

Article

Organic and Mineral Fertilization on the Photosynthetic, Nutritional, and Productive Efficiency of (*Ficus carica* L.) Subjected to Conduction Systems in a Semi-Arid Region of Brazil

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Abstract

Fig tree growth and development are highly susceptible to variations influenced by abiotic factors and management practices, including fertilization and training systems. This study aimed to evaluate the effect of organic and mineral fertilization on the photosynthetic, nutritional, and productive efficiency of fig trees subjected to different training systems in semi-arid regions. The experimental design was randomized blocks in a 5 × 4 factorial scheme, with three blocks and three plants per plot. The treatments consisted of five fertilizer sources (mineral fertilizer (NPK) applied at a dose of 126 g N, 90 g P, and 90 g K per plant (M); and four organic sources—cattle manure (CM), organic compost (OC), chicken litter (CL), and sheep manure (SM), all applied at a dose of 10 kg per plant); and four types of training systems (plants with two branches (2B), three branches (3B), four branches (4B), and espalier). Our results demonstrated that the mineral fertilizer (M) and chicken litter (CL) treatments yielded the highest results, particularly in photosynthetic performance. Fig trees fertilized with mineral fertilizer and subjected to the 3B system showed enhanced net photosynthesis (36.96 $\mu\text{mol m}^{-2} \text{s}^{-1}$) and, consequently, higher productivity of 21.28 t ha^{−1}. Similarly, plants fertilized with chicken litter (CL) under the 4B system produced comparable results. These findings demonstrate that the use of mineral and organic fertilizers, combined with an appropriate training system, is a viable strategy for optimizing fig productivity and profitability in semi-arid conditions.

Keywords: fig tree; chlorophyll content; yield; gas exchange; pruning systems

1. Introduction

Ficus (Moraceae) is one of the largest genera of angiosperms and is classified as pantropical, comprising more than 800 species distributed across many continents. These species include deciduous and evergreen terrestrial trees, shrubs, hemi-epiphytes, holo-epiphytes, rheophytes, vines, and climbers that adapt well to tropical and subtropical climates [1]. *Ficus* species play a multifunctional role in ecosystems, resulting in considerable ecological importance. Their presence is vital for the survival of a multitude of species, including birds, mammals, and some reptiles and fish worldwide [2]. In Brazil, the genus is notably diverse. The morphological variation, complexity, and enormous diversification of *Ficus* in the Neotropics make this genus an essential element for understanding diversification in species-rich biomes, such as the two main blocks of neotropical rainforests. The Amazon (AM), with about 50 species, and the Atlantic Forest (AF), with about 35 species, play a fundamental role in tropical forest ecosystems as a keystone resource for fauna [3].

Among these, *Ficus carica* L., commonly known as the fig tree, is one of the earliest cultivated fruit trees in the world. It is the most commercially important species of the genus due to its value for food and medicinal purposes. Native to Southwest Asia and the Eastern Mediterranean, it has been cultivated for over 11,000 years and has spread globally due to its exceptional adaptability to diverse soil and climatic conditions [4]. Unpruned, it is generally a tree 15 to 20 feet tall, with numerous spreading branches and a trunk rarely more than 7 feet in diameter [5]. The largest producers are Türkiye, Egypt, Morocco, and Algeria, accounting for more than 50% of global production [6]. The fruit has substantial commercial value and is used in various forms, including fresh, dried, and canned, and it is an essential ingredient in many food products, such as jellies and jams [7].

This adaptability makes it a promising candidate for regions seeking to diversify their agricultural output. In this context, introducing the fig tree emerges as a potential option for expanding fruit production in the Brazilian Nordeste. Although it is considered to be a temperate climate species, the fig tree stands out for its exceptional adaptability to diverse edaphic and climatic environments [8]. However, Brazilian fig productivity is still considered to be low, and its growth is subject to variations influenced by management practices, such as fertilization and training systems [9–11]. Therefore, it is necessary to study and implement new cultivation systems to enhance the productivity of the fig tree.

Among these systems, pruning is a crucial technique to ensure optimal fig production as, without this management, plants exhibit disordered growth, self-shading, and low fruit production [12]. This relevance is attributed to the commercial value of the fruits, which not only represent an essential complement to human nutrition, providing energy compounds such as starches, sugars, and fibers, but are also significant sources of minerals essential to metabolism, including calcium and phosphorus, as well as vitamins, amino acids, and antioxidants [13].

Additionally, it has been demonstrated that figs have high commercialization potential, both in their natural form and for industrial use [14]. In Brazil, commercial fig cultivation is primarily based on a single cultivar, ‘Roxo de Valinhos,’ due to its high vigor, productivity, robustness, and ease of adaptation to the Brazilian intensive pruning management system [15,16].

This intensive pruning management is a hallmark of the current commercial fig production system. In the current commercial fig production system in the central Brazilian producing regions, it is common to perform drastic winter pruning, eliminating the branches that produced fruit in the previous cycle (fruit-bearing stems), resulting in four or five main structural branches on the tree, known as the open vessel system (goblet). Under these conditions, Brazilian fig productivity is still considered to be low [17–19]. Therefore,

it is necessary to study and implement new cultivation systems to enhance the productivity of the fig tree.

Beyond pruning, another critical aspect of fig cultivation that requires attention is fertilization. The study of various fertilization methods is a common practice in research involving multiple species as it plays a crucial role in the development and production of fruits [10,19–22]. The growing demand for food, driven by population growth, underscores the need to optimize agricultural production [23].

This gap is particularly relevant given that chemical fertilizers are recognized for boosting plant productivity. However, their prolonged and uncontrolled use can have adverse effects on soil, such as acidification and a reduction in microbial biomass, compromising soil fertility and, consequently, the sustainable capacity to support the healthy growth and productivity of species [20].

In contrast to synthetic fertilizers, organic fertilization provides a viable and sustainable alternative for cultivating a wide range of plant species. This approach plays a crucial role in enhancing the long-term health of agricultural ecosystems. Improving soil organic matter and enriching microbial biomass and biodiversity create a more resilient and productive soil environment [24]. The use of organic fertilizers also helps to reduce reliance on external synthetic inputs, thereby mitigating adverse environmental impacts such as soil acidification and nutrient runoff, which are common in conventional systems. Despite the demonstrated benefits of organic fertilization, a critical gap remains in research investigating its specific effects on the physiological responses of fig trees, particularly in semi-arid environments [9,25].

In this context, despite the growing importance of fig trees in the northeast region, a critical gap remains in understanding how management practices, such as different pruning systems and fertilization methods, affect the plant's ecophysiological responses in semi-arid conditions. Understanding these responses, such as photosynthetic efficiency and gas exchange, is crucial for optimizing productivity and ensuring the sustainability of cultivation under these conditions. Specifically, there is a lack of studies investigating the physiological responses of fig trees to organic fertilization.

This gap is particularly relevant because, as Średnicka-Tober et al. [21] report, the use of organic fertilizers can influence plant metabolism, leading to an increase in the profile of secondary metabolites in plant tissues. They also explain that organic crops can function as a stress condition for the plant as nutrients are released slowly depending on the type of fertilizer used, differing entirely from mineral fertilization, which is characterized by the rapid and instantaneous availability of nutrients.

In this context, finding viable sources of organic nutrients is essential. This way, animal manures represent one of the most common, accessible, and economical sources of organic fertilizers for agricultural production [22]. Several animal sources, including cows, goats, sheep, horses, poultry, and pigs, provide manure that can be used as soil amendments to improve organic carbon content, enhance nutrient absorption, and promote healthy plant growth [26]. Animal manures differ in nutrient content, and their nutritional composition varies according to the type of animal, its diet, and the method of manure preservation [22]. These differences in nutrient content play an essential role regarding the impact of manure on soil properties.

Consequently, it is important to consider the long-term effects of using these agricultural inputs since repeated application of animal manure can lead to beneficial changes in soil properties [26]. Therefore, monitoring and sustainable management practices are necessary to ensure that the continued use of these organic fertilizers is beneficial without compromising soil health and productivity in the long term.

In this context, we hypothesized that combining a specific training system with organic fertilization can optimize nutrient availability and plant structure, promoting superior physiological responses and resulting in greater photosynthetic efficiency and fig productivity in a semi-arid environment.

We hope that the results of this study demonstrate that the adoption of training systems and organic fertilization are viable and beneficial practices for fig cultivation, providing support for optimizing management and increasing profitability for producers in the Brazilian semi-arid region and offering valuable insights for the management of the crop in other arid and semi-arid areas globally.

Therefore, this study aimed to evaluate the effect of organic and mineral fertilization on the photosynthetic, nutritional, and productive efficiency of fig trees subjected to different training systems in semi-arid regions.

2. Materials and Methods

2.1. Characterization of the Experimental Area

The study was carried out at the Rafael Fernandes Experimental Farm, belonging to the Federal Rural University of the Semi-Arid (UFERSA), Mossoró, western region of the state of Rio Grande do Norte, Brazil, whose geographic coordinates are 5°03'37" S latitude and 37°23'50" W longitude, with an altitude of 78 m and flat relief. According to Köppen, the region's climate is classified as 'BSh', a hot tropical semi-arid type, characterized by well-defined periods: dry (prolonged) and wet (short and irregular). The region's vegetation type is the open arboreal Caatinga, and the soil of the area is classified as Typical Dystrophic Red Argisol [27,28].

