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Performance Assessment of Pigeonpea and Millet Intercropping in Different Systems

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Authors' contributions

This work was carried out in collaboration among all authors. Author PKP conceived and designed the study, established the field trial and wrote the first draft of the manuscript. Author PMM conducted statistical analysis and edited the manuscript. Author IOPM was responsible for data collection, compilation, and processing. Author SB managed literature searches, helped in crop management and data collection. Author BSN managed literature searches and edited the manuscript. Author SKB performed the computation for the competition function. All authors read and approved the final manuscript.

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ABSTRACT

In this investigation effort has been made for evaluation of pigeonpea-millet intercropping systems under rainfed kharif upland condition in coastal Odisha. The trial was targeted for the horizontal expansion of both pulses and millets and enhance productivity per unit land area for poverty alleviation. Field experiment was conducted at the Nutri-Crops Research Station, OUAT, Berhampur. Altogether 10 treatments including 6 intercropping combinations with four sole crops of

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pigeonpea (GRG-152), finger millet (Shreeratna), proso millet (TNAU-202) and little millet (OLM-217) were laid out in randomized block design with three replications. The yield of individual component crops in intercropping combinations were always less than their respective yield in sole crops. The percentage of reduction in grain yield of pigeonpea in intercropping system was found minimum (4.38%) with proso millets in 2:5 proportion and maximum (23.78%) with finger millet in 1:3 proportion, as compared to the sole crop yield. However combined yield expressed as pigeonpea equivalent yield were always found higher than the sole crops of both component. Performance of paired row sowing (mean PEY 1873kg /ha) was found superior to that of single row intercropping (mean PEY 1780 kg /ha). Intercropping with finger millet was found most remunerative (mean PEY 1918 kg/ha) followed by that with proso millet (mean PEY 1858 kg /ha). Pigeonpea+finger millet (2:5) recorded maximum pigeonpea equivalent yield of the system (1999 kg/ ha), maximum net return (Rs.90,446/-), B:C ratio (2.65). The next remunerative system was pigeonpea sown with proso millet in 2:5 proportion (PEY 1894 kg/ ha), which also recorded maximum LER(1.68) of the system. It was concluded that the pigeonpea with finger millet or proso millet in 2:5 proportion may be recommended under kharif rainfed upland situation for eastern and south eastern coastal plain zone of Odisha for higher productivity and profitability.

Keywords: Competition functions; equivalent yield; intercropping; LER; parching sorghum; pigeonpea; speciality corn.

1. INTRODUCTION

"The rapidly rising food needs due to mounting population pressure and progressively shrinking per capita agricultural land availability warrants the intensification of the cropping system in the country. Pulses are climate smart, nutrient efficient, low duty crops and play an important role in sustaining intensive agriculture by improving soil properties. Millets are nutri-cereals and low duty crops and considered excellent crops for diversification in cropping systems. Both pulses and millets are climate resilient future crops under climate change scenario and combinedly termed as nutri-crops. Intercropping is an agronomic management tool for resource optimization, production enhancement per unit land, insurance against climatic aberrations and adoption strategy for reducing climate change impact" (Kumar et al.,2023, Doubi et al., 2016). Pigeonpea (Cajanus cajan L. Millsp) is one of the most ancient and versatile grain legume crop in India with 80 per cent of global production and grown across the country under diverse agro-ecosystem. Being a wide spaced long duration crop, it comfortably accommodate intercrops and compatible with several crops in an intercropping system (Willey, 1979). Kushwaha and Mehta (2023) reviewed the pigeonpea based intercropping system and found that many legumes, cereals and oilseed crops compatible and having synergistic association. Garuda et al. (2018) studied the pigeonpea based intercropping system under different land configuration and found the maximum equivalent yield with pigeonpea + mungbean combination. Kathmale et al. (2014) recommended pigeonpea+groundnut intercropping with 1:3 proportion for maximum productivity, profitability and rain water use efficiency. Several chemistry of compatibility observed in pigeonpea and millet partnership. Millets harvested before active reproductive phase in pigeonpea. Millets can grow in additional series without affecting pigeonpea plant population. Pigeonpea has deep tap root system against shallow fibrous root system of millet indicating better and uniform nutrient uptake from soil. As a pulse crop pigeonpea enriches soil fertility status through BNF and leaf shading at maturity. Millets are also low exhaustive crop and thus the combination may be a sustainable approach for soil fertility point of view. Both are low duty crop having high water use efficiency. Both are compatible as having similar agro ecological situation (kharif rainfed upland) and sowing widow. Fabaceae - Poaceae family combination has potentiality for pest management of the system. It reduce biotic stresses through push-pull concept and enhance profitability per unit land area during a specific period. Nutritionally both crops are having immense health benefits for human beings and hence are considered as the future crops (Lakshmikala et al., 2022). Panda et al. (2022) studied on prospects of vegetable crops in pigeonpea based intercropping system in Odisha. "The development of intercropping systems for sustainable tropical agriculture is expected to withstand a wide range of ecological and climatic factors, adapted to climate change and meeting the nutritional and economic requirements of the local populations" (Doubi et

