Effect of the Cultivation Medium and Cutting Position and Their Interaction on the Growth and Root Morphology of Fig Cuttings

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This study evaluated the influence of the cutting position (terminal, middle, and basal) and the growth medium [soil only; soil + biochar (BC); soil + phosphorus solubilizing bacteria (PSB); soil + arbuscular mycorrhizal fungi (AMF); soil + BC + PSB + AMF] on vegetative growth attributes and root morphology, soil microbial carbon and respiration, available phosphorus, and the rate of its absorption in fig trees (*Ficus carica* L.). The results demonstrated that using soil + BC + PSB + AMF as a growth medium for the medium cutting gave the highest plant height, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, root length, and root surface area, as well as the absorbed phosphorus by cuttings compared to the other growth media used. Besides, the vegetative growth attributes and root morphology of middle cuttings were better than those of terminal or basal cuttings. Besides, using soil + BC + PSB + AMF as a cultivation medium increased phosphorus availability in the soil for medium, terminal, and basal cuttings.

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INTRODUCTION

The fig tree, (*Ficus carica* L.) is a subtropical, deciduous fruit tree that is a member of the Moraceae family. It is a substantial shrub or small tree with a thin, twisted trunk and strongly lobed, three- to five-lobed leaves (Dahale *et al.* 2018).

Fig fruit contain natural sugars and organic acids that improve their quality (Mahmoudi *et al.* 2018). They are a rich source of carbohydrates, acids, minerals such as manganese, copper, magnesium, and calcium, vitamins such as K and β-carotene, polyphenols, flavonoids, fiber, and other healthful substances (Mahmoudi *et al.* 2018). Figs are rich in antioxidants including phenolic acids, flavonoids, carotenoids, and anthocyanins (Walia *et al.* 2022). Additionally, fig is consumed in fresh or dried form and serves as a critical source of trace elements, especially iron, calcium, and potassium. Also, it is an excellent source of vitamins such as vitamin B1 and B2 (Kösoğlu *et al.* 2022).

Cutting propagation is an effective method for large-scale clonal propagation of woody plants, with success depending primarily on rooting ability, root system quality, and

subsequent plant establishment (Neves *et al.* 2006; Gratieri-Sossella *et al.* 2008). It involves the formation of adventitious roots from plant segments under suitable environmental conditions (Hartmann *et al.* 2011). Thicker cuttings generally show better shoot development because their greater carbohydrate reserves support early root and shoot growth (Dias *et al.* 2013). The success of propagation through cuttings in fruit crops relies on several key factors, including the physiological state and age of the mother plant, harvest timing, lignification level, application of plant growth regulators, type of rooting medium, and growing conditions (Boliani *et al.* 2019), as well as the different rooting ability of each plant species (Bellini *et al.* 2014). In fig, hardwood cuttings are widely used for commercial propagation because they are simple, economical, and suitable for producing true-to-type plants on a large scale (Singh and Rattanpal 2017). Stem cuttings are the most widely used and effective method for propagating figs in agriculture, allowing for rapid production of uniform, parent-like plants. Typically, cuttings are taken from mature woody plants aged 1 to 3 years during the dormant season when sap flow is minimal (Boliani *et al.* 2019). This method is also regarded as one of the easiest techniques for asexual fig propagation (Singh *et al.* 2025). Besides, semi-hardwood cutting is the primary method due to its higher success rate and lower cost. Nursery professionals prefer this technique because it is easier to perform and supports the production of medium to large quantities of plants. Additionally, this method ensures a steady supply of cultivars with excellent rooting ability, which explains its widespread popularity among practitioners (Santos-Rufo *et al.* 2024).

Using biochar (BC) as a soil amendment offers benefits such as carbon sequestration, improved soil water retention, increased mycorrhizal fungal activity, and enhanced soil organic matter (Woolf *et al.* 2010). Biochar has little to no significant effect on crop growth (Spokas *et al.* 2012). The application of BC as a soil amendment or cultivation substrate is associated with improved soil water retention, increased beneficial soil micro-organisms, and enhanced soil organic matter, all of which are essential for the growth and development of crops and plant species (Thomas and Gale 2015). Optimal levels of BC input have been shown to enhance soil pore structure (Sun *et al.* 2015), thereby enhancing crop development through improved root growth in coastal saline-affected soil (Dahlawi *et al.* 2018). Various levels of BC amendment to soil for nursery plants and crops have been documented to enhance plant vigor and nutrient uptake, thereby promoting the growth and production of high-quality seedlings (Vaughn *et al.* 2015). BC enhances crop growth by stimulating soil microbial activity, which improves soil quality, fertility, and crop yields (Cheng *et al.* 2017). It also boosts the transpiration rate by enhancing soil water retention, thereby improving water use efficiency in plants. As a result, BC is used in regions with limited water resources (Fischer *et al.* 2019). BC can also improve key soil chemical properties, including pH, cation exchange capacity, and total carbon content, thereby enhancing nutrient retention and maintaining soil fertility (Giagnoni *et al.* 2019). Applying BC to mango tree soil enhanced several growth metrics, such as trunk thickness, shoot length and diameter, tree productivity, and leaf nutrient content (Harhash *et al.* 2022). BC is promoted as a soil amendment that can simultaneously sequester carbon to combat climate change and enhance soil fertility, supporting the food requirements of a growing population. It improves cation exchange capacity, increases base cation saturation, reduces bulk density, boosts moisture retention, and raises pH (Kumar *et al.* 2023). BC enhances soil porosity by forming channels and spaces that facilitate air and water movement, ultimately supporting nutrient absorption and boosting crop yields (Lu *et al.* 2023).