The experiment was conducted from August 2021 to April 2022 (9 months), covering the entire first production cycle of the 'Roxo de Valinhos' fig tree under the annual management system adopted in the region. The period was determined to capture the plant's immediate physiological and productive response to the different fertilization and training systems studied. During the experimental period (August 2021 to April 2022), the following meteorological data were collected from the ASA space meteorological station (Meliponário Imperatriz) and Rafael Fernandes experimental station. The fig (*Ficus carica* L.) production cycle lasted from August to April, beginning with drastic pruning in August. A complete absence of precipitation (0 mm) in August and October and high average temperatures (27.0 °C to 28.0 °C) characterized the climatic conditions during this initial period. This combination of high temperatures and drought (August to October) coincided with the most sensitive phases of the cycle: budbreak and initial vegetative growth. Beginning in December, when the crop reached the fruit expansion (syconium) stage and the beginning of harvest, there was a change in the water regime with the first rainfall (approximately 50 mm). The average temperature peaked in this month (28.5 °C). The final period, from February to April, corresponded to the peak of the harvest and was the most challenging. Average temperatures remained high (28.0 °C in February), and precipitation increased significantly, contributing to a cumulative total of 185 mm at the end of the cycle (April) (Figure 1).

The organic sources, cattle manure (CM), organic compost (OC), chicken litter (CL), and sheep manure (SM), used in this study were analyzed for their chemical characteristics according to the Embrapa protocol [29] (Table 1).

Before implementing the experiment, soil samples were collected from the 0–20 cm depth layer of the entire experimental area to characterize the initial conditions. A composite sample was prepared by homogenizing 10 random subsamples collected across the plot in a zigzag pattern. These samples were then dried in the shade, crushed, and passed through a 2 mm mesh sieve (TFSA) to facilitate chemical analyses [29] (Table 2).

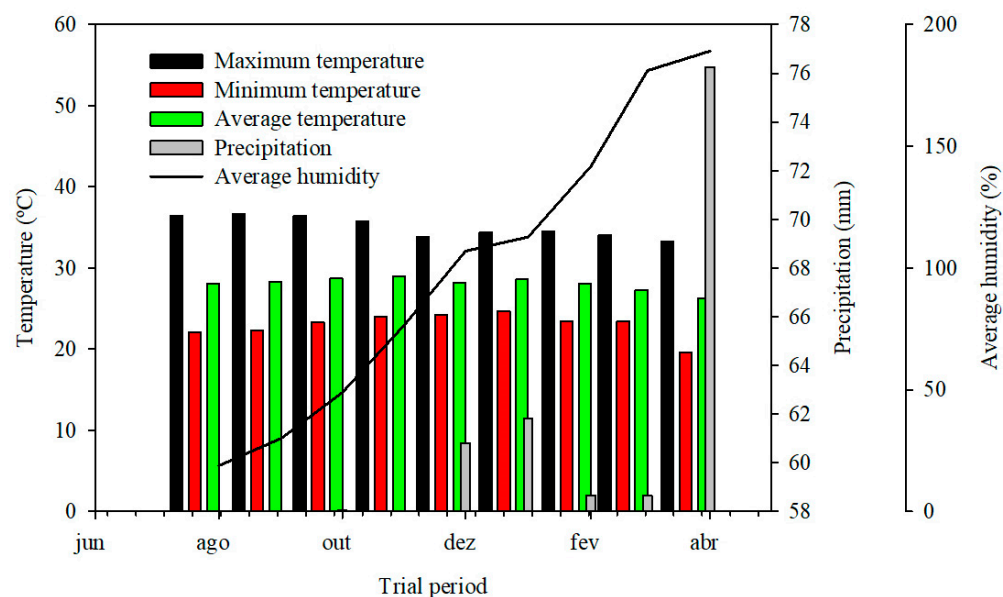


Figure 1. Air temperature (°C), relative humidity (%), and precipitation (mm) during the experiment (August 2021 to April 2022) in Mossoró, Rio Grande do Norte—Brazil.

Table 1. Chemical characteristics of the organic sources, cattle manure (CM), organic compost (OC), chicken litter (CL), and sheep manure (SM), used in the study. Mossoró, Rio Grande do Norte—Brazil.

Samples	pH	EC	OM	P	K ⁺	Na ⁺		
	H ₂ O	dS m ⁻¹	g kg ⁻¹		mg dm ³			
CM	6.61	1.92	44.10	199.10	824.80	214.90		
OC	7.30	5.43	41.61	513.60	521.50	683.30		
CL	7.61	5.89	46.60	513.60	502.70	186.61		
SM	8.02	7.33	39.12	234.00	240.20	866.10		
Samples	Ca ²⁺	Mg ²⁺	Al ³⁺	(H + Al)	SB	CEC	V	PES
		cmol dm ³				%		
CM	10.48	0.77	0	0	14.877	14.877	100	14.39
OC	15.60	6.21	0	0	39.061	39.061	100	34.02
CL	5.88	6.99	0	0	30.287	30.287	100	29.24
SM	15.68	1.24	0	0	30.562	30.562	100	18.78

P, K⁺, Na⁺: Mehlich extractant 1; Al³⁺; (H + Al) = 0; Ca²⁺, Mg²⁺: KCl extractant 1.0 mol L⁻¹; pH: hydrogen potential; EC: electrical conductivity; SB: sum of base; CEC: cation exchange capacity; OM: Walkley-Black wet digestion; PES: percentage of exchangeable sodium.

Table 2. Chemical characteristics of soil with mineral fertilization (SM), soil with cattle manure (SCM), soil with organic compost (SOC), soil with chicken litter (SCL), and soil with sheep manure (SSM) at the beginning of the experiment. Mossoró, Rio Grande do Norte—Brazil.

Samples	pH	EC	OM	P	K ⁺	Na ⁺
	H ₂ O	dS m ⁻¹	g kg ⁻¹		mg dm ³	
SM	7.36	0.07	22.77	73.50	62.50	0.06
SCM	7.93	0.16	23.96	74.30	62.50	0.13
SOC	7.50	0.08	23.30	74.31	66.90	0.07
SCL	7.42	0.08	23.84	58.80	49.90	0.07
SSM	7.95	0.15	23.71	53.70	62.50	0.11

Table 2. *Cont.*

Samples	Ca ²⁺	Mg ²⁺	Al ³⁺	(H+Al)	SB	CEC	V	PES
	cmolc dm ³						%	
SM	1.65	1.35	0	0	3.29	3.29	100	6.66
SCM	3.00	1.40	0	0	4.74	4.73	100	4.21
SOC	2.32	1.40	0	0	4.02	4.02	100	5.74
SCL	2.05	1.42	0	0	3.71	3.71	100	4.44
SSM	2.78	2.07	0	0	5.14	5.14	100	3.22

P, K⁺, Na⁺: Mehlich extractant 1; Al³⁺; (H + Al) = 0; Ca²⁺, Mg²⁺: KCl extractant 1.0 mol L⁻¹; pH: hydrogen potential; EC: electrical conductivity; SB: sum of base; CEC: cation exchange capacity; OM: Walkley–Black wet digestion; PES: percentage of exchangeable sodium.

After the experimental period ended, soil samples were collected from the 0–20 cm depth layer of the entire experimental area to characterize the initial conditions. A composite sample was prepared by homogenizing 10 random subsamples collected across the plot in a zigzag pattern. These samples were then dried in the shade, crushed, and passed through a 2 mm mesh sieve (TFSA) to facilitate chemical analyses [29] (Table 3).

Table 3. Chemical characteristics of soil with mineral fertilization (SM), soil with cattle manure (SCM), soil with organic compost (SOC), soil with chicken litter (SCL), and soil with sheep manure (SSM) at the end of the experiment. Mossoró, Rio Grande do Norte—Brazil.

Samples	pH	EC	OM	P	K ⁺	Na ⁺
	H ₂ O	dS m ⁻¹	g kg ⁻¹		mg dm ³	
SM	7.91	0.09	6.00	1903.67	0.16	0.11
SCM	8.08	0.07	6.37	169.77	0.13	0.11
SOC	8.4	0.08	6.12	222.09	0.18	0.13
SCL	8.22	0.11	6.70	1438.88	0.21	0.14
SSM	8.17	0.10	6.25	213.19	0.16	0.15

Samples	Ca ²⁺	Mg ²⁺	Al ³⁺	(H+Al)	SB	CEC	V	PES
	cmolc dm ³						%	
SM	3.22	0.65	0	0	4.15	4.15	100	3.97
SCM	2.15	0.53	0	0	2.92	2.92	100	4.63
SOC	3.63	0.38	0	0	4.32	4.32	100	4.08
SCL	2.66	0.67	0	0	3.68	3.68	100	5.74
SSM	2.42	0.99	0	0	3.72	3.72	100	4.42

P, K⁺, Na⁺: Mehlich extractant 1; Al³⁺; (H + Al) = 0; Ca²⁺, Mg²⁺: KCl extractant 1.0 mol L⁻¹; pH: hydrogen potential; EC: electrical conductivity; SB: sum of base; CEC: cation exchange capacity; OM: Walkley–Black wet digestion; PES: percentage of exchangeable sodium.

2.2. Materials and Growing Conditions

The plants in this study were of the *Ficus carica* L. species, ‘Roxo of Valinhos’. They were planted in the experimental area in March 2017, with a spacing of 2 m by 3 m. Four months after planting the orchard, the first formative pruning was completed at a height of 40 cm. Four months after the first formative pruning, the second formative pruning was carried out to form the branches of each plant (primary vegetative branches).

