

## Article

# Alley Cropping and Organic Compost: An Efficient and Sustainable Agro-Ecological Strategy for Improving Turmeric (*Curcuma longa* L.) Growth and Attributes

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**Abstract:** Alley cropping is a sustainable agriculture approach that improves ecosystem services while also promoting biodiversity. The current study was conducted over two seasons, 2019/2020 and 2020/2021, to examine the impact of leucaena–turmeric alley cropping and organic compost addition as agroforestry systems on the growth, yield and characteristics of the turmeric crop. Alley cropping included four treatments: control (turmeric as sole crop), turmeric cultivated between leucaena trees pruned at 1 m height, leucaena trees pruned at 1.5 m height and unpruned leucaena trees. Meanwhile, organic compost rates were control (received recommended NPK) and 17 and 34 m<sup>3</sup> ha<sup>−1</sup>. This study's results showed that growing turmeric in between rows of unpruned leucaena resulted in maximum turmeric plant growth, production and characteristics. Minimum turmeric growth and yield parameters were recorded with plants grown between pruned leucaena at 1 m and those where the turmeric was the sole crop. In addition, compost addition at 34 m<sup>3</sup> ha<sup>−1</sup> led to maximum growth, yield and attributes of the turmeric crop. Compost addition and alley cropping were shown to be an effective and sustainable agro-ecological system for increasing turmeric output and quality. The study demonstrated the importance of selecting the appropriate crop–tree combination in this system and it was discovered that leguminous leucaena trees significantly contributed to improving fertility and nutrient availability, which in turn improved the growth characteristics of turmeric, particularly the leaf-area index and its nutrient content, which are beneficial to the characteristics of the rhizome yield and curcumin content.

**Keywords:** alley cropping; leucaena; turmeric; organic compost; curcumin

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## 1. Introduction

Sustainable farming refers to agricultural systems and procedures that try to reduce the depletion of natural resources in the soil. Sustainable farming approaches strive to preserve more organic matter in the soil, reduce erosion and keep more carbon in the soil. These practices improve the resilience and long-term health of the soil, ultimately leading to higher yields. Sustainable agriculture development should achieve a balance between economic and environmental/social goals [1]. One of the most pressing concerns faced due to climate change, food insecurity and a dwindling agricultural resource base is how to build profitable farming systems that optimize the use of arable land and enhance farmer incomes. Agroforestry, which allows farmers to efficiently use their land resources at reduced environmental costs while producing a range of crops at different times, neatly solves these difficulties [2].

Agroforestry is a farming practice suitable for enhancing the ecosystem services produced by cropping systems. Among agroforestry systems, the alley-cropping system is

characterized by the intercropping of crops and wide-row trees [3]. These systems offer a variety of products, including food, feed, fibers, fuel wood and timber, in addition to increasing the potential delivery of agro-ecosystem services [4].

Comparing to conventional agricultural practices, alley cropping is a more ecologically friendly strategy for land usage, biomass generation and sustainable food production. Alley cropping can deliver biomass resources in a sustainable manner and benefit the environment at the same time because it is a highly adaptable, low-input system [5]. In alley-cropping, a primary crop species is intercropped with a different plant species that grown in numerous horizontal strips [6]. With a variety of crop plants, trees, ground-vegetation cover and plant canopy, alley-cropping can provide complex vegetation structural diversity compared to monocultures, improving soil fertility (depending on the used species), water quality and carbon cycling [7,8].

Alley-cropping also serves as a potential adaptation strategy for reducing the consequences of climate change throughout its ecological advantages, such as buffers for weather extremes, reduced soil erosion, increased biodiversity and efficient nutrient and water utilization [9]. One problem of combining crop production with trees is that they may compete for nutrients, water and light, especially in areas where these resources are scarce [10]. Several researchers have found that due to competition, alley cropping diminished crop and/or tree yields, but its land-use efficiency was still high [11–13]. Because of the potential loss in crop yield, farmers are often hesitant to implement agroforestry systems [14,15]. Alley cropping enables the farmers to effectively utilize available resources and yield more benefits. Choosing suitable associated crops and mitigating the competition between trees and crops is crucial in designing alley-cropping systems [16].

Agroforestry and livestock feeding systems that use leguminous plants show potential for bridging the enormous demand and supply gaps in terms of animal feed and fodder. *Leucaena* (*Leucaena leucocephala*), is a miracle tree known for its rapid growth, versatility, capacity to fix nitrogen, adaptation to a variety of environments, strong coppicing ability, etc. and it finds usage in an agroforestry system [17]. Due to all these properties, *Leucaena* has become a model tree for alley farming. In alley farming, hedgerow trees are kept clipped throughout the cropping season to reduce crop shade and increase crop output [18,19].

On the other hand, organic farming impacts the physical, chemical and biological characteristics of soil, which in turn improves its fertility. It is considered an environmentally safe source, reduces pollution, is a renewable source for plant and soil nutrition and is less expensive compared to chemical fertilizers. Organic farming has increased tremendously in importance over the past 20 years, including in developing countries and the global market for organic products has grown [20].