al., 2016). "However, it is well established that different species growing together in the same place compete for nutrients, water and light" (Ghose, 2004). Kumawat et al. (2017) through extensive review found intercropping with pigeionpea has potentiality for doubling farm income. Maini and Sandhu (2022) standardized row spacing of pigeonpea under intercropping system. Intercrops deserve to have their own nutrient demand in an intercropping system for potential production (Pande et al., 2013; Sekhan et al., 2023). At UAS, Bengaluru Devika et al. (2024) recorded maximum net monetary return (Rs. 2,96,750/ha) with B: ratio of 4.61 with Pigeonpea+ sweet corn intercropping system (1:2). Sudharani et al. (2020) recommended pair row planting system in pigeonpea for higher productivity and land equivalent ratio. Hence, effort has been made for evaluation of pigeonpea-millet intercropping systems under rainfed *kharif* upland condition in coastal Odisha. The trial was targeted for the horizontal expansion of both pulses and millets and enhance productivity per unit land area for poverty alleviation in Odisha.

2. MATERIALS AND METHODS

2.1 Experimental Site and Weather Conditions

A field experiment was conducted over two consecutive years (2023-24 to 2024-25) at the Nutri-Crops Research Station, OUAT, Berhampur-761001, which comes under the east and south eastern coastal plain agro-climatic zone of Odisha with the GPS location 19.36^{o}N latitude, 84.77^{o} E longitude and an altitude of 34m above the mean sea level (MSL).The soil of the experimental site was sandy loam in texture, slightly acidic with pH 6.2 having medium organic carbon (0.54%), medium available nitrogen (288.7 kg/ha), medium available phosphorus (18.33 kg/ha) and medium available potassium (191 kg/ha). During crop growth period (June to December) a total rainfall of 1108.5 mm (mean of two years) received in 57 rainy days (mean of two years).

2.2 Experimental Design and Treatments

Altogether 10 treatments including 6 intercropping combinations viz. T_1:Sole pigeonpea (PP): Var. GRG-152(Bheema); T_2:Sole finger millet(FM): Var. Shreeratna (OEB-601); T_3: Sole proso millet (PM): Var.TNAU-202; T_4:Sole little millet(LM). Var. OLM-217; T_5: PP+FM (1:3); T_6: PP+FM (2:5); T_7:PP+PM (1:3); T_8: PP+PM (2:5); T_9: PP+LM (1:3); T_{10}: PP+LM (2:5) were laid out in randomized block design with three replications. Row spacing of sole crops millets were maintained as 22.5 cm and that of pigeonpea as 90 cm. Intercrops were taken as additional series with row spacing of 22.5cm. Row spacing between two rows of pigeonpea in pair row system was adjusted as 45cm, that created an inter pair row spacing of 135cm to accommodate five rows of millets with inter row spacing of 22.5cm without sacrificing the pigeonpea population. The gross plot size was 30.24 m^2 (7.2m X 4.2m). Crops were sown simultaneously during July under rainfed upland condition. FYM @ 5 tonnes per hectare incorporated at the time of land preparation. Recommended fertilizer dose has been applied to the sole crops and the proportionate dose as per plant population ratio to the component crops in intercropping system in furrows. All fertilizer applied as basal in pigeonpea and split application in millet crop components. Observations on yield of pigeonpea and component crops were taken at harvest, converted to pigeonpea seed equivalent yield (PSEY) and were tabulated and statistically analysed. Analysis of variance was performed by using the online statistical programme OPSTAT. Comparisons of treatment mean values were performed at p=0.05.

