



Exploring the use of Cropping Indices over the Growth and Yield Performance for Selecting Okra–Cowpea Intercropping Systems

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Abstract

Intercropping of crops has several advantages over monocropping systems, offering efficient utilization of farm resources. While growth and yield remain primary determinants of intercropping success, factors such as crop selection, farm resources, cropping period, and competition also influence outcomes. The choice of appropriate evaluation methods becomes significant for sustainable crop management. Therefore, employing suitable evaluation methods is crucial in the choice of an intercropping system. To address this, three intercropping systems were established in a randomized complete block design (RCBD): single row of okra with single row of cowpea (T_1), single row of okra with double–row of cowpea (T_2), and double–row of okra with single row of cowpea (T_3). Additionally, monocropping systems of each crop were established for evaluation of cropping indices. Cropping indices such as land equivalent ratio (LER), relative yield total (RYT), area time equivalent ratio (ATER), competition index (CI), aggressivity index (Ai) and multiple cropping index (MCI) were applied to assess the intercropping systems. We found that the most favourable combination was T_3 based on cropping indices, contrasting with outcomes from growth and yield analysis (T_1 and T_2). T_3 exhibited a yield advantage of 4.2%, with no observed crop competition and maximal land utilization (>95%), establishing cowpea as the dominant crop in these systems. In conclusion, while growth and yield analysis have been practiced in evaluating intercropping systems, this study emphasizes the importance of incorporating cropping indices to comprehensively assess efficiency and sustainability in intercropping practices.



Article History

Received: 06 June 2024

Accepted: 02 July 2024


Keywords

Cropping Indices;
Intercropping Systems;
Growth;
Okra–Cowpea;
Yield.

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Doi: <http://dx.doi.org/10.12944/CARJ.12.2.11>

Introduction

As the world's population continues to grow (8.5 billion by 2030 and 9.7 billion by 2050), it will be essential to produce more foods to secure the growing population in near future.^{1,2} Therefore, the agricultural production should be increased from 60% to 110% by 2050 to meet these increasing demands.³ In general, there are two ways of increasing crop production; 1) extend the cultivation area, 2) increase the yield in unit area. Expansion of the crop area is influenced by several factors, such as prolonged drought, crop failure, pest and disease damage, labour shortage, and high cost of fertilizer.^{4,5} To meet the rising food demands of global population, it is becoming more crucial to enhance the crop production in unit land area.⁶ It is crucial to increase resource use efficiency, particularly for small-scale farmers in regions with short growing seasons⁷ and rainfed areas.⁸ To overcome these challenges, increasing crop production per unit area is a fruitful pathway to utilize the farm resources such as land, labour, capital, water, fertilizer, solar energy, and other environmental factors.^{6,9,10} Due to the abrupt change in climate in recent decades, farmers have been facing crop failure in the monocropping system. To solve the problems, practicing the intercropping systems is extremely important to safeguard the farmers from failure and ensure the maximum utilization of farm resources and environmental factors.

Intercropping is defined as 'an agricultural practice of cultivating two or more crops in a given area (spatial) at the same time (temporal) with a definite row arrangement'.^{11,12} The main benefits of intercropping include increasing yield, better use of growth resources, sharing of physical support, shade and shelter amongst the crops, improved soil erosion control, and protection for small farmers when one crop may fail and by making the best possible use of the land and labour resources available over a specific period of time.¹³⁻¹⁷ Intercropping of crops ensures efficient resource utilizations by crops with varying heights, rooting depths, and nutrient requirements, reduces soil erosion, and suppresses weed growth, all of which contribute to greater crop yield stability.^{18,19} The relatively high yield can be obtained by intercropping systems due to the complementarity use of environmental resources such as land, soil nutrients, light, and water²⁰

at temporal and spatial exploitation of available resources.²¹

In the okra-cowpea intercropping system, intercropping ensures efficient use of environmental factors and other resources to maximize crop yield.¹⁸ The okra is widely cultivated in tropical and sub-tropical climatic conditions. Immature pods are harvested as the economic yield of the okra.²² Okra is one of the most important commercial vegetables in Sri Lanka and is used by people in their daily lives.²³ Cowpea is the most significant crops in fulfilling this role among the various leguminous plants, and currently offer excellent potential for maintaining soil fertility over time.^{24,25}

Intercropping systems are typically assessed through either growth and yield performance or cropping indices. However, relying solely on growth and yield data for evaluation is not sustainable way. Intercropping involves two or more crops, subject to various influences such as land area, crop maturity, resource allocation, competition, and environmental conditions. These factors significantly impact system performance. Cropping indices offer a more comprehensive approach to evaluating intercropping systems. They consider the interactions between crops and their environment, providing insights beyond growth and yield parameters. The effectiveness of intercropping systems in comparison to monocropping was evaluated using a variety of metrics. Several cropping indices were proposed to describe crop competition, yield advantages, utilization of farm resources, and economic benefits.²⁶⁻³⁰ By incorporating cropping indices can better capture the efficiency and sustainability of intercropping practices. This holistic evaluation approach enables farmers and researchers to make informed decisions regarding crop selection, resource allocation, and management strategies, ultimately contributing to more resilient and productive agricultural systems. Thus, while growth and yield analysis remain essential, integrating cropping indices enhances the precision and effectiveness of intercropping system evaluations, paving the way for more sustainable agricultural practices. However, selecting a suitable cropping system through the evaluation of the crop performance in an intercropping system using cropping indices was limited. Therefore, we designed

the different intercrop combinations for okra and cowpea to select suitable intercropping systems. The objectives of the study were 1) to assess the okra–cowpea intercropping systems based on growth and yield parameters; 2) to evaluate the okra–cowpea intercropping systems using cropping indices such as yield efficiency, crop competition, and land utilization efficiency indices.

Materials and Methods

Study Site

The experiment was conducted at the Crop Farm, Department of Agronomy, Faculty of Agriculture, University of Jaffna in Kilinochchi district, Sri Lanka. The study site is located at geographical coordinates of 80° 39' E longitude and 9° 32' N latitude. The study area comes under the agroecological zone of dry zone low county (DL₃), northern region of the country. The climate conditions during the experiment were characterized as dry and hot based on the agroecological zone of the country. The average elevation of the study area is about 67 m above mean sea level. This location's average annual air temperature ranged from 28°C to 33°C, and the average annual precipitation ranged from 1,040 mm to 1,560 mm.^{31,32} The experiment was conducted between the first week of March and the last week of June 2022, coinciding with the season of the selected crops.³³

Experimental set up

The crops okra and cowpea were chosen as the experimental crops for this study. Okra [*Abelmoschus esculentus* (L.) Moench.] is one of the major and commercial vegetables in Sri Lanka and it belongs to the family of Malvaceae.^{23,34} The maturity period of Okra is 90 to 100 days, and its height ranges from 0.5 to 4.0 m.^{35,36} The okra can be cultivated in any agroclimatic zone, except in the upcountry wet zone. The okra variety Haritha is more suitable for dry zone than wet zone and it is resistant to leaf mosaic virus. The first harvest can be done in about 50 days. It can produce an average yield is about 10-15 t ha⁻¹. The cowpea [*Vigna unguiculata* (L.) Walp.] is one of the major pulse crops in Sri Lanka and belongs to the family of Fabaceae.³³ The cowpea is a drought-tolerant crop and can be cultivated in low rainfall areas.³⁷ The cowpea variety Waruni has characteristics of erect and determinate growth habits and is suitable for intercropping with

vegetables. It takes about 55-65 days to harvest and can produce an average yield of 1.6 t ha⁻¹. In our study, the selected varieties Haritha and Waruni have a maturity period of 90 and 70 days, respectively.³³