Turmeric (*Curcuma longa* L.) is an herbaceous perennial crop belonging to the family Zingiberaceae. It is used in medicines, cosmetics and drugs as well as in food industries. Most chemical compositions consist of pale yellow to the orange-yellow volatile oil, which is composed of number of sesquiterpenes, monoterpenes, zingiberene,  $\alpha$ - and  $\beta$ -turmerone, curcumin and other components. The rhizome also has an important role in indigenous medicine, as well as in anti-cancer and anti-viral activities. This plant incorporates a yellowish coloring known as curcumin, starch, an acrid volatile oil, calcium chlorides, gum and woody fiber [21]. Due to the growing importance of this plant, as well as the fact that the curcuma plant is one of the finest and most costly in the global market, there is a lack of information on its growth and chemical makeup in Egyptian conditions. Finding the best agricultural practices to improve its traits and active substances is of utmost significance [22].

The current experiment was to study the growth, yield and attribute performance of turmeric as a valuable medicinal crop under the alley-cropping system of leucaena–turmeric and organic-compost supplementation in newly reclaimed lands in Upper Egypt.

## 2. Materials and Methods

The current study was carried out over two seasons, 2019/2020 and 2020/2021, on recently reclaimed lands of the Agricultural Research Station in Al-Marashda, Agriculture Research Centre, Qena governorate, Egypt (latitude 26°09' N, longitude 32°42' E). Fresh seeds of leucaena (*Leucaena leucocephala*) were obtained from healthy trees on the Al-Marashda farm. Seeds were soaked in previously boiled water for 2 h and were then sown in rows 2 × 4.5 m apart in February 2019 and 2020. The trees were left without pruning until the date of turmeric planting on 1 November of each year. Rhizomes of turmeric (*Curcuma longa*) were obtained from Sekem Companies, Cairo, Egypt. The chemical and physical properties of the soil are shown in Table 1 and the chemical analysis of the used irrigation water for the experimental site is shown in Table 2. The other agricultural practices were carried out as recommended for the cultivation of the turmeric plant by the Agricultural Research Centre, Ministry of Agriculture and Water Resources, Egypt.

**Table 1.** Physical and chemical characteristics of the experimental soil site.

Texture Class	Particle Size Distribution			CaCO <sub>3</sub> %	EC dSm <sup>−1</sup>	pH (1:5)	
	Sand %	Silt %	Clay %				
Sandy	83.3	11.7	5.0	12.50	3.03	8.05	
Cations (meq L <sup>−1</sup> )				Anions (meq L <sup>−1</sup> )			
Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>++</sup>	Mg <sup>++</sup>	CO <sub>3</sub> <sup>−</sup>	HCO <sub>3</sub> <sup>−</sup>	Cl <sup>−</sup>	SO <sub>4</sub> <sup>−</sup>
29.02	0.75	12.0	6.2	0.0	0.82	30.6	17.9

**Table 2.** Chemical analysis of the used irrigation water for the experimental site.

TDS mg L <sup>−1</sup>	pH	EC (dSm <sup>−1</sup> )	Soluble Cations (mg L <sup>−1</sup> )				Soluble Anions (mg L <sup>−1</sup> )			
			Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>	CO <sub>3</sub> <sup>−</sup>	HCO <sub>3</sub> <sup>−</sup>	SO <sub>4</sub> <sup>−</sup>	Cl <sup>−</sup>
220.5	7.50	321.3	25.5	7.8	30.6	5.2	23.7	105.5	40.6	30.2

### 2.1. Experimental Design

This experiment used a split-plot design with 12 combination treatments and 3 replicates. The main plot was assigned for organic-compost treatments: control (recommended NPK fertilization; 26 units 15% calcium super phosphate, 50 units 33.5% ammonium nitrate and 38 units 48% potassium sulphate), 17 m<sup>3</sup> ha<sup>−1</sup> or 34 m<sup>3</sup> ha<sup>−1</sup> during the preparation of soil before planting turmeric rhizomes. The chemical properties of the used organic compost in this study are shown in Table 3. On 1 November, leucaena trees were periodically pruned at a height of 1 m or 1.5 m or left without pruning. The sub plot was assigned for turmeric alleys between leucaena trees in an alley-cropping system: control (turmeric as a sole crop), leucaena pruned at 1 m, leucaena pruned at 1.5 m, or leucaena with no pruning. The turmeric rhizomes were planted in rows at a distance of 20 cm between plants and 50 cm between rows and the experimental plot was 2 × 4.5 m.

**Table 3.** Chemical analysis of the used compost in the experimental site.

Character	pH	EC (dSm <sup>−1</sup> )	OM %	N %	P %	K %	C/N Ratio	Moisture Content %	O.C %	Ca %
Value	7.2	4.6	47.3	1.2	1.3	1.7	1:16	27.7	20.2	5.7

### 2.2. Growth and Yield Parameters

On 1 May in each season, the plant height (cm), number of tillers plant<sup>−1</sup>, leaf-area index (cm<sup>2</sup>), number of rhizomes per plant, fresh weight of rhizomes per plant (g), fresh weight of rhizomes per plot (kg) and yield of rhizomes per hectare (ton) were measured on six randomly selected plants from each treatment.