The plants in the espalier system were pruned at a height of 40 cm from the ground, with their primary branches, measuring 75 cm on each side, tied horizontally to steel cables. The espalier structure was assembled with four posts 10 m apart. The steel cables were stretched 40, 80, and 1.80 cm above the ground. The first production pruning of the experiment was carried out on 27 August 2021. The plants were pruned, result-

ing in 5 cm long branches so that vegetative buds could be produced on each branch. Thirty days after production pruning, the excess productive branches were thinned, allowing each plant to remain with two productive branches (two branches—four productive branches; three branches—six productive branches; four branches—eight productive branches; espalier—six productive branches) (Figure 2).

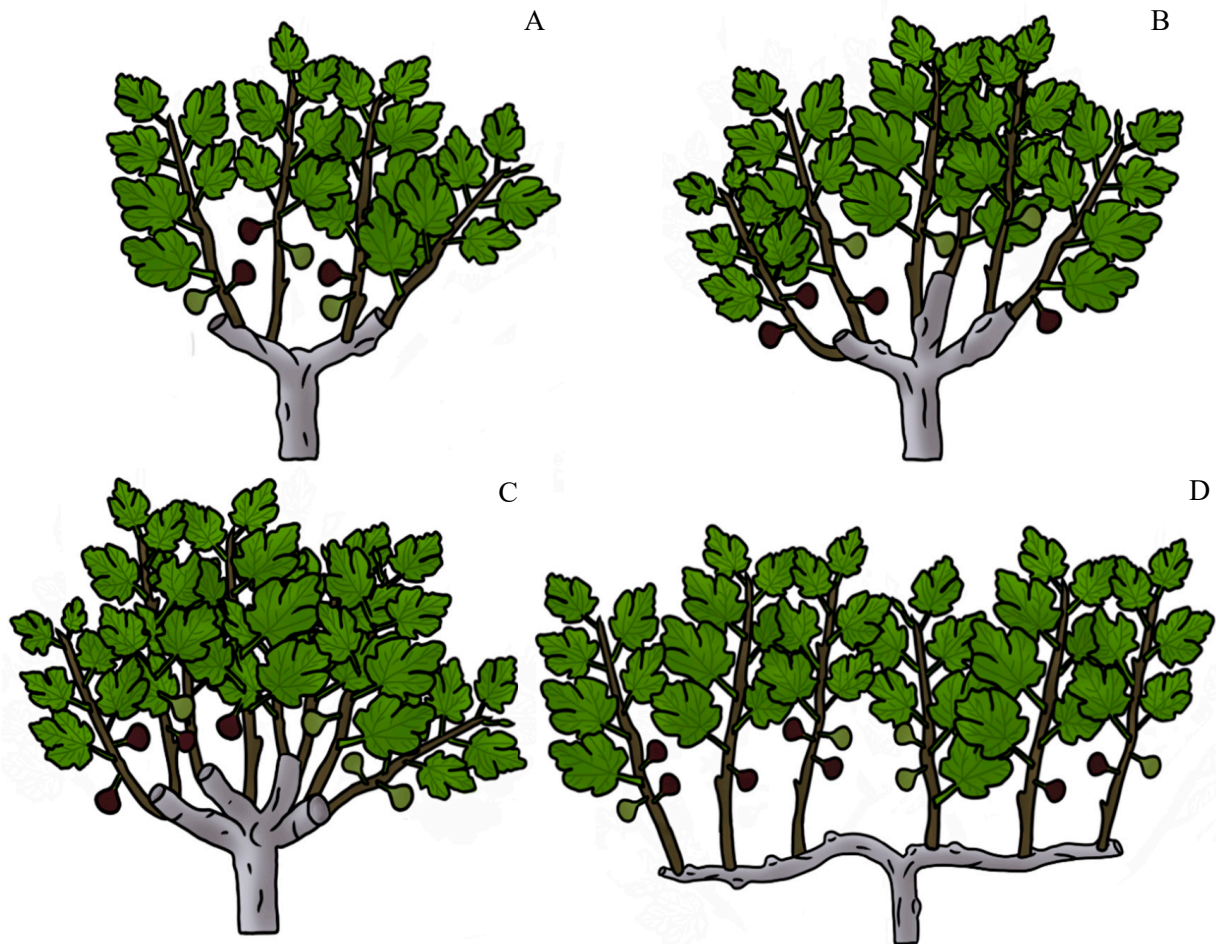


Figure 2. Training systems used in fig trees: two branches (A), three branches (B), four branches (C), and espalier (D).

The fig tree was fertilized using two systems: conventional (with mineral fertilizers) and organic. Plants under the organic system received an application of 10 kg per plant (fresh weight) of organic sources. This dosage was established based on the practices recommended by [10] for this crop in the semi-arid region. The organic material was applied superficially, distributed in a half-moon shape around the trunk, corresponding to the canopy projection area of the plant (ou: within the wetted zone of the micro-sprinkler). The sources used were cattle manure (CM), organic compost (OC), chicken litter (CL), and sheep manure (SM). The chicken litter was applied fresh, while the other organic sources were cured, as described in [10].

Mineral fertilizer was applied superficially via the soil in a half-moon shape, according to the essential fertilization recommendation for fig trees, receiving 126 g per plant^{−1} of nitrogen, 90 g per plant^{−1} of potassium, and 90 g per plant^{−1} of phosphorus per cycle [10,30]. The mineral sources used were nitrogen–ammonium sulfate (22% N), potassium–potassium chloride (60% K), and phosphate–simple superphosphate (52% P₂O₅). P fertilization was carried out once after pruning, and the other two, N and K, were applied at 15-day intervals, divided into three applications.

The irrigation system consisted of a micro-sprinkler system with a 75 L h^{-1} (Rivulis Rondo micro-sprinkler, Israel) on a 60 cm stake. It lasted 1 h daily, with one sprinkler per plant and a break on rainy days.

To control weeds, regular cleaning between the rows was carried out using a brush cutter and manual weeding. Whenever necessary, the thieving branches and new shoots were removed with pruning shears.

2.3. Experimental Design

The experimental design employed was a randomized block design in a 5×4 factorial scheme, with three blocks and three plants per plot, totaling 180 plants. Each plot measured 4 m (length) by 3 m (width), resulting in a total area of 12 m^2 . In each plot, the central plant was considered the useful plant for data collection, and the two surrounding plants served as lateral borders. A minimum distance of 3.0 m was maintained between plots and between blocks to ensure the complete isolation of the treatments. The treatments consisted of five fertilizer sources: one conventional fertilizer, composed of mineral fertilizer (M) (N, P, and K), and four organic sources: cattle manure (CM), organic compost (OC), chicken litter (CL), and sheep manure (SM), and four types of training systems (plants with two branches, three branches, four branches, and espalier).

2.4. Variables Analyzed

The following variables were determined:

Gas exchange: The plants were evaluated only once, at the beginning of the production period (150 days after pruning), regarding gas exchange, between 7:00 and 9:00 a.m. The evaluations were performed on fully expanded healthy leaf per useful plant (for a total of three leaves per plot), located in the upper third of each plant, with a portable infrared carbon dioxide analyzer (IRGA) model LCPro+ Portable Photosynthesis System[®] (ADC Bio Scientific Limited, UK) LCPro+ with temperature control at 25°C , irradiation of $1200 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$, and airflow of 200 mL min^{-1} . Obtain net photosynthesis (A_N) in $\mu\text{mol (CO}_2\text{) m}^{-2} \text{ s}^{-1}$, transpiration (E) in $\text{mmol (H}_2\text{O) m}^{-2} \text{ s}^{-1}$, stomatal conductance (g_s) in $\text{mol (H}_2\text{O) m}^{-2} \text{ s}^{-1}$, internal CO_2 concentration (C_i) in $\text{mol (CO}_2\text{) m}^{-2} \text{ s}^{-1}$, and leaf temperature (L_t) in $^\circ\text{C}$. Using this data, the instantaneous water use efficiency (WUE) was quantified as the ratio of net photosynthesis to transpiration (A_N/E) in $\mu\text{mol m}^{-2} \text{ s}^{-1}/\text{mmol (H}_2\text{O) m}^{-2} \text{ s}^{-1}$. The instantaneous carboxylation efficiency (A_N/C_i) was quantified as the ratio of net photosynthesis to internal CO_2 concentration (A_N/C_i) [31].

Chlorophyll fluorescence was evaluated using a pulse-modulated fluorometer model OS5p from Opti Science. This protocol utilized an actinic illumination source with a saturating multi-flash pulse, coupled to a photosynthetically active radiation determination clip (PAR-Clip), after the leaves had been adapted to darkness for 30 min. Under these conditions, the maximum quantum efficiency of PSII (F_v/F_m) was estimated [31].

The chlorophyll content index was determined using an electronic chlorophyll content meter (ClorofiLOG[®], CFL 1030) (Falker, Porto Alegre, RS, Brazil) only once at the beginning of the production period (150 days after pruning) in all plants comprising the experimental unit. In each plant, young and fully expanded leaves were selected from the upper middle third, without signs of pest or disease attack, for measurement at three equidistant points on the adaxial surface of each leaf. The values of chlorophyll a, chlorophyll b, and total were obtained.

The nutritional content of the leaves was determined by selecting young fully expanded leaves exposed to the sun from the upper middle third of each plant in the experimental unit without any signs of pest or disease attack [32]. Then, the contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined

after sulfuric digestion, and iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) after dry digestion [29].

Fruit yield: The productivity was determined through weekly harvesting and weighing the fresh fruits from the central useful plant of each experimental unit throughout the entire production cycle (August 2021 to April 2022). To determine productivity, the total commercial fresh weight per plot was calculated, and the ratio of commercial production to area was then calculated based on the number of plants and spacing. The results were expressed in tons per hectare (t ha^{-1}).

