



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(8): 1155-1160
Received: 02-05-2026
Accepted: 06-06-2026

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Evaluation of pigeonpea equivalent yield and intercropping indices of pigeonpea based leafy vegetables intercropping system

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i8o.6398>

Abstract

Pigeonpea is one of the world's most important grain legumes and ranks second in India after chickpea. Its slow initial growth and long duration make it a suitable base crop for intercropping with short-duration leafy vegetables, thereby improving overall productivity and soil health. The present investigation evaluated various pigeonpea-based leafy vegetable intercropping systems using pigeonpea-equivalent yield (PEY) and different competition indices. A field experiment was conducted at the Post Graduate Institute Research Farm, MPKV, Rahuri, Ahilyanagar, Maharashtra, during the two consecutive *kharif* seasons of 2019–2020 and 2020–2021. The experiment comprised 13 treatments arranged in a randomized block design with three replications. Based on pooled results, pigeonpea + spinach (1:3) produced the significantly highest PEY. Pigeonpea + fenugreek (1:3) recorded higher values for land-equivalent ratio (LER), aggressivity, area-time-equivalent ratio (ATER), relative crowding coefficient (RCC), and price-equivalent ratio. The highest competition ratio (CR) was observed in the pigeonpea + dill (1:3) system.

Keywords: Nanourea, Conventional Urea, Growth, LAI, Yield and Wheat.

Introduction

India is the world's largest producer of pigeonpea (*Cajanus cajan*), cultivating approximately 4.90–5.05 million hectares and producing 4.22–4.34 million tonnes annually, with an average productivity of about 850–861 kg ha⁻¹ in recent years (Kumari *et al.*, 2023; ICRISAT, 2024). The major pigeonpea-growing states include Maharashtra, Uttar Pradesh, Karnataka, Madhya Pradesh, Andhra Pradesh, and Gujarat. Among them, Maharashtra contributes the largest share of the country's area and production. Recent estimates indicate that the crop occupies nearly 1.20–1.36 million hectares in the state, with production ranging from 1.20 to 1.30 million tonnes and an expected productivity of approximately 890–900 kg ha⁻¹ during 2023–2024 (Kumari *et al.*, 2023). During 2022–2023, Maharashtra reportedly recorded an area of 2.96 million hectares, production of 3.17 million tonnes, and productivity of 1,074 kg ha⁻¹ (MAFW, Agricultural Statistics at a Glance, 2023).

Globally, India contributes nearly 81% of the area under pigeonpea and approximately 79–90% of its total production. Other important pigeonpea-producing countries include Malawi, Myanmar, Tanzania, and Kenya. Malawi records the highest productivity, at approximately 1,698 kg ha⁻¹. Although India leads in total production, its average productivity remains lower than that of several African countries (Mahendraraj *et al.*, 2024).

The low productivity of pigeonpea is associated not only with its cultivation on marginal and sub-marginal lands but also with inadequate and imbalanced fertilizer application. These constraints adversely affect crop productivity, agricultural sustainability, soil health, and the environment. The rapidly increasing global population and limited availability of natural resources have intensified concerns regarding food security for present and future generations. Therefore, effective crop-production and resource-management strategies must be explored. Among the available approaches, intercropping is an environmentally friendly practice that can improve yield potential, diversify food production, and address several constraints associated with conventional cropping systems.

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Intercropping refers to the simultaneous cultivation of two or more crops on the same piece of land. It improves the spatial and temporal efficiency of land use while facilitating the optimal utilization of available resources. The principal advantages of intercropping include higher and more stable yields, reduced production risks, improved distribution of labour throughout the cropping season, and greater diversification of food and income sources. This soil and crop management practice also provides biological insurance, improves soil properties, and supports the effective management of weeds, insect pests, and diseases (Chatterjee and Mandal, 1992). By increasing farm productivity and profitability, pigeonpea-based intercropping systems represent a valuable production strategy, particularly for farming communities in developing countries.

Materials and Methods

The experiment entitled “Performance of Leafy Vegetables in Pigeonpea-Based Intercropping System Followed by *Rabi* Vegetables under Different Nutrient Levels” was conducted during 2019–2020 and 2020–2021 at the Post Graduate Instructional Farm, Central Campus, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahilyanagar district, Maharashtra. The experimental site was located in Survey No. 50 of Block B.