Plant growth-promoting rhizobacteria (PGPR) support plant growth both directly and indirectly. They do this by colonizing the rhizosphere and providing vital nutrients through processes such as nitrogen fixation, phosphorus solubilization, and iron chelation. Additionally, PGPR produce phytohormones such as indole-3-acetic acid, gibberellins, cytokinins, and ethylene, which promote root and shoot development and help plants tolerate stresses like salinity and drought. As a result, phosphorus solubilizing bacteria (PSB) are a crucial part of sustainable agriculture because they improve soil health and decrease dependence on synthetic fertilizers (de Andrade *et al.* 2023). PSB can promote the breakdown and mineralization of soil phosphates by secreting organic and inorganic acids, releasing phosphatases (Bashan *et al.* 2013), and chelating metal cations with organic acids to promote the release of phosphate ions (Rawat *et al.* 2021). PSB is vital in the soil phosphorus cycle, as it mineralizes organic phosphorus by secreting acids and hydrolyzes inorganic phosphorus minerals using enzymes. This process solubilizes insoluble phosphorus, thereby boosting the available phosphorus levels in soils (Liang *et al.* 2020). Rhizosphere microorganisms are crucial in regulating the soil phosphorus cycle and can transform insoluble phosphorus into forms that plants can absorb, thereby enhancing phosphorus availability (Elhaissoufi *et al.* 2022). Microbial fertilizers aid in restoring soil ecosystems, thereby enhancing nutrient uptake, supporting crop growth, and boosting plants' resistance to both biotic and abiotic stresses (Prisa *et al.* 2023; Wang *et al.* 2024).

Arbuscular mycorrhizal fungi (AMF) are symbiotic fungi that colonize the roots of approximately 90% of vascular plant species (Lekberg *et al.* 2013). The mycorrhizal structure formed by AMF and fruit tree roots provides several benefits, including expanding the roots' nutrient-uptake range, enhancing nutrient absorption, and aiding nutrient transfer. This, in turn, promotes the growth, yield, and quality of fruit trees (Seguel *et al.* 2013). Inoculated plants with AMF exhibit altered physiological functions, such as respiration and photosynthesis, and improved host water-use efficiency (Jayne and Quigley 2014; Augé *et al.* 2016). These fungi help plants absorb nutrients and water *via* an extensive hyphal network outside the roots (Solaiman and Mickan 2014). AMF have the potential to reduce nutrient leaching from soils (Cavagnaro *et al.* 2015) and to preserve plant growth in nutrient-limited environments (Nadeem *et al.* 2017). AMF are among the most essential microbial groups in agricultural ecosystems, especially in horticultural production (Emmanuel and Babalola 2020). AMF, a beneficial soil microorganism, supports the host plant by improving root growth, nutrient absorption, soil health, and stress tolerance (Wipf *et al.* 2019). Mycorrhizal formation enhances citrus seedling growth, photosynthesis, root structure, and nutrient uptake (Wu and Zou 2010). An inoculant derived from the rhizosphere of *Citrus unshiu* markedly increased leaf contents of P, K, Ca, Mg, and Zn in trifoliate orange seedlings (Wu *et al.* 2019). AMF also boost plant tolerance to abiotic stresses and resistance to biotic challenges (Jiang *et al.* 2020), supporting overall growth and development. The mycelial network created by AMF facilitates soil mineral nutrient dissolution, improves soil structure (Qu *et al.* 2019), and helps regulate root osmotic balance (Arif *et al.* 2020). These fungi are widespread soil microorganisms that form symbioses with over 80% of terrestrial plants' roots, playing crucial roles in promoting growth, nutrient absorption, and defense against environmental stresses (Boyno *et al.* 2025).

The study aimed to evaluate the influence of different cultivation media and stem cutting positions on the rooting and growth performance of fig (*Ficus carica* L.) cuttings and to determine the most suitable combination of cultivation medium and cutting position for producing vigorous fig cuttings.

EXPERIMENTAL

The experiment was conducted during the 2024 agricultural season at the Nursery of the Department of Horticulture, Faculty of Agriculture - Saba Basha, Alexandria University, Egypt, to study the effect of different growing media: soil, soil + BC, soil + AMF, soil + PSB, and soil + BC+ AMF + PSB, and positions of stem cuttings (terminal, middle, or basal) on the rooting and growth of fig cuttings. Soil samples used in this study were collected from Nubaria, El Beheira Governorate, Egypt, from 0 to 30 cm depth. The soil was air-dried, mechanically ground, and sifted through a 2-mm mesh to achieve uniform particle size. It was then thoroughly mixed to ensure sample consistency. Soil characteristics were analyzed following the method of Page *et al.* (1982).

Fig cuttings

The cuttings were collected in December 2025 from 10-year-old fig trees cultivated in Marsa Matruh Governorate, Egypt. Healthy cuttings, 20 to 30 cm in length, 2 to 3 in thickness, and containing 3 to 5 buds, were selected from healthy two-year-old branches of mother plants known to be free from diseases and characterized by high yield and good fruit quality and characteristics. After collection, the cuttings were stored horizontally in moist soil until planting to prevent desiccation. The cuttings were cultivated in pots, one cutting per pot, from the start of April 2025 to October 2025, with each cutting planted so that one or two buds remained visible above the soil surface.

