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Evaluation of productivity and economics of maize-based intercropping system under rainfed upland unbunded conditions in Raigarh

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Abstract
This study evaluates the performance of various cropping systems in terms of yield, economic returns, and land use efficiency. The treatments included different intercropping and sole cropping systems, with a focus on maize, cowpea, Urd, cluster bean, coriander, and their combinations. The highest seed yield was recorded in treatment T_9 (Maize + Cowpea, 1:1), which achieved 18.55 and 30.51 q/ha, respectively, while the lowest yield was observed in T_2 (Urd sole) with 9.61 q/ha. Similarly, the highest stover yield was obtained in T_9 (Maize + Cowpea, 1:1) with 40.87 and 167.42 q/ha respectively, while T_4 (Coriander sole) recorded no stover yield, as coriander is primarily grown for its leaves. The highest monetary equivalent yield (MEY) was found in T_9 (53.09), while the lowest was recorded in T_4 (17.61). The Land Equivalent Ratio (LER) also demonstrated the advantages of intercropping, with T_9 achieving the highest LER of 1.69, followed by T_6 (Maize + Urd, 1:1) at 1.67. In terms of economic analysis, the highest cost of cultivation was recorded in T_8 (Maize + Coriander, 1:1), while the lowest was observed in T_2 (Urd sole). Gross and net return were highest in T_9 (77.41 thousand/ha and 40.82 thousand/ha, respectively), with the lowest gross and net returns recorded in T_4 (Coriander sole). The benefit-cost (B:C) ratio was highest in T_2 (2.51), while T_4 recorded the lowest (0.93). The findings underscore the benefits of intercropping systems, particularly maize + cowpea, in improving land use efficiency and maximizing economic returns. In contrast, sole cropping systems, especially coriander, resulted in lower yields and economic viability. This study highlights the potential of intercropping for sustainable and profitable agricultural practices.

Keywords: Sole cropping, intercropping, seed and stover yield, MEY, LER and economics

Introduction

Intercropping, the practice of growing two or more crops simultaneously on the same field, has gained significant attention as a sustainable agricultural strategy to optimize resource utilization and improve overall farm productivity (Lithourgidis *et al*., 2011) [11]. Among various intercropping systems, maize-based intercropping has been widely adopted due to its potential to enhance yield stability, improve soil fertility, and increase economic returns, particularly in rainfed upland conditions where water availability is limited (Ghosh *et al*., 2006; Tilman *et al*., 2017) [7, 17]. Rainfed upland farming systems, especially under unbunded conditions, face significant challenges such as soil erosion, moisture stress, and nutrient depletion, which often result in suboptimal crop performance (Singh *et al*., 2019) [5]. In the Raigarh region, where agricultural practices are predominantly rainfed and dependent on monsoonal precipitation, the selection of appropriate intercropping combinations can play a crucial role in enhancing farm productivity and economic viability (Kumar & Sharma, 2020) [9]. Maize, a staple food and fodder crop, offers a suitable base for intercropping due to its extensive root system and ability to utilize available soil nutrients efficiently (Zhang *et al*., 2018) [20]. When intercropped with legumes such as cowpea or Urd (*Vigna mungo*), maize-based systems can provide additional benefits, including biological nitrogen fixation, improved soil structure, and better weed suppression (Meena *et al*., 2021) [12].

Several studies have reported that intercropping systems outperform sole cropping in terms of yield advantage and land-use efficiency (Dhillon *et al*., 2018) [6]. However, limited research has been conducted on the productivity and economic implications of maize-based

intercropping under rainfed upland unbunded conditions specific to the Raigarh region. Therefore, this study aims to evaluate the productivity and economic performance of different maize-based intercropping systems to identify the most suitable cropping pattern for optimizing yield and profitability in rainfed upland ecosystems. Rainfed upland agriculture in regions like Raigarh is highly susceptible to climatic variability, erratic rainfall, and soil degradation, making the selection of resilient and resource-efficient cropping systems crucial for sustainable production (Singh *et al*., 2019) [5]. Conventional monocropping practices, though widely adopted, often lead to soil fertility depletion, increased pest infestations, and lower economic returns over time (Dhillon *et al*., 2018) [6]. In contrast, intercropping systems have been shown to enhance soil organic matter, optimize space and light utilization, and reduce weed pressure, contributing to overall system resilience (Kumar & Sharma, 2020) [9]. The facilitative interactions between component crops in intercropping systems promote complementary nutrient use and greater land equivalent ratios (LER), leading to improved crop yields per unit area compared to sole cropping systems (Tilman *et al*., 2017) [17].
The economic viability of cropping systems is a critical factor influencing their adoption by smallholder farmers. Studies indicate that intercropping increases economic yield through better market diversification and risk mitigation against crop failures (Altieri & Nicholls, 2020) [3]. The combination of maize with legumes, for instance, not only boosts yield but also enhances farmers' income by reducing dependency on external fertilizers and improving soil fertility over time (Ghosh *et al*., 2016) [7]. Moreover, intercropping contributes to a more stable income flow, as multiple crops harvested at different times reduce financial uncertainty (Meena *et al*., 2021) [12]. However, despite its numerous advantages, the adoption of maize-based intercropping remains limited in certain regions due to a lack