Australian Journal of Crop Science AJCS

Aust J Crop Sci. 19(06):689-696 (2025) | https://doi.org/10.21475/ajcs.25.19.06.p337

ISSN:1835-2707

# Optimizing land resources through vegetable crop production (Cucumber and Beans) on cocoa farms

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***Submitted:* *18/02/2025***

***Revised:* *17/05/2025***

***Accepted:* *18/06/2025***

**Abstract:** Vegetable crops can be cultivated by diverse agricultural strategies, including the intensification of underutilised land, such as cocoa-based dry land. Generally, the terrain beneath cocoa plants remains unutilised or exposed, resulting in suboptimal land utilisation. This inefficiency indicates that planting and cultivation areas are not entirely optimised. This study seeks to assess vegetable production (cucumber and beans) on optimally managed cocoa-based land by employing cocoa tree maintenance strategies to establish a conducive microclimate for vegetables. The study was carried out in the Palolo District, adjacent to the Lore Lindu National Park Conservation Area. A factorial design employing a two-factor randomised block design (RBD) was implemented. The initial component comprised of two pruning treatments, whereas the subsequent factor included beans and cucumbers, yielding four treatment combinations: PB1 (heavy pruning + beans), PB2 (light pruning + beans), PB3 (heavy pruning + cucumbers), and PB4 (light pruning + cucumbers). Each treatment was reproduced four times, yielding a total of 16 treatment units. The findings indicated that the growth of both vegetable varieties enhanced significantly. The vine length of both vegetables was greater with rigorous pruning than with light pruning. Fruit length, seed count per harvest, and fruit weight were superior with vigorous pruning in comparison to light pruning. Bean production beneath cocoa was 3-6 tonnes per hectare lower than that of monoculture planting, although cucumber achieved a potential yield of 30-43 tonnes per hectare.

**Keywords:** Cocoa Land, Vegetables, Crop Production.

## Introduction

The idea of land optimisation should ideally pertain to the inherent circumstances of forest resources, which are composed of diverse types arranged systematically (Kremen and Merenlender, 2018; Magioli et al., 2019). It highlights the necessity for land resource management technologies to be conceived and developed within a landscape system characterised by biodiversity (Hadid et al., 2018). The effective use of cultivation area on a parcel of land, employing a comprehensive land use strategy concerning temporal factors, botanical traits, and spatial parameters, exemplifies the maximisation of land resources while ensuring economic stability for landowners (Khan et al., 2018; O'Neill and Maravelias, 2021).

Telles et al. (2021) assert that augmenting or altering production on a parcel of land will yield sustainable output while preserving or sustaining land capability (Ruggerio, 2021; Ahmad, 2022; Kuzmich, 2022). Cocoa is a plantation commodity that necessitates shade or other plants with elevated canopies to shield it from sunlight (Sumilia et al., 2019; Agele et al., 2016; McQueen and Treonis, 2020). This circumstance signifies that although the area above the cocoa canopy is employed, the region below it is frequently unoccupied (Agele et al., 2016).

Hadid et al. (2020) assert that chilli and tomato plants are appropriate for cultivation on cocoa-based land utilising moderate to heavy pruning strategies, resulting in no notable differences in output. Regular pruning is essential in cocoa production to enhance the photosynthetic process. If cocoa trees are not pruned, they will produce dense canopies and will not establish productive structures (Cubillos, 2023; Niether et al., 2020; Salazar et al., 2018).

Despite the acknowledged ecological advantages and crop diversification potential of cacao agroforestry systems, empirical research on the impact of varying cocoa pruning intensities on the growth and yield of specific vegetable crops, such as beans and cucumbers, beneath the cacao canopy remains scarce. Most previous research has been on intercropping cereals e.g., maize (Butolo et al., 2023) or the overall advantages of agroforestry, with no emphasis on the adaptation, yield potential, and physiological responses (leaf and vine growth) of vegetable crops in diverse light microenvironments created by cacao pruning.

Moreover, inadequate pruning may result in the proliferation of pests and diseases, as well as a reduction in harvest yields (Riedel et al., 2019). This indicates that the area beneath cocoa can be enhanced with other vegetable crops (Buyer et al., 2017; Acheampong et al., 2019). Cocoa agroforestry systems exhibit superior overall production, enhanced potential for climate change mitigation and adaptation, and improved support for biodiversity relative to cocoa monoculture (Niether et al., 2020).