Biochar application and preparation

BC was applied at a level of 50 g BC kg^{-1} soil, corresponding to a 5% (w/w) BC-to-soil ratio. BC was produced from fallen guava leaves in the Soil Chemistry Laboratory, Soil and Agricultural Chemistry Department, Faculty of Agriculture, Saba Basha, Alexandria University, Egypt. The guava leaf waste was pyrolyzed at 400 °C for 3 h under limited oxygen conditions, following the procedure described by Odesola and Owoseni (2010). The resulting BC was crushed and sieved to obtain particles passing through a 2-mm sieve.

PSB

This material contained *Bacillus megaterium* and *Pseudomonas striata*. PSB was cultured in Nutrient Broth medium and incubated at 30 °C for 48 h on a rotary shaker at 150 rpm to achieve a cell concentration of 10^8 to 10^9 colony-forming units per milliliter (CFU/mL). A liquid carrier formulation was prepared by supplementing the bacterial broth with 2% (v/v) glycerol and 0.5% (w/v) polyvinylpyrrolidone (PVP) as cell protectants and adhesion agents to maintain cell viability and enhance root colonization. The bacterial suspension was applied at a rate of 10 to 20 mL per kg of soil (or per pot). Alternatively, the roots of cuttings/cuttings were immersed in the bacterial suspension for 15 to 30 min before planting.

AMF

The applied mix of AMF species was *Rhizoglomus macrocarpium* (GM) and *Rhizoglomus irregularis* (GI). The first was obtained from the Department of Plant Nutrition, Göttingen, University of Göttingen, Germany. The second species was obtained from the Department of Plant Pathology at Hanover University, Germany. These AMF species were activated in the Soil Microbiology lab – Soil and Agriculture Chemistry Dept,

Faculty of Agriculture – Saba Basha, Alexandria University, Egypt. 20 mL of AMF inoculum was added to the fig cuttings, and in total, the rate was 500 A-mycorrhizal spores per pot.

Table 1 shows the applied treatments, Table 2 shows the soil analysis, and Table 3 shows the biochar composition.

Table 1. Treatments Applied to Fig Cuttings

First Factor		Second Factor	
Medium of cultivation		Cutting Position	
Soil (control)		Terminal (C1)	
Soil + Biochar (BC)		Middle (C2)	
Soil + PSB		Basal (C3)	
Soil + AMF			
Soil + Mix			
Interaction of medium of cultivation × Cutting position			
Soil	C1	Soil + AMF	C1
	C2		C2
	C3		C3
Soil + BC	C1	Soil + mix	C1
	C2		C2
	C3		C3
Soil + PSB	C1	BC: Biochar; PSB: Plant growth-promoting rhizobacteria; AMF: Arbuscular Mycorrhizal Fungi; Mix: Soil + Biochar + PSB + AMF	
	C2		
	C3		

Table 2. Experimental Soil Characteristics

Mechanical Analysis								
Organic matter (%)	$CaCO_3$ (%)	EC dSm^{-1} (1:1)	pH (1:1)	Soil texture	Sand (%)	Silt (%)	Clay (%)	
0.49	17	1.8	8.4	Sand clay Loam	60.12	10.88	29	
Available Macronutrients (mg/ kg soil)			Soluble Cations and Anions (meq/ L)					
N	P	K	Ca	Mg	Na	K	HCO_3	Cl	SO_4
214	6.2	395	3.3	3.32	6.8	3.9	4.9	6.7	5.8

Table 3. Physical and Chemical Properties of Biochar

pH (1:5)		EC (1:5) dSm^{-1}		Biochar yield %		Moisture content %	
7.8		1.2		19.8		5.4	
N%	K%	P%		Ca %	Mg%	Na %	
0.90	0.41	0.73		2.15	0.77	0.39	
Fe	Mn	Cu	Zn	CEC (meq/100 gm)	C%	C/N	
mg/kg							
322	196	55.13	66.5	32	59.88	66.53	

The treatments were arranged as a factorial experiment in a randomized complete block design (RCBD) with five replicates; the first factor was the medium of cultivation; the second factor was the position of cuttings. The total number of experimental units was 5 × 3 × 5 = 75. The effect of these treatments was studied by studying their impact on root

growth traits (average root length (cm), fresh root weight (g), and dry root weight (g) and vegetative growth traits (average shoot length (cm), shoot diameter (mm), fresh weight of vegetative parts (g), and dry weight of vegetative parts (g).

Quantifying root length (RL)

Using a 0.5 mm sieve, half of the soil from each pot, including about half of the root system, was carefully washed multiple times with tap water to obtain a completely soil-free root sample. The leftover soil was set aside to measure available P in the soil. The roots were then gently dried with paper towels to remove any remaining moisture (Schenk and Barber 1979). To measure root length (RL), the line intersect method was used. Each replicate involved taking three subsamples of fresh roots, each weighing 0.3 g. Root length was calculated using the formula by Tennant (1975),

$$\text{RL (cm)} = \frac{\text{RFW}}{0.1\text{g}} \times N \times 1.5714 \quad (1)$$

where RL is root length (cm), RFW is root fresh weight (g), and N is sum of horizontal and vertical crossing. The surface area of root cylinder (SA) was calculated as follows (Barber 1995),

$$\text{SA} = 2\pi \times r_0 \times \text{RL} \quad (2)$$

where r_0 is the root radius (cm), which was calculated using the methods of Barber (1995).

Available phosphorus

Phosphorus availability was determined by extracting soil samples with 0.5 N $NaHCO_3$, following the procedure described by Song *et al.* (2019). The phosphorus concentration in the resulting extracts was quantified colorimetrically using the ascorbic acid–molybdenum blue method at 406 nm (Cho and Nielsen 2017).