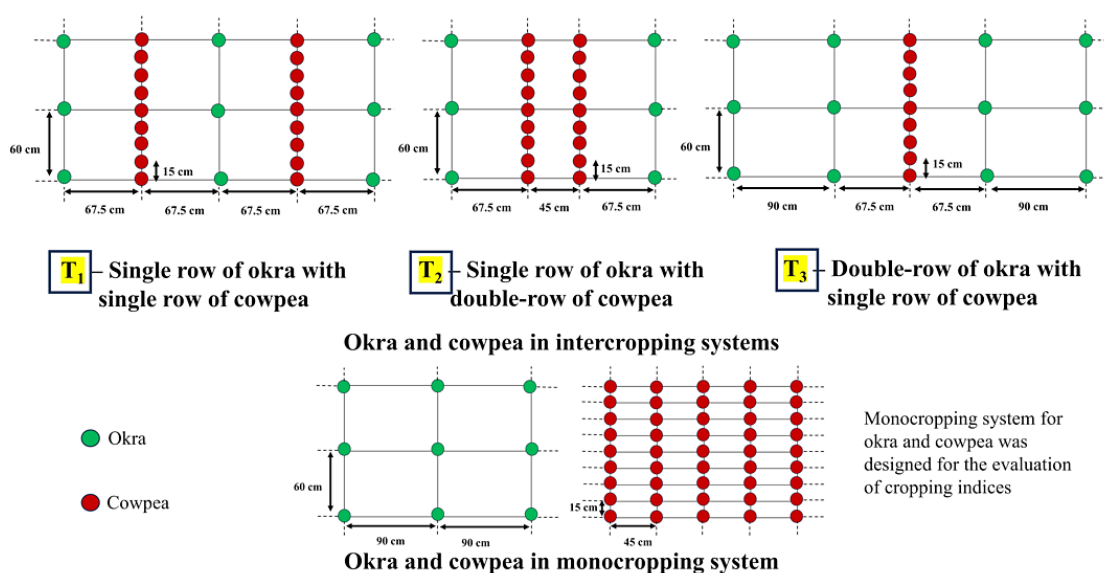
To find the performance of the cropping systems, different okra–cowpea intercropping systems were designed. Three intercropping systems as treatments with three replicates laid out at a Randomized Complete Block Design (RCBD) (Table 1) such as single row of okra with single row of cowpea (T₁), single row of okra with double-row of cowpea (T₂), and double-row of okra with single row of cowpea (T₃). The recommended spacing was applied to design the different intercropping systems (Fig. 1). In addition to the intercropping systems, monocropping of each crop was established with three replicates to evaluate the cropping indices as per the formula. In the monocropping system, the spacing of okra and cowpea was 90 cm × 60 cm, and 45 cm × 15 cm, respectively. In intercropping systems, inter-row spacing was varied according to the design of the intercropping system. Maximum spread of a crop's canopy allowed in between the rows based on the recommended spacing to avoid the canopy overlapping. We calculated the inter-row spacing in the intercropping system based on the maximum canopy spread of okra and cowpea in between the rows. Due to this, the plot size of the treatments (T₂ and T₃) was varied. Intra-row spacing was maintained as monocropping systems for all treatments. Intra-row spacing for okra and cowpea were 60 cm and 15 cm, respectively. To avoid the boarder effect, additional plots were established in surroundings of each treatment.

Field Preparation and Planting

The land was ploughed using a disc plough and then, the soil was made as fine tillth condition using a rotavator. The area was raked using a field rake to remove weeds, stones, soil clods, and other undesired items. Blocking for treatments was done perpendicular to the slope as a gradient to eliminate the source of error such as moisture and nutrients. Each block was designed as field plots to comprise all treatments. Prepared plots were marked into planting holes for seeding of okra and cowpea. Okra and cowpea were row-seeded in the field according to the treatment's layout. Around 2 seeds were planted in one hill for both okra and cowpea.³³

Table 1: Experimental treatments with the spacing in inter-row and intra-row and plot size.

Treatment	Treatment description	Inter-row spacing	Intra-row spacing	Plot size
T ₁	Single row of okra with single row cowpea	Between okra and cowpea: 67.5 cm	Okra: 60 cm; cowpea: 15 cm	3.6 m × 3 m
T ₂	Single row of okra with double-row of cowpea	Between okra and cowpea: 67.5 cm; within the cowpea (double-row): 45 cm	Okra: 60 cm; cowpea: 15 cm	3.6 m × 2.6 m
T ₃	Double-row of okra with single row of cowpea	Between okra and cowpea: 67.5 cm; within the okra (double-row): 90 cm	Okra: 60 cm; cowpea: 15 cm	3.6 m × 4.05 m

**Fig. 1: Schematic diagram of field plot design for each treatment.**

Crop Management Practices

The agronomic management practices were done according to the recommendation of the Department of Agriculture, Sri Lanka. For both cowpea and okra, irrigation was given at 2-day intervals at the initial stage to maintain continuous moisture and ensure maximum germination. Then, the irrigation interval was increased to 4 days throughout the experimental period. However, irrigation was determined based on the moisture condition of the soil. Surface-flood irrigation was applied to the soil for maintaining a 50 mm water depth. The fertilizer was applied based on the recommendation of each crop (Table 2). The

nitrogen (N), phosphorous (P), and potassium (K) was applied through urea (46% N), Triple super phosphate (TSP) (44% P₂O₅), and muriate of potash (MOP) (60% K₂O), respectively 38. For okra, the first application of fertilizer was done as a basal mixture consisting of urea, TSP and MOP. Then the fertilizer was applied three times as top dressing (TD₁ – TD₃) consisting of urea and MOP, 2 weeks after planting (2-WAP), 5-WAP, 8-WAP, respectively. For cowpea, the first dose of fertilizer applied as basal mixture consisted of urea, TSP, and MOP, then it was applied as TD1 at once during the flowering stage.³³

Table 2: Amount and frequency of fertilizer application for okra and cowpea

Treatment		Urea (kg/ha)	TSP (kg/ha)	MOP (kg/ha)
Okra	Basal	50	195	25
	TD1 (2–WAP)	100		50
	TD2 (5–WAP)	100		50
	TD3 (8–WAP)	100		50
Cowpea	Basal	35	100	75
	TD1	30		

TSP – Triple super phosphate; MOP – Muriate of potash; TD – Top dressing;
WAP – Weeks after planting