Butolo et al. (2023) investigated the utilisation of maize as an intercrop within cocoa cultivation beneath coconut canopies. The findings demonstrated that all evaluated maize types successfully adapted to the shaded environment under coconut trees. Rajab et al. (2016) discovered that cocoa production systems beneath shade trees improve carbon storage and sequestration while maintaining cocoa bean yields. Multi-shade tree systems offer substantial ecological advantages while maintaining productivity. Djokoto et al. (2017) examined vegetable crop diversification in Ghana's cocoa belt, revealing that cocoa farmers are more inclined to engage in vegetable cultivation. This diversification presents significant potential to enhance income and food security.

Research on the introduction or cultivation of diverse vegetable commodities on cocoa-based land is essential to acquire baseline data regarding the most adaptive and productive vegetable commodities, as well as to improve land productivity, thereby optimising land resources for sustainable agricultural management and food security.

## Results and Discussion

### *Vegetative growth of plants*

Plants have a remarkable ability to adapt to various light conditions (Ruberti et al., 2012), ranging from very low to very high light environments. In low light conditions, plants must absorb sufficient light to survive by maximizing the amount of light absorbed (Sulistyowati et al., 2019). Conversely, in high light conditions or when plants are light-saturated, they must maximize their light utilization capacity while also managing excess light (Perrella et al., 2020).

Each plant species responds differently to various light environments (Poorter et al., 2019). This study attempts to adapt vegetable crops, typically grown as monocultures in open fields, to shaded environments with the expectation that the planting and growing spaces beneath the canopy can be optimized with seasonal crops. The vegetative growth of vegetables introduced under the cocoa canopy is presented in Figure 1.

Vegetative growth of the plants increased over time. The number of leaves on both vegetable types grew exponentially throughout the observation period, as did the vine length of the bean plants. However, the vine length of cucumbers showed active growth until 45 days after planting, after which the growth rate levelled off (Figure 1)

Plant growth is a process that occurs in both space and time. During this process, plants absorb energy, water, and nutrients from their environment, but their need for these growth factors varies depending on their growth phase (Tan et al., 2018; Saloner and Bernstein, 2020; Tan et al., 2024). Furthermore, each species and variety has its own way of growing and developing as a result of interactions with the environment. This means that plant growth is an interactive process that continuously occurs between the changing plant and its changing environment (He et al., 2022; Ding et al., 2020).

The results of the analysis of variance on the effects of cocoa pruning treatments and the variation of vegetable types introduced under cocoa showed differing impacts on each vegetative growth parameter, as presented in Table 1. This indicates that each variety responds differently to cocoa pruning in terms of growth and development (Ofori and Padi, 2020)

Table 1 shows that the cocoa pruning treatments/light intensity variations and differences in vegetable types have a highly significant effect on the number of leaves formed from 30 to 60 days after planting (DAP) and on vine length from 15 to 60 DAP. Additionally, the interaction between these two treatments has a highly significant effect on leaf formation at 45 and 60 DAP and a significant effect on vine length from 30 to 60 DAP.

The effects of cocoa pruning treatments and vegetable type variations are highly significant on leaf count and vine length. The results of the interaction effects on leaf count are presented in Table 2.

Table 2 shows that both heavy and light cocoa pruning resulted in a higher number of leaves on bean plants compared to cucumber plants (Riedel et al., 2019; Govindaraj and Jancirani, 2017). Furthermore, beans produced more leaves under heavy pruning than under light pruning. For cucumber plants, there was no significant difference in leaf count between light and heavy pruning.

Leaves play a crucial role in the photosynthesis process (Ashraf and Harris, 2013). According to (Niether et al., 2020) and (Esche et al., 2023), pruning cocoa trees can create better conditions for the plants. Sunlight can penetrate all parts of the cocoa tree as well as the canopy of the plants beneath it. Increased light interception by the canopy, along with improved air circulation and sufficient $CO_2$ availability, enhances the rate of photosynthesis, ultimately increasing the availability of photosynthates essential for plant growth and development (Paradiso and Proietti, 2022; Matsuda and Murakami, 2016).

In addition to leaf count, another vegetative parameter affected by cocoa pruning and vegetable type variation is vine length. The effects of treatment interactions on vine length are presented in Table 3.