The soil of the experimental field was clay loam in texture. According to the fertility criteria proposed by Muhr *et al.* (1965), the soil was low in available nitrogen (205.56 kg ha⁻¹), medium in available phosphorus (18.84 kg ha⁻¹), and high in available potassium (435.72 kg ha⁻¹). Its electrical conductivity was within the normal range at 0.32 dS m⁻¹, while the soil reaction was moderately alkaline, with a pH of 8.4. The bulk density, field capacity, and permanent wilting point were 1.32 g cm⁻³, 33.53%, and 18.11%, respectively. Analysis of DTPA-extractable micronutrients indicated that the soil contained Fe, Mn, Cu, and Zn at concentrations of 0.54, 1.20, 3.50, and 4.50 mg kg⁻¹, respectively. The soil was reported to be sufficient in Fe, Mn, and Cu but deficient in Zn. Its mechanical composition consisted of 7.22% coarse sand, 12.78% fine sand, 35.36% silt, and 44.14% clay. The experiment was laid out in a randomized block design with 13 treatments, each replicated three times. Seven treatments consisted of sole cropping: sole pigeonpea (T₁), sole coriander (T₂), sole spinach (T₃), sole sorrel (T₄), sole safflower (T₅), sole dill (T₆), and sole fenugreek (T₇). The remaining treatments comprised pigeonpea-based intercropping systems: pigeonpea + coriander (T₈), pigeonpea + spinach (T₉), pigeonpea + sorrel (T₁₀), pigeonpea + safflower (T₁₁), pigeonpea + dill (T₁₂), and pigeonpea + fenugreek (T₁₃). All intercrops were established at a 1:3 row ratio. Protective irrigation was applied whenever prolonged dry spells occurred.

Pigeonpea Equivalent Yield (kg ha⁻¹)

Pigeonpea Equivalent Yield of Intercrops (kg ha⁻¹)

The pigeonpea-equivalent yield of each intercropping system was calculated using the prevailing market prices of the component crops

$$PEY = \frac{\text{Yield of intercrop} \times \text{Selling price of intercrop}}{\text{Selling price of pigeonpea grain}}$$

Here, yield of intercrop while grown under sole cropping.

Pigeonpea Equivalent Yield of System (kg ha⁻¹)

$$PEY = PP \text{ yield} + \frac{\text{Grain yield of intercrop} \times \text{Selling price of intercrop}}{\text{Selling price of pigeonpea grain}}$$

Here, yield of intercrop while grown with Pigeonpea and yield of Pigeonpea grown with respective intercrop.

Intercropping indices

Land Equivalent Ratio (LER)

The land equivalent ratio (LER) represents the relative area required under sole cropping to produce the same yield obtained from an intercropping system under comparable management conditions (Willey *et al.*, 1983; Fetene, 2003). It measures the efficiency with which an intercropping system utilizes environmental resources compared with sole cropping and indicates the extent of its yield advantage. Therefore, LER is widely used to evaluate the productivity and land-use efficiency of intercropping or mixed-cropping systems. It also expresses the total area required under the respective sole crops to achieve a yield equivalent to that produced by the intercrops (Willey, 1985). An LER greater than 1 indicates that intercropping improves resource-use efficiency and provides a yield advantage. Conversely, an LER below 1 indicates that intercropping adversely affects the growth and yield of the component crops. The land-equivalent ratio (LER) was calculated using the formula given below to evaluate the productivity and economic advantage of each intercropping system.

$$\text{Land Equivalent Ratio (LER)} = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

Where,

Y_{ab}=Yield of pigeonpea in association with with intercrop

Y_{ba}=Yield of intercrop in association with pigeonpea

Y_{aa}= Yield of sole pigeonpea

Y_{bb}=Yield of sole intercrop

If value of LER is >1, then intercropping is considered to be advantageous,

If LER is <1, then intercropping is disadvantageous and

If LER is =1, then it indicates no profit, no loss from the intercropping

Area Time Equivalent Ratio (ATER)