Two weeks after the sowing of seeds, thinning out was done for both okra and cowpea. The seedlings were thinned at 7–8 cm tall. The unhealthy and unvigoured seedlings were removed during the thinning operation. Manual weeding was done at every 2–week intervals. Fertilizer was applied after removing weeds for both okra and cowpea. Insect pests such as blister and cucumber beetles were found at the initial stage of the crop's growth. Fruit borer damage was observed at the pod formation stages of cowpea and okra. Recommended insecticides were used to control these insect–pest damages.³³

Harvesting of Crops

The fruit was harvested when it was of marketable size and quality, a stage at which it could be sold to the market.³⁹ We followed the marketable size and quality of okra and cowpea as immature and mature stages, respectively. For okra, harvesting was started 50 days after planting. Harvesting was done by hand with the stalk at 2–day intervals in the morning to avoid damage to the pods. The harvesting time of okra was decided when the pods were in the immaturity stage and easily snapped off the tender shoot. For cowpea, harvesting was started 50 days after planting when pods were fully matured. The harvesting time of cowpea was decided by the indication of turning of pods' colour from green to pale yellow. The cowpea seeds were separated by crushing them with sticks after drying well in the sun for 2–3 days. After that, cleaned seeds were dried until the moisture content was about 10% and stored them in air-tight packages in a dry and cool place.^{33,40}

Recording of Growth and Yield Parameters

Growth and yield parameters were recorded during the vegetative, reproductive, and maturity periods

(Table 1). From each treatment, five plants were selected randomly and tagged per plot and from which, all the growth parameters were measured. The yield of both crops was recorded per plot for all treatments.

Growth Parameters

Plant height of okra and cowpea was measured in cm at 2–week intervals. Plant height was recorded by measuring the length of the selected plant from the bottom of the stem to the terminal bud.⁴¹ Number of leaves and branches per plant in both okra and cowpea was counted.

Yield Parameters

For okra, the number of flowers per plant, number of pods per plant, pod yield per hectare ($t\ ha^{-1}$), weight per pod (g), pod length (cm), and pod circumference (cm) were measured. For cowpea, number of flowers per plant, number of pods per plant, pod yield per hectare ($t\ ha^{-1}$), and grain yield per hectare ($t\ ha^{-1}$), number of grains per pod, and pod length (cm) were measured. After each picking, the yield of okra and cowpea was recorded in treatment wise. When the picking was completed, the yield per plant of individual treatment was enumerated. The number of pods per plant for okra and cowpea was counted. The average pod weight of okra was measured at the end of the experiment, and it is a proportion of the total yield weight to the total number of pods. The pod weight was measured using a digital balance. In okra and cowpea, pod length was measured using meter tape from randomly selected five pods on each treatment and then the average was calculated. The circumference of the okra pod was measured with the help of thread and meter tape. The average number of grains per pod was

counted for cowpea from randomly selected five pods in treatment wise and then the average was calculated. In cowpea, grain yield was recorded in kg when constant weight was achieved after drying.

Table 3: Parameters measured for growth and yield of okra and cowpea.

Parameter category	Parameter
Growth parameters	Plant height (cm)
	Number of leaves per plant
	Number of branches per plant
Yield parameters	Number of flowers per plant
	Number of pods per plant
	Pod yield per hectare (t ha ⁻¹) ¹
	Weight per pod (g)
	Length of the pod (cm)
	Circumference of the pod (cm) ²
Grain yield per hectare (t ha ⁻¹) ³	
	Number of grains per pod ⁴

¹Fresh pod weight was measured for okra as it is marketable yield, while dry pod weight was measured for cowpea as it is marketable yield;² only measured for okra as it is harvested as fresh pod weight;^{3,4} measured for cowpea as it is harvested as dry pod

In addition to the growth and yield parameters, we measured the chlorophyll content of the leaf using a SPAD Chlorophyll meter.

Evaluation of Cropping System using Cropping Indices

The following cropping indices were used. The cropping indices were categorized into yield efficiency indices, crop competition indices, and land utility efficiency indices for evaluation.

Yield Efficiency Indices

Harvest index (HI), Land equivalent ratio (LER), relative yield total (RYT), and area time equivalent ratio (ATER) were used to estimate the efficiency of yield.

Harvest index (HI)

The harvest index (HI) is a well-known index used to evaluate the yield efficiency at the time of harvest. It is calculated using the economic yield

of the crop divided by the total biological yield.^{42,43} If the economic yield is 50 % of the total, then the HI value was 0.5. A high value indicates the good yield of the crops. HI for okra and cowpea were calculated using the following equation (1) and (2), respectively.

$$\text{HI okra} = \text{Y okra pod} / \text{Y okra biological total} \quad \dots(1)$$

$$\text{HI cowpea} = \text{Y cowpea pod} / \text{Y cowpea biological total} \quad \dots(2)$$

Where, Y = yield of the respective crop in each treatment

Land equivalent ratio (LER)

The LER represents how much additional land area is needed for establishing the monocropping system in order to get the same crop production in an intercropping system (Equation 3). The LER indicates that intercropping system use the resources efficiently than monocropping system.⁴⁴ Yield is considered as advantage when LER value is greater than one, likewise, yield is disadvantage when the LER value is less than 1.⁴⁵ When the LER = 1, there is no gain or no loss in yield.

$$\text{LER} = (\text{Yi okra} / \text{Ym okra}) + (\text{Yi cowpea} / \text{Ym cowpea}) \quad \dots(3)$$

Where, Yi = intercrop yield; Ym = monocrop yield

Relative yield total (RYT)

The RYT measures how much yield is to be obtained from the intercropping system when the population is maintained as same as in the monocropping system. The RYT is sum of a proportion of intercrop yields of a crop to monocropping yield of component crop from the same replacement series (Equation 4). The RYT represents the yield advantage based on unit area and unit population. When the LER is calculated at equal amount of plant population in unit area basis then it is known as RYT.⁴⁶⁻⁴⁸

$$\text{RYT} = (\text{Yi okra} + \text{Yi cowpea}) / (\text{Ym okra} + \text{Ym cowpea}) \quad \dots(4)$$

Where, Yi = intercrop yield; Ym = monocrop yield

Area time equivalent ratio (ATER)

In addition to the yield of each intercrop, the ATER includes the cropping maturity period of each crop in a cropping system (Equation 5) compared to the HI, LER, and RYT. The ATER is more explainable than LER and RYT.^{49,50} When the crop maturity period is

same for both crops in intercropping system, then the value of ATER is equal to LER. When the value of ATER is > 1, there is a yield advantage, when it is < 1, yield disadvantage and when ATER is 1, then there is no gain or loss in yield.

$$\text{ATER} = 1/t \{[(d \text{ okra} \times Y_i \text{ okra})/Y_m \text{ okra}] + [(d \text{ cowpea} \times Y_i \text{ cowpea})/Y_m \text{ cowpea}]\} \quad \dots(5)$$

Where, Y_i = intercrop yield; Y_m = mono crop yield; d = growth period of the crops in days; t = time in days for which field remained occupied.

Crop Competition Indices

Competition index (CI), relative crowding coefficient (RCC), and aggressivity index (A) were used to estimate the crop competition in the intercropping systems.