Table 3 illustrates that both heavy and light pruning resulted in longer vine lengths in beans compared to cucumber vines. Additionally, both bean and cucumber plants exhibited superior vine lengths with heavy pruning, distinctly different from those under light pruning.

This suggests that vegetative growth in beans is more robust and adaptable, making it suitable for optimizing land use under cocoa in an intercropping system, even though most vegetable crops, including beans and cucumbers, are traditionally cultivated in open fields under monoculture systems (Maure et al., 2019).

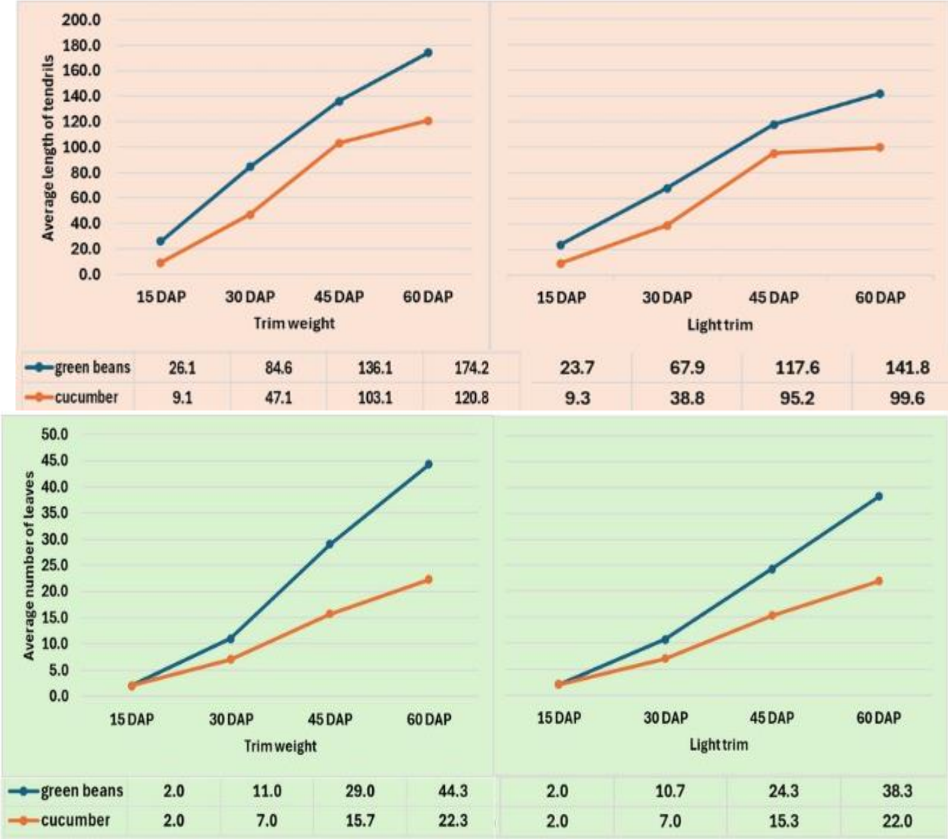


**Figure 1.** Average vegetative growth of vegetable plants.

**Table 1.** Analysis of Variance Results on the Effects of Cocoa Pruning and Vegetable Crop Types on Vegetative Growth

| No. | Variable observed | | F Test | | |
|---|---|---|---|---|---|
| | | | P x J | P | J |
| 1 | Number of leaves | 15 DAP | ns | ns | ns |
| | | 30 DAP | ns | ns | ** |
| | | 45 DAP | ** | ** | ** |
| | | 60 DAP | ** | ** | ** |
| 2 | Tendril Length | 15 DAP | ns | ns | ** |
| | | 30 DAP | * | ** | ** |
| | | 45 DAP | * | ** | ** |
| | | 60 DAP | * | ** | ** |

Note: ns = Not significant; * = Significant, ** = Highly significant, P = Pruning, J = Vegetable type

Table 2. Average Number of Leaves of bean and cucumber plants in the Cocoa Pruning Interaction treatment and Vegetable Type Variations.

| Treatment | 45 DAP | | 60 DAP | |
|---|---|---|---|---|
| | Beans | Cucumber | Beans | Cucumber |
| Heavy pruning | $29.0^{b}$q | $15.7^{a}$p | $44.3^{b}$q | $22.3^{a}$p |
| Light pruning | $24.3^{b}$p | $15.3^{a}$p | $38.3^{b}$p | $22.0^{a}$p |
| HSD 0.05 | 1.12 | 1.12 | 1.24 | 1.24 |

Note: Mean values followed by different letters in the same **column** (a, b) are significantly different at the 5% level. Mean values followed by different letters in the same **row** (p, q) are significantly different at the 5% level based on HSD test.