2.3 Economics and competition functions

Economics of the treatments were calculated and compared on basis of the pigeonpea seed equivalent yield (PSEY) for economic feasibility. Minimum support price (MSP) of crops were taken into account and the mean of two years are mentioned in Table 1. Gross monetary return (GMR) from the intercropping system were calculated by multiplying PSEY with pigeonpea MSP. Cost of production (COP) was computed for individual treatments. The net monetary return (NMR) was computed by deducting COP from GMR. Benefit cost ratio (BCR) was calculated on basis of the proportion of GMR and COP.

Competition function such as land equivalent ratio (LER), monetary advantage index (MAI), competition ratio (CR), aggressivity (A), relative crowdibg coefficient (RCC) were calculated as follows.

i) The land equivalent ratio (LER), which is the relative land area under sole crop required to produce the same yield achieved in intercropping, was calculated

by using the formula given by Willey and Osiru, 1972.

LER = LERa + LERb = (Yab/Yaa) + (Yba/Ybb)

Where, LER a and LERb are individual LER of both crops; Yab and Yba are yields of crop 'a' and 'b' respectively in mixed stand. Yaa and Ybb are pure crop yield of crop 'a' and 'b' respectively.

ii) The monetary advantage index (MAI) was calculated as suggested by Willy (1979) gives the absolute value of the genuine yield advantage in intercropping.

MAI= Value of combined intercrop yield X [(LER-1)/LER]. Higher the index, better is the cropping system.

iii) Competition ratio (CR) is the ratio of individual LER of two component crops, but correcting for the proportions in which they were initially sown. It was calculated as under:

CRa = (LERa / LERb)X (Zba / Zab) and CRb = (LERb / LERa)X (Zab / Zba)

Where, CRa and CRb are the competition ratios of crop 'a' in mixture with 'b' and crop 'b' in mixture with 'a' respectively; LERa and LERb are individual LER of both crops; Zba and Zab are sowing proportions of crop 'b' with 'a' and 'a' with 'b' respectively. The competition ratio more than one indicates that the crop is dominant in the system.

iv) Aggressivity (A) determines the competitive abilities of the component crops and calculated as suggested by Mc Gilchrist, 1965). It gives a simple measure of how much the relative yield increase in component crop 'a' is greater than that for crop 'b'. It is if zero, then both component crops are equally competitive. Positive value stands for dominant and negative value for dominated, the numerical values of both the crops being the same.

Aggressivity for 'a' (Aab) = Yab / (Yaa X Zab) – Yba / (Ybb X Zba) ;

Aggressivity for 'b' Aba= Yba / (Ybb X Zba)- Yab / (Yaa X Zab)

Where, Aab and Aba are the Aggressivities of crop 'a' in mixture with 'b' and crop 'b' in mixture with 'a' ; Yab and Yba are yields of crop 'a' and 'b' respectively in mixed stand., Yaa and Ybb are pure crop yield of crop 'a' and 'b' respectively. Zba and Zab are sowing proportions of crop 'b' with 'a' and 'a' with 'b' respectively.

v) Relative crowding co-efficient (RCC) indicates whether a species grown in mixture population has produced more or less yield than expected in pure stand (de Wit, 1960).

RCCa=Kab = (Yab X Zba) / (Yaa –Yab)Zab;

RCCb= Kba = (Yba X Zab) / (Ybb –Yba) Zba;

RCCa+b= Ka+b= Kab +Kba

Where, Kab and Kba are the Relative crowding co-efficients of crop 'a' in mixture with 'b' and *vice versa* ; Yab and Yaa are yields of crop 'a' in mixed stand and pure crop respectively; Yba and Ybb are yields of crop 'b' in mixed stand and pure crop respectively. Zba and Zab are sowing proportions of crop 'b' with 'a' and 'a' with 'b' respectively. Ka+b is the RCC of the system. When K>1, there is yield advantage, K=1, there is no difference and K < 1, there is yield disadvantage.

