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Venu Gopala RLM Kola
P.G. Research Scholar, Dept. of
Agronomy, Agricultural college,
Bapatla, ANGRAU, Andhra
Pradesh, India

P Munirathnam
Senior Prof. & University Head,
Dept. of Agronomy, ANGRAU,
Andhra Pradesh, India

T Kiran Kumar
Senior Scientist, Dept. of
Agronomy, ICAR-NIRCA, Andhra
Pradesh, India

KM Dakshina Murthy
Professor & Head, Dept. of
Agronomy, Agricultural college,
Rajmahendravaram, ANGRAU,
Andhra Pradesh, India

Y Sudha Rani
Assistant Controller of
Examinations, ANGRAU, Andhra
Pradesh, India

Corresponding Author:
Venu Gopala RLM Kola
P.G. Research Scholar, Dept. of
Agronomy, Agricultural college,
Bapatla, ANGRAU, Andhra
Pradesh, India

Enhancing the productivity of maize through intercropping under paired row planting

Venu Gopala RLM Kola, P Munirathnam, T Kiran Kumar, KM Dakshina Murthy and Y Sudha Rani

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Abstract

A field experiment was conducted on clay soils of ICAR-NIRCA, Katheru, Rajamahendravaram, during rabi, 2024-25 to assess the influence of intercropping under paired row planting on maize productivity and to find out the suitability of these intercrops with maize under paired row planting. The experiment consisted of ten treatments replicated thrice in a Randomised Block Design (RBD), which included maize as main crop and radish, carrot and bhendi as intercrops in different row proportions with maize. The results of the experiment indicated that significantly higher MEY was obtained from maize + carrot (2:2) system on par with maize + radish (2:2) and maize + bhendi (2:2) systems. Other intercropping indices such as LER, LEC, ATER and NER were also observed to be higher with maize + carrot (2:2) system followed by maize + radish (2:2) and maize + bhendi (2:2) systems. Hence, it can be concluded that productivity of maize can be improved by intercropping with carrot, radish and bhendi. Land usage can also be improved by these intercropping systems as evident from higher LER values. PER of intercropping systems were higher, which indicates that intercropping of vegetables with maize aids in extra monetary returns as compared with sole maize cultivation.

Keywords: Maize, Intercropping, Paired row system, Productivity and Land use

Introduction

Maize (*Zea mays* L.) is one of the world's most important crops that was domesticated in Central America and is now extensively cultivated as a cereal crop. In India, maize ranks as the third most important cereal crop after rice and wheat (Chaudhari *et al.*, 2018) ^[6]. It has gained the esteemed title of "Queen of Cereals" worldwide due to its extraordinary genetic yield potential (Parimaladevi *et al.*, 2019) ^[15]. About two to three percent of the world's corn production is grown in India, with Andhra Pradesh being a key producer. Despite its importance, maize's long duration, utilisation of more space between rows, slow growth during initial phases are some of the drawbacks that can be addressed to get additional yields. A technique of growing two or more crops simultaneously on the same piece of land is called intercropping (Andrews and Kassam, 1976) ^[3]. Intercropping guarantees greater resource usage and leads to higher production and more effective use of the resources available (Launay *et al.*, 2009 and Mucheru-Muna *et al.*, 2010) ^[11, 13]. On the other hand, optimum planting density of maize can also be achieved by altering both inter and intra row spacing. Two closely spaced rows of maize can be paired together, separated by a wider gap from the next pair, which is called as the paired row system of maize cultivation. It provides additional space to grow an intercrop without compromising maize productivity and also optimizes light interception, nutrient use and yield potential. However, selection of a suitable intercrop is a crucial step for successful maize based intercropping, particularly under paired row planting. Vegetables, also known as protective foods are suitable intercrops for maize as they are of shorter duration and require less space (Chaudhari *et al.*, 2018) ^[6]. Keeping all these things in view, carrot, radish and bhendi were selected as intercrops and an experiment was designed to find out the suitability of these intercrops with maize under paired row planting and to find out the influence of these intercropping systems on maize productivity.