### 2.3. Chemical Analysis

The essential oil % was determined in each treatment by using the hydro-distillation method of the American Spice Trade Association [23]. In addition, curcumin content (%) was determined using the method described by Manjunath et al. [24].

A leaf sample was collected from each turmeric plant and dried at 70 °C for 24 h. It was ground and digested to determine the content of nitrogen, phosphorus and potassium. The N content was determined using the modified microKjedahl method, as described by Jackson [25], while the P content was estimated calorimetrically according to method of Murphy and Riley [26]. Potassium percentage was determined by using atomic absorption flame photometry (3300), as described by Wilde et al. [27].

### 2.4. Statistical Analysis

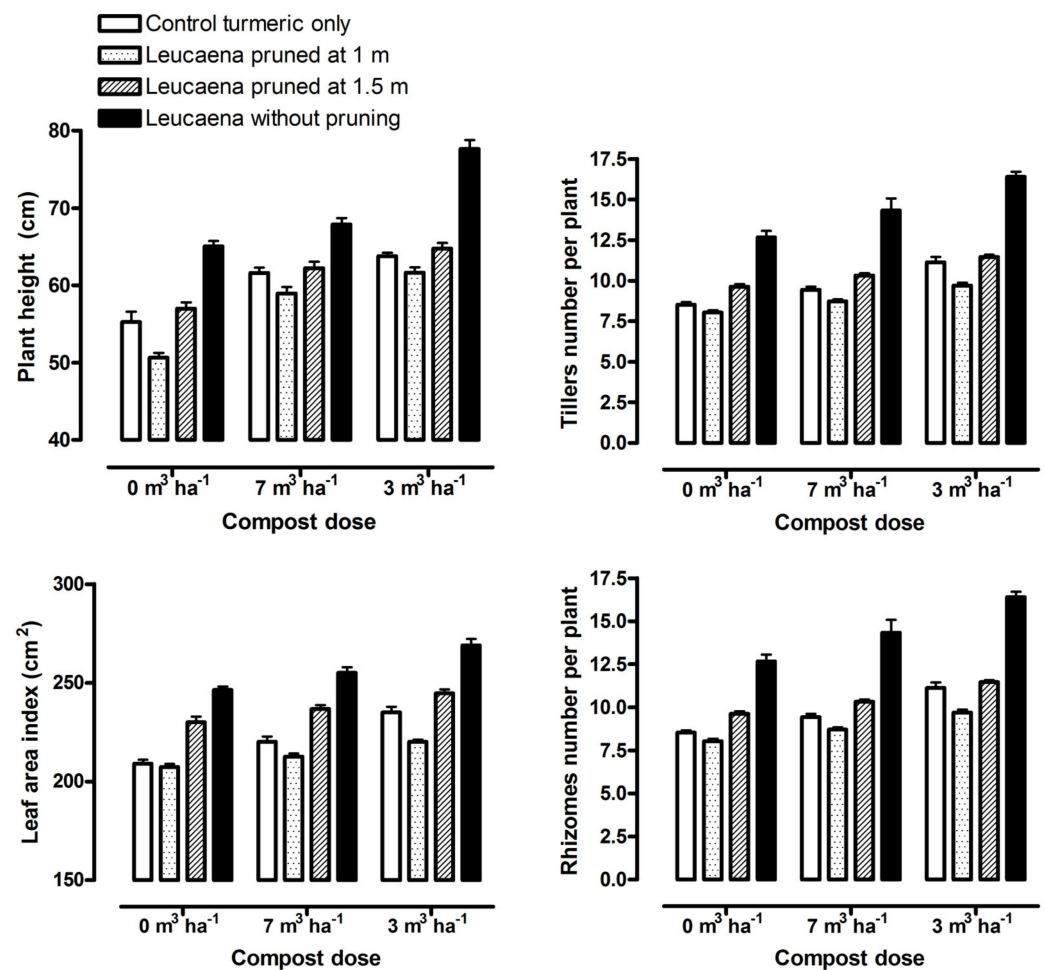
Obtained data from the two seasons were tabulated, pooled and subjected to statistical analysis by using Michigan Statistical Program Version C (MSTATC). The analysis of variance (ANOVA) was performed and the means were compared using the least significant differences (LSD) test at 5% level [28].

## 3. Results

ANOVA analysis revealed that turmeric growth, yield and attributes significantly differed as they were affected by compost doses, alley-cropping systems and the interactions between these. Increasing the compost dose led to significant increments in vegetative growth parameters: plant height, tiller number per plant, leaf-area index and rhizome number per plant (Figure 1). In the same way, the fresh weight of rhizomes per plant and rhizome yield per hectare significantly increased with increasing compost dose (Figure 2). Leaf nitrogen, phosphorus and potassium content also clearly increased with increasing the compost doses from 17 to 34 m<sup>3</sup> ha<sup>-1</sup> (Figure 3). Essential-oil content also increased significantly with increasing compost dose, although curcumin concentration did not alter much at 17 m<sup>3</sup> ha<sup>-1</sup> compost dose, but significant increments were shown at the compost dose of 34 m<sup>3</sup> ha<sup>-1</sup> with respect to control (Figure 4). The maximum values of all vegetative growth, yield parameters and attributes were observed under the 34 m<sup>3</sup> ha<sup>-1</sup> dose of compost treatment.