***Vegetable crop production***

Typically, cocoa plants are spaced 3m x 3m apart, leaving approximately 32 rows or about 30% of the land that has remained unproductive, which can be utilized as growing space for vegetable crops. Vegetables generally require varying amounts of light, which is why most vegetables are cultivated in monoculture systems. The presence of shade plants can affect their yield.

Crop production is usually controlled by environmental factors according to the genetic requirements of the plants. Ecologically, crop production can be assessed by the total biomass produced, while economically, it is measured by the yield of harvestable fruits or seeds (Carlson et al., 2017). Observations on the production of vegetable crops introduced under

**Table 3.** Average Tendril Length from the Interaction of Cocoa Pruning with Variations in Vegetable Types.

| Treatment | 30 DAP | | 45 DAP | | 60 DAP | |
|---|---|---|---|---|---|---|
| | Beans | Cucumber | Beans | Cucumber | Beans | Cucumber |
| Heavy pruning (tw) | $84.6^{b}$q | $47.1^{a}$q | $136.1^{b}$q | $103.1^{a}$q | $174.2^{b}$q | $120.8^{a}$q |
| Light pruning (lt) | $67.9^{b}$p | $38.8^{a}$p | $117.6^{b}$p | $95.2^{a}$p | $141.8^{b}$p | $99.6^{a}$p |
| HSD 0.05 | 4.43 | 4.43 | 5.71 | 5.71 | 5.63 | 5.63 |

Note: Mean values followed by different letters in the same column (a, b) indicate significant differences between treatments. Mean values followed by different letters in the same row (p, q) indicate significant differences across observation periods. Values are based on factorial ANOVA under a randomized block design with HSD test at the 5% significance level.

**Table 4.** Analysis of Variance Results on the Effect of Cocoa Pruning and Vegetable Types on Production

| No. | Observed variable | F Test | | |
|---|---|---|---|---|
| | | P x J | P | J |
| 1. | Fruit length | * | ** | ** |
| 2. | number of fruits per harvest, | ** | ** | ** |
| 3. | fruit weight | ** | ** | ** |

Note: tn = Not significantly different; * = Significantly different; ** = Highly significantly different; P = Pruning; J = Vegetable type.