Materials and Methods

The present investigation was carried out at the Research Farm of ICAR-National Institute for Research on Commercial Agriculture (NIRCA) (formerly CTRI), Katheru, Rajamahendravaram, which is situated at an altitude of 14 m above MSL, 17.0005° N latitude and 81.8040° E longitude, comes under the Godavari Agro-climatic zone of Andhra Pradesh. The experiment was conducted during *rabi*, 2024-25, included ten treatments replicated thrice in a randomised block design (RBD). The treatments included T₁: Sole Maize (80/40 cm x 20 cm), T₂: Sole Radish (40 cm x 10 cm), T₃: Sole Carrot (40 cm x 10 cm), T₄: Sole Bhendi (40 cm x 30 cm), T₅: Maize + Radish (2:1), T₆: Maize + Carrot (2:1), T₇: Maize + Bhendi (2:1), T₈: Maize + Radish (2:2), T₉: Maize + Carrot (2:2) and T₁₀: Maize + Bhendi (2:2). The soil of the experimental site was clayey in texture, slightly alkaline in reaction, low in electrical conductivity, organic carbon and nitrogen, medium in phosphorus and high in potassium. The weekly mean minimum temperature ranged from 16.8 to 23.1°C with an average of 20.4°C. The weekly mean relative humidity ranged from 77.5 to 90.2 per cent with an average of 85.0 per cent and 43.2 to 69.4 per cent with an average of 53.9 per cent at 08: 30 hrs and 14: 30 hrs, respectively. However, no rainfall was recorded during the crop growth period. Maize was sown at a spacing of 80/40 x 20 cm (paired row spacing), carrot and radish at 40 x 10 cm and bhendi at 40 x 30 cm spacing. Recommended doses of 240 kg N, 80 kg P₂O₅ and 80 kg K₂O ha⁻¹ (for maize), 60 kg N, 40 kg P₂O₅ and 60 kg K₂O ha⁻¹ (for carrot and radish), 120 kg N, 60 kg P₂O₅ and 60 kg K₂O ha⁻¹ (for bhendi) were applied through urea, diammonium phosphate and muriate of potash, respectively. When required, other field operations like plant protection measures were taken. Intercropping indices were calculated by using standard formulae as follows:

Maize Equivalent Yield (MEY)

Maize equivalent yield was computed by converting yield of intercrops on the basis of prevailing market price of individual crop following the formula of Bandyopadhyay (1984) [4] as given below:

$$\text{Maize equivalent yield} = Y_m + (Y_i \times P_i) / P_m$$

Where, Y_{im} = Yield of intercrop maize, Y_i = Yield of intercrop, P_m = Market price of maize and P_i = Market price of intercrop.

Land Equivalent Ratio (LER)

The land use efficiency is generally determined by calculating land equivalent ratio (LER) (Mead and Willey, 1980) [12].

$$\text{LER} = Y_{ab} / Y_{aa} + Y_{ba} / Y_{bb}$$

Where, Y_{ab} = Intercrop yield of crop 'a', Y_{ba} = Intercrop yield of crop 'b', Y_{aa} = Pure stand crop yield of 'a' and Y_{bb} = Pure stand crop yield of 'b'.

When, LER = 1: no advantage of intercrop, LER < 1: intercropping reduces total yield, LER > 1: intercropping increase total yield and thus beneficial

Land Equivalent Coefficient (LEC)

To evaluate the relationship and output potential of a crop mixture, the Land Equivalent Coefficient (LEC) was created (Adetiloye and Ezedinma, 1983) [1]. The LEC was calculated by using the following formula.

$$\text{LEC} = (Y_{ab} / Y_{aa}) \times (Y_{ba} / Y_{bb})$$

Where, Y_{aa} and Y_{bb}: pure crop yield of maize and intercrops respectively, Y_{ab} and Y_{ba}: yield of main crop and intercrops in mixture.

Competition Ratio (CR)

The Competition Ratio was created to evaluate intercrop competition in order to measure the extent to which one component crop is more competitive than the other. It was calculated by the formula given below.

$$\text{CR}_{\text{maize}} = (\text{LER}_{\text{maize}} / \text{LER}_{\text{intercrop}}) \times (Z_{ba} / Z_{ab})$$

Where, 'Z_{ab}' and 'Z_{ba}' represent their sowed proportion of maize crop and intercrop.