Alkali phosphatase enzyme

Alkaline phosphatase enzyme activities were measured using the p-nitrophenol (PNP) method, following the procedure outlined by Tabatabai and Bremner (1969).

Plant P uptake

Plant sample powders (shoot and root) were wet-digested using an H_2SO_4-H_2O_2 method (Lowther 1980). The plant P content was measured using the vanadomolybdo-phosphoric technique (Jackson 1973), and using the $NaHCO_3$ (0.5 N, pH = 8.5) method (Olsen *et al.* 1954).

Plant P Uptake=Plant Dry Weight (g)×Plant P Concentration (mg P/g dry weight)

Soil microbial biomass carbon

Soil microbial biomass carbon (MBC) was determined using the chloroform fumigation–extraction technique described by Vance *et al.* (1987), with modifications to enable spectrophotometric determination. Briefly, microbial biomass carbon was estimated from the difference in extractable organic carbon between fumigated and non-fumigated soil samples using 0.5 M K_2SO_4 as the extraction solution. Soil samples were exposed to chloroform for 24 h to lyse microbial cells and release intracellular carbon compounds, which were subsequently extracted and quantified using a total organic carbon analyzer (Brookes *et al.* 1985). Microbial biomass carbon was calculated from the difference in

extractable carbon between fumigated and non-fumigated samples and corrected using an extraction efficiency coefficient (KEC = 0.45) to account for incomplete carbon recovery (Murage and Voroney 2007). All treatments were analyzed using six independent replicates to ensure the reliability and accuracy of the measurements.

Soil microbial respiration

Soil microbial respiration was measured by quantifying CO_2 released from fresh soil samples incubated under controlled laboratory conditions. The soil samples were sieved through a 2-mm mesh, adjusted to 60% of their water-holding capacity, and kept at 25 °C in airtight containers. The CO_2 produced was captured in a 0.1 M NaOH solution and later analyzed by back titration with 0.1 M HCl after 24 to 72 h of incubation (Anderson 1982; Zibilske 1994). Blank controls were used to account for background CO_2 absorption. The results are expressed as mg CO_2–C per gram of dry soil per day (Jenkinson and Powlson 1976).

Statistical Analysis

Statistical analyses were performed using a factorial experiment with two factors, cutting position and cultivation media, arranged in a Randomized Complete Block Design (RCBD) in CoHort Software, version 6.311 (Pacific Grove, CA, USA). The main effects of cutting position and cultivation media, as well as their interaction, were analyzed. Significant differences among treatment means were compared using the least significant difference ($LSD_{0.05}$) test, as described by Snedecor and Cochran (1990).

RESULTS

Table 4 shows how cultivation medium, cutting position, and their interaction influenced plant height, shoot fresh weight (SFW), and shoot dry weight (SDW) in fig cuttings.

The cultivation medium strongly influenced all measured growth parameters. The soil + Mix treatment produced the highest values, with plant height, shoot fresh weight, and shoot dry weight reaching 40.9 cm plant^{-1}, 50.5 g plant^{-1}, and 7.4 g plant^{-1}, respectively. This was followed by soil + AMF, which recorded 31.9 cm plant^{-1}, 41.9 g plant^{-1}, and 6.11 g plant^{-1}, respectively. The soil treatment showed the lowest results across all parameters, with 17.3 cm for plant height, 24.5 g for shoot fresh weight, and 3.27 g for shoot dry weight per plant.

Significant differences among the three cutting positions were found across all measured parameters. Cutting position C2 showed the highest measurements for plant height at 27.9 cm per plant, shoot fresh weight at 37.2 g per plant, and shoot dry weight at 5.37 g per plant. Conversely, C1 and C3 produced shorter plants, measuring 25.3 and 25.6 cm respectively. For shoot fresh weight, C1 had the lowest at 34.0 g, while C3 was slightly higher at 34.4 g. Shoot dry weight was lowest in C3 at 4.8 g, with C1 close behind at 4.9 g.

The interaction between cultivation medium and cutting position showed significant differences among treatments. The highest values for all three parameters were obtained from soil + Mix with C2, which recorded 43.5 cm plant^{-1} for plant height, 53.8 g plant^{-1} for shoot fresh weight, and 7.9 g plant^{-1} for shoot dry weight. The lowest plant height (16.8 cm plant^{-1}) and shoot fresh weight (24.3 g plant^{-1}) were recorded with soil +

C1, while the lowest shoot dry weight (3.13 g plant^{-1}) was also recorded with soil + C1. Within each cultivation medium, C2 generally produced the highest values compared with C1 and C3.

Overall, the results show that C2 and soil + Mix produced the highest values for the measured growth parameters, while the interaction treatment soil + Mix × C2 recorded the highest individual values.