Competition index (CI)

The Competition index (CI) compares the yield of a crop intercropping system over its monocropping system separately. CI is estimated based on unit area basis and resembles the yield difference of a crop in intercropping system over its monocropping system (Equation 6). When the yield of crop in intercropping system is higher than its monocropping yield at unit area basis, the system is considered positive. But, when the yield is low in intercropping system over its monocropping, it is considered as negative effect and there will be a crop competition.⁵¹

$$\text{CI} = \{(Y_m \text{ okra} - Y_i \text{ okra}) \times (Y_i \text{ cowpea} - Y_m \text{ cowpea})\} / (Y_m \text{ okra} \times Y_i \text{ okra}) \quad \dots(6)$$

Where, Y_i = intercrop yield; Y_m = monocrop yield;

Relative Crowding Coefficient (RCC)

The relative crowding coefficient (RCC) measures the relative competitiveness of a crop in the intercropping system based on the yield and their occupied area.⁴⁸ The RCC compares the yield of a crop in intercropping system over its monocropping system. The RCC for okra and cowpea are given in equations 7 and 8, respectively. The negative value indicates strong competitiveness whereas the positive value represents the weak competitiveness in the intercropping system. The value of RCC is > 1, equal 1, and < 1 represents the yield advantage, no advantage or disadvantage and yield disadvantage, respectively.

$$\text{RCC okra} = \{Y_i \text{ okra} / (Y_m \text{ okra} - Y_i \text{ okra})\} \times (Z \text{ cowpea} / Z \text{ okra}) \quad \dots(7)$$

$$\text{RCC cowpea} = \{Y_i \text{ cowpea} / (Y_m \text{ cowpea} - Y_i \text{ cowpea})\} \times (Z \text{ okra} / Z \text{ cowpea}) \quad \dots(8)$$

Where, Y_i = intercrop yield; Y_m = mono crop yield; Z = proportion of the land occupied by the crop

Aggressivity index (Ai)

The aggressivity index (A_i) is an index of dominance, and it is used to estimate the competitive relationship in intercropping system.⁵² The A_i for okra and cowpea is given in equations 9 and 10, respectively. Zero value indicates that both crops are equally competitive. Positive sign represents that the crop is dominant, likewise, negative value indicates that crop is dominated by other crop.

$$A_i \text{ okra} = \{Y_i \text{ okra} / (Y_m \text{ okra} - Z \text{ okra})\} - \{Y_i \text{ cowpea} / (Y_m \text{ cowpea} - Z \text{ cowpea})\} \quad \dots(9)$$

$$A_i \text{ cowpea} = \{Y_i \text{ cowpea} / (Y_m \text{ cowpea} - Z \text{ cowpea})\} - \{Y_i \text{ okra} / (Y_m \text{ okra} - Z \text{ okra})\} \quad \dots(10)$$

Where, Y_i = intercrop yield; Y_m = monocrop yield; Z = proportion of the land occupied by the crop

Land Utility Efficiency Index

Multiple cropping index (MCI) was used to estimate the efficiency of land utilization. The MCI is the proportion of land area utilized by the crops in intercropping system to the total land area available for the cultivation. The MCI value is expressed in percentage.⁵³ The high value of MCI indicates the efficient utilization of land in the intercropping system.

$$\text{MCI} = \{(a \text{ okra} + a \text{ cowpea}) / A_t\} \times 100 \quad \dots(11)$$

Where, a = area occupied by the crop; A_t = total land area available for cultivation

Statistical Analysis

Analysis of variance test was performed in Statistical software SAS 9.1 and mean separation was done by using the least significance difference (LSD) method at $p < 0.05$ and the standard error (SE) was calculated.

Results

We presented the results in three sections, such as the results obtained from the analysis of growth parameters, yield parameters, and cropping indices.

Growth Parameters

Plant Height

Fig. 2 shows the results of plant height in cm at 2-week intervals for okra and cowpea. The results show that there was an increasing trend in plant height with weeks. The okra height was not significantly differed among the treatments from 2-

WAP to 8-WAP. The highest plant height of okra was (35.15 ± 2.87 cm) in T₂ at 8-WAP. The plant height of cowpea was not significantly different at 2-WAP and 4-WAP. At 6-WAP, plant height of cowpea was significantly higher in T₁ (19.00 ± 0.83 cm) and T₂ (19.03 ± 1.00 cm) and these were not significantly different within them, whereas it was least significant in T₃ (15.56 ± 2.27 cm). The plant height of cowpea was significantly higher in T₂ (22.73 ± 0.78 cm) followed by T₁ (21.40 ± 1.17 cm) and it was least significant in T₃ (18.27 ± 0.81 cm) at 8-WAP.

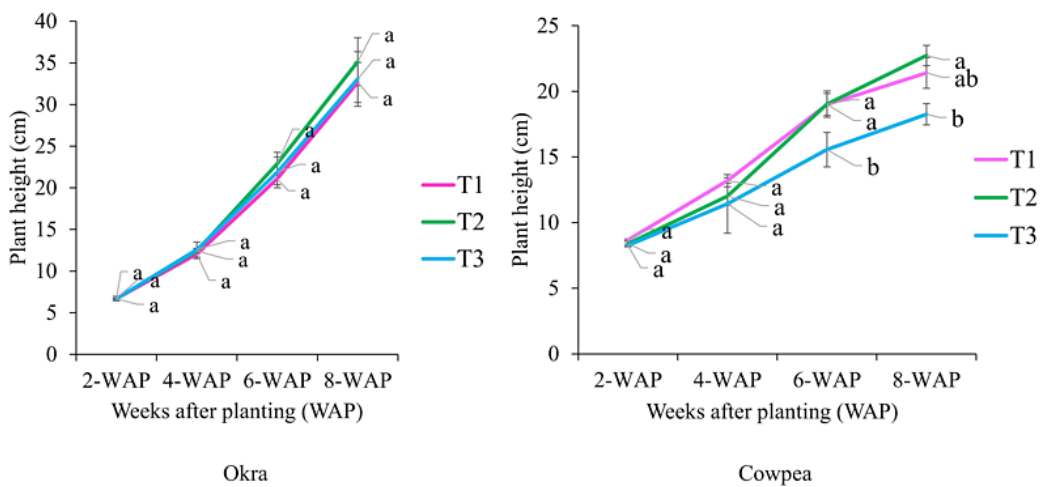


Fig. 2: Average plant height of okra (left) and cowpea (right) under different treatments. Means with the same letter within the treatments are not significantly different at p=0.05.