Net Effect Ratio (NER)

The ratio of the sum of observed yields to the sum of expected yields calculated according to the proportions of each crop in the mixture.

$$\text{NER} = (Y_1 + Y_2) / (P_1 M_1 + P_2 M_2)$$

Where, M₁ and M₂ are the yields of sole maize and sole intercrop respectively, Y₁ and Y₂ are the yields of maize and intercrops in intercropping and P₁ and P₂ are sown proportions of maize and intercrop in intercropping respectively.

Relative Crowding Coefficient (K)

The Relative Crowding Coefficient (K) is a measure of the relative dominance of one species over the other in a mixture (Banik *et al.*, 2006) [5]. In the present study, the K was calculated as follows:

$$K = (K_{\text{maize}} \times K_{\text{intercrop}}),$$

$$K_{\text{maize}} = Y_{ml} \times Z_{lm} / ((Y_m - Y_{ml}) \times Z_{ml}),$$

$$K_{\text{intercrop}} = Y_{lm} \times Z_{ml} / ((Y_l - Y_{lm}) \times Z_{lm})$$

Where, Y_{ml} and Y_{lm} are the yields of maize and intercrops, Z_{ml} and Z_{lm} were the proportions of maize and intercrop in the mixture, respectively.

When the value of K is greater than 1, there is a yield advantage; when K is equal to 1, there is no yield advantage; when it is less than 1.00, there is a disadvantage.

Aggressivity (A)

Aggressivity is often used to determine the competitive relationship between two crops used in the mixed cropping (Willey, 1979) [17]. The aggressivity was calculated by following formulae:

$$A_{\text{maize}} = [Y_{ab} / (Y_{aa} \times Z_{ab}) - Y_{ba} / (Y_{bb} \times Z_{ba})]$$

$$A_{\text{intercrop}} = [Y_{ba} / (Y_{bb} \times Z_{ba}) - Y_{ab} / (Y_{aa} \times Z_{ab})]$$

Where: 'Y_{aa}' and 'Y_{bb}' represent sole crop yield of maize and intercrop respectively, 'Y_{ab}' and 'Y_{ba}' represent mixed yield of main crop and intercrops and 'Z_{ab}' and 'Z_{ba}' represent their sowed proportion of maize crop and intercrop.

Area Time Equivalent Ratio (ATER)

In terms of the amount of time required by component crops in the intercropping system, the area time equivalent ratio offers more accurate assessment of the yield benefit of intercropping over monocropping (Heibsch, 1980).

$$\text{ATER} = [(RYa \times ta) + (RYb \times tb)]/T$$

Where, RY: Relative yield of main crop or intercrop, RYa: Intercrop yield of maize with associated crop / Pure stand yield of maize (LER_a), RYb: Intercrop yield of associated crop / Pure stand yield of associated crop (LER_b), t: duration for main crop or intercrop and T: duration of intercropping system.

Price Equivalent Ratio (PER)

It is the ratio of price obtained under an intercropping system as compared to the price that could have been obtained under sole cropping.

The PER can be mathematically represented as follows:

$$\text{PER} = (Yab \times Yap) + (Yba \times Ybp) / [1/2 (Yaa \times Yap + Ybb \times Ybp)]$$

Where:

- Yaa = yield of component crop 'a' as sole crop
- Ybb = yield of component crop 'b' as sole crop
- Yab = yield of component crop 'a' as intercrop in combination with 'b'
- Yba = yield of component crop 'b' as intercrop in combination with 'a'
- Yap = market price of produce of component crop 'a'
- Ybp = market price of produce of component crop 'b'

Statistical Analysis

The data generated on various parameters was statistically analysed by applying the technique of analysis of variance contained in the procedures suggested by Gomez and Gomez (1984) [7].

Results and Discussion

Maize Equivalent Yield

Maize equivalent yield was significantly influenced by vegetables intercropping with maize. Significantly higher MEY (13952 kg ha⁻¹) was obtained from maize + carrot (2:2) intercropping system, which was found to be on par with maize + bhendi (2:2) (13174 kg ha⁻¹) and maize + radish (2:2) (13090 kg ha⁻¹) intercropping systems, whereas significantly lower MEY (7914 kg ha⁻¹) was obtained from solitary maize. However, it was comparable with maize + bhendi (2:1) intercropping system.