2.5. Statistical Analysis

The results were subjected to the Shapiro–Wilk normality test and the Bartlett homogeneity test. Subsequently, they were subjected to an analysis of variance using the F probability test ($p < 0.5$). The occurrence of a significant interaction was analyzed using Tukey’s test to examine the unfolding of the interaction at the 5% probability level using the statistical program System for Analysis of Variance—SISVAR v. 5.6 (Lavras, MG, Brazil) [33]. The main effects were analyzed separately only when the interaction was non-significant (isolated factors).

3. Results

3.1. Gas Exchange

The studied factors, including fertilization sources (mineral and organic) and conduction systems, interacted significantly (based on the p -value less than the chosen significance level) and influenced the physiology of the fig trees. There were significant interactions for water use efficiency (WUE), transpiration (E), stomatal conductance (g_s), leaf temperature (LT) ($p < 0.01$), internal CO_2 concentration (C_i) ($p < 0.01$), instantaneous carboxylation efficiency (A_N/C_i) ($p < 0.01$), net photosynthesis (A_N) ($p < 0.01$), and maximum quantum efficiency of PSII (F_v/F_m) ($p < 0.05$). Due to these significant interaction effects, the combined means were analyzed using the Tukey test ($p < 0.05$) to compare treatment combinations and interpret the results.

Plants that received mineral fertilization showed higher water use efficiency (WUE) in the 2B, 3B, and 4B systems (7.14 , 8.19 , and $6.84 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$), respectively. Only in the espalier system did fertilization (OC) have a WUE of $5.35 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$, similar to mineral fertilization of $5.72 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$. Notably, the highest WUE with fertilization (M) was obtained in the systems with fewer branches, 2B and 3B, emphasizing the 3B system of $8.19 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$, which was statistically superior to the other systems (Table 4).

OC, CM, and CL presented median and similar values among the organic sources. Only SM resulted in lower WUE for the conduction systems 2B ($2.12 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$), 3B ($3.17 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$), 4B ($3.91 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$), and espalier ($3.76 \text{ } (\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$). Reductions in WUE of around 70.31%, 61.39%, 42.84%, and 34.27% were recorded, respectively (Table 4).

The lowest E was obtained with mineral fertilization in the 2B, 3B, and 4B systems, presenting transpiration rates of 5.02 , 4.56 , and $4.97 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$, respectively. The highest E value was observed in the 2B system, using SM and CL of $9.22 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ and $8.32 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$, respectively, and in the 3B system, using SM and CL of $8.28 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ and $8.17 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$, with no statistically significant difference. With 4B, the organic fertilizers did not differ statistically from each other and had higher E than the mineral fertilizers. In the espalier system, the lowest E was obtained

with CM and M of 6.17 and 6.34 mmol H₂O m⁻² s⁻¹, respectively, and the highest *E* was obtained using CL of 7.99 mmol H₂O m⁻² s⁻¹ (Table 4).

Table 4. Water use efficiency ($WUE = A_N/E$) [(μmol m⁻² s⁻¹) (mo H₂O m⁻² s⁻¹)⁻¹], transpiration (*E*) (mmol H₂O m⁻² s⁻¹), and stomatal conductance (*g_s*) (mol de H₂O m⁻² s⁻¹) in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
WUE				
M	7.14 ± 0.46 aAB	8.19 ± 1.11 aA	6.84 ± 0.25 aBC	5.72 ± 0.20 aC
CM	4.82 ± 0.13 bA	4.70 ± 0.08 bA	4.71 ± 0.18 bA	4.91 ± 0.08 abA
OC	5.45 ± 0.38 bA	4.51 ± 0.22 bA	4.77 ± 0.24 bA	5.35 ± 0.04 aA
CL	4.64 ± 0.13 bA	4.24 ± 0.29 bcA	5.22 ± 0.27 bA	4.62 ± 0.37 abA
SM	2.12 ± 0.006 cB	3.17 ± 0.02 cAB	3.91 ± 0.18 bA	3.76 ± 0.02 bA
CV (%)	11.45			
E				
M	5.02 ± 0.26 cB	4.56 ± 0.63 cB	4.97 ± 0.06 bB	6.34 ± 0.26 cA
CM	6.32 ± 0.11 bC	7.12 ± 0.16 bAB	7.71 ± 0.28 aA	6.17 ± 0.29 cC
OC	6.42 ± 0.34 bA	6.73 ± 0.13 bA	6.83 ± 0.23 aA	6.96 ± 0.34 bcA
CL	8.32 ± 0.27 aA	8.17 ± 0.26 aA	6.98 ± 0.19 aB	7.99 ± 0.35 aA
SM	9.22 ± 0.08 aA	8.28 ± 0.06 aB	7.55 ± 0.24 aB	7.59 ± 0.08 abB
CV (%)	5.91			
g _s				
M	0.41 ± 0.04 bB	0.47 ± 0.08 bAB	0.57 ± 0.02 aA	0.51 ± 0.03 abAB
CM	0.41 ± 0.02 bB	0.50 ± 0.03 bAB	0.59 ± 0.04 aA	0.39 ± 0.03 bB
OC	0.43 ± 0.05 bA	0.48 ± 0.02 bA	0.46 ± 0.03 aA	0.48 ± 0.04 abA
CL	0.76 ± 0.08 aA	0.65 ± 0.02 aAB	0.48 ± 0.02 aC	0.62 ± 0.06 aBC
SM	0.77 ± 0.02 aA	0.53 ± 0.02 abB	0.47 ± 0.04 aB	0.50 ± 0.02 abB
CV (%)	11.69			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

The stomatal conductance (*g_s*) of plants subjected to the 2B and 3B systems was similar, with the lowest *g_s* observed with the M (0.41 and 0.47 mol (H₂O) m⁻² s⁻¹), CM (0.41 and 0.50 mol (H₂O) m⁻² s⁻¹), and OC (0.43 and 0.48 mol (H₂O) m⁻² s⁻¹) fertilizations, respectively, which did not differ statistically among them. As in *E*, the highest *g_s* values were verified using SM (0.77 and 0.53 mol (H₂O) m⁻² s⁻¹) and CL (0.76 and 0.65 mol (H₂O) m⁻² s⁻¹) in the 2B and 3B systems. In the espalier system, the highest *g_s* values were obtained using a CL of 0.62 mol (H₂O) m⁻² s⁻¹. Only the 4B system did not differ statistically between the sources studied (Table 4).

Plants fertilized with SM presented the highest *C_i* in the 2B, 3B, and espalier systems of 280, 218, and 200.33 μmol mol⁻¹, respectively, which may indicate internal CO₂ accumulation. In the system with 4B, there was a more significant accumulation of *C_i* with mineral fertilization, with 205.33 μmol mol⁻¹. With 3B, the M and CM sources presented the lowest *C_i* of 155.67 and 169.00 μmol mol⁻¹. In turn, 4B had the lowest *C_i* with CL (146.00 μmol mol⁻¹), and, in the espalier system, lower values were verified using OC and CM of 140.33 and 158.33 μmol mol⁻¹, respectively (Table 5).

The instantaneous carboxylation efficiency (A_N/C_i) was similar to the results of internal CO₂ concentration. The lower-efficiency plants (A_N/C_i) were observed to be fertilized with SM in the 2B (0.07), 3B (0.12), and espalier systems (0.14). In the 4B system, lower A_N/C_i values were also observed with M fertilization (0.17), although they did not differ

statistically from those with SM (0.16). It is worth noting that lower A_N/C_i values led to reductions in the photosynthetic rate (Table 5).

Table 5. Internal CO₂ concentration (C_i) ($\mu\text{mol mol}^{-1}$), instantaneous carboxylation efficiency (A_N/C_i), and rate of CO₂ assimilation or photosynthesis (A_N) ($\mu\text{mol m}^{-2} \text{s}^{-1}$) in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
<i>Ci</i>				
M	139.67 ± 13.02 bB	155.67 ± 21.73 bB	205.33 ± 12.72 aA	162.33 ± 6.12 abB
CM	163.33 ± 7.06 aB	169.00 ± 4.04 bA	166.00 ± 7.00 abA	158.33 ± 2.93 bA
OC	138.67 ± 19.63 bB	184.00 ± 9.54 abA	165.33 ± 8.95 abAB	140.33 ± 2.03 bB
CL	177.67 ± 7.17 bAB	189.00 ± 15.10 abA	146.00 ± 10.54 bB	169.00 ± 12.34 abAB
SM	280.00 ± 0.58 aA	218.00 ± 2.08 aB	183.33 ± 11.57 abB	200.33 ± 2.19 aB
CV (%)	9.82			
<i>A_N/Ci</i>				
M	0.26 ± 0.03 aA	0.24 ± 0.03 aA	0.17 ± 0.02 bB	0.22 ± 0.01 aAB
CM	0.19 ± 0.01 aB	0.20 ± 0.003 abA	0.22 ± 0.02 abA	0.19 ± 0.003 abA
OC	0.26 ± 0.04 abA	0.16 ± 0.01 bcB	0.20 ± 0.01 abAB	0.26 ± 0.007 aA
CL	0.22 ± 0.009 abA	0.19 ± 0.03 abcA	0.26 ± 0.02 aA	0.22 ± 0.03 aA
SM	0.07 ± 0.001 bC	0.12 ± 0.001 cAB	0.16 ± 0.01 bA	0.14 ± 0.001 bA
CV (%)	15.92			
<i>A_N</i>				
M	35.65 ± 1.04 aA	35.94 ± 0.64 aA	33.96 ± 1.30 abA	36.26 ± 0.78 aA
CM	30.45 ± 0.28 bB	33.45 ± 0.80 abAB	36.29 ± 1.20 aA	30.28 ± 1.11 bB
OC	34.72 ± 0.89 abAB	30.30 ± 1.11 bcB	32.50 ± 0.79 abBC	37.15 ± 1.55 aA
CL	38.53 ± 0.47 aA	34.63 ± 2.32 abA	36.37 ± 1.09 aA	36.71 ± 1.94 aA
SM	19.56 ± 0.21 cB	26.28 ± 0.08 cA	29.42 ± 0.40 bA	28.56 ± 0.18 bA
CV (%)	5.95			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

The highest A_N/C_i values varied among the studied conduction systems. In the 2B system, the highest A_N/C_i was obtained with M (0.26), which did not differ statistically from OC (0.26) and CL (0.22). With 3B, the highest A_N/C_i values were obtained with mineral fertilizer (0.24) and CM (0.20), which were statistically equal. In the 4B system, the organic fertilizers CL, CM, and OC presented efficiencies of 0.26, 0.22, and 0.20, respectively, which were statistically equal. In the espalier system, the highest efficiencies were obtained with OC (0.26), followed by CL (0.22) and M (0.22), which were statistically equal (Table 5).