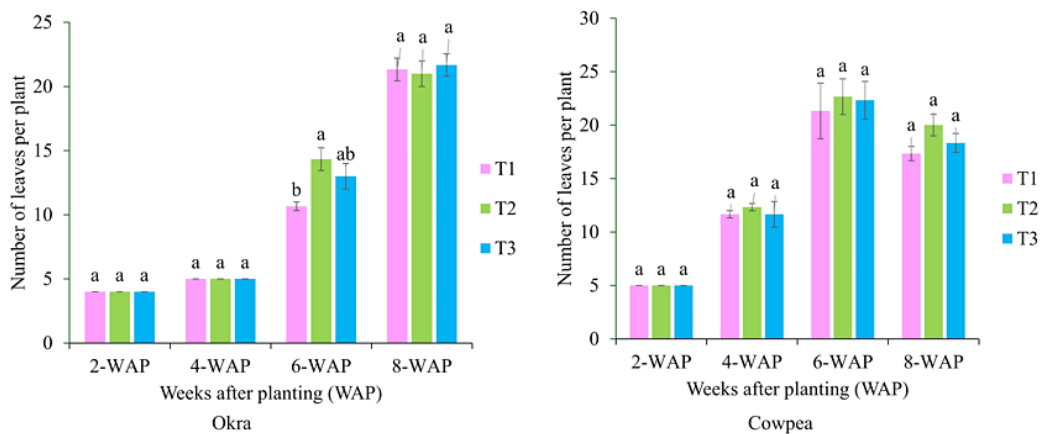


Fig. 3: The average number of leaves for okra (left) and cowpea (right) with weeks under different treatments. Means with the same letter within the treatments are not significantly different at p=0.05.

Number of leaves

The results of the number of leaves per plant for okra and cowpea are represented in Fig. 3. The number of leaves in okra showed an increasing trend from 2–WAP to 8–WAP. The number of leaves in okra was not significant with weeks except at 6–WAP where T_2 (14.33 ± 0.88) had a higher number of leaves. The highest number of okra leaves was observed in T_3 (21.67 ± 0.88) at 8–WAP. In cowpea, the number of leaves increased from 2–WAP to 6–WAP and there was a slight decline at 8–WAP. The number of cowpea leaves was not significantly different among the treatments with weeks. The highest number of leaves in cowpea was observed in T_2 (22.67 ± 1.67) at 6–WAP.

Number of Branches

The results of the number of branches at a 2–week interval is represented in Fig. 4. The number of branches was increased from 6–WAP to 8–WAP in both okra and cowpea. In okra, the number of branches was significantly high in T_2 (3.47 ± 0.13) followed by T_1 (3.07 ± 0.07), and it was least significant in T_3 (2.70 ± 0.25) at 6–WAP. There was no significant difference in branch number within the treatment at 8–WAP, where the highest number was observed in T_2 (5.13 ± 0.30). In cowpea, the number of branches was not significantly different among the treatments at both 6–WAP and 8–WAP and the highest number of branches was recorded in T_3 (3.33 ± 0.33) at 8–WAP.

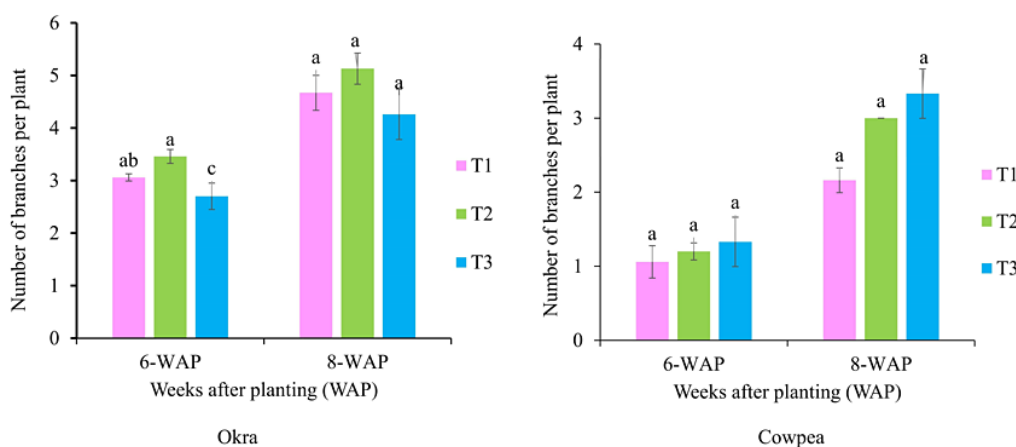


Fig. 4: Average number of branches of okra (left) and cowpea (right) at 6–WAP and 8–WAP under different treatments. Means with the same letter within the treatments are not significantly different at $p=0.05$.

Yield Parameters

The number of flowers for both okra and cowpea is represented in Fig. 5, while other yield parameters are given in Table 4 for okra and Table 5 for cowpea such as the number of pods per plant, pod yield, pod weight, pod length, pod circumference, and number of grains per pod.

The number of flowers in okra showed an increasing trend from 5–WAP to 7–WAP, and then, there was a slight reduction at 9–WAP. The number of flowers in okra was significantly high in T_1 with weeks (Fig. 5). At 5–WAP, the number of flowers in okra was significantly high in T_1 (2.10 ± 0.06) and it was least significant in both T_2 (1.40 ± 0.06) and T_3 (1.22 ± 0.06).

Similar significant trend was recorded at 7–WAP and 9–WAP for number of okra flowers. The number of okra flowers was significantly high in T_1 (5.80 ± 0.15) followed by T_2 (4.23 ± 0.09), and it was least significant in T_3 (3.47 ± 0.09) at 7–WAP. Similarly, it was significantly higher in T_1 (5.55 ± 0.05) followed by T_2 (4.14 ± 0.12) and least significant in T_3 (3.58 ± 0.29) at 9–WAP. In cowpea, the number of flowers showed an increasing trend from 5–WAP to 6–WAP, and then, there was a decline at 7–WAP. The number of cowpea flowers was not significant within the treatments from 5–WAP to 7–WAP. The highest number of cowpea flowers was recorded in T_3 (6.03 ± 0.09) at 6–WAP.

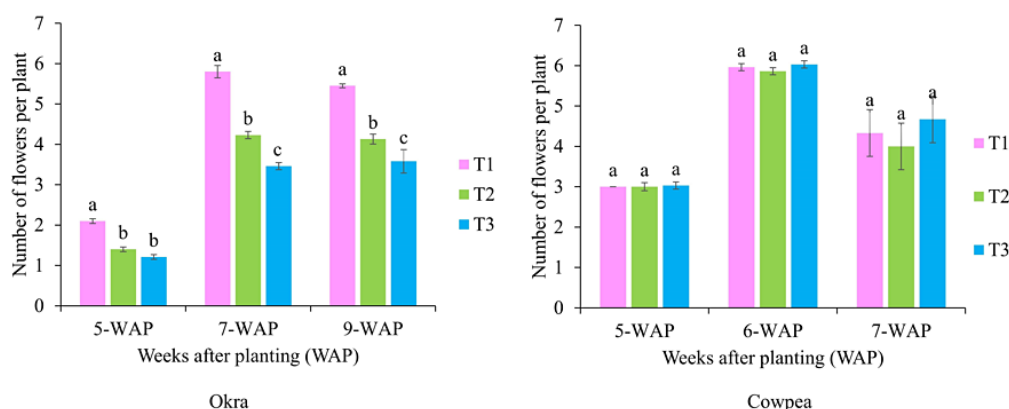


Fig. 5: Average number of flowers of okra (left) and cowpea (right) with weeks under different treatments. Means with the same letter within the treatments are not significantly different at $p=0.05$