The higher MEY values of these 2:2 ratio intercropping systems might be due to additional yield compared to sole crops and higher intercrop yield compared to 2:1 combination. The higher prices of these intercrops apart from yields also contributed to overall enhancement of MEY in these treatments. The lower MEY value of sole maize might be due to absence of additional yield from intercrop. Similarly, Sowjanya *et al.* (2023) [16] also stated that MEY of intercropping system was influenced by market prices of main crop and intercrops.

Land Equivalent Ratio (LER)

The Land Equivalent Ratio (LER) of various intercropping systems were found to higher than 1.0 indicated that intercropping treatments had a higher land use efficiency than sole crops in the study. LER values of intercropping systems

ranged from 1.11 to 1.48 indicating yield advantage of intercropping. Higher LER value of 1.48 was recorded under paired row maize intercropped with two rows of carrot indicating 48% advantage over sole cropping of maize or carrot. However, it was followed by paired row maize intercropped with two rows of radish (1.44) and paired row maize intercropped with two rows of bhendi (1.38). Lower LER *i.e.*, 1.11 was recorded with maize + bhendi (2:1) system.

All the intercropping systems had higher LER values, which are greater than unity *i.e.*, 1.0, indicating that they were physiologically and physically more efficient than their sole crops and that the enhanced yield of intercropped vegetables compensated for the main crop's yield loss. However, the improved use of natural (land and light) and added (fertilizer and water) resources might be attributed to superior LER in intercropping systems as compared to maize sole cropping. similar results were given by Chaudhari *et al.* (2018) [6], Hossain *et al.* (2021) [9] and Alam *et al.* (2024) [2].

Land Equivalent Coefficient (LEC)

Higher LEC value (0.54) was obtained from paired row maize intercropped with two rows of carrot, which indicated that intercropping is more productive than sole cropping. It was closely followed by paired row maize intercropped with two rows of radish (0.51) and paired row maize intercropped with two rows of bhendi (0.47). The lower value of LEC was recorded under paired row maize intercropped with one row of bhendi (0.24).

The variation in LEC values among different intercropping systems highlights the impact of crop arrangement and interaction. The higher LEC value observed in paired row maize intercropped with two rows of carrot suggests that this combination maximized resource utilization. It could be due to efficient nutrient sharing and complementary growth habits. The slightly lower values for radish and bhendi indicate varying degrees of competition and synergy among crops. The lower recorded LEC in paired row maize intercropped with one row of bhendi may be attributed to increased competition for nutrients, light, and water, limiting overall productivity. However, as the values are dependent on LER, it followed similar trend as that of LER. LEC values greater than 0.25 indicated yield advantage of intercropping as reported by Parimaladevi *et al.* (2019) [15].

Competition Ratio (CR)

Higher CR value of maize (1.51) was recorded under maize + radish (2:1) intercropping system which meant that maize in this intercropping system was 1.5 times competitive and produced 1.5 times as much yield as expected. It was followed by maize + radish (2:2) system with CR of 1.47 and maize + bhendi (2:1) with CR of 1.42. Lower value of CR of maize (1.30) was obtained from paired row maize intercropped with two rows of bhendi. Competition ratio values of intercrops ranged from 0.71 to 0.77, which meant that intercrops produced 0.71 to 0.77 times of their expected yield.

Higher values of CR of maize might be because of maize that reached the target population and produced yields that were comparable to those of a sole crop when grown in an additive intercropping scheme under paired row planting (Kataria *et al.*, 2023) [10].

Net Effect Ratio

Net effect ratio of various intercropping systems ranged from 1.13 to 1.42. However, higher value of NER *i.e.* 1.42 was observed in maize + carrot 2:2 system, which indicated that

intercropping system produced 42% more yield and is 42 times as productive as sole maize. It was closely followed by maize + radish 2: 2 system (1.36) and maize + bhendi 2: 2 system (1.34). Lower NER i.e. 1.13 was observed in maize + radish 2:1 system, which indicated that intercropping system produced 13% more yield and is 13 times as productive as sole maize. The higher NER values in 2:2 intercropping systems might be attributed to the additional yield offered by an extra row of intercrop compared to 2:1systems.