Table 4. Influence of Cultivation Medium, Cutting Position on Plant Height, Shoot Fresh Weight, and Shoot Dry Weight of Fig

Experimental Factors		Plant Height (cm/plant)	Shoot Fresh Weight (g/plant)	Shoot Dry Weight (g/plant)
First Factor		**Medium of the Cultivation**		
Soil		17.31e	24.53e	3.27e
Soil + Biochar		19.20 d	26.86d	3.75d
Soil + PSB		21.95c	32.30c	4.64c
Soil + AMF		31.91b	41.88b	6.11b
Soil + Mix		40.88a	50.50a	7.42a
$LSD_{0.05}$		0.46	0.38	0.18
Second Factor		**Cutting Position**		
C1		25.29b	34.00c	4.92b
C2		27.90a	37.21a	5.37a
C3		25.57b	34.43b	4.83b
$LSD_{0.05}$		0.36	0.29	0.14
Interaction		**Medium of the Cultivation × Cutting position**		
		Shoot length (cm)	SFW	SDW
Soil	C1	16.77i	24.27i	3.13i
	C2	18.07h	25.03i	3.37hi
	C3	17.10i	24.30i	3.30i
Soil + BC	C1	19.03g	26.10h	3.73gh
	C2	19.40g	27.93g	3.80g
	C3	19.17g	26.53h	3.73gh
Soil + PSB	C1	20.73f	30.97f	4.58f
	C2	24.47e	34.33e	5.05e
	C3	20.67f	31.60f	4.30f
Soil + AMF	C1	30.67d	40.00d	5.88d
	C2	34.03c	45.00c	6.73c
	C3	31.03d	40.63d	5.73d
Soil + Mix	C1	39.23b	48.67b	7.27b
	C2	43.53a	53.77 a	7.91a
	C3	39.87b	49.07b	7.08b
$LSD_{0.05}$		0.80	0.65	0.31

The data in Table 5 show that the cultivation medium significantly influenced root development. The soil-only treatment showed the lowest values for all traits, with root fresh weight at 10.2 g/plant, root dry weight at 1.58 g/plant, root length at 19.5 cm/plant, and root surface area at 496 cm²/plant. Adding BC enhanced all these root parameters, and using PSB further improved them. Combining soil with AMF yielded markedly better results than using soil alone, soil with BC, or soil with PSB. The most effective treatment was consistently the soil + mix, which yielded a root fresh weight of 36.5 g per plant, a root dry weight of 6.10 g per plant, a root length of 108 cm, and a root surface area of 2220 cm².

Cutting position C2 produced the highest values across all measured root traits. Specifically, it recorded root fresh weight at 23.2 g/plant, root dry weight at 3.81 g/plant, root length at 70.6 cm/plant, and root surface area at 1430 cm^2/plant. These results were significantly greater than those for C1 and C3. The latter two cutting positions exhibited similar responses, with no significant differences observed between them for the traits studied.

The interaction between cultivation medium and cutting position showed a similar pattern. Across all media, C2 generally produced the greatest root growth. The lowest overall performance was observed for C3 grown in soil for root fresh weight (9.90 g/plant) and root dry weight (1.51 g/plant), while the lowest root length was recorded for C1 in soil (16.1 cm/plant). The lowest root surface area was also observed for C1 in soil (448 cm^2/plant).

Table 5. Influence of Cultivation Medium, Cutting Position on Root Fresh Weight, Root Dry Weight, Root Length, and Root Surface Area of Fig

Experimental Factors		Root Fresh Weight (g/plant)	Root Dry Weight (g/plant)	Root Length (cm/plant)	Surface Area of Roots (cm^2/plant)
First Factor		**Medium of the Cultivation**			
Soil		10.17e	1.58e	19.47e	496.44e
Soil + Biochar		13.64d	2.23d	40.47d	832.19d
Soil + PSB		19.66c	3.35c	65.59c	1271.75c
Soil + AMF		28.80b	4.63b	87.03b	1773.86b
Soil + Mix		36.53a	6.10a	107.68a	2222.35 a
$LSD_{0.05}$		0.53	0.14	2.94	35.21
Second Factor		**Cutting Position**			
C1		21.06b	3.47b	60.02b	1255.65b
C2		23.19a	3.81a	70.55a	1431.72a
C3		21.03b	3.45b	61.58b	1270.59b
$LSD_{0.05}$		0.41	0.11	2.27	27.28
Interaction		**Medium of the Cultivation ×Cutting position**			
Soil	C1	9.93 i	1.57j	16.13 j	448.45k
	C2	10.67 i	1.66j	25.71i	586.80 j
	C3	9.90i	1.51j	16.59j	454.06k
Soil + BC	C1	13.03 h	2.10 i	36.22h	769.95 i
	C2	15.10g	2.43h	49.04 g	964.37h
	C3	12.80 h	2.15i	36.16h	762.24 i
Soil + PSB	C1	19.20f	3.16g	59.34f	1195.59g
	C2	20.62 e	3.68f	71.26e	1358.26e
	C3	19.15f	3.22g	66.18e	1261.41f
Soil + AMF	C1	27.83d	4.62d	83.08d	1703.78d
	C2	30.43c	4.91c	94.01c	1895.47c
	C3	28.13d	4.36e	83.99d	1722.35d
Soil + Mix	C1	35.30b	5.90b	105.32b	2160.47b
	C2	39.13a	6.39a	112.73a	2353.68a
	C3	35.17b	6.00b	104.98b	2152.89b
$LSD_{0.05}$		0.92	0.24	5.09	60.99

In contrast, the soil + Mix × C2 combination produced the highest values for all evaluated parameters, with 39.1 g/plant root fresh weight, 6.39 g/plant root dry weight, 113 cm/plant root length, and 2353.7 cm^2/plant root surface area. The corresponding values for

C1 and C3 under the same medium were lower but remained substantially greater than those obtained under the other cultivation media. Overall, these findings show that C2 combined with the soil + Mix medium was the most successful treatment for improving root biomass, elongation, and surface development in fig cuttings.