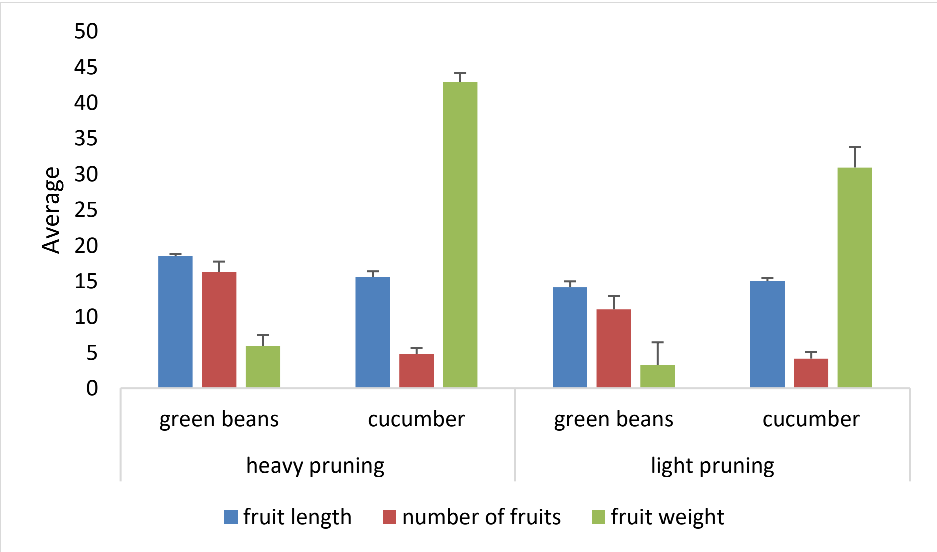


**Figure 2.** Average fruit length, number of fruits, and fruit weight.

cocoa canopy with pruning treatments are presented in Figure 2. Figure 4 shows that vegetables planted under heavily pruned cocoa trees are more productive compared to those under light pruning. Although the bean production, ranging from 3 to 6 tons/ha, is still far below its potential yield of 10 to 17.2 tons/ha, cucumber production reached 42 tons/ha, exceeding its potential yield of 40 tons/ha. The length of the cucumber fruit generally meets the standard size, ranging from 15 to 20 cm, while the length of bean pods even exceeds the typical range of 15 to 17 cm.

The treatment of cocoa pruning and the introduction of various vegetable species under cocoa show a consistent impact across all production parameters presented in Table 4.

Table 4 demonstrates that the interaction between cocoa pruning treatments and variations in vegetable types has a highly significant effect on all observed production parameters. This indicates that the effect of one factor on the outcome (dependent variable) depends on the level or category of the other factor.

The interaction effects significantly influence all production parameters, suggesting that the tested factors are interdependent. Different cocoa pruning methods result in varied impacts on the growth and development of the crops cultivated beneath them in an intercropping system (Riedel et al., 2019; Tosto et al., 2022).

Optimal plant growth can be observed through the healthy formation of stems, branches, and leaves, which supports efficient photosynthesis and leads to the production of a substantial amount of photosynthates (Fathi, 2022; Evans, 2013; Miyoshi et al., 2021; Brazel and Ó'Maoileídigh, 2019). These photosynthates are used for growth during the vegetative phase and for the generative phase of the plant. During the generative phase, photosynthates are used for the formation of flowers and fruits, leading to higher or greater production, reflected in the number, size, and weight of the fruits produced (Poethig, 2013; Hamid et al., 2020). The results of the BNJ 0.05 test on the production parameters are presented in Table 5.

**Table 4.** Analysis of Variance Results on the Effect of Cocoa Pruning and Vegetable Types on Production

| No. | Observed variable | F Test | | |
|---|---|---|---|---|
| | | P x J | P | J |
| 1. | Fruit length | * | ** | ** |
| 2. | number of fruits per harvest, | ** | ** | ** |
| 3. | fruit weight | ** | ** | ** |

Note: tn = Not significantly different; * = Significantly different; ** = Highly significantly different; P = Pruning; J = Vegetable type.

**Table 5.** Average Fruit Length, Number of Fruits, and Fruit Weight from the Interaction of Cocoa Pruning with Vegetable Type Variations.

| Treatment | Fruit Length | | Fruits per Harvest | | Fruit Weight | |
|---|---|---|---|---|---|---|
| | Beans | Cucumber | Beans | Cucumber | Beans | Cucumber |
| Heavy Pruning | 18.5$^{b}$q | 15.6$^{a}$p | 16.3$^{b}$q | 4.8$^{a}$p | 5.9$^{a}$q | 42.9$^{b}$q |
| Light Pruning | 14.2$^{a}$p | 14.2$^{a}$p | 11.1$^{b}$p | 4.2$^{a}$p | 3.2$^{a}$p | 30.9$^{b}$p |
| HSD 0.05 | 2.35 | 2.35 | 1.53 | 1.53 | 2.22 | 2.22 |

Note: Means followed by different letters in the same column (a, b) are significantly different at the 5% level. Means followed by different letters in the same row (p, q) are significantly different at the 5% level based on HSD test.