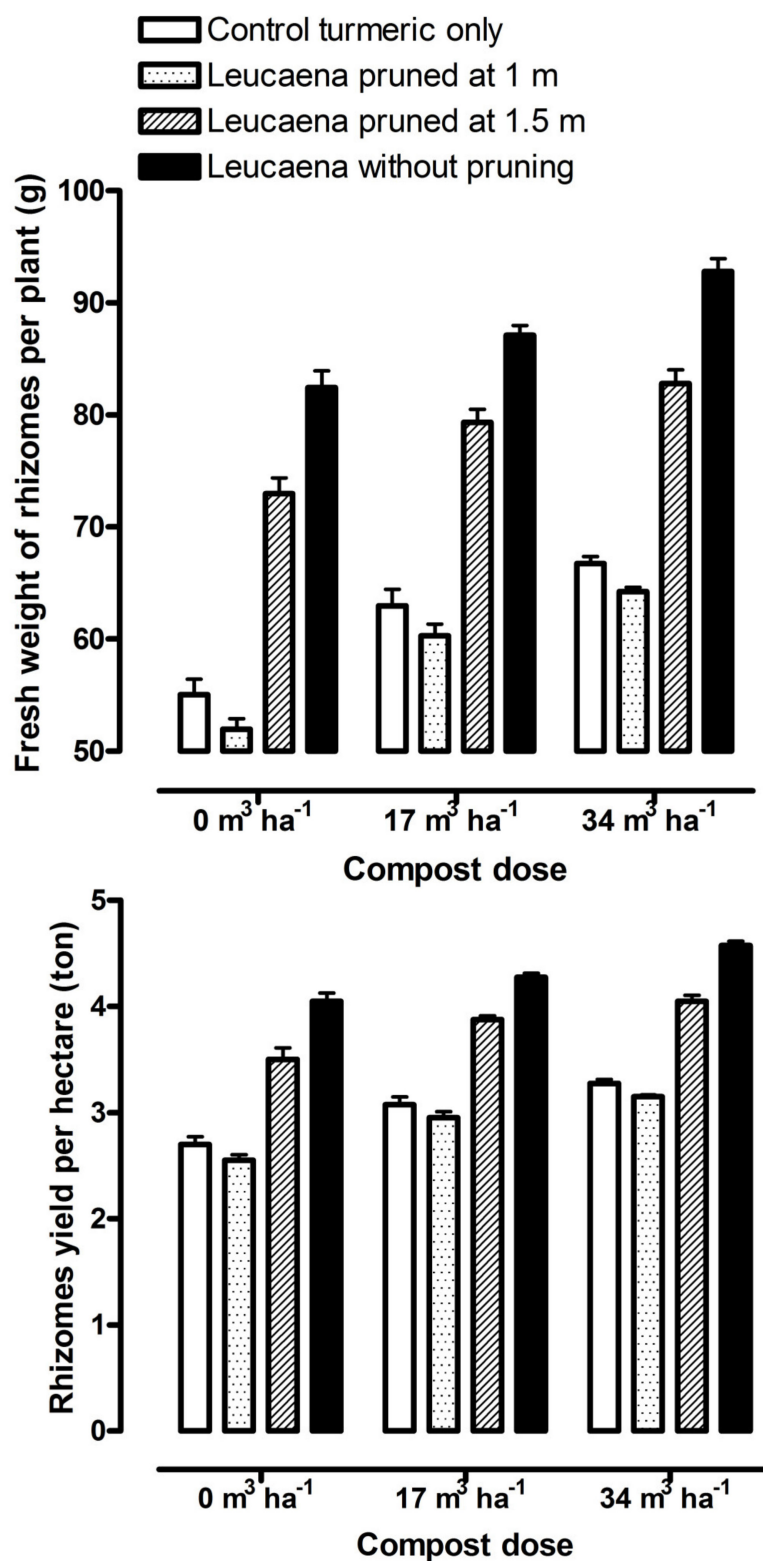
In terms of alley-cropping treatments, compared to the control (turmeric plants as a sole plant), the vegetative growth and yield parameters had significantly lower values when turmeric was alleyed between leucaena trees pruned at 1 m, while turmeric alleyed between leucaena trees pruned at 1.5 m and leucaena trees with no pruning had significantly higher values (Figures 1 and 2). Meanwhile, there were no significant differences between the control and turmeric alleyed within leucaena trees pruned at 1 m in terms of chemicals, essential oil, or curcumin content, while significant increments clearly appeared when turmeric was alleyed between leucaena trees pruned at 1.5 m and leucaena trees with no pruning (Figures 3 and 4). All vegetative growth, yield parameters and attributes were significantly higher when turmeric was alleyed between non-pruned leucaena trees.

All in all, the highest values of vegetative growth and yield parameters as well as chemical, essential oil and curcumin content were found in turmeric plants alleyed between leucaena trees with no pruning and treated with compost at a dose of 34 m<sup>3</sup> ha<sup>-1</sup>. The lowest values of vegetative growth and yield parameters were seen in turmeric plants alleyed between leucaena trees pruned at 1 m and the lowest chemical, essential oil and curcumin content was found when turmeric was grown as a sole crop (control).