The 2B and espalier systems showed similar behavior regarding fertilizer sources. The highest A_N rates were obtained with the use of CL, with 38.53 and 36.71 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively, followed by M, with 35.65 and 36.26 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively, and OC, with 34.72 and 37.15 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively, statistically equal. It is also noteworthy that using the organic sources CL and OC, which are statistically equal, increased the A_N of fig trees by 2B to 49.23% and 43.66%, respectively. In the espalier system, the use of CL and OC fertilizers also increased the A_N of fig trees by 22.20% and 23.12%, respectively, compared to SM (Table 5).

Plants submitted to the 3B system presented higher A_N , with means of 35.94 $\mu\text{mol m}^{-2} \text{s}^{-1}$, 34.63 $\mu\text{mol m}^{-2} \text{s}^{-1}$, and 33.45 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively, statistically equal. In this condition, using CL increased A_N by 24.11% compared to SM. The highest A_N was obtained in the 4B system, with a CL of 36.37 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and a CM of 36.29 $\mu\text{mol m}^{-2} \text{s}^{-1}$, which were statistically equal. In this system, these organic sources represented increases of 19.11% and 18.93% in the A_N of fig trees compared to SM (Table 5).

As in WUE , E , g_s , C_i , and A_N/C_i , it was observed that the A_N of plants fertilized with SM was impaired in all the conduction systems studied, causing a considerable reduction in the photosynthesis of the plants in each system. In 2B, this reduction was more pronounced than in the other systems used, representing a 49.23% decrease, which is among the highest photosynthetic rates obtained in this system. In the different systems, 3B, 4B, and espalier, reductions of 26.88%, 19.11%, and 22.20%, respectively, were observed (Table 5).

The maximum quantum efficiency of PSII (F_v/F_m) varied according to the fertilizer sources and conductive systems used. There was no difference in the F_v/F_m values obtained in the 2B system for the fertilizer sources. The plants in the 3B system had higher F_v/F_m values, with an OC of 0.77, which did not differ statistically from CM and CL. The lowest F_v/F_m values were obtained in plants with M and SM of 0.70, which were statistically equal. With 4B, the organic sources had higher values, with CL fertilization of 0.76 standing out, and M fertilization provided the lowest value, 0.68. In the espalier system, the highest F_v/F_m values were obtained with OC, followed by SM, and the lowest values were obtained in CM, with a value of 0.68 (Table 6). The conduction systems used differed statistically only in bovine fertilization, where plants with 3B had the highest F_v/F_m values, 0.76, and espalier promoted the lowest value, 0.68 (Table 6).

Table 6. Maximum quantum efficiency of PSII (F_v/F_m) in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
	F_v/F_m			
M	0.72 ± 0.02 aA	0.70 ± 0.01 bA	0.68 ± 0.003 bA	0.72 ± 0.007 abA
CM	0.73 ± 0.02 aAB	0.76 ± 0.02 abA	0.73 ± 0.02 abAB	0.68 ± 0.003 bB
OC	0.75 ± 0.01 aA	0.77 ± 0.02 aA	0.73 ± 0.03 abA	0.76 ± 0.003 aA
CL	0.73 ± 0.01 aA	0.75 ± 0.02 abA	0.76 ± 0.01 aA	0.74 ± 0.01 abA
SM	0.73 ± 0.01 aA	0.70 ± 0.02 bA	0.70 ± 0.009 abA	0.75 ± 0.003 aA
CV (%)	3.98			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

3.2. Chlorophyll Content Index

The chlorophyll content index, composed of chlorophyll a , b , and total contents, was significantly influenced by the fertilizer sources (mineral and organic) and conduction systems at the level of ($p < 0.01$) for the fertilizer sources and conduction systems studied. Due to these significant interaction effects, the combined means were analyzed using the Tukey test ($p < 0.05$) to compare treatment combinations and interpret the results.

The chlorophyll a content varied between the fertilization sources and the 2B, 3B, and 4B conduction systems. The highest chlorophyll a content in the 2B system was obtained with an M of 27.10, and the lowest value was reported with a CM of 21.37. The other sources did not differ from each other in this system. However, with 3B, the highest chlorophyll a content was obtained with CM of 24.83, followed by CL and M. The lowest content was obtained with an SM of 21.80. The plants with 4B presented the highest chlorophyll a content, with a CM of 24.73 and an SM of 23.83, and the lowest value was recorded when an OC of 21.23 was used. The plants submitted to the espalier system did not differ statistically between the sources (Table 7).

The chlorophyll b levels exhibited similar behavior to those of chlorophyll a in the fertilizer sources and training systems. In the 2B and espalier systems, the highest chlorophyll b levels were obtained with M of 12.60 and 11.27, respectively. The lowest chlorophyll b values were obtained with a CM of 7.53 in the 2B system, and with espalier at a CM of

9.06 and CL at 9.53, which were statistically equal. However, when there was an increase in the number of branches using the 3B and 4B systems, the highest chlorophyll b levels were obtained using CM in the order of 11.63 and 10.57, respectively. The lowest chlorophyll b levels for the 3P and 4P systems were verified using OC with 8.35 and SM with 8.90, respectively (Table 7).

Table 7. Chlorophyll content index—chlorophyll *a*, chlorophyll *b*, and chlorophyll total in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
Chlorophyll <i>a</i>				
M	27.10 ± 0.44 aA	24.63 ± 0.13 abB	23.40 ± 0.15 abB	24.63 ± 0.64 aB
CM	21.37 ± 0.23 cB	24.83 ± 0.39 aA	24.73 ± 2.37 aA	22.83 ± 0.43 aB
OC	23.57 ± 0.19 bA	22.83 ± 0.43 bcAB	21.23 ± 1.69 cB	24.00 ± 0.47 aA
CL	23.77 ± 0.48 bA	24.23 ± 0.52 abA	21.73 ± 3.23 bcB	23.27 ± 0.13 aAB
SM	24.03 ± 0.37 bA	21.80 ± 0.44 cB	23.83 ± 0.24 aA	23.93 ± 0.35 aA
CV (%)	3.34			
Chlorophyll <i>b</i>				
M	12.60 ± 0.21 aA	11.10 ± 0.41 aB	9.63 ± 0.44 abC	11.27 ± 0.38 aAB
CM	7.53 ± 0.18 cC	11.63 ± 0.32 aA	10.57 ± 0.24 aA	9.06 ± 0.56 bB
OC	8.87 ± 0.45 bcAB	8.35 ± 0.38 cB	10.13 ± 0.41 abA	10.03 ± 0.45 abA
CL	9.50 ± 0.55 bA	10.33 ± 0.52 abA	10.15 ± 0.52 abA	9.53 ± 0.067 bA
SM	9.25 ± 0.28 bA	9.20 ± 0.31 bcA	8.90 ± 0.17 bA	9.93 ± 0.42 abA
CV (%)	6.53			
Total chlorophyll				
M	40.36 ± 0.34 aA	34.96 ± 0.47 abBC	32.43 ± 0.12 bcC	36.88 ± 0.27 aB
CM	28.80 ± 0.23 dB	37.13 ± 0.83 aA	35.67 ± 0.62 aA	30.70 ± 0.77 cB
OC	32.50 ± 0.35 cAB	31.07 ± 0.89 cB	34.03 ± 1.09 abA	34.77 ± 0.70 abA
CL	32.63 ± 0.41 cA	34.37 ± 0.87 abA	29.53 ± 1.77 cB	32.47 ± 0.29 bcA
SM	36.53 ± 1.03 bA	32.60 ± 0.63 bcB	33.40 ± 0.49 abB	34.77 ± 0.37 abAB
CV (%)	3.74			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

For total chlorophyll values, the 2B and espalier systems presented the highest levels with mineral fertilization of 40.36 and 36.88, respectively. The lowest levels were verified using CMs of 28.80 and 30.70, representing reductions of 28.64% and 16.76%, respectively (Table 7).

However, when the 3B and 4B systems were used, the plants fertilized with CM presented the highest total chlorophyll values, 37.13 and 35.67, respectively, equivalent to increases in total chlorophyll content of 16.32% and 17.21%, respectively, compared to the lowest levels reported by OC of 31.07 and CL of 29.53, respectively (Table 7).