Relative Crowding Coefficient (RCC) (K)

Higher K value (24.2) was observed under maize + radish (2:2) system indicating that the system produced higher yield than expected and hence, there was yield advantage with system. It was followed by paired row maize intercropped with 2 rows of carrot (16.5). Though the least value of K (1.7) was obtained from maize + bhendi (2:1), since the value was greater than 1.0, it indicated yield advantage. The superior K values were recorded with 2:2 intercropping systems than 2:1 intercropping systems might be due to higher yield as well as greater row proportion compared to 2:1 intercropping systems.

Aggressivity (A)

With a positive sign for maize and a negative sign for intercrops, regardless of the intercropping system, maize was the dominating crop (+ve) and intercrops (radish, carrot and bhendi) were the dominated crops (-ve). However, numerically higher value of ‘A’ (0.47) among all the treatments was observed under maize + radish (2:2) system. Lower value of ‘A’ (0.29) was recorded from maize +bhendi (2:1) system. ‘A’ values of various intercrops ranged from -0.29 to -0.47 indicating that they were dominated by maize. The positive value of ‘A’ for maize across all intercropping systems indicated its superior competitive ability for resources like light, nutrients and space. The relatively higher value of ‘A’ in the paired row maize + two rows radish system might be due to spatial advantage and efficient resource utilization by maize, while radish, being a less vigorous crop and harvested early, offered minimal competition. Conversely, the lower ‘A’ value in maize + bhendi (2:1) system might be attributed to the stronger competitive pressure exerted by bhendi due to its vigorous growth, which might have constrained maize performance.

Area Time Equivalent ratio

All intercropping systems had values of ATER higher than one,

showing an advantage in time and land usage across all intercrops. The higher value of ATER (1.39) was recorded when carrot was intercropped with maize in 2:2 ratio, whereas lower value (1.01) was obtained from radish intercropped with maize in 2:1 ratio. The higher ATER values of all the intercropping systems might be due to the better utilisation of resources by both the species of the mixture. Higher ATER values of intercropping systems were also reported by Parimaladevi *et al.* (2019) ^[15], Nandi *et al.* (2022) ^[14] and Kataria *et al.* (2023) ^[10].

Price Equivalent Ratio (PER)

Numerically the higher PER (1.48) was observed from maize + carrot (2:2) system, which indicated that by intercropping carrot with maize, 1.48 times price was obtained as compared with sole maize cultivation.

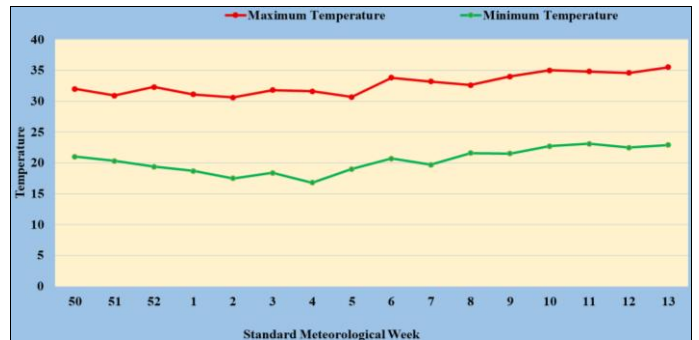


Fig 1: Weekly mean maximum and minimum temperature (°C) during the crop growth period (13th December 2024 to 28th March 2025)

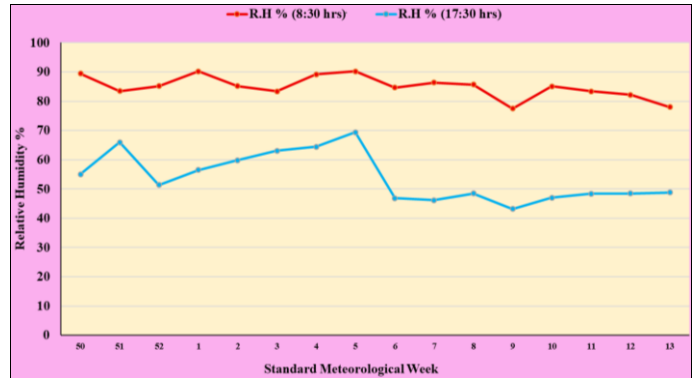


Fig 2: Weekly mean relative humidity (%) during the crop growth period (13th December 2024 to 28th March 2025)