3. RESULTS AND DISCUSSION

3.1 Yield and Pigeonpea Seed Equivalent Yield

The yield of intercrops were converted to pigeonpea equivalent yield considering the sale rate proportions for comparison (Table 1). Pooled data of two years (2023-24 and 2024-25) revealed that yield of individual component crops in intercropping combinations were always less than their respective yield in sole crops. Similar results were reported by Panda et al. (2003) in case of pigeonpea and yambean intercropping. The percentage of reduction in grain yield of pigeonpea in intercropping system was found minimum (4.38%) with proso millets in 2:5 proportion and maximum (23.78%) with finger millet in 1:3 proportion, as compared to the sole crop yield. Proso millet has an additional benefit of early maturity (65-70DAS) as compared to other millets. Thus it least interfere the reproductive stage of pigeonpea and recorded lowest reduction in pigeonpea production. Reddy et al. (1993) also reported that intercropping did not reduce the pigeonpea yield significantly. However combined yield expressed as pigeonpea seed equivalent yield were always

found higher than the sole crops of both component in intercropping system. The result was in conformity with the findings of Panda et al.(2022). The result also corroborated with the findings of Ahlawat (1998) and Das et al. (2002). Performance of paired row sowing (mean PSEY 1873kg /ha) was found superior to that of single row intercropping (mean PSEY 1780 kg /ha). The result was in conformity with Sudharani et al. (2020). Navi et al. (2024) from trials conducted at Zonal Agricultural Research Station, GKVK, UAS, Bengaluru also recommended paired row planting of pigeonpea in intercropping system. Paired row planting offer more inter space between two pair rows and thus provide scope for more light interception and more photosynthate accumulation. Among three combinations, intercropping with finger millet was found most remunerative (mean PSEY 1918 kg/ha) followed by that with proso millet (mean PSEY 1858 kg /ha). Among intercrops, finger millet gave maximum PSEY (720 kg/ha) when sown with pigeonpea in 2:5 proportion. This treatment also recorded maximum pigeonpea seed equivalent yield of the system (1999 kg/ ha). The next remunerative system was pigeonpea sown with proso millet in 2:5 proportion with PSEY 1894 kg/ ha.

3.2 Economics

The yield of the intercrops in each treatment was converted to the pigeonpea seed equivalent yield (PSEY) with the conversion factor based on the ratio of minimum support price of both the crops for each year and the mean data presented in Table 2. The Economics of individual treatments was computed by multiplying the PSEY with the minimum support price of pigeonpea for two years and the mean values of gross monetary return, cost of production, net monetary return and benefit-cost ratio are presented in Table 2. Gross monetary return from intercropping system was always more than respective sole crops. Panda et al.(2003) also found similar results in pigeon pea-yam bean intercropping system in West Bengal. Maximum gross monetary return (Rs. 1,45,446/ha) was recorded with pigeonpea + finger millet in 2:5 proportion closely followed by pigeonpea + proso millet in 2:5 proportion (Rs. 1,37,823/ ha). The maximum net monetary return (Rs. 90,446 /ha) and B:C ratio (2.65) were recorded with pigeonpea + finger millet in 2:5 proportion followed by pigeonpea + proso millet in 2:5 proportion (Rs.82,823/ha and 2.51 respectively). The lowest values of PSEY (537 kg/ha), gross monetary return (Rs. 39,058/ ha), net return (Rs. 10,058/ha) and B:C ratio (1.35) were associated with sole proso millet crop. This indicates that during *kharif* season farmers should take proso millet as an intercrop with pigeonpea in additional series rather than a sole crop for higher productivity and profitability.

3.3 Competition Functions

Different competition functions such as land equivalent ratio (LER), monetary advantage index (MAI), competition ratio (CR), aggressivity(A), relative crowding coefficient (RCC) were calculated and interpreted for evaluation of intercropping compatibility of the systems (Table 3). Intercropping of compatible crops always have yield advantages over respective sole crops (Panda et al. 2003).

