia Ramos, Packer A.P. Ana Paula, D.M. Milori, J.O. Marcatto, C.E. Cerri, C.A. Andrade, Organic matter of tropical soil with coffee growth in a CO2 enriched atmosphere, Horticulture Int. J. 3 (6) (2019) 283–289, https://doi.org/10.15406/hij.2019.03.00143.

[51] P.A. Sanchez, Properties and Management of Soils in the Tropics, Cambridge University Press, UK, 2019.

[52] Y. Oka, Mechanisms of nematode suppression by organic soil amendments, Appl. Soil Ecol. 44 (2010) 15–30.

[53] F.L. Martins Neto, N. De Paula Pimenta M. Peralta-Antonio, Evangelista J.S. Pinto Coelho, R.H. Silva Santos, Soil chemical characteristics on coffee plantations fertilized with continuous application of compost and green manure, Commun. Soil Sci. Plant Anal. 51 (2020) 829–838.

[54] Gusmini Adrinal, I. Darfis, Elsa L. Putri, Performance of some soil physical properties of arabica coffee plantation in solok regency, Earth and Environ. Sci. 741 (2020). https://10.1088/1755-1315/741/1/012028.

[55] N. Pampuro, F. Caffaro, E. Cavallo, Reuse of animal manure: a case study on stakeholders' perceptions about pelletized compost in northwestern Italy, Sustainability 10 (2018) 20–28.

[56] A. Chemura, A. Waheed, F.S. Hamid, D. Kutywayo, V. Chingwara, Effect of organic and inorganic fertilizer on growth, yield and economic performance of Coffee, Pakistan J. Sci. Technol. 29 (2) (2010) 11–15.

[57] L. Kouadio, P. Tixier, V. Byrareddy, T. Marcussen, S. Mushtaq, B. Rapidel, R. Stone, Performance of a process-based model for predicting robusta coffee yield at the regional scale in Vietnam, Ecol. Model. 443 (2021) 109469, https://doi.org/10.1016/j.ecolmodel.2021.109469.

[58] T. Negash, S. Kinfu, T.W. Wana, A. Daba, Determination of light and nitrogen extinction coefficient for a coffee plants at different growth stages and canopy layers, Int. J. Botany Stud. 6 (3) (2021) 836–841.

[59] A. Wegari, M. Amin, Early growth response of hararghe coffee selections to soil moisture deficit at seedling stage at mechara, eastern Ethiopia, Universal J. Agric. Res. 8 (6) (2020) 223–232, https://doi.org/10.13189/ujar.2020.080603.

[60] C.A. Bohórquez, H.E. Martinez, R.H. Santos, Kinetic parameters of nitrate absorption by adult coffee trees, Front. Sustain. Food Syst. 21 (2021), https://doi.org/10.3389/fsufs.2021.677580.

[61] L.O.E. Silva, R. Schmidt, G.P. Valani, A. Ferreira, A. Ribeiro-Barros, F.L. Partelli, Root trait variability in Coffea canephora genotypes and its relation to plant height and crop yield, Agronomy (2020), https://doi.org/10.3390/agronomy10091394.

[62] E. Defrenet, O. Roupsard, K.V. Meersche, F. Charbonnier, J.P. Pe′rez-Molina, E. Khac, I. Prieto, A. Stokes, C. Roumet, B. Rapidel, E.M. Filho, V.J. Vargas, D. Robelo, A. Barquero, C. Jourdan, Root biomass, turnover and net primary productivity of a coffee agroforestry system in Costa Rica: effects of soil depth, shade trees, distance to row and coffee age, Ann. Bot. 118 (2016) 833–851, https://doi.org/10.1093/aob/mcw153.

[63] M. Worku, T. Astatkie, Growth responses of arabica coffee (Coffea arabica L.) varieties to soil moisture deficit at the seedling stage at Jimma, Southwest Ethiopia, J. Food Agric. Environ. 8 (1) (2010) 195–200.

[64] A. Chemura, B.T. Mudereri, A.W. Yalew, Climate change and speciality coffee potential in Ethiopia, Sci. Rep. 11 (2021) 8097, https://doi.org/10.1038/s41598-021-87647-4.

[65] H.M. Teixeira, F.J. Bianchi, Maria Cardoso I.M. Irene, P. Pablo Tittonell, M. Marielos Pena-Claros, Impact of agroecological management on plant diversity and soil-based ecosystem services in pasture and coffee systems in the Atlantic Forest of Brazil, Agric. Ecosyst. Environ. 305 (2021) 107171, https://doi.org/10.1016/j.agee.2020.107171.

[66] B.P. Muvunyi, P.Y.K. Sallah, L. Dusengemungu, J.Y. Zhang, Assessment of genetic diversity of coffee accessions in Rwanda and its implication for coffee breeding, Am. J. Plant Sci. 8 (2017) 2461–2473, https://doi.org/10.4236/ajps.2017.810167.

[67] W.N. Rodrigues, M.A. Tomaz, M.A.G. Ferrão, L.D. Martins, T.V. Colodetti, S.V.B. Brinate, J.F.T. Amaral, F.M. Sobreira, M.A. Apostólico, Biometry and diversity of Arabica coffee genotypes cultivated in a high-density plant system, Genet. Mol. Res. 15 (1) (2016) 15017724, https://doi.org/10.4238/gmr.15017724.

[68] G. Oliosi, J.A. Giles, W.P. Rodrigues, J.C. Ramalho, F.L. artelli, Microclimate and development of Coffea canephora cv. Conilon under different shading levels promoted by Australian cedar (Toona ciliata M. Roem. var. Australis), Aust. J. Crop. Sci. 10 (4) (2016) 528–538, https://doi.org/10.21475/ajcs.2016.10.04.p7295x.

[69] A. Netsere, T. Kufa, Review of arabica coffee nursery management research in Ethiopia, J. Biol. Agric. Healthcare 5 (11) (2015) 20–26.

[70] C. Guo, Y. Shen, F. Shi, Effect of temperature, light, and storage time on the seed germination of pinus bungeana zucc. Ex endl.: the role of seed-covering layers and abscisic acid changes, Forests 11 (2020) 300, https://doi.org/10.3390/f11030300.

[71] F.M. DaMatta, C.P.R. Ronchi, M. Maestri, R.S. Barros, Ecophysiology of coffee growth and production, Braz. J. Plant Physiol. 19 (4) (2008) 485–510.

[72] V. Letort, S. Sabatier, M. Okoma, M. Jaeger, P. Reffye, Internal trophic pressure, a regulator of plant development? Insights from a stochastic functional-structural plant growth model applied to Coffea trees, Ann. Bot. 126 (4) (2020) 687–699, https://doi.org/10.1093/aob/mcaa023.

[73] M. Milla, S. Oliva, S. Leiva, R. Silva, O. Gamarra, M. Barrena, J. Maicelo, Características morfológicas de variedades de café cultivadas en condiciones de sombra, Acta Agronómica 68 (4) (2019) 271–277, https://doi.org/10.15446/acag.v68n4.70496.

[74] J. Gil, Indicadores bióticos del cambio climático: casos granadilla y café, Revista Yachay 8 (1) (2019) 522–529, https://doi.org/10.36881/yachay.v8i1.130.