**Figure 1.** Plant height (cm), tiller number per plant, leaf-area index (cm<sup>2</sup>) and number of rhizomes per plant of *Curcuma longa* in response to alley-cropping and organic-compost treatments as pooled data of the two seasons of 2021 and 2022.

Leaf-area index is significantly associated with the vegetative growth and yield traits especially tiller number per plant, rhizome number per plant and rhizome yield (99, 96 and 97%, respectively), as shown in Figure 5. The amount of micronutrients in turmeric leaves increased as a result of increasing of soil's fertility and nutrient availability due to compost addition as well as nitrogen fixation by leguminous leucaena trees. The yield of rhizomes was associated mainly with nitrogen and potassium content (95 and 96%, respectively). In addition, the micronutrients nitrogen, phosphorus and potassium were highly associated with curcumin content (95, 94 and 93%, respectively), as shown in Figure 6.



**Figure 2.** Fresh weight of rhizomes per plant (g) and fresh weight of rhizomes per hectare (ton) of *Curcuma longa* in response to alley-cropping and organic-compost treatments as pooled data of the two seasons of 2021 and 2022.



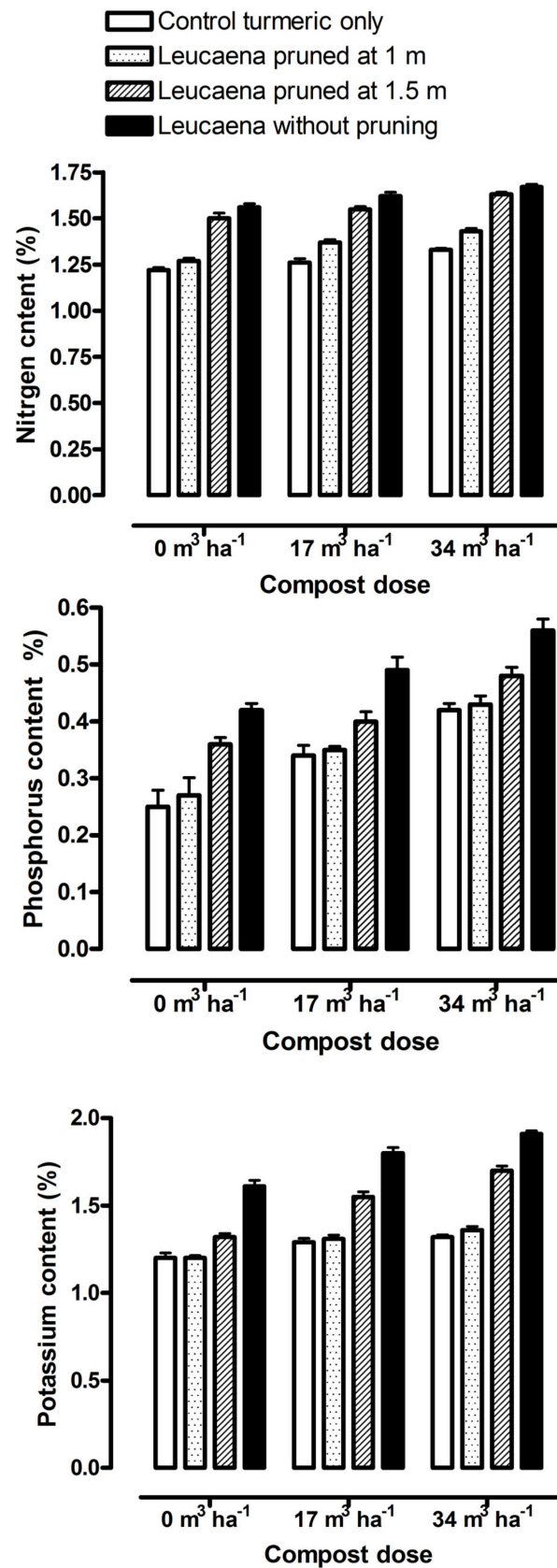


Figure 3. Nitrogen, phosphorus and potassium contents (%) in leaves of *Curcuma longa* in response to alley-cropping and organic-compost treatments as pooled data of the two seasons of 2021 and 2022.