Land equivalent ratio of component ‘a’ (pigeon pea) in intercropping combinations was found maximum (0.96) with pigeon pea: proso millet in 2:5 proportion. Among intercrops (component ‘b’), proso millet registered maximum LER (0. 72) when intercropped with pigeonpea in 1:2 proportion. This indicates that both component crops of pigeonpea + proso millet system have exhibited their maximum productivity under 2:5 proportion planting geometry, which proved their compatibility. When LER of the system was computed, pigeon pea: proso millet also registered highest LER (1.68) showing its compatibility and high productivity. This intercropping combination also registered the maximum monetary advantage index (Rs. 55,602/-) which proved its profitability. Though the individual LER of the component crops were found to be less than one, but the system LER was always found more than one indicating the yield advantage of all the pigeonpea-millet intercropping systems. Higher the index better is the cropping system. Similar result was found by Panda et al. (2022).

Individual competition ratios of both the component crops were computed and presented in Table 3. Competition ratio of pigeonpea in intercropping combinations was always recorded more than one indicating the dominance of pigeonpea over the millets. On the other hand all the intercrops recorded less than one value and thus it can be assumed that the pigeonpea crop was dominant in the system and the intercrops were dominated. Competition ratio of pigeonpea when sown with proso millet in 1:3 proportion was recorded the maximum value (13.02) indicating the dominance of pigeonpea over proso millet.

Table 1. Performance of pigeonpea+ millet intercropping systems under varying proportions (2023-25)

Sl.No.	Treatment	Yield of intercrop (kg/ha)				Yield of PP (kg/ha)			% reduction of PP yield
		2023-24	2024-25	Mean	PSEY	2023-24	2024-25	Mean	
T1	Sole pigeonpea (PP)	0	0	0	0	1526	1628	1577	0
T2	Sole finger millet(FM)	2124	1968	2046	1132	0	0	0	-
T3	Sole proso millet (PM)	1016	926	971	537	0	0	0	-
T4	Sole little millet(LM)	1248	1124	1186	656	0	0	0	-
T5	PP+FM (1:3)	1234	1064	1149	635	1186	1218	1202	23.78
T6	PP+FM (2:5)	1428	1178	1303	720	1224	1334	1279	18.9
T7	PP+PM (1:3)	662	592	627	347	1463	1486	1475	6.47
T8	PP+PM (2:5)	732	664	698	386	1492	1524	1508	4.38
T9	PP+LM (1:3)	748	716	732	405	1318	1232	1275	19.15
T10	PP+LM (2:5)	786	654	720	398	1372	1284	1328	15.79

Price of Pigeonpea grain =Rs.70/kg (2023-24, MSP) and Rs.75.50/kg (2024-25, MSP); Millets (MSP)
Price of Millets =Rs.38.46/kg (2023-24, MSP) and Rs.42.90/kg (2024-25, MSP);
Pigeonpea Equivalent yield: 1kg millet = 0.54kg pigeonpea(2023-24) and 0.568 kg pigeonpea (2024-25)

Table 2. Economics of pigeonpea+ millet intercropping systems under varying proportions (2023-25)

Sl.No.	Treatment	Total PSEY of system (kg/ha)	Gross monetary return (Rs)	Cost of production (Rs)	Net return (Rs)	B:C ratio
T1	Sole pigeonpea (PP)	1577	114867	45000	69867	2.55
T2	Sole finger millet(FM)	1132	82341	33500	48841	2.46
T3	Sole proso millet (PM)	537	39058	29000	10058	1.35
T4	Sole little millet(LM)	656	47688	29000	18688	1.65
T5	PP+FM (1:3)	1837	133626	55000	78626	2.43
T6	PP+FM (2:5)	1999	145446	55000	90446	2.65
T7	PP+PM (1:3)	1821	132507	55000	77507	2.41
T8	PP+PM (2:5)	1894	137823	55000	82823	2.51
T9	PP+LM (1:3)	1680	122128	55000	67128	2.23
T10	PP+LM (2:5)	1726	125369	55000	70369	2.29
	S.E. (m) +	97.2				
	CD (p=0.05)	276.2				
		12.8				