Table 6. Influence of Cultivation Medium, Cutting Position on Plant P Uptake, Available P, and Alkaline Phosphatase Activity of Fig

Experimental Factors		Plant P Uptake (mg P/plant)	Available P in Soil (mg/kg soil)	Alkaline Phosphatase Enzyme (µg p-NP/g soil/ h)
First Factor		**Medium of the Cultivation**		
Soil		0.53e	5.13e	15.22e
Soil + Biochar		0.80d	6.44d	51.22d
Soil + PSB		1.38c	17.72c	161.33c
Soil + AMF		2.73b	21.41b	180.55b
Soil + Mix		5.25a	28.22a	208.67a
$LSD_{0.05}$		0.08	0.96	2.30
Second Factor		**Cutting Position**		
C1		1.96b	15.59a	122.87a
C2		2.53a	16.08a	123.53a
C3		1.93b	15.69a	123.80a
$LSD_{0.05}$		0.06	0.74	1.78
Interaction		**Medium of the Cultivation × Cutting position**		
Soil	C1	0.50h	5.20d	15.33e
	C2	0.59h	5.17d	15.00e
	C3	0.50h	5.03d	15.33e
Soil + BC	C1	0.74g	6.43d	51.00d
	C2	0.86g	6.60d	52.67d
	C3	0.79g	6.30d	50.00d
Soil + PSB	C1	1.29f	17.27c	160.33c
	C2	1.63e	18.10c	161.67c
	C3	1.21f	17.80c	162.00c
Soil + AMF	C1	2.51d	21.03b	179.67b
	C2	3.28c	22.20b	180.33b
	C3	2.41d	21.00b	181.67b
Soil + Mix	C1	4.75b	28.00a	208.00a
	C2	6.26a	28.33a	208.00a
	C3	4.74b	28.33a	210.00a
$LSD_{0.05}$		0.14	1.66	3.99

The results presented in Table 6 showed that the cultivation medium significantly affected all the parameters studied. The Soil + Mix treatment recorded the highest P uptake (5.25 mg P/plant), followed by Soil + AMF (2.73 mg P/plant), Soil + PSB (1.38 mg P/plant), Soil + BC (0.80 mg P/plant), and Soil (0.53 mg P/plant). All cultivation media differed significantly from each other. Cutting position, C2 recorded the highest plant P uptake (2.53 mg P/plant), followed by C1 (1.96 mg P/plant) and C3 (1.93 mg P/plant). C2 was significantly higher than C1 and C3. Available P in soil ranged from 15.6 to 16.1

mg/kg soil, with no significant differences among cutting positions. Similarly, alkaline phosphatase activity ranged from 123.9 to 123.8 µg p-NP/g soil/h, with no significant differences among cutting positions.

For available P in soil, the highest value was recorded under Soil + Mix (28.2 mg/kg soil), followed by Soil + AMF (21.4 mg/kg soil) and Soil + PSB (17.7 mg/kg soil). Soil + BC and Soil recorded lower values of 6.44 and 5.13 mg/kg soil, respectively.

A similar trend was observed for alkaline phosphatase activity. The Soil + Mix treatment recorded the highest activity (209 µg p-NP/g soil/h), followed by Soil + AMF (181 µg p-NP/g soil/h) and Soil + PSB (161 µg p-NP/g soil/h). The lowest values were recorded under Soil + BC (51.2 µg p-NP/g soil/h) and Soil (15.2 µg p-NP/g soil/h).

The interaction between cultivation media and cutting position significantly affected plant P uptake. The highest value was recorded for Soil + Mix × C2 (6.26 mg P/plant), followed by Soil + Mix × C1 (4.7 mg P/plant) and Soil + Mix × C3 (4.74 mg P/plant). The lowest values were recorded for Soil × C1 and Soil × C3 (0.50 mg P/plant for each). Available P in soil under the interaction treatments ranged from 5.03 to 28.3 mg/kg soil. The highest values were recorded with Soil + Mix × C2 and Soil + Mix × C3 (28.33 mg/kg soil for each), followed by Soil + Mix × C1 (28.0 mg/kg soil). The lowest value was recorded for Soil × C3 (5.03 mg/kg soil).

Alkaline phosphatase activity ranged from 15.0 to 210 µg p-NP/g soil/h. The highest activity was recorded for Soil + Mix × C3 (210 µg p-NP/g soil/h), followed by Soil + Mix × C1 and Soil + Mix × C2 (208 µg p-NP/g soil/h for each). The lowest activity was recorded for Soil × C2 (15.00 µg p-NP/g soil/h).

The results in Table 7 demonstrated that the cultivation medium had a highly pronounced effect on both soil microbial respiration and microbial biomass carbon. Soil microbial respiration increased progressively with the addition of microbial inoculants and BC. The lowest value was recorded in the soil-only treatment (0.13 CO_2-C mg/g dry soil/day), followed by soil + BC (0.21), soil + PSB (0.73), and soil + AMF (0.83). The soil + mix treatment recorded the highest respiration rate (1.28) and was significantly higher than all other media treatments. A similar trend was observed for soil microbial biomass carbon, which increased from 31.3 mg/kg in soil alone to 84.9 mg/kg with BC, 212 mg/kg with PSB, 254 mg/kg with AMF, and reached the highest value of 321 mg/kg in the soil + mix treatment.

Regarding cutting position, no significant differences were observed among the three cutting positions for either soil microbial respiration or soil microbial biomass carbon. Soil microbial respiration ranged from 0.63 to 0.65 CO_2-C mg/g dry soil/day, with C1 recording the highest value (0.65), followed by C2 (0.64) and C3 (0.63). Similarly, soil microbial biomass carbon ranged from 180 to 181 mg/kg, with the highest value recorded under C1 (181 mg/kg). The common significance letter (a) indicates that these differences were not statistically significant.