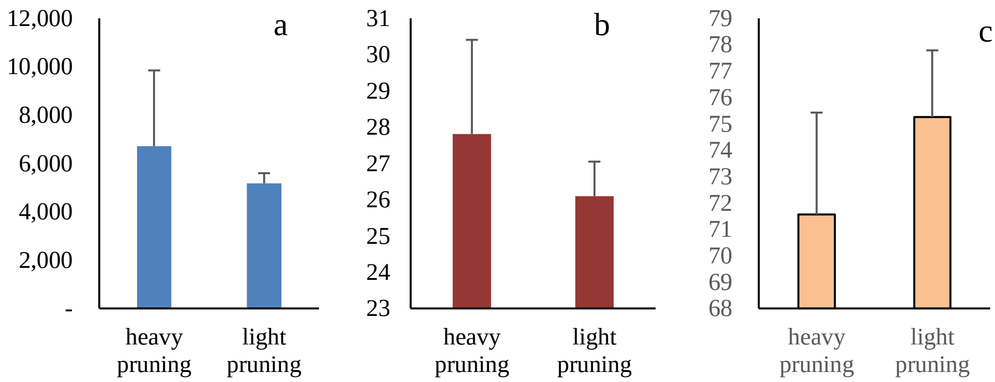


**Figure 3.** (a) Average light intensity , (b) Temperature, and (c) Humidity under two different cacao pruning methods.

Table 5 indicates that the heavy pruning treatment resulted in a greater length and number of bean pods, which were distinct from the length and number of cucumber fruits. However, cucumbers under the same treatment exhibited a higher fruit weight compared to beans. In contrast, light pruning produced beans and cucumbers with similar fruit lengths, though differences were observed in the number and weight of fruits. The number of bean pods was higher and significantly different from that of cucumbers, whereas cucumbers were heavier than beans (Nakada-Freitas et al., 2019).

Furthermore, bean plants under heavy pruning showed superior fruit length, number, and weight compared to those under light pruning. Conversely, cucumber plants exhibited similar fruit length and number under both heavy and light pruning treatments. However, cucumbers subjected to heavy pruning yielded fruits with greater weight, differing significantly from those under light pruning.

Pruning of cacao is carried out to reduce shading effects or to enhance light penetration to the crops introduced beneath it (Niether et al., 2020; Riedel et al., 2019). Light is a critical environmental factor that can regulate plant production. The primary function of light for plants is to drive the process of photosynthesis, which is essential for carbohydrate formation. Sunlight, in the form of electromagnetic waves, is converted by plants through photosynthesis and various other physiological processes into chemical energy in the form of carbohydrates (Bailey-Serres et al., 2018; Johnson, 2016). Part of this chemical energy is reduced or broken down into kinetic and thermal energy through respiration, while the remainder is transformed into various types of organic compounds via plant metabolism.

The metabolic processes of each plant vary depending on genetic factors and their interaction with environmental conditions. Vegetable crops require optimal light, which is why they are often cultivated in monoculture systems. Consequently, the presence of cacao as a shade plant can influence their production. Field observations show that beans and cucumbers planted under heavily pruned cacao produced higher yields. This indicates that heavy pruning of cacao (200 cm – 250 cm) provides sufficient growing space for other crops with lower canopy morphology, including vegetables like beans and cucumbers. This is consistent with the findings of Hadid et al. (2020), which suggest that vegetable production

(chili peppers and tomatoes) on cacao-based land with heavy pruning or 75% light exposure tends to be higher compared to moderate or light pruning methods.
Pruning also influences the microenvironmental conditions (temperature, humidity) within the cacao agroecosystem. Different levels of pruning result in varying microenvironmental conditions (Figure 3), which ultimately impact plant growth and production (Al-Saif et al., 2023).
Figure 3 illustrates that the level of cacao pruning is positively correlated with light penetration and temperature within the agroecosystem, but negatively correlated with humidity (Tosto et al., 2022). Heavier pruning, where more and longer cacao branches are removed, results in higher light penetration (6,714 Lux) and increased air circulation within the agroecosystem. This leads to a decrease in air moisture or humidity (72%), making the air mass lighter and causing the temperature (28°C) to rise. This observation aligns with the findings of Niether et al. (2020), who stated that tree pruning enhances canopy openness and light transmission. Conversely, lighter pruning, which involves removing fewer branches, results in lower light penetration into the agroecosystem (5,174 Lux), thus maintaining relatively higher humidity (75%) and lower temperature (26°C).
The differences in climatic elements may be small, but the resulting production between beans and cucumbers under the two pruning levels is significantly distinct. The yield of bean and cucumber plants cannot be directly compared due to the genetic and morphological differences in the shape and volume of their fruits, even though the characteristics of these two plants are relatively similar. In terms of fruit number, beans will naturally produce more, but in terms of weight, cucumbers will undoubtedly be heavier.
Rowe et al. (1998) stated that each species and variety has its own mechanism for growth and interaction with the environment, possessing specific requirements for growth factors that manifest in their morphological structure. Morphological differences between plants and even between varieties can be leveraged to achieve desired effects in their interactions with the environment.