The number of pods per plant in okra was significantly higher in and T_1 (13.25 ± 0.14) followed by T_2 (9.54 ± 0.34), and it was least significant in T_3 (8.09 ± 0.34) (Table 4). The number of pods per plant in cowpea was not significantly different among the treatment and the highest values was recorded in both T_1 (9.00 ± 0.58) and T_2 (9.00 ± 0.00) (Table 5). The pod yield in okra was significantly high in T_1 ($3.40 \pm 0.02 \text{ t ha}^{-1}$), followed by T_2 ($3.20 \pm 0.05 \text{ t ha}^{-1}$), and it was least significant in T_3 ($3.06 \pm 0.03 \text{ t ha}^{-1}$) (Table 4). The pod yield in cowpea was significantly high in both T_1 ($0.31 \pm 0.01 \text{ t ha}^{-1}$) and T_2 ($0.22 \pm 0.01 \text{ t ha}^{-1}$)

and these were not significantly different within them where it was least significant in T_3 ($0.12 \pm 0.00 \text{ t ha}^{-1}$) (Table 5). The pod weight of okra was not significantly different among the treatments and the highest number was observed in T_2 ($36.67 \pm 1.67 \text{ g}$) (Table 4). The number of grains per pod in cowpea was not significantly different and the highest number was recorded in T_1 (13.67 ± 0.33) (Table 5). The grain yield in cowpea was significantly high in T_2 ($0.22 \pm 0.01 \text{ t ha}^{-1}$) followed by T_1 ($0.15 \pm 0.01 \text{ t ha}^{-1}$) and it was least significant in T_3 ($0.08 \pm 0.00 \text{ t ha}^{-1}$) (Table 5).

Table 4: Results of the yield parameters of okra.

Treatments	Number of pods per plant	Pod yield (t ha^{-1})	Weight per pod (g)	Pod length (cm)	Pod circumference (cm)
T_1	13.25 ± 0.14 (13.50–13.00) a	3.40 ± 0.02 (3.42–3.37) a	36.67 ± 1.67 (40–35) a	19.53 ± 0.73 (20.50–18.10) a	7.53 ± 0.37 (8.25–7.00) a
T_2	9.54 ± 0.34 (9.81–9.20) b	3.20 ± 0.05 (3.28–3.10) b	36.10 ± 3.09 (40–30) a	18.9 ± 0.26 (19.40–18.50) a	7.33 ± 0.09 (7.50–7.20) a
T_3	8.09 ± 0.34 (8.60–7.45) c	3.06 ± 0.03 (3.12–3.02) c	32.77 ± 1.47 (35–30) a	19.13 ± 0.47 (20–18.40) a	7.50 ± 0.15 (7.70–7.20) a

means values are given with \pm standard error (SE) and range (maximum–minimum); means with the same letter within the column are not significantly different at $p=0.05$.

Table 5: Results of the yield parameters of cowpea.

Treatments	Number of pods per plant	Pod yield (t ha ⁻¹)	Grain yield (t ha ⁻¹)	Number of grains per pod	Pod length (cm)
T ₁	9.00 ± 0.58 (10–8) a	0.22 ± 0.01 (0.24–0.20) a	0.15 ± 0.01 (0.16–0.14) b	13.67 ± 0.33 (14–13) a	16.98 ± 0.37 (17.57–16.30) a
T ₂	8.67 ± 0.67 (10–8) a	0.31 ± 0.01 (0.32–0.30) a	0.22 ± 0.01 (0.23–0.20) a	12.00 ± 0.58 (13–11) a	16.20 ± 0.49 (17.10–15.40) a
T ₃	9.00 ± 0.00 (9–9) a	0.12 ± 0.00 (0.12–0.11) b	0.08 ± 0.00 (0.08–0.08) c	12.33 ± 0.33 (13–12) a	16.17 ± 0.12 (16.40–16.00) a

means values are given with ± standard error (SE) and range (maximum–minimum); means with the same letter within the column are not significantly different at p=0.05.

The pod length was not significantly different among the treatments in both okra and cowpea. The highest pod length was recorded for T₁ in okra (19.53 ± 0.73 cm) and cowpea (13.67 ± 0.33 cm) (Table 4) (Table 5). The pod circumference of okra was not significantly different among the treatments and the highest value was observed in T₁ (7.53 ± 0.37 cm) (Table 4).

Cropping Indices

The results of cropping indices are represented in Table 6. For the estimation of cropping indices, yield of the intercropping systems was evaluated using monocropping yield. The average yield of okra and cowpea in monocropping system was 4.54 ± 0.03 t ha⁻¹ and 1.03 ± 0.02 t ha⁻¹, respectively.

Yield Efficiency Indices

Harvest index (HI) was not significantly different among the treatments. However, okra had a higher HI value (0.44–0.50) than cowpea (0.12–0.21). The highest land equivalent ratio (LER) was recorded significantly in T₃ (1.002) followed by T₂ (0.922), and it was least significant in T₁ (0.851). Based on LER, a slight yield advantage was recorded in T₃ (0.2 %), and a yield disadvantage was recorded for in T₂ (7.8 %) and T₁ (14.9 %). Significantly, the highest relative yield total (RYT) was recorded for T₃ (1.042) followed by T₂ (0.959), and it was least significant in T₁ (0.873). Based on RYT, yield advantage was

recorded in T₃ (4.2 %), whereas yield disadvantages were recorded in T₂ (4.1%) and T₁ (12.7 %). The area time equivalent ratio (ATER) was less than one in all intercropping systems. The highest ATER was recorded significantly in T₃ (0.954), followed by T₂ (0.878) and it was least significant in T₁ (0.802). Based on the ATER, all okra–cowpea intercropping systems had yield disadvantage and it was 4.6 %, 12.22 %, and 19.8 % in T₃, T₂ and T₁, respectively.

Competition Indices

The competition index (CI) was significantly higher in T₁ (8.421), followed by T₂ (5.867) and it was least significant in T₃ (3.018). All treatments had a positive value for CI (> 0). The Relative crowding coefficient (RCC) of okra was significantly high in T₃ (1.089) followed by T₂ (0.758) and it was least significant in T₁ (0.481). The RCC of cowpea was significantly high in T₁ (1.131) followed by T₂ (1.106) and it was least significant in T₃ (0.952). The value of RCC in okra was > 1 in T₃, and < 1 in T₁ and T₂. The value of RCC in cowpea was < 1 in T₃ and > 1 in T₁ and T₂. The cowpea had had a positive aggressive index (Ai) value in all treatments, while it was negative value for okra.

Land Utilization Efficiency Indices

The multiple cropping index (MCI) was 98.35 %, 96.3 %, and 95.06 %, in T₃, T₂, and T₁, respectively, and had not statistically different within them.

Table 6: Results of the cropping indices with the treatments

Treatment	HI okra	HI cowpea	LER	RYT	ATER	CI	RCC okra	RCC cowpea	Ai okra	Ai cowpea	MCI
T1	0.479 a	0.157 a	0.851 c	0.873 c	0.802 c	8.421 a	0.481 c	1.131 a	-0.003 a	0.003 a	96.30%
T2	0.499 a	0.202 a	0.922 b	0.959 b	0.878 b	5.867 ab	0.758 ab	1.106 b	0 b	0.001 b	95.06%
T3	0.468 a	0.213 a	1.002 a	1.042 a	0.954 a	3.018 c	1.089 a	0.952 c	0 b	0.001 b	98.35%

means with the same letter within the column are not significantly different at $p=0.05$.