Table 1: Maize Equivalent Yield (Kg ha⁻¹) of intercropping systems

Treatments	Maize yield (kg ha ⁻¹)	Intercrop yield (kg ha ⁻¹)	Maize Equivalent Yield (MEY)
T ₁ : Sole Maize (80/40 x 20 cm)	7914	-	7914
T ₂ : Sole Radish (40 x 10 cm)	-	15225	11073
T ₃ : Sole Carrot (40 x 10 cm)	-	12793	11630
T ₄ : Sole Bhendi (40 x 30 cm)	-	10427	11848
T ₅ : Maize + Radish (2:1)	6957	4676	10358
T ₆ : Maize + Carrot (2:1)	6973	4248	10835
T ₇ : Maize + Bhendi (2:1)	6275	3080	9775
T ₈ : Maize + Radish (2:2)	6591	8936	13090
T ₉ : Maize + Carrot (2:2)	6624	8061	13952
T ₁₀ : Maize + Bhendi (2:2)	6065	6256	13174
SEm±	489.9	-	987.5
CD (P = 0.05)	1067	-	2074
CV (%)	8.9	-	10.6

Note: Price of Maize = Rs. 21 kg⁻¹, Radish = Rs. 15 kg⁻¹, Carrot = Rs. 20 kg⁻¹, Bhendi = Rs. 25 kg⁻¹

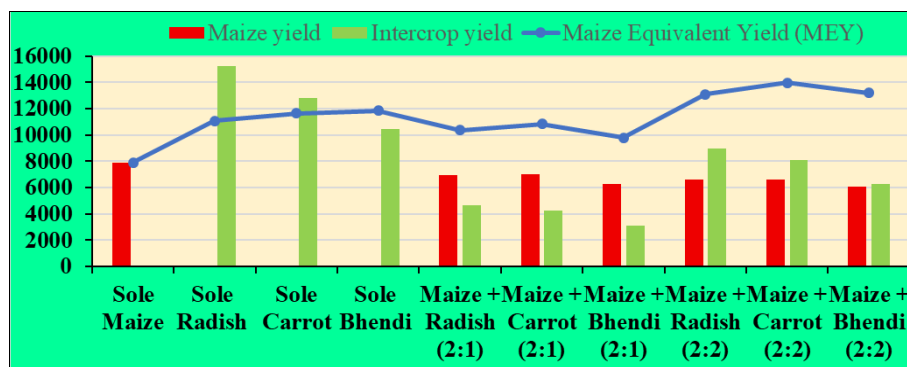
Fig 3: Maize Equivalent Yield (Kg ha⁻¹) of intercropping systems

Table 2a: Intercropping indices of maize intercropping systems

Treatments	Land Equivalent Ratio (LER)	Land Equivalent Coefficient (LEC)	Competition Ratio (CR)		Net Effect Ratio (NER)
			CR _{maize}	CR _{intercrop}	
T ₁ : Sole Maize (80/40 x 20 cm)	-	-	-	-	-
T ₂ : Sole Radish (40x 10 cm)	-	-	-	-	-
T ₃ : Sole Carrot (40x 10 cm)	-	-	-	-	-
T ₄ : Sole Bhendi (40x 30 cm)	-	-	-	-	-
T ₅ : Maize + Radish (2:1)	1.21	0.28	1.51	0.72	1.13
T ₆ : Maize + Carrot (2:1)	1.23	0.30	1.40	0.76	1.18
T ₇ : Maize + Bhendi (2:1)	1.11	0.24	1.42	0.77	1.07
T ₈ : Maize + Radish (2:2)	1.44	0.51	1.47	0.71	1.36
T ₉ : Maize + Carrot (2:2)	1.48	0.54	1.38	0.75	1.42
T ₁₀ : Maize + Bhendi (2:2)	1.38	0.47	1.30	0.77	1.34