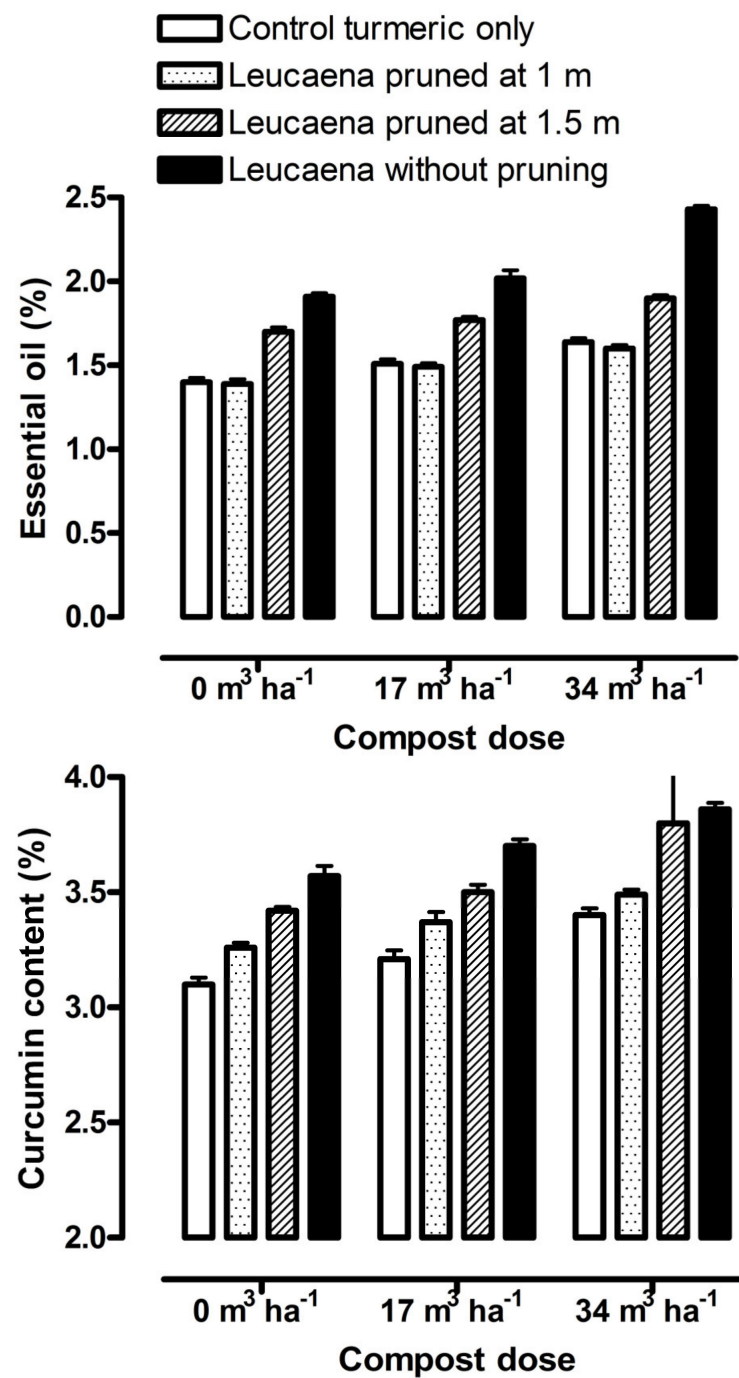
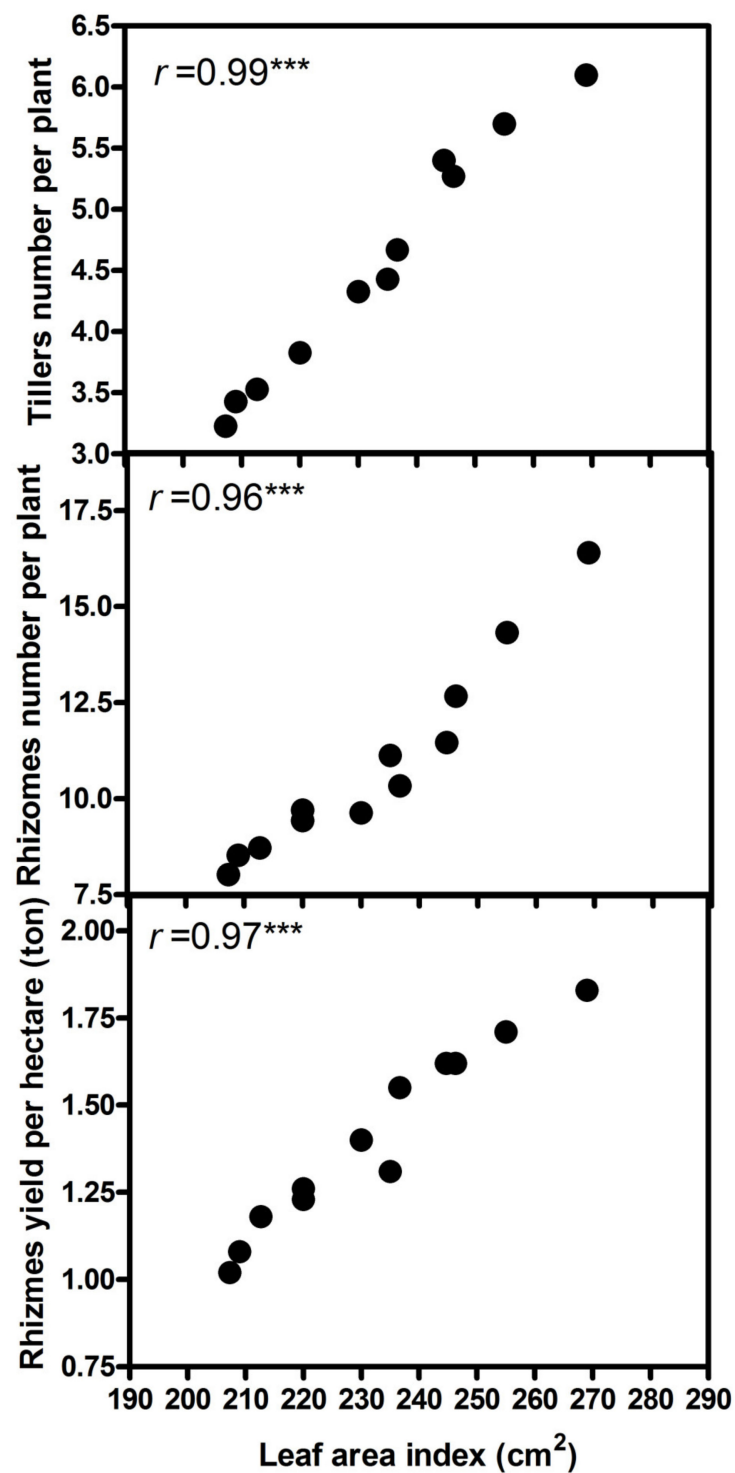