Discussion

Selection of Cropping Systems and Design

In this study, we established the okra–cowpea intercropping systems (T_1 , T_2 and T_3). In addition to the intercropping systems, we established the monocropping of okra and cowpea for the use of cropping indices. The land, irrigation, and rainfall, availability of labour, and capital resources determine the type of cropping systems practiced in an area.^{54–56} The primary goal of intercropping is to increase yield over a pure stand on the same amount of land over a specific period.¹³ The crop competition often happened in any intercropping system when the component crops are not providing complementary effects.⁵⁷ Due to competitive, complementary, or facilitative interactions, intercropping grain legumes with other crops has the potential to increase the use efficiency of nitrogen sources.⁵⁸ Therefore,

we selected the okra and cowpea from vegetable and grain legumes, respectively to design the different intercropping systems and we ensured the optimum space for each crop during the design of each treatment to minimize the competition. The combination of okra and cowpea intercropping system has been practiced due to many beneficial effects.⁵⁹ including risk reduction through crop failure insurance, better resource utilization by crops with varying heights, rooting depths, and nutrient requirements.^{18,60} Cowpea is a most important crops in fulfilling many roles among the various leguminous plants.²⁵ Several patterns were designed for okra cowpea intercropping system in previous studies.^{61,62} However, in this study we used the three mostly used cropping patterns for okra–cowpea intercropping systems for the evaluation.

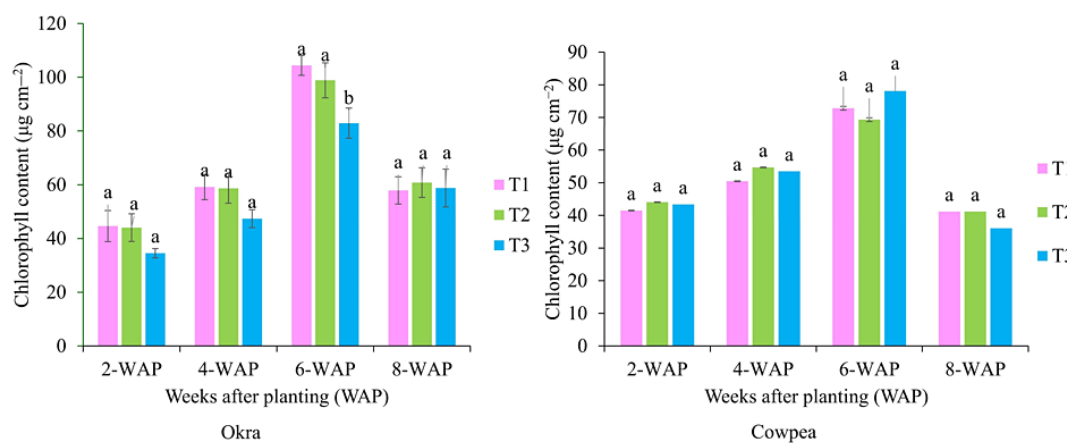


Fig. 6: Chlorophyll content of okra (left) and cowpea (right) with weeks under different treatments. Means with the same letter within the treatments are not significantly different at $p=0.05$

Our focus was to explore the use of cropping indices, therefore, in this study, soil nutrient and plant nutrient analysis was not studied. However, we measured the chlorophyll content in each crop from 2–WAP to 8–WAP (Fig. 6). The chlorophyll content in the crops is affected by available nitrogen and environmental stresses.⁶³ The chlorophyll content was not significantly different among the treatments in cowpea. Similarly, the chlorophyll content was not significantly different among the treatments in okra except this was significantly high in T₁ and T₂ at 6–WAP. Therefore, we assumed that the effect of nodulation or ability of Nitrogen provision did not affect the treatments. However, the chlorophyll content was high at 6–WAP for both okra and cowpea. It may be correlated to growth stages.

Growth Parameters

We assessed the plant height, number of leaves and number of branches as growth parameters for okra and cowpea. The growth characteristics of the crops is dependent on the selection of intercropping system.^{14,64} Plant height of okra was significantly different with different patterns of okra–cowpea intercropping whereas the plant height of cowpea was not significantly different.⁶² Our plant height value was higher, and the leave number was consistent with the value of previous study, similarly, in the same study, plant height and leave number were 17.78–31.13 cm and 7–11.25, respectively in okra whereas these were 9.18–55.03 cm, 17.25–27 in cowpea in okra–cowpea intercropping system, however, they used different varieties of okra and cowpea.⁶¹ The number of leaves is an important growth parameter, which is affected by genetic and environmental factors. The no significant different observed for number of leaves in okra–cowpea intercropping in 2–8 WAP except in 6–WAP.⁶² This was consistent with our study, the number of leaves was not significantly different for both okra and cowpea except for okra at 6–WAP. In a previous study, there was an increasing trend of pod number with the increased branch number, but crop yield was decreased with the increased branch number. They also found that yield was increased with branch number at initial and then plateaued.⁶⁵

Based on the growth parameters, T₂ was provided the significantly higher plant height for cowpea, whereas number of leaves and branch number were not significant. For okra, the number of leaves

and branches were significantly high in T₂, whereas plant height was not significantly different. It may be due to the high number of cowpea population in T₂ than okra. Based on the growth characteristics of both okra and cowpea, comparatively T₂ was performed well.

Yield Parameters

For yield parameters, number of flowers, number of pods, number of grains, average pod weight, grain yield, number of grains per pod, pod length and circumference were assessed. Among the yield parameters, fresh pod weight was measured for okra as it is marketable yield, while dry pod weight was measured for cowpea as it is the marketable yield. There was a huge difference in heritabilities between intercrop over monocrop.⁶⁶ In our study the number of flowers in cowpea was not significantly different among the treatments with weeks, however, it was significantly high in T₁ for okra. The number of pods in okra was high in T₂ whereas it was not significant in cowpea. The number of pods in okra were consistent with,⁵⁹ who found that weight per pod ranged from 12 to 16, but weight per pod was lower (11.87–15.06 g) than our value (32.77–36.77 g). However, pod yield of okra (6.58–8.89 t ha⁻¹) and grain yield of cowpea (3.54–7.19 t ha⁻¹) were higher than our value in okra. There was a huge difference in heritabilities between intercrop over monocrop cowpea intercropping systems (Table 4; Table 5), this was due to varietal characteristics. Our pod yield of okra (3.06–3.4 t ha⁻¹) was higher in a study,⁶¹ the value from 0.26–1.88 t ha⁻¹, similarly, our pod yield of cowpea (0.12–0.31 t ha⁻¹) was lower than the same study 61 that pod yield cowpea ranged from 0.65 to 2.68 t ha⁻¹ in under okra–cowpea intercropping. In this study, monocropping yield of okra (4.54 ± 0.03 t ha⁻¹) and cowpea (1.03 ± 0.02 t ha⁻¹) was lower than the recommended yield of okra (10–15 t ha⁻¹) and cowpea (1.6 t ha⁻¹), this may be attributed to specific location of the study area, water stress during the research period, pest, and disease infection. However, our monocropping and intercropping yield was comparable with previous study in this region.^{61,62} Fruit quality is crucial to marketability and is primarily correlated with the distinctive pod length.⁶⁷ In this study, pod length was not significantly different among the treatments for both okra and cowpea. For pod length, the average values of cowpea genotypes ranged from 10.90 to 29.87 cm,⁶⁸ our value of pod length for cowpea

ranged from 16.2 to 17.67 cm. Pod length is one of several agronomic characteristics that are linked to grain yield in cowpea. In our study, cowpea grain yield was significantly low in T_3 . Single row of okra with single row of cowpea gave the highest yield in the intercropping system.⁶⁹ This result was consistent with our study and pod yield was significantly high in single row of okra with single row of cowpea (T_1).⁶¹ and single row of okra with double-row of cowpea showed a high growth and yield performance with a combination of fertilizer treatments in the intercropping system. In this study, it is consistent with cowpea grain yield, and it was significantly high in single row of okra with a double-row of cowpea (T_2).⁶¹