3.3. Nutritional Content

The two factors studied also affected the nutritional content of the leaves. There was a significant interaction for the macronutrients N, P, K, Ca, and Mg ($p < 0.01$), as well as for the micronutrients Fe, Zn, and Mn ($p < 0.01$). The conduction systems significantly influenced Cu in isolation ($p < 0.01$). Due to these significant interaction effects, the combined means were analyzed using the Tukey test ($p < 0.05$) to compare treatment combinations and interpret the results.

The 2B system presented the highest nitrogen content using M (50.84 g kg^{−1}) and CL (49.91 g kg^{−1}), which were statistically equal (Table 8). In the espalier system, the highest content was obtained with mineral fertilization (56.90 g kg^{−1}), followed by the

second-highest value (CL; 49.90 g kg⁻¹). The lowest N contents were obtained using SM (36.08 g kg⁻¹) and OC (43.01 g kg⁻¹) in the 2B and espalier systems, respectively. In the 3B system, the highest contents were obtained with M (49.70 g kg⁻¹) and OC (47.90 g kg⁻¹), while the lowest was obtained with SM (32.43 g kg⁻¹). In the 4B system, the highest content was obtained using OC (49.71 g kg⁻¹), which did not differ statistically from CL (48.30 g kg⁻¹) (Table 8).

Table 8. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
Nitrogen (N) (g kg ⁻¹)				
M	50.84 ± 1.11 aB	49.70 ± 1.16 aB	43.27 ± 0.23 bC	56.90 ± 2.17 aA
CM	48.04 ± 1.31 abA	42.00 ± 1.29 bcB	47.91 ± 1.69 bA	48.25 ± 1.04 bcA
OC	43.58 ± 0.009 bB	47.90 ± 0.02 abAB	49.71 ± 0.85 aA	43.01 ± 0.27 cB
CL	49.91 ± 0.23 aA	41.76 ± 0.58 cB	48.30 ± 3.23 abA	49.90 ± 0.15 bA
SM	36.08 ± 1.78 cB	32.43 ± 3.59 dB	31.97 ± 0.01 bB	45.24 ± 0.45 bcA
CV (%)	5.62			
Phosphorus (P) (g kg ⁻¹)				
M	0.79 ± 0.01 cAB	0.65 ± 0.03 bB	0.61 ± 0.05 aB	0.94 ± 0.03 aA
CM	1.11 ± 0.06 bA	0.56 ± 0.01 bB	0.69 ± 0.01 aB	0.67 ± 0.004 abB
OC	0.60 ± 0.05 cA	0.81 ± 0.006 abA	0.54 ± 0.001 aA	0.61 ± 0.02 bA
CL	1.15 ± 0.09 bA	0.77 ± 0.01 abB	0.69 ± 0.01 aB	0.82 ± 0.18 abB
SM	1.55 ± 0.06 aA	1.04 ± 0.18 aB	0.78 ± 0.008 aB	0.79 ± 0.13 abB
CV (%)	15.72			
Potassium (K) (g kg ⁻¹)				
M	22.50 ± 0.23 aAB	20.22 ± 0.62 bcB	21.42 ± 1.16 aB	21.47 ± 0.73 abA
CM	21.02 ± 0.46 abA	21.73 ± 0.54 abB	21.29 ± 0.46 aB	22.33 ± 0.62 aB
OC	20.87 ± 0.01 abA	23.18 ± 0.01 Aa	20.50 ± 0.008 aA	19.25 ± 0.58 bcA
CL	19.29 ± 0.08 bA	18.34 ± 0.15 Cb	19.63 ± 0.06 abB	18.00 ± 0.85 cB
SM	20.85 ± 0.99 abA	20.04 ± 1.25 bcB	17.90 ± 0.04 bB	20.09 ± 0.39 abcB
CV (%)	5.13			
Calcium (Ca) (g kg ⁻¹)				
M	9.72 ± 0.06 aA	8.76 ± 0.49 abA	8.56 ± 0.24 bA	8.53 ± 0.20 cA
CM	9.15 ± 0.06 abA	10.51 ± 0.59 aA	9.35 ± 0.04 bA	10.18 ± 0.52 bcA
OC	7.86 ± 0.01 bC	7.93 ± 0.03 cB	10.25 ± 0.20 abB	12.09 ± 0.93 aA
CL	10.23 ± 0.17 aB	10.17 ± 0.08 bA	11.94 ± 0.78 aA	11.65 ± 0.43 abAB
SM	10.54 ± 0.85 aA	10.18 ± 0.69 aAB	8.86 ± 0.09 bB	11.14 ± 0.06 abA
CV (%)	7.64			
Magnesium (Mg) (g kg ⁻¹)				
M	3.13 ± 0.16 aBC	3.64 ± 0.08 abA	2.96 ± 0.02 abC	3.67 ± 0.05 aA
CM	2.93 ± 0.10 aA	2.84 ± 0.20 aB	2.69 ± 0.03 bA	3.10 ± 0.17 bA
OC	3.21 ± 0.24 aA	2.97 ± 0.01 aB	3.49 ± 0.01 aA	3.38 ± 0.03 abA
CL	3.41 ± 0.13 aA	3.29 ± 0.21 abA	3.00 ± 0.03 abA	3.32 ± 0.01 abA
SM	3.24 ± 0.21 aAB	2.89 ± 0.10 bB	1.89 ± 0.01 cC	3.74 ± 0.18 aA
CV (%)	7.60			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

The espalier system's highest phosphorus (P) content was obtained using an M fertilizer of 0.94 g kg⁻¹, which did not differ statistically from the CL, SM, and CM sources. The lowest value was obtained with an OC of 0.61 g kg⁻¹. The highest content in the 2B system was obtained with an SM of 1.55 g kg⁻¹, while the lowest values were obtained with M

(0.79 g kg⁻¹) and OC (0.60 g kg⁻¹). The highest content in the 3B system was obtained with SM, with 1.04 g kg⁻¹, not differing statistically from CL and OC. The lowest contents were verified with M with 0.60 g kg⁻¹ and CM with 0.56 g kg⁻¹. The plants with 4B did not differ statistically among the fertilizer sources (Table 8).

The highest potassium (K) content was verified using M fertilization at 22.50 g kg⁻¹ in the 2B system, which did not differ statistically from the CM, OC, and SM sources. In the 3B system, the highest K content was obtained with OC, which was 23.18 g kg⁻¹. In the 4B system, the highest values were obtained using the M (21.42 g kg⁻¹), CM (21.29 g kg⁻¹), and OC (20.50 g kg⁻¹) sources, which were statistically equal. The highest K content was obtained with CM of 22.33 g kg⁻¹ in the espalier system, not differing statistically from the M fertilization of 21.47 g kg⁻¹. Fertilization with CL corresponded to the lowest K values (19.29, 18.34, and 18.00 g kg⁻¹) in the 2B, 3B, and espalier systems. In the 4B system, the weakest content was obtained from the SM of 17.90 g kg⁻¹ (Table 8).

The highest calcium (Ca) contents in plants subjected to the 2B system were obtained using SM with 10.54 g kg⁻¹, CL of 10.23 g kg⁻¹, and M with 9.72 g kg⁻¹. In the 3B system, the highest contents were obtained with CM (10.51 g kg⁻¹), SM (10.18 g kg⁻¹), and CL (10.17 g kg⁻¹), statistically equal. In the 2B and 3B systems, the lowest Ca contents were verified with OC, corresponding to 7.86 and 7.93 g kg⁻¹, respectively. However, in the 4B system, fertilization with CL provided the highest value (11.94 g kg⁻¹). The lowest contents were obtained using CM, SM, and M, statistically equal. In the espalier system, the use of OC provided the highest value of 12.09 g kg⁻¹, followed by CL and SM, and the lowest Ca content was obtained with M fertilization of 8.53 g kg⁻¹ (Table 8).

The plants submitted to the 2B system did not exhibit significant differences in magnesium (Mg) content among the different fertilizer sources used. In the 3B system, the highest magnesium content was obtained with M (3.64 g kg⁻¹), which was statistically equal to that of CL (3.64 g kg⁻¹); the other sources did not differ significantly. The plants with 4B presented the highest Mg contents using OC (3.49 g kg⁻¹), followed by CL (3.00 g kg⁻¹) and M (2.96 g kg⁻¹), which were statistically equal, and the lowest content was verified with SM (1.89 g kg⁻¹). In the espalier system, the highest Mg contents were obtained with SM (3.74 g kg⁻¹) and M (3.67 g kg⁻¹), and the lowest Mg content was obtained with the use of CM (3.10 g kg⁻¹) (Table 8).

The highest iron (Fe) content in plants subjected to the 2B system was obtained using an OC equivalent to 388.10 mg kg⁻¹, and the other sources did not differ significantly from this value. In the 3B system, the highest Fe content was verified in fig trees fertilized with OC of 437.28 mg kg⁻¹, and the lowest content was verified in plants fertilized with CM of 207.64 mg kg⁻¹. In the 4B system, the highest contents corresponded to CL and OC fertilizations of 346.26 and 305.72 mg kg⁻¹, respectively, and the lowest value was obtained with M fertilization with 117.07 mg kg⁻¹. In the espalier system, the highest Fe content was obtained with CL with 308.21 mg kg⁻¹, and the lowest Fe contents were obtained using the OC and SM sources (Table 9).

Plants submitted to the 2B system did not differ significantly in zinc (Zn) content for the sources used. Plants with 3B presented higher Zn contents, as measured by SM, CM, and OC, which were statistically equivalent. The lowest contents were obtained with CL and M, which did not differ from each other. In the 4B and espalier systems, the highest Zn contents were also verified using SM of 47.76 and 43.61 mg kg⁻¹, respectively. The lowest values were observed in plants fertilized with a CL of 29.84 mg kg⁻¹ and a CM of 36.34 mg kg⁻¹ (Table 9).