The area-time equivalent ratio (ATER) is defined as the ratio of hectare-days required under sole cropping to the hectare-days used under intercropping to produce equivalent quantities of each component crop. Although LER is commonly used to assess intercropping advantages, it does not account for differences in the duration for which component crops occupy the field. It is also based on harvested yields rather than the desired yield proportions of the component crops. Furthermore, selecting an appropriate sole-crop yield as the standard for comparing mixture yields may be difficult. Therefore, ATER provides a more realistic assessment of the yield advantage of intercropping over sole cropping by considering variations in the growth duration of component crops across different intercropping systems (Hiebsch, 1987) ^[5].

$$ATER = \frac{(L_a \times D_a) + (L_b \times D_b)}{\text{Total duration of intercropping system in days}}$$

$$L_a = \frac{\text{Grain yield of pigeonpea grown with intercrop}}{\text{Grain yield of sole pigeonpea}}$$

$$L_b = \frac{\text{Grain yield of intercrop grown with pigeonpea}}{\text{Grain yield of sole intercrop}}$$

Where,

Da=Duration of pigeonpea crop

Db= Duration of intercrop

The interpretation of ATER involves:

ATER = > 1 implies yield advantage

ATER=1implies no effect of intercropping

ATER = < 1 shows yield disadvantage.

Aggressivity (A)

Aggressivity is an intercropping index used to assess the dominance and competitive relationship between component crops. It indicates the relative increase in the yield of crop “a” compared with crop “b” when the two crops are grown together (McGilchrist, 1965) ^[14]. The aggressivity (A) of pigeonpea intercropped with different crops was calculated using the following formula:

$$A_{ab} = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}}$$

Where,

- Aab = aggressivity value
- Yab = yield of pigeonpea (crop a) when grown with intercrop b
- Yba = yield of intercrop b when grown with pigeonpea (crop a)
- Yaa = yield of pigeonpea (crop a) under sole cropping
- Ybb = yield of intercrop b under sole cropping
- LERa = partial land-equivalent ratio of pigeonpea
- LERb = partial land-equivalent ratio of the intercrop
- Zab = sown proportion of pigeonpea in the intercropping system
- Zba = sown proportion of the intercrop in the intercropping system

The aggressivity value is interpreted as follows:

- When Aab>0, pigeonpea is the aggressive or dominant crop, whereas the intercrop is dominated.
- When Aab<0, the intercrop is dominant, whereas pigeonpea is suppressed or dominated.
- When Aab=0, neither crop is dominant, and both component crops are equally competitive.

Thus, a positive aggressivity value indicates the competitive superiority of the main crop over the intercrop. Conversely, a negative value indicates that the intercrop is more competitive than the main crop. A value of zero indicates an equal competitive relationship between the two crops.

Relative Crowding Coefficient

The relative crowding coefficient (RCC) indicates whether a component crop grown under intercropping produces a higher or lower yield than expected based on its corresponding sole-crop yield. It is used to assess the yield advantage and degree of competition between component crops in a replacement-series

intercropping system. RCC demonstrates whether intercropping provides a yield advantage, although it does not directly quantify the magnitude of that advantage. It also measures the relative dominance of one component crop over another and is denoted by K.

$$K_{ab} = \frac{Y_{ab} \times Z_{ba}}{(Y_{aa} - Y_{ab}) \times Z_{ab}}$$

$$K_{ba} = \frac{Y_{ba} \times Z_{ab}}{(Y_{bb} - Y_{ba}) \times Z_{ba}}$$

The value of K is calculated as:

$$K = Kab \times Kba$$

Where,

- Kab represents the relative crowding coefficient of crop a when intercropped with crop b.
- Kba represents the relative crowding coefficient of crop b when intercropped with crop a.
- La and Lb are the partial land-equivalent ratios of crops a and b, respectively.

The RCC values are interpreted as follows:

For crop a:

- If Kab<1, crop a produces a lower yield than expected.
- If Kab=1, crop a produces the expected yield.
- If Kab>1, crop a produces a higher yield than expected.

For crop b:

- If Kba<1, crop b produces a lower yield than expected.
- If Kba=1, crop b produces the expected yield.
- If Kba>1, crop b produces a higher yield than expected.