## Materials and methods

### *Study site*

The investigation was conducted in Tongoa Village, Palolo Subdistrict, Sigi Regency, at an elevation of 990 meters above sea level (−1.243707° S, 120.218973° E). The area has a humid tropical climate with high annual rainfall and relative humidity levels ranging from 80% to 90%. The soil in the study area is classified as Ultisol, which is typically acidic and low in essential nutrients. Soil analysis revealed a loamy texture with very good porosity (46–53%), moderate to fairly quick permeability, and bulk density within the mineral soil range. The soil pH was neutral; however, levels of nitrogen, phosphorus, potassium, and organic carbon were low. The cation exchange capacity (CEC) was also poor, indicating that soil fertility could be improved through the application of organic matter and balanced fertilization strategies.

### *Plant materials and experimental design*

The research employed three varieties of plant materials: cocoa (*Theobroma cacao* L.), beans (*Phaseolus vulgaris* L.), and cucumbers (*Cucumis sativus* L.). Cacao, a perennial tropical crop, constituted the predominant land use in the research area, esteemed for its economic significance and enduring cultivation. The cacao trees used in this study were 22-years-old and belonged to a local variety, commonly referred to as "*bibit asalan*." Beans and cucumbers, both rapidly growing annual vegetables, were incorporated as intercrops to assess their growth response and interaction with the soil environment within cacao-based land systems. The bean variety used was *Pandawa*, while the cucumber variety was *Pandawa Hybrid*.
The research was conducted using demonstration plots measuring 5m x 40m. Each plot consisted of 16 cocoa trees, with a length of 5 meters (2 trees) and a width of 40 meters (14 cocoa trees). Heavy pruning was performed by removing 50% of the canopy from two adjacent cocoa trees. Light pruning involved removing 50% of the canopy from one cocoa tree. The open spaces created by pruning were planted with beans and cucumbers.
The research employed a two-factor factorial design utilising a Randomised Block Design (RBD) as the foundational structure. The initial element was pruning, which included both hard and mild pruning, while the subsequent factor was vegetable crops, including beans and cucumbers. The treatments consisted of four combinations: heavy pruning with beans (PB1), mild pruning with beans (PB2), heavy pruning with cucumbers (PB3), and light pruning with cucumbers (PB4). Each treatment was reproduced across four groups, resulting in a total of 16 treatment combinations. The study lacked a control group of unpruned cocoa plants. The exclusion was predicated on the planting configuration at the study location, where cocoa trees were arranged at 3 × 3 meters, leading to a dense canopy if unpruned. A dense canopy markedly diminishes light infiltration and modifies the microclimate below, rendering the environment inadequate for the best cultivation of understory crops such as beans and cucumbers.

### *Observation variables*

Data on the growth and yield of vegetable crops were collected using a 1 m × 2 m quadrat sampling method, with each quadrat containing 12 bean plants and 8 cucumber plants. The observed growth variables included leaf length (cm), measured from the base to the tip of the leaf, and vine length (cm), measured from the base to the tip of the vine, both recorded at 15, 30, 45, and 60 days after planting. Yield parameters included fruit length (cm), number of fruits per harvest, and fruit weight (g), with measurements taken at harvest. In addition to plant data, environmental conditions were monitored, including temperature, humidity (using an HTC 2 Thermohygrometer), and light intensity (using a digital lux meter LX1330). These environmental observations were recorded hourly over a 7-day period to capture diurnal variation.

### *Data analysis*

The observational data were analyzed using factorial design variance analysis based on a Randomized Block Design (RBD) as outlined by Steel and Torrie (1981). If the F-test results indicate a significant effect, the analysis will be followed by a 5% Honest Significant Difference (HSD) test.

## Conclusions

We concluded that vegetable crops such as beans and cucumbers can be successfully cultivated within cacao agroecosystems using a pruning system. While bean yields under cacao are reduced by approximately 3–6 tons per hectare compared to monoculture systems, cucumber yields remain high, with a potential production range of 30–43 tons per hectare. This indicates that with appropriate canopy management through pruning, cacao-based intercropping systems can support productive vegetable cultivation.

## Acknowledgement

The authors would like to express their sincere gratitude to the Dean of the Faculty of Agriculture, Tadulako University, for providing financial support for this research. Special thanks are also extended to all enumerators for their valuable assistance in data collection.

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