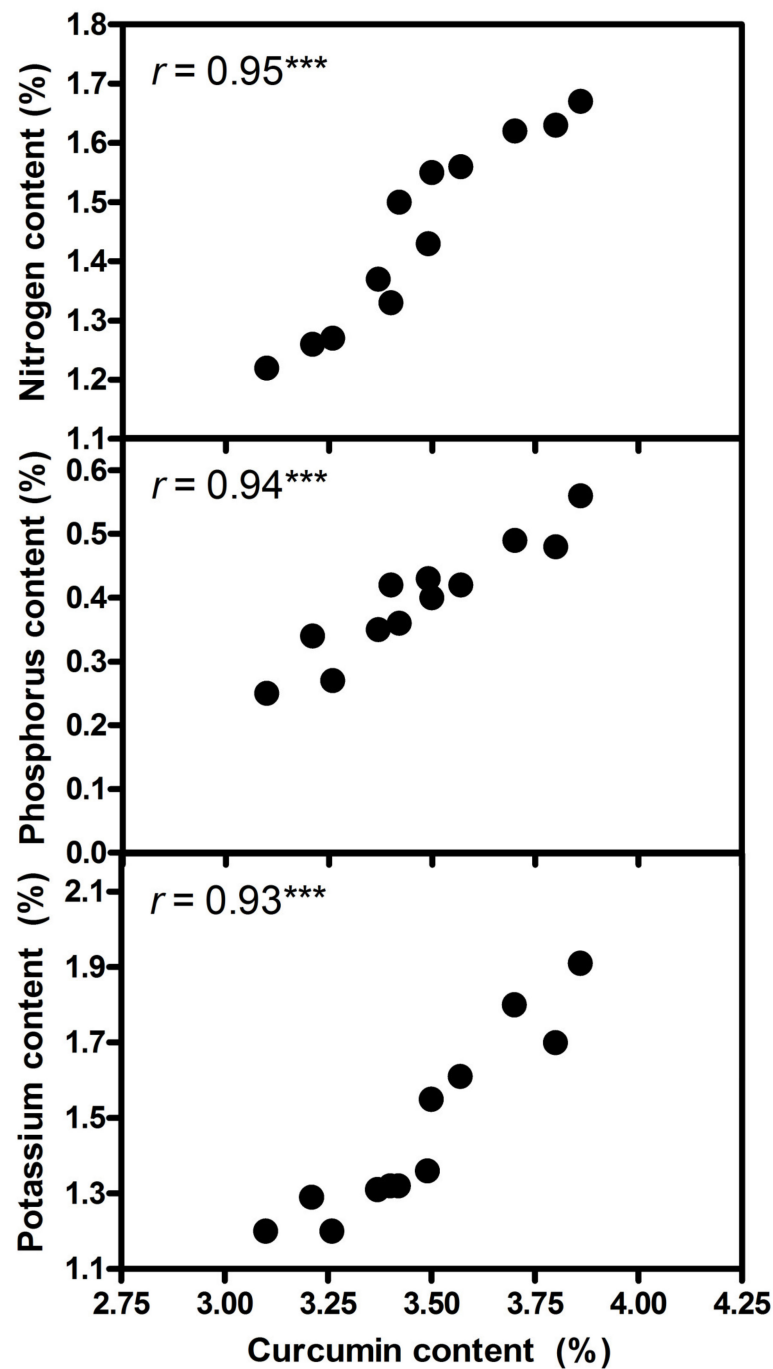