Based on the yield parameters, T_1 was a suitable combination of intercropping system for okra pod yield whereas T_2 was suitable for number of flowers and number of branches. In cowpea, T_2 was a suitable combination of intercropping system for grain yield, whereas other yield parameters were not significant. Comparatively, the results of yield parameters were closely related to growth parameters in both okra and cowpea intercropping systems.

Cropping Indices

In this study, the efficiency of intercropping systems was explained by different cropping indices including yield-based, competition-based and land area-based. The efficacy was determined based on what type of indices were used. The harvest index (HI) was influenced by genotypes, environment, and crop management practices.^{70,71} In our study, we used the same variety of okra and cowpea for all cropping systems in the same environment where all the agronomic management practices were done according to the recommendation. Therefore, the HI index of the okra and cowpea was not significantly changed among the treatments. The HI values for okra in our study ranged from 0.4 to 0.5 and this value was within the range of the most intensively farmed cereals (0.44–0.6).⁴³ Similarly, the HI value for the cowpea ranged from 0.2 to 0.5,^{72,73} whereas our value was closer to the minimum (0.12–0.21). This may be due to the varietal characteristics of each crop. This result showed that the proportion of economic yield to the total biological yield was higher in okra than cowpea.

There is no difference in the yield between intercrop and monocrop when LER, RYT and ATER has a value of 1,⁷⁴ whereas > 1 represents the yield advantages. In our study, yield advantage was observed in T_3 based on LER and RYT. This finding agreed with,⁷⁵ who reported that the value of LER was > 1 in okra and cowpea intercropping. The LER value of 1.1 and 1.48 for single row of okra with single row of cowpea and double-row of okra with single row of cowpea, but our value was < 1 for those, this may be due to the different spacing and varieties used.⁶⁹ The LER value ranged from 1.14 to 2.71 in okra–cowpea intercropping.^{59,76} The yield advantages demonstrated with okra–cowpea intercrops were referable to the soil Nitrogen economy often associated with the inclusion of legumes in the mixture.⁵⁸ The LER value is limited to unit land area, and it doesn't consider the unit area population. Therefore, we applied the RYT to determine the efficiency in more explainable.

The selection of crops in the intercropping system, such as the intercrops crop combination, has an impact on yield and yield components at different densities.⁷⁷ It was clearly noted that based on the RYT, when maintaining the population density in both monocropping and intercropping, under intercropping systems yield advantage was high in every intercropping system.⁶⁴ However, the crop competition will lower the RYT in the intercropping system. Thus, the RYT value of < 1 indicates fierce competition.⁷⁸ In our study, RYT was > 1 for in T_3 indicating that there was a yield advantage. However, the ATER is the most effective way to estimate the yield advantage because this index is based on crop maturity periods of the intercrops and long duration of the intercrop than LER and RYT which only deal with yield. In our study, the ATER was < 1 for all treatments which indicated there is no yield advantage when duration of intercrops included in the estimation. The ATER value ranging from 1.25 to 2.66 in okra–cowpea intercropping, and the okra with a double-row and cowpea with three-row recommended as a good combination.⁶²

Based on the competition index (CI), all treatments had a positive value (> 1) and these results showed that there was no competition between okra and cowpea in all intercropping systems. Value of the

RCC was also >1 among the treatment for both crops, this also further accurately ensure, there was no crop competition between okra and cowpea in intercropping systems. The cowpea had a positive A_i value whereas okra had negative value and this result showed that cowpea was a dominant crop in the intercropping systems while okra was dominated by cowpea. The results of MCI showed that the land was utilized with higher efficiency ($>95\%$) (Table 6).

The limitation of our study is in our focus solely on the application of cropping indices for evaluating okra–cowpea intercropping systems, neglecting soil characteristic measurements such as soil nutrients. Future research should prioritize soil analysis to provide valuable insights into the growth and yield performance of intercropping systems. Additionally, while we aimed to assess intercropping systems primarily through growth and yield performance, we acknowledge the potential influence of other factors such as nodulation of legumes and root mycorrhization,⁷⁹ which were not directly measured in this study. Moreover, our evaluation criteria were limited to yield efficiency, competition indices, and land utilization indices, overlooking economic indices⁸⁰ that could further inform intercropping system selection.³⁰ Furthermore, our experimental trial was conducted over a single season, potentially limiting the generalizability of our findings. Future studies should consider long–term trials across multiple seasons and locations, encompassing a broader range of intercropping patterns, to more comprehensively evaluate the sustainability of okra–cowpea intercropping systems using cropping indices for management practices.

Conclusions

In this study, we evaluated okra–cowpea intercropping systems using both growth and yield performance and cropping indices. The outcomes differed between these two approaches. While growth and yield analysis selected single row okra with single row cowpea (T_1) and single row okra with double–row cowpea (T_2), cropping indices identified double–row okra with single row cowpea (T_3) as the most suitable combination. T_3 not only demonstrated a yield advantage but also exhibited

minimal crop competition and maximal land utilization across all intercropping systems. Cowpea emerged as the dominant crop in the intercropping systems. By considering factors like unit area land, population, relative crowding, aggressivity, and crop maturity, cropping indices offered a more strength in assessment for selection of suitable intercropping system. This underscores the importance of supplementing growth and yield analysis with cropping indices for evaluating intercropping efficiency. Therefore, we recommend prioritizing the application of cropping indices over the growth and yield alone when selecting intercropping systems for optimal agricultural productivity.

Acknowledgements

This experiment was carried out at the Crop Farm of the Faculty of Agriculture, University of Jaffna, Sri Lanka. The authors would like to express sincere appreciation to the staff of the Crop Farm and Department of Agronomy, Faculty of Agriculture, University of Jaffna for facilitating the research and providing the necessary Farm Machinery and provisioning Laboratory facilities.

Funding Sources

No financial support received from any organization or individuals

Conflict of Interest

The authors declare that there are no conflicts of interest.

Data Availability Statement

The data collected from the field are available on request from the corresponding author.

Informed Consent Statement

Not applicable

Author's Contribution

KA: conceptualization and design of the study, wrote the manuscript and design figures and tables, JK: Editing and revising of manuscript SS: Field guidance, designs and farm facilities for experimental work.

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