The highest manganese (Mn) content in the 2B system was obtained using CL equivalent to 41.03 mg kg⁻¹, which did not differ from the other organic sources. The lowest Mn content was obtained with M fertilization (29.39 mg kg⁻¹). The plants with 3B presented the

highest content of CM (46.79 mg kg⁻¹), not differing statistically from SM (38.52 mg kg⁻¹), and the lowest contents were observed in M (20.95 mg kg⁻¹) and OC (16.98 mg kg⁻¹). The plants with 4B had the highest Mn content, using CL of 41.05 mg kg⁻¹, and the lowest was obtained with SM of 16.58 mg kg⁻¹. In the espalier system, the highest contents were obtained with M fertilization (38.94 mg kg⁻¹), followed by SM (35.56 mg kg⁻¹), which were statistically equal, and the lowest contents were obtained using CM (22.24 mg kg⁻¹) and CL (2.98 mg kg⁻¹) (Table 9).

Table 9. Iron (Fe) (mg kg⁻¹), zinc (Zn) (mg kg⁻¹), and manganese (Mn) (mg kg⁻¹) in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
Iron (Fe) (mg kg ⁻¹)				
M	180.27 ± 27.66 bBC	314.28 ± 48.38 bA	117.07 ± 0.62 cC	229.81 ± 74.36 abAB
CM	171.24 ± 7.21 bA	207.64 ± 12.58 cA	248.91 ± 4.42 abA	244.47 ± 5.55 abA
OC	388.10 ± 0.62 aAB	437.28 ± 0.73 aA	305.72 ± 1.27 aB	184.70 ± 11.59 bC
CL	275.65 ± 25.17 bA	259.97 ± 1.25 bcA	346.26 ± 7.77 aA	308.21 ± 15.71 aA
SM	233.06 ± 59.71 bA	230.10 ± 23.64 bcA	176.71 ± 0.62 bcA	176.40 ± 19.98 bA
CV (%)	3.34			
Zinc (Zn) (mg kg ⁻¹)				
M	40.10 ± 3.43 aA	29.04 ± 1.46 bB	36.61 ± 1.89 bcA	38.48 ± 0.55 abA
CM	39.43 ± 0.96 aAB	45.43 ± 3.33 aA	40.14 ± 0.85 bAB	36.34 ± 1.47 bB
OC	43.64 ± 0.34 aA	42.86 ± 0.03 aA	39.32 ± 0.14 bA	41.61 ± 4.70 abA
CL	39.62 ± 0.12 aA	34.49 ± 0.55 bAB	29.84 ± 1.16 cB	38.41 ± 1.26 abA
SM	42.65 ± 0.76 aA	45.93 ± 2.39 aA	47.76 ± 0.16 aA	43.61 ± 0.31 aA
CV (%)	6.53			
Manganese (Mn) (mg kg ⁻¹)				
M	29.39 ± 2.84 bAB	20.95 ± 1.60 cB	37.92 ± 6.21 abA	38.94 ± 4.94 aA
CM	36.56 ± 0.97 abB	46.79 ± 3.78 aA	29.26 ± 2.66 bBC	22.24 ± 0.61 bC
OC	37.12 ± 0.01 abA	16.98 ± 0.04 cB	39.92 ± 2.60 abA	30.46 ± 2.21 abA
CL	41.03 ± 0.09 aA	33.34 ± 0.07 bA	41.05 ± 1.66 aA	20.98 ± 0.67 bB
SM	33.40 ± 5.18 abA	38.52 ± 3.32 abA	16.58 ± 0.17 cB	35.56 ± 0.28 aA
CV (%)	3.74			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

The highest Cu contents were verified in the espalier system, equivalent to 1.39 mg kg⁻¹, which did not differ statistically from the 2B (1.15 mg kg⁻¹) and 3B (1.17 mg kg⁻¹) systems. The 4B system resulted in a lower content of 1.03 mg kg⁻¹ (Table 10).

Table 10. Copper (Cu) (mg kg⁻¹) in fig trees subjected to different conduction systems.

Conduction Systems	Copper (Cu) (mg kg ⁻¹)
2 Branches	1.15 ± 0.03 ab
3 Branches	1.17 ± 0.04 ab
4 Branches	1.03 ± 0.06 b
Espalier	1.39 ± 0.14 a
CV (%)	21.94

Means followed by the same lowercase letter in the column do not differ by Tukey's test ($p > 0.05$). Mean ± standard deviation.

3.4. Productivity

The studied factors, fertilization sources (mineral and organic), and conduction systems interact significantly and influenced the productivity at the level of ($p < 0.01$). Due to

these significant interaction effects, the combined means were analyzed using the Tukey test ($p < 0.05$) to compare treatment combinations and interpret the results (Figure 3).

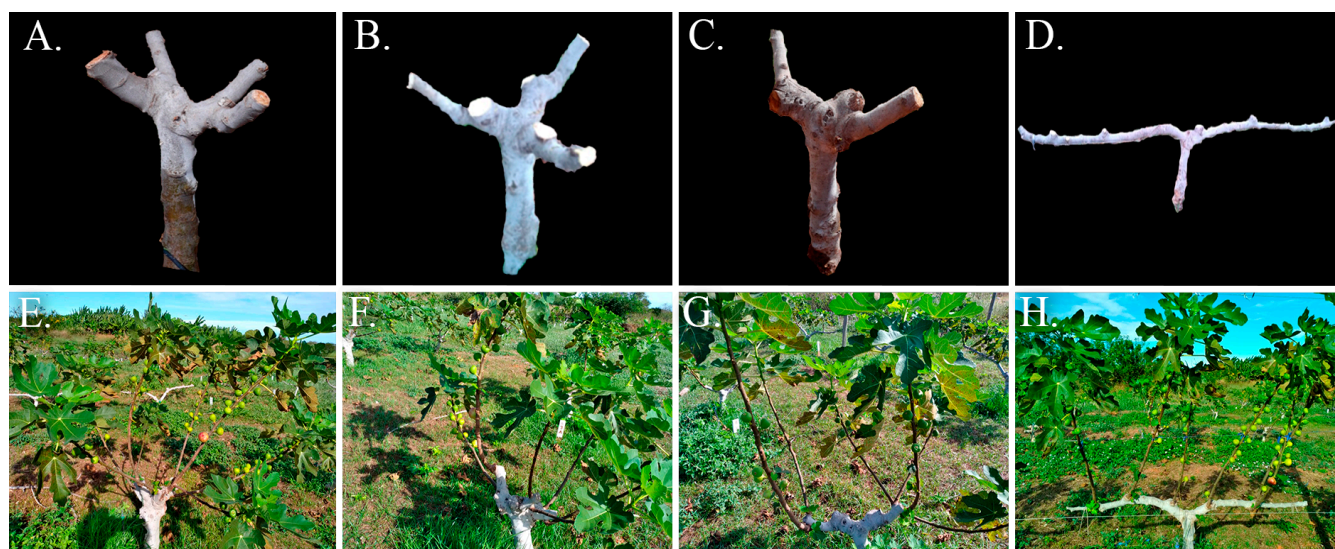


Figure 3. Training systems used in fig trees: two branches (A,E), three branches (B,F), four branches (C,G), and espalier (D,H).

Although the plants that received organic sources exhibited net photosynthesis similar to those that received mineral sources, this was not the case for the productivity of fig trees. Plants that received mineral fertilization presented higher productivity than the organic sources used, emphasizing the 2B, 3B, and espalier systems (12.79 , 21.28 , and 7.36 t ha^{-1} , respectively). Further, 3B was statistically superior to the other systems used with mineral fertilization with 21.28 t ha^{-1} . The other organic sources used in these systems did not differ significantly from one another (Table 11).

Table 11. Productivity (t ha^{-1}) in fig trees subjected to different mineral and organic fertilization and training system sources.

FA	2 Branches	3 Branches	4 Branches	Espalier
	Productivity (t ha^{-1})			
M	$12.79 \pm 2.45 \text{ aB}$	$21.28 \pm 1.26 \text{ aA}$	$7.82 \pm 0.84 \text{ aC}$	$7.36 \pm 1.29 \text{ aC}$
CM	$2.19 \pm 0.07 \text{ bA}$	$3.28 \pm 0.23 \text{ bA}$	$4.10 \pm 0.14 \text{ bcA}$	$2.66 \pm 0.19 \text{ bA}$
OC	$4.41 \pm 0.24 \text{ bA}$	$2.72 \pm 0.36 \text{ bA}$	$3.01 \pm 0.31 \text{ cA}$	$2.52 \pm 0.23 \text{ bA}$
CL	$4.46 \pm 0.77 \text{ bAB}$	$5.33 \pm 1.01 \text{ bAB}$	$6.51 \pm 0.34 \text{ abA}$	$3.22 \pm 0.12 \text{ bB}$
SM	$1.41 \pm 0.02 \text{ bA}$	$2.77 \pm 0.11 \text{ bA}$	$1.37 \pm 0.09 \text{ cA}$	$2.69 \pm 0.24 \text{ bA}$
CV (%)	26.91			

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ by Tukey's test ($p > 0.05$). Mean $\pm$ standard deviation. M: Mineral; CM: cattle manure; OC: organic compost; CL: chicken litter; SM: sheep manure.

It is noteworthy that, in the 4P system, there was equivalence regarding the organic and mineral sources in the productivity of fig trees, with an emphasis on the CL source, which, in addition to having presented considerable net photosynthesis, provided a productivity of 6.51 t ha^{-1} , similar to the mineral 7.82 t ha^{-1} (Table 11).