Note: LER >1 indicates yield advantage, LER <1 indicates yield disadvantage, LER=1 indicates no advantage of intercrop; LEC >0.25 indicates advantage of intercropping

Table 2b: Intercropping indices of maize intercropping systems

Treatments	Relative crowding Coefficient (K)	Aggressivity (A)		Area Time Equivalent Ratio (ATER)	Price Equivalent Ratio (PER)
		A _{maize}	A _{intercrop}		
T ₁ : Sole Maize (80/40 x 20 cm)	-	-	-	-	-
T ₂ : Sole Radish (40x 10 cm)	-	-	-	-	-
T ₃ : Sole Carrot (40x 10 cm)	-	-	-	-	-
T ₄ : Sole Bhendi (40x 30 cm)	-	-	-	-	-
T ₅ : Maize + Radish (2:1)	4.3	0.38	-0.38	1.01	1.09
T ₆ : Maize + Carrot (2:1)	4.7	0.32	-0.32	1.18	1.10
T ₇ : Maize + Bhendi (2:1)	1.7	0.29	-0.29	1.09	0.99
T ₈ : Maize + Radish (2:2)	24.2	0.47	-0.47	1.07	1.37
T ₉ : Maize + Carrot (2:2)	16.5	0.40	-0.40	1.39	1.48
T ₁₀ : Maize + Bhendi (2:2)	5.1	0.34	-0.34	1.35	1.35

Note: K >1 indicates yield advantage, K <1 indicates yield disadvantage, K=1 indicates no advantage of intercrop; Positive 'A' value indicates dominating crop, Negative 'A' value indicates dominated crop; ATER >1 indicates advantage in time and land usage.

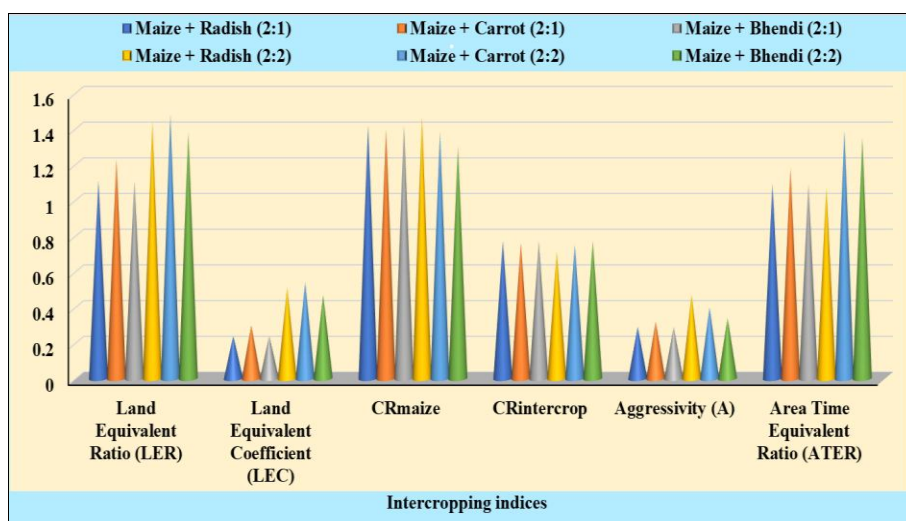


Fig 4: Intercropping indices of maize + vegetable intercropping systems

Conclusion

The study elucidates the effects of intercropping vegetables with maize under paired row planting. Intercropping vegetables with maize is productive, which is evident from higher MEY values of these intercropping systems. By intercropping vegetables with maize, land can be utilised efficiently as the same land is used to produce more crops simultaneously, which is evident from higher LER values. Furthermore, intercropping vegetables with maize offers additional yield and monetary advantage as evident from higher values of K, LEC, ATER, NER and PER respectively.

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Research Content: Original and has not been published.

Author's Contribution

First Author: Execution of the field experiment, data collection, statistical analysis and preparation of manuscript.

Second Author: Conceptualization, technical guidance, interpretation of results, review as Guide of the first author for my Master's degree and manuscript corrections.

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