Price of Pigeonpea grain =Rs.70/kg (2023-24, MSP) and Rs.75.50/kg (2024-25, MSP);Millets (MSP)

Table 3. Competition functions of pigeonpea+ millet intercropping systems (2023-25)

Sl. No.	Treatment	Land equivalent ratio (LER)			Monetary Advantage Index (Rs)	Competition ratio		Aggressivity		Relative crowding coefficient		
		LERa	LERb	LERa+b		CRa	CRb	Aab	Aba	Kab	Kba	Ka+b
T1	Sole pigeonpea (PP)	1.00		1.00	0	-	-	-	-	-	-	-
T2	Sole finger millet(FM)		1.00	1.00	0	-	-	-	-	-	-	-
T3	Sole proso millet (PM)		1.00	1.00	0	-	-	-	-	-	-	-
T4	Sole little millet(LM)		1.00	1.00	0	-	-	-	-	-	-	-
T5	PP+FM (1:3)	0.76	0.56	1.32	32563	12.21	0.82	2.1	-2.1	9.62	0.43	10.05
T6	PP+FM (2:5)	0.81	0.64	1.45	45210	7.91	0.13	1.78	-1.78	10.51	0.71	11.22
T7	PP+PM (1:3)	0.94	0.65	1.59	48907	13.02	0.08	2.59	-2.59	43.38	0.61	43.99
T8	PP+PM (2:5)	0.96	0.72	1.68	55602	8.33	0.12	2.1	-2.1	53.51	1.04	54.55
T9	PP+LM (1:3)	0.81	0.62	1.43	36634	11.76	0.09	2.22	-2.22	12.67	0.54	13.21
T10	PP+LM (2:5)	0.84	0.61	1.45	39033	8.61	0.08	1.87	-1.87	13.06	0.63	13.69

Component a=pigeonpea; b= intercrops; LER= Land equivalent ratio; MAI = Monetary advantage index; CR= Competition ratio; Aab= Aggressivity of a in relation to b; Aba= Aggressivity of b in relation to a
Relative crowding coefficient of pigeonpea in mixture with intercrop=Kab, RCC of intercrop with pigeonpea=Kba

Aggressivities of crop 'a' (pigeon pea) and crop 'b' (intercrop) was calculated and presented in Table 2. The data indicates that aggressivity of crop 'a' (pigeon pea) was found to have positive values always and the maximum (2.59) was recorded with pigeonpea + proso millet intercropping system. Conversely, aggressivity of all the intercrops were found negative. This indicates that pigeonpea was dominant and intercrops were dominated in the system.

The RCC of a given species in mixture indicates whether it has produced more or less yield than expected in pure stand. RCC of pigeon pea (Kab) , intercrops (Kba) and the intercropping system (Ka+b) were computed and exhibited in Table 3. The data revealed that pigeonpea has maximum yield advantage (Kab=53.51) when sown with proso millet in 2:5 proportion. Among intercrops proso millet registered maximum co-efficient (1.04) when sown in 2:5 proportion with pigeon pea. RCC of pigeon pea and respective intercrops were added for computing total RCC of the system. The data revealed that the treatment T8 (pigeonpea : proso millet =2:5) registered highest system relative crowding coefficient (Ka+b) (54.55) showing its superiority and yield advantage over other cropping systems.

4. CONCLUSION

i) Paired row system of planting was found always superior to the single row planting of pigeonpea in an intercropping system.
ii) Among narrow spaced millets finger millet was found most suitable as an intercrop with pigeonpea because of having more yield potential than little millet and proso millet.
iii) System productivity in a successful intercropping is always more than that obtained from the sole cropping of the individual componenent crops.

Considering for higher productivity and profitability for enhancing farmers income per unit area, intercropping of pigeon pea + finger millet (2:5) and pigeonpea+ proso millet (2:5) may be recommended under *kharif* rainfed upland situation of eastern and south eastern coastal plain zone of Odisha.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTEREST

Authors have declared that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest. There was no competing interest exist.

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