The interaction between cultivation medium and cutting position showed that the response of microbial activity was primarily associated with cultivation media, while differences among cutting positions within each medium were relatively small. For soil microbial respiration, values under soil alone ranged from 0.12 to 0.14, whereas the soil + mix treatment produced the highest values, ranging from 1.25 to 1.30 CO_2-C mg/g dry soil/day. Likewise, microbial biomass carbon was lowest in the soil treatments (30.3 to 32.0 mg/kg) and highest under the soil + mix treatments (319 to 322 mg/kg).

Overall, soil + mix was the most effective cultivation medium, producing the greatest soil microbial respiration and microbial biomass carbon regardless of cutting

position. The results indicate that the application of the microbial mix substantially enhanced soil microbial activity and biomass compared with soil alone, whereas cutting position had no significant effect on either parameter.

Table 7. Influence of Cultivation Medium, Cutting Position on Soil Microbial Respiration and Soil Microbial Biomass Carbon of Fig

Experimental Factors		Soil Microbial Respiration (CO_2-C mg/g dry soil/day)	Soil Microbial Biomass Carbon (mg/Kg)
First Factor		**Media of the Cultivation**	
Soil		0.13e	31.33e
Soil + Biochar		0.21d	84.89d
Soil + PSB		0.73c	211.55c
Soil + AMF		0.83b	254.33b
Soil + Mix		1.28a	320.55a
$LSD_{0.05}$		0.04	4.82
Second Factor		**Cutting Position**	
C1		0.65a	180.93a
C2		0.64a	180.13a
C3		0.63a	180.53a
$LSD_{0.05}$		0.03	3.73
Interaction		**Media of the Cultivation × Cutting Position**	
Soil	C1	0.12d	32.00e
	C2	0.14d	30.33e
	C3	0.13d	31.67e
Soil + BC	C1	0.22d	84.00d
	C2	0.21d	85.33d
	C3	0.22d	85.33d
Soil + PSB	C1	0.76bc	212.67c
	C2	0.73c	210.00c
	C3	0.71c	212.00c
Soil + AMF	C1	0.83b	254.00b
	C2	0.83b	254.33b
	C3	0.84b	254.67b
Soil + Mix	C1	1.30a	322.00a
	C2	1.29a	320.67a
	C3	1.25a	319.00a
$LSD_{0.05}$		0.08	8.34

DISCUSSION

The results demonstrated the positive effects of soil application of biochar, plant growth-promoting rhizobacteria (PSB), arbuscular mycorrhizal fungi (AMF), and their combinations on the growth of fig cuttings, root development, and soil properties. These results were in agreement with the findings of Sohi *et al.* (2010), who stated that biochar (BC) can directly improve soil fertility by supplying nutrients and enhancing soil characteristics such as porosity, surface area, and cation exchange capacity (Singh *et al.* 2010). Additionally, its application is beneficial for organic farming, as it helps sustain soil organic matter and reduce dependence on fertilizers. BC stimulates plant growth by enhancing root development, particularly the elongation of absorptive roots, thereby improving the uptake and accumulation of nutrients in various plant tissues (Martínez-Gómez *et al.* 2022). Furthermore, utilizing BC can lead to the longer-term retention of soil carbon, strengthening climate change mitigation efforts, which is particularly important for organic farming (Gattinger *et al.* 2012). Several studies have shown that the rise in crop productivity following BC application is closely associated with improvements in soil quality, notably enhanced availability of elements (Clough *et al.* 2013) and water-holding capacity (Baronti *et al.* 2014). BC is known to enhance plant growth, increase soil water retention, decrease the bioavailability of heavy metals and toxins, influence soil microbial diversity and populations, and lessen nutrient leaching. These effects can lead to reduced fertilizer requirements and lower environmental contamination (Biederman and Harpole 2013). Adding BC to organically managed soil reduces bulk density, enhances soil moisture retention, and boosts microbial activity (Ulyett *et al.* 2014) and plant N availability in an organic lettuce production system (Pereira *et al.* 2015). Adding BC can improve physical and chemical soil properties (Jeffery *et al.* 2015), increase nutrient availability, strengthen aggregate stability (Molnar *et al.* 2016), and boost soil carbon storage (Wang *et al.* 2017). Using BC as a potting and growing substrate improves soil conditions, including nutrient levels, cation exchange capacity, and organic carbon, in poorer soils, leading to significant improvements in crop growth (Thomas and Gale 2015). Furthermore, applying BC increases soil nutrient levels such as N, P, K, and Mg, which enhances crop CO_2 absorption and utilization, leading to greater dry matter production (Lu *et al.* 2016). BC's extensive pores and high specific surface area help improve soil structure by reducing bulk density and tensile strength (Blanco-Canqui 2017), while also enhancing water retention (Razzaghi *et al.* 2020). BC enhances soil quality by changing its physicochemical characteristics and stimulating microbial activity. It can boost microbial biomass and modify the composition and diversity of microbial communities, supporting key processes such as carbon mineralization, nutrient cycling, and enzyme function. These impacts are greatly influenced by BC properties such as pH, nutrient levels, pore size, pore volume, and surface area (Palansooriya *et al*. 2019). During drought stress, applying BC can boost photosynthesis by enhancing water-use efficiency, stomatal conductance, chlorophyll levels, and photosynthetic rates (Abideen *et al.* 2020). BC is rich in N, P, K, Ca, and Mg (Okebalama and Marschner 2023). Applying BC to the soil of pear trees significantly enhanced shoot length, shoot diameter, leaf area, leaf chlorophyll content, and leaf mineral content. Additionally, BC improved soil microbial biomass, leading to a notable increase in the availability of phosphorus, nitrogen, and potassium (Almutairi *et al.* 2024).