Figure 4. Essential oil (%) and curcumin (%) in rhizomes in of *Curcuma longa* in response to alley-cropping and organic-compost treatments as pooled data of the two seasons of 2021 and 2022.





**Figure 5.** Coefficient correlation of leaf-area index and tiller number per plant, rhizome number per plant and rhizome yield per hectare. \*\*\* Significance at probability level of  $< 0.0001$ .



**Figure 6.** Coefficient correlation of curcumin content and nitrogen, phosphorus and potassium contents. \*\*\* Significance at probability level of  $< 0.0001$ .

#### 4. Discussion

A key issue in agroforestry management is the need to maximize mutual benefits and minimize interspecific competition between all components, allowing agroforestry to achieve high efficiency and sustainability [29]. Alley cropping is an agroforestry strategy that involves growing crops between closely spaced rows of trees. Tree–crop combinations in alley cropping were developed with both production and ecological benefits in mind and can be highly diverse. The first and perhaps most important decision in designing an alley-cropping system is the selection of the tree species. Ashraf et al. [30] recommended the need for careful crop selection in the management and planning of future alley-cropping systems in order to maximize the environmental advantages that can be obtained from such a

system. In this study, turmeric–leucaena has been used for the alley-cropping system and compared to turmeric crops as a sole crop.

Moreover, Purnomo et al. [31] indicated that the higher yield of rhizomes in between trees compared to under a sole crop indicates that the photorespiration process does occur and means that this plant is adapted to low light intensity. The data of this study showed that the highest values of vegetative growth and yield parameters as well as attributes such as micronutrient content (N, P and K), essential oil and curcumin content were obtained when turmeric was planted between unpruned leucaena trees. In contrast, planting turmeric between leucaena trees pruned at 1 m had negative impacts on some of the vegetative growth and yield parameters. This can be explained by the negative effect of the competition between the tree roots and the crop for nutrients and water resources and the fact that pruning trees at low altitudes reduces their positive role of providing a suitable microclimate.

Alley-cropping systems are known to affect microclimatic factors and are often characterized by a high structural diversity [5]. According to Ashraf et al. [30], several alley-cropping systems have great potential for use in climate-smart agriculture. Reduced wind speeds, mild temperatures (owing to lower radiation intensities) and a better water-control system (greater air and soil moisture, lower evaporation losses from the soil surface) are just a few of the advantages of this microclimate [5]. The decline in soil fertility, especially in newly reclaimed lands, is recognized as the main factor in the decrease in the productivity of these lands. Therefore, cropping systems that are based on perennial trees, especially legumes as green manure with appropriate management procedures have been used as an important means of sustaining crop productivity in poor farmland [32].

In addition, alley cropping using leguminous shrubs and trees that are pruned periodically to increase the organic matter is attracting interest as an alternative option to improve crop and soil productivity in the tropics and semi-arid tropical regions [33]. Moreover, the ability of the tree legume to fix nitrogen enables it to grow in soils with low fertility and adverse conditions. Once planted, it improves the growing conditions of the other species and creates a balanced plant ecosystem. Tree legume is a good source of organic material for green manure. Legume leaves contain 2.5–5.5% nitrogen and are incorporated into the soil to improve fertility, nutrient retention and moisture [34].

Whitehead and Marney [35] reported that legume-based intercrops might improve nutrient supply and growth; these benefits depend on the selection of species and their tolerance to light levels under tree-based intercropping. In this study, in addition to the alley-cropping system, organic compost was added at two doses—17 and 34 m<sup>3</sup> ha<sup>−1</sup> compared to control. Increasing compost dose produced significantly higher values of all traits. This is because of the positive effect of organic compost in improving soil fertility by increasing organic matter and nutrient content.

The findings of this study are consistent with previous findings; our results proved that the growth and vigor of the turmeric plant was improved under unpruned legume tree and at a higher rate of organic compost. Shade and organic compost as sources of nutrients had positive effects on the soil and turmeric plants [36–39]. These results indicated the positive effect of soil nutrition and shade on curcumin synthesis, assimilation and translocation in turmeric rhizomes [39]. Painkra et al. [40] showed that farmyard manure at 100% dose on turmeric under a *Pongamia pinnata*-based agroforestry system produced higher growth parameters such as plant height and number of tillers/plant.

Purnomo et al. [31] revealed that cultivating turmeric with the *Albizia chinensis* tree and application of a small amount of fertilizer to turmeric was enough for efficient production. The microclimate under the cropping system is modified by the presence of trees and the growth response of turmeric under such conditions may be different from the sole crop. Turmeric growth and yield production showed a positive response under the agroforestry system compared to sole crops [39]. In addition, Ebeid et al. [41] revealed that alley cropping of *Sesbania sesban* with *Cymbopogon citratus* improved soil fertility, plant height, number of tillers, number of leaves and herb yield of *C. citratus*. In addition,

Chowdhury et al. [42] proved that the highest performance of turmeric was due to a turmeric–neem-based agroforestry system and applying cow dung and dolo choon.

Leaves play a vital role of the photosynthetic process. In addition, the leaf area is one of the leaf's characteristics and reflects the potential for light absorption. Our study showed that turmeric plant under leucaena tree stands and receiving 34 m<sup>3</sup> ha<sup>−1</sup> had higher leaf-area index, indicating that the leaves were wider when the plant received the lower light intensity. These results are in agreement with that of Painkra et al. [40], Sinclair and Gardner [43] and Mattera et al. [44].

## 5. Conclusions

Based on the study's findings, it can be concluded that compost addition and the turmeric–leucaena alley-cropping-system are efficient and sustainable agro-ecological systems for improving turmeric growth, yield traits and attributes. The study demonstrated the importance of selecting the right crop–tree combination in this system, where it was discovered that leguminous trees, such as leucaena, play a significant role in enhancing the soil's fertility and nutrient availability, which in turn improve the growth characteristics of turmeric, particularly leaf-area index and nutrient content, which is advantageous to the characteristics of rhizome yield and curcumin content.

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