4. Discussion

Successful fig tree management involves several practices that promote plant development and increased fruit production. Crop management practices, such as fertilization

and pruning, can significantly affect the crop's phenological patterns to maximize output. In this study, we observed that mineral fertilization yielded higher productivity compared to other organic sources. The average fig productivity observed in our study in 2022 was 18.22 t ha^{-1} [34]. It is emphasized that only combining mineral fertilization with the 3B system had productivity above the national average for fig trees (21.28 t ha^{-1}). The other combinations studied were below the national productivity. Moura et al. [10] reported productivity values of 10.18 t ha^{-1} for figs under conventional and organic cultivation and training systems in semi-arid conditions.

The total amount of light received during a crop's growth phases is related to its yield and is influenced by pruning, which consequently increases light input to the plant. Light is assimilated during photosynthesis. In this process, plants convert light energy into chemical energy, playing a central role in plant metabolism [35]. Therefore, the combination of mineral fertilization and the 3B system may have provided better architecture and improved light absorption by plants, resulting in greater assimilation and productivity (Figure 3).

Furthermore, this result is primarily due to the ability of mineral fertilization to provide an immediate supply of essential nutrients (N and P), efficiently synchronizing with the peak nutritional demand of the fig tree after pruning. In contrast, organic sources (CM, OC, and SM), originating from different animals, exhibit slow release that, in a single cycle, usually fails to meet the instantaneous nutritional needs of high-yielding fruit crops. Furthermore, due to the pandemic, the fig trees were left unattended and unfertilized for a year before the commencement of this study. Therefore, it is believed that the fig trees under organic management have not recovered their full production potential. Since organic fertilizers release nutrients slowly, they often fail to meet the crop's critical nutritional needs [36,37].

Due to their high nutrient content, chicken litter and cattle manure are widely used as organic fertilizers in agriculture. This benefits the physical, chemical, and biological properties of the soil by releasing nutrients to plants, making them easily accessible to producers. Chicken litter is considered to be richer in nutrients, such as nitrogen, calcium, and phosphorus, than other organic sources, including cattle manure and organic compost [10,38].

The CL (chicken litter) source achieved similar productivity to M in system 4B due to its composition and higher mineralization rate (Figure 3). As reported by Moura et al. [10] and corroborated by our composition data (Table 1), CL has exceptionally high levels of P and N, resulting in a mineralization rate three times higher than that of other manures [39], which enables it to approach the efficiency of mineral fertilizers. However, as can be seen in Table 3, phosphorus apparently became concentrated in the soil since it is a nutrient that is not very mobile, indicating low absorption by fig trees, as evidenced by the low levels in the leaves (Table 8). This result confirms that the quality and decomposition rate of organic material are more critical factors than simply adding biomass.

Leaf analysis revealed that treatments with chicken manure litter (CL) resulted in high nitrogen (N) levels, a crucial component of the RuBisCO enzyme and chlorophyll (Tables 7 and 8, respectively). This increased N input directly correlated with higher carboxylation efficiency (Table 5), indicating that the primary mechanism behind the increased net photosynthesis was the optimization of the biochemical capacity of the leaf mesophyll rather than increased CO_2 availability through stomata.

The contrast between the poultry manure and sheep manure treatments in the two-branch system highlights this mechanism since, although both presented high stomatal conductance (g_s), the low N content in the SM treatment resulted in severe biochemical limitation (A_N/C_i of 0.07, Table 5), resulting in a low photosynthetic rate (A_N). Additionally,

the maintenance of a high quantum efficiency of photosystem II (Fv/Fm) in the organic treatments (Table 6) indicates that the photosynthetic apparatus was more resilient to stress [40].

Variations in final productivity are intrinsically linked to adjustments in photosynthetic machinery and water use. To assess physiological integrity, the maximum quantum efficiency of PSII (Fv/Fm) was evaluated, which is an essential photochemical quenching parameter that determines the maximum quantum yield of PSII. It is also the most frequently used parameter in chlorophyll fluorescence analysis. Under normal conditions, Fv/Fm shows minimal variation and is not influenced by species or various conditions [41]. The mean values of (Fv/Fm) remained high (close to 0.80—Table 6), indicating that the plants were healthy, and the chlorophyll *a/b* ratio was stable at 3:1 (Table 7). These results demonstrate that, under all the management systems (mineral and organic), the fig trees did not suffer significant photooxidative stress, maintaining the integrity of their photosynthetic apparatus. The absence of photoinhibition suggests that the observed limitations in productivity do not result from structural damage but rather from functional and regulatory constraints [42].

In this context, we observed that the mineral treatment achieved better water use efficiency (WUE) and lower leaf temperatures, especially in systems 2B and 3B (Tables 4 and 5, and Figure 3). This behavior reflects more efficient stomatal regulation, with lower transpiration (E) and stomatal conductance (g_s) rates. This optimization in WUE is agronomically advantageous as it allows the plant to maximize carbon fixation while minimizing water loss under semi-arid conditions.

In contrast to the efficiency of mineral fertilization, fig trees fertilized with organic sources (CM, OC, and CL) tended to have more significant stomatal aperture (g_s) and greater transpiration (E). Although a high g_s suggests a greater potential for gas exchange and CO_2 uptake [43], the water use efficiency (WUE) obtained was only intermediate (Table 4). A similar A_N/C_i to that of mineral fertilization suggests that the plant was attempting to maximize carbon fixation. Still, this high g_s did not translate into a higher A_N , resulting in greater water loss per unit of CO_2 fixed. This reinforces the hypothesis that nutritional limitation prevented the full realization of photosynthetic potential [44].

The sheep manure (SM) treatment, however, presented an even more severe restriction, being a failure point in the experiment. SM not only resulted in low WUE but also led to significantly lower carboxylation efficiency (A_N/C_i) in all the systems (Table 5), as evidenced by the high C_i levels. This accumulation of CO_2 in the mesophyll, without proper utilization, indicates a biochemical limitation in photosynthesis. The substrate was available but not used due to the inefficiency of the Rubisco enzyme or the low regeneration of cofactors (NADPH and ATP) [40,44–46].

Chatzistathis et al. [22] reported high Na levels in the sheep manure used in a study with different organic sources, emphasizing that one of the adverse effects of applying animal manure may be salt accumulation. This risk may be increased by the continuous application of animal manure, which depends on both its quality (resulting from its chemical composition due to its animal origin) and quantity. Therefore, the constant application of SM could be hazardous and lead to soil salinization.

The mineralization rate of sheep manure is generally lower than that of other frequently used organic sources, which is related to the characteristics of the diet of the animals responsible for producing this compound when sheep are fed forage. There may be an accumulation of recalcitrant components, such as lignin and tannins, which directly affect the mineralization rate of the manure and, consequently, the supply of nutrients [20].

Organic sources provide a slow and gradual release of nutrients throughout the production cycle, matching the net photosynthesis of fig trees that received mineral fertilization.

However, the explanations of how organic fertilization benefits the photosynthetic process remain uncertain. It is believed that the beneficial effect of comprehensive nutrition on the physical and chemical properties of soil may lead to enhanced nutrition for plants, increasing the profile of secondary metabolites in plant tissues and benefiting the physiological processes of plants [47,48].

Some authors only report the effects of organic fertilization on photosynthetic variables, whether positive, such as Efthimiadou et al. [48] in sweet corn and Ye et al. [49] in Jujube Pear, which reported higher rates of A_N with organic fertilizer, or harmful, such as Bilalis et al. [50] in tobacco, or no effect in kiwi [49].

Furthermore, such measurements are directly or indirectly related to all the stages of light-dependent photosynthetic reactions, including electron transport, water splitting, establishment of the pH gradient across the thylakoid membrane, and ATP synthesis, which is essential for assessing the fitness and integrity of the internal photosynthesis apparatus [51].

Regarding chlorophyll content, it was observed that the source with CM provided higher levels of chlorophyll *a*, *b*, and total under 3B and 4B conditions. Cattle manure is commonly used in crops because it has a low carbon–nitrogen (C: N) ratio, low lignin content, and high levels of cellulose, contributing to its rapid mineralization, in addition to having considerable amounts of nutrients, especially nitrogen, which is essential for the chlorophyll molecule and chloroplast activity [52,53].

While our results clearly demonstrate the impact of treatments on physiological indicators and the first harvest, it is essential to note that this study spanned 9 months; for perennial crops such as fig trees, the long-term effects of fertilizer sources on soil fertility and cumulative productivity may differ significantly. Therefore, we suggest that future studies be conducted across multiple production cycles to validate whether the observed trends persist, especially under organic management, which exhibits cumulative effects on soil.

The results of this study clearly demonstrate that mineral fertilization, especially when combined with the 3B training system, is the most efficient strategy for enhancing first-harvest productivity due to its ability to optimize physiological processes rapidly.

5. Conclusions

Fig trees fertilized with minerals and subjected to the 3B system proved to be the most efficient strategy as it maximized productivity and photosynthesis in the first cycle due to the immediate availability of nutrients.

Fig trees fertilized with chicken manure and subjected to the 4B system stood out as a more viable alternative, presenting photosynthetic and productive performance similar to that of the mineral treatment, which is due to their more favorable mineralization rate.

The use of sheep manure proved to be unviable, resulting in lower photosynthetic rates and productivity, leading to a series of biochemical limitations and the risk of using low-quality organic sources in the semi-arid environment.

Based on this evidence, the essential future direction is to conduct multi-cycle studies to quantify the cumulative effects of organic sources on improving soil properties and confirm the long-term economic and productive sustainability of the fig tree.

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