Arbuscular mycorrhizal fungi (AMF) serve as an extension of the plant roots, helping host plants access soil water and nutrients through extensive extraradical hyphae, while also receiving carbon from the plants (Gutjahr and Paszkowski 2013). Inoculating

citrus with AMF affects growth positively by promoting root hair development, improving root structure (Liu *et al.* 2018), increasing nutrient and water uptake (Zhang *et al.* 2018), enhancing yield and fruit quality (Ortas 2018), and bolstering resistance to stress (Liu *et al.* 2019). Ortas (2018) examined how mycorrhizal fungi influence the growth and nutrient absorption of micro propagated cherry, grapevine, fig, and banana rootstocks during acclimation and establishment. Plants inoculated with mycorrhizae had higher shoot and root dry weights and greater nutrient uptake than non-mycorrhizal plantlets. Specifically, mycorrhizal inoculation significantly enhanced the absorption of P and Zn. Inoculating citrus with AMF increased nutrient levels in the leaves. These nutrient concentrations were significantly higher than in leaves from citrus not inoculated with AMF (Shao *et al.* 2018). Incorporating AMF into the soil-plant system improves the absorption of elements including P, N, K, S, Ca, and Zn (Turrini *et al.* 2018). Begum *et al.* (2019) mentioned that AMF also enhances soil water and nutrient availability and improves water regulation, thereby increasing plant tolerance to drought, temperature stresses, heavy metals, salinity, pathogens, and metal contamination. The mycelial network formed by AMF aids in decomposing soil mineral nutrients and improves soil structure (Qu *et al.* 2019). It also regulates root osmotic balance (Arif *et al.* 2020) and encourages root growth and dry matter buildup, further supporting overall plant growth and development (Liu *et al.* 2021). This symbiotic association contributes to the development of a dynamic and functional ecosystem by affecting nutrient cycling, decomposition processes, soil structure, belowground biodiversity, and plant community ecology (Zhang *et al.* 2020). Endophytic fungi associated with plants play roles similar to AMF by enhancing levels of nutrients including phosphorus, nitrogen, potassium, and magnesium. They also influence phytohormones such as auxins, gibberellins, and cytokinins, which support plant growth, promote root development, and boost crop yield and quality (Baron and Rigobelo 2022).

Phosphate-solubilizing bacteria (PSB) have been shown to enhance nutrient utilization and yield (Richardson and Simpson 2011). Additionally, PSB has been found to secrete organic acids, such as citric, oxalic, and lactic acid, to lower soil pH and thereby dissolve mineral phosphates. Furthermore, *Bacillus* and *Streptomyces* in soil can produce enzymes such as phosphatases, phosphodiesterases, and phospholipases to hydrolyze complex organic phosphates, thereby promoting the mineralization of organic phosphorus in plants (Yu *et al.* 2012). PSB play a crucial role in maintaining soil ecosystem health, aiding plants in adapting to nutrient-poor soils, supporting the phosphorus cycle, and promoting sustainable ecological development (Bulgarelli *et al.* 2013). Delaporte-Quintana *et al.* (2017) showed that phosphorus is essential for plant growth and crucial for managing various cellular processes, including cell division, elongation, substance transport, and metabolism. Phosphorus is an essential nutrient for plants, playing a key role in the formation of sugars, nucleic acids, carbohydrates, and lipids. It is fundamental to energy production, nucleic acid synthesis, cell division, the development of new tissues, and various signaling processes in plants. In addition, phosphorus is crucial for metabolic activities and enzyme regulation, and it supports important physiological functions, including root development and flowering (Malhotra *et al.* 2018).

The middle cuttings in fig produced the highest success rate for viability, as well as in the number, length, and volume of roots. This can be attributed mainly to the fact that they contain more stored carbohydrates than terminal cuttings. Furthermore, the accumulated food reserves facilitated by plant growth regulators accelerated sprouting, thereby enhancing carbohydrate utilization at the cutting base via photosynthesis (Sing 2018). This concept aligns with Supriyanto and Prakasa's (2011) explanation that a plant's

rooting ability depends on carbohydrate levels and hormonal balance in the cutting material.

CONCLUSIONS

1. Middle Cutting exhibited the best overall performance, significantly improving vegetative growth, root development, and phosphorus uptake compared with terminal and basal cuttings.
2. Soil + Mix (AMF + PSB + BC) was the most effective cultivation medium, markedly enhancing plant growth, root development, phosphorus availability and uptake, and soil microbial activity.
3. The Soil + Mix × middle cutting combination produced the highest overall vegetative and root growth, including plant height, shoot biomass, root biomass, root length, and root surface area.
4. The integrated Soil + Mix treatment significantly stimulated soil biological activity, resulting in the highest microbial respiration (1.28 CO_2-C mg g^{-1} dry soil day^{-1}) and microbial biomass carbon.
5. Overall, the findings indicate that middle cutting cuttings grown in the Soil + Mix medium represent the most promising treatment for enhancing early establishment, vegetative and root growth, phosphorus acquisition, and biological activity in fig propagation.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All the required data are included in the manuscript.

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