For the overall intercropping system:

- If K<1, the intercropping combination of crops a and b has a yield disadvantage because it produces less than the expected yield.
- If K=1, there is no yield difference between intercropping and sole cropping, indicating that the expected yield is obtained.
- If K>1, the intercropping combination provides a yield advantage by producing more than the expected yield.

Competition Ratio (CR)

The competition ratio is an effective index for determining the competitive abilities of component crops within an intercropping system (Willey and Rao, 1980). It offers certain advantages over the relative crowding coefficient (K) and aggressivity (A). The competition ratio is calculated from the partial land-equivalent ratios of the component crops while also accounting for their respective sowing proportions in the intercropping system.

$$CR = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} \div \frac{Y_{ba}}{Y_{bb} \times Z_{ba}}$$

- If CRa>1, crop a is more competitive than crop b.
- If CRa<1, crop b is more competitive than crop a.
- If CRa=1, both component crops possess equal competitive ability.

Relative Crowding Coefficient (RCC)

The relative crowding coefficient (RCC) determines whether a component crop grown in an intercropping system produces a greater or lower yield than expected from its corresponding sole-crop performance. It indicates the presence of a yield advantage under intercropping and evaluates the degree of competition between component crops in a replacement-series design. Although RCC identifies whether an intercropping advantage exists, it does not directly quantify the extent of that advantage. It also expresses the relative dominance of one component crop over another and is denoted by K.

$$K_{ab} = \frac{Y_{ab} \times Z_{ba}}{(Y_{aa} - Y_{ab}) \times Z_{ab}}$$

$$K_{ba} = \frac{Y_{ba} \times Z_{ab}}{(Y_{bb} - Y_{ba}) \times Z_{ba}}$$

It represents the ratio of the economic return obtained under intercropping to the return that could have been realized under sole cropping.

$$PER = \frac{(Y_{ab} \times Y_{aa}) + (Y_{ba} \times Y_{bb})}{\frac{1}{2}(Y_{aa} \times Y_{aa} + Y_{bb} \times Y_{bb})}$$

Where,

- Yaa = yield of component crop *a* under sole cropping
- Ybb = yield of component crop *b* under sole cropping
- Yab = yield of component crop *a* when intercropped with crop *b*
- Yba = yield of component crop *b* when intercropped with crop *a*
- Yap = prevailing market price of the produce obtained from crop *a*
- Ybp = prevailing market price of the produce obtained from crop *b*

Price Equivalent Ratio (PER)

Table 1: Pigeonpea equivalent yield, land equivalent ratio and aggressivity of pigeonpea and intercrops as influenced by different treatments

Treatments	Pigeonpea grain yield (kg ha ⁻¹)	Intercrop yield (kg ha ⁻¹)	Pigeonpea equivalent yield (kg ha ⁻¹)	Land Equivalent Ratio (LER)	Aggressivity	
	At Harvest	At Harvest	At Harvest	At Harvest	Pigeonpea	Intercrop
	Pooled	Mean	Pooled	Mean	Mean	Mean
T ₁ – Sole Pigeonpea	2045	-	2045	1.00		
T ₂ – Sole Coriander	-	5740	1313	1.00		
T ₃ – Sole Spinach	-	11980	2537	1.00		
T ₄ – Sole Sorrel	-	4868	866	1.00		
T ₅ – Sole Safflower	-	6475	2030	1.00		
T ₆ – Sole Dill	-	8822	2168	1.00		
T ₇ – Sole fenugreek	-	4294	1128	1.00		
T ₈ – PP + Coriander (1:3)	1675	4144	2641	1.56	2.30	-2.30
T ₉ – PP + Spinach (1:3)	1564	8567	3376	1.48	2.11	-2.11
T ₁₀ – PP + Sorrel (1:3)	1597	3737	2267	1.55	2.10	-2.09
T ₁₁ – PP + Safflower (1:3)	1652	4723	3133	1.54	2.26	-2.26
T ₁₂ – PP + Dill (1:3)	1746	6381	3322	1.58	2.44	-2.44
T ₁₃ – PP+ Fenugreek (1:3)	1801	3289	2664	1.65	2.50	-2.50
S.E.m (±)	57.69	-	20.96	0.01	-	-
C.D. at 5 %	168.39	-	59.60	0.03	-	-
General Mean	1726	6085	2269	1.26	2.28	-2.28

Table.2: Area time equivalent ratio, Relative crowding coefficient, Competition ratio and Price equivalent ratio of pigeonpea as influenced by different treatments

Treatments	Area Time equivalent Ratio (ATER)	Relative Crowding Coefficient (RCC)			Competition Ratio (CR)		Price Equivalent Ratio (PER)	
		Kab	Kba	K (kab x kba)	Pigeonpea	Intercrop		
		Mean	Mean	Mean	Mean	Mean	2019	2020
T ₁ – Sole Pigeonpea	1.00	-	-	-	-	-	-	-
T ₂ – Sole Coriander	1.00	-	-	-	-	-	-	-
T ₃ – Sole Spinach	1.00	-	-	-	-	-	-	-
T ₄ – Sole Sorrel	1.00	-	-	-	-	-	-	-
T ₅ – Sole Safflower	1.00	-	-	-	-	-	-	-
T ₆ – Sole Dill	1.00	-	-	-	-	-	-	-
T ₇ – Sole fenugreek	1.00	-	-	-	-	-	-	-
T ₈ – PP + Coriander (1:3)	1.01	13.58	0.93	12.67	3.34	0.30	1.56	1.57
T ₉ – PP + Spinach (1:3)	0.93	9.76	0.83	8.13	3.22	0.31	1.47	1.48
T ₁₀ – PP + Sorrel (1:3)	0.98	10.72	1.14	12.18	3.03	0.33	1.55	1.56
T ₁₁ – PP + Safflower (1:3)	0.95	12.62	0.90	11.33	3.32	0.30	1.53	1.54
T ₁₂ – PP + Dill (1:3)	1.02	17.52	0.90	15.71	3.51	0.29	1.58	1.58
T ₁₃ – PP+ Fenugreek (1:3)	1.07	22.08	1.09	24.08	3.45	0.29	1.68	1.68
S.E.m (±)	0.01	-	-	-	-	-	-	-
C.D. at 5 %	0.03	-	-	-	-	-	-	-
General Mean	1.00	14.38	0.96	14.01	3.31	0.29	1.56	1.57

Result and Discussion

Pigeonpea equivalent yield (PEY) kg ha⁻¹

The pooled mean pigeonpea-equivalent yield (PEY) was 2,269 kg ha⁻¹ (Table 1). Intercropping different crops with pigeonpea significantly increased PEY compared with the sole-cropping systems. Among the evaluated combinations, pigeonpea + spinach (T₉) recorded the significantly highest pooled PEY of 3,376 kg ha⁻¹, surpassing all other sole- and intercropping treatments. This superior performance indicates a highly complementary interaction between pigeonpea and spinach under intercropping. Overall, the findings demonstrate that intercropping pigeonpea with suitable companion crops can substantially increase productivity through complementary interactions and more efficient utilization of available resources. Similar findings were reported by Pawar *et al.* (2004) [17] and Lavanya *et al.* (2018) [9].

Land-Equivalent Ratio

All sole-cropping treatments (T₁–T₇) recorded an LER of 1.00 during both experimental years and on a pooled mean basis (Table 1). Sole cropping serves as the reference point for comparison, and an LER of 1.00 indicates no land-use advantage or disadvantage. Among the intercropping treatments, pigeonpea + fenugreek (T₁₃) at a 1:3 row ratio recorded the highest pooled total LER of 1.65. This treatment was followed by pigeonpea + dill (T₁₂), which registered a pooled total LER of 1.58.

The observed yield advantage may be attributed to the temporal and spatial complementarity between pigeonpea and the component intercrops, greater resource-use efficiency, improved soil health, favourable modification of the crop microclimate, and enhanced yield stability. Thus, pigeonpea-based intercropping represents a sustainable and productive alternative to sole cropping by improving overall land productivity and resource-use efficiency. These findings agree with those of Chaudhary *et al.* (2017) [1], Kujur and Ahamad (2018) [7], and Kumar *et al.* (2018).

Aggressivity (A)

Pigeonpea was the dominant component in all evaluated intercropping systems, as demonstrated by its positive aggressivity values (Table 1). The highest dominance was recorded in the pigeonpea + fenugreek system, indicating that pigeonpea was considerably more competitive than fenugreek when the two crops were grown together. Accordingly, fenugreek was strongly suppressed by pigeonpea, as reflected by its highly negative aggressivity value.

The lowest positive aggressivity values for pigeonpea were observed in its combinations with spinach and sorrel, indicating a relatively balanced competitive relationship. Spinach experienced the least suppression and consequently exhibited greater competitive ability than the other intercrops grown with pigeonpea. The dominance of pigeonpea across most combinations demonstrates its strong competitive nature, which can substantially influence the growth and productivity of the associated intercrops. These results are consistent with the findings of Maitra *et al.* (2000) [12] and Chaudhary *et al.* (2017) [1].

Area-Time Equivalent Ratio (ATER)

All sole-cropping systems recorded an ATER of 1.00, indicating the absence of any relative advantage among them. In comparison, most intercropping systems recorded ATER values above 1.00, reflecting greater productivity over time. Pigeonpea + fenugreek (T₁₃) recorded the significantly highest pooled mean ATER of 1.07. It was followed by pigeonpea + dill (T₁₂) and

pigeonpea + coriander (T₈), both of which recorded an ATER of 1.01 during the two experimental years and on a pooled mean basis.

The mean ATER values of the intercropping treatments ranged from 0.93 to 1.07. The results indicate that combining pigeonpea with fenugreek, dill, or coriander was particularly advantageous compared with sole cropping. This benefit may be attributed to the complementary use of resources, greater compatibility between the component crops, efficient exploitation of available growth factors, and higher overall productivity. Similar findings were documented by Maitra *et al.* (2001) [13], Patil *et al.* (2010) [16], Pradhan *et al.* (2014) [18], and Dhandayuthapani and Latha (2015).

Relative crowding coefficient

The RCC or K value indicates yield advantage or disadvantage (combined yield from pigeonpea and intercrop) under intercropping system. Highest Kab value for pigeonpea was observed in pigeonpea + fenugreek intercropping system, indicating that pigeonpea outperformed expectations, while spinach showed low kba (0.83) likely due to shading. Among the intercrops sorrel recorded highest Kba value (1.14). The Pigeonpea + Fenugreek (T₁₃) and Pigeonpea + Dill (T₁₂) intercropping system showed the highest RCC values with mean values of 24.08 and 15.71, respectively. This indicates a high level of compatibility and efficient resource utilization, resulting in minimal competition between pigeonpea and these intercrops. Further, the Pigeonpea + Coriander (T₈) showed moderately high (mean K=12.67) RCC value. These values represent the good compatibility of these crops, though not as high as with fenugreek and dill. The similar findings is reported by Chaudhary *et al.*, (2017) [1] and Moinuddin (2017) [15].

Price equivalent ratio

The results data presented in Table.2 revealed that the Pigeonpea + Fenugreek (T₁₃) intercropping system recorded numerically higher price equivalent ratio (1.68 and 1.68 respectively) over rest of the intercropping systems throughout both the years. However, it was followed by treatment Pigeonpea+Dill (T₁₂), which recorded price equivalent ratio of 1.58 and 1.58 during 2019 and 2020. Furthermore, the treatment Pigeonpea + Spinach (T₉) intercropping system registered numerically lowest price equivalent ratio (PER) (1.47 and 1.48, respectively) during 2019 and 2020.

Conclusion

The present study demonstrated that pigeonpea + fenugreek intercropping system significantly enhanced highest land equivalent ratio, area time equivalent ratio, relative crowding coefficient, price equivalent ratio and aggressivity. The highest value of competition ratio recorded in pigeonpea+dill intercropping system. All intercropping system recorded land equivalent ratio greater than one suggesting their superior land use efficiency compared to sole cropping. Looking ahead future research should focus on long term impact on pigeonpea based intercropping system on soil health, nutrient dynamics. Further evaluation of diverse intercrop combination including legume and other vegetables can help enhance system resilience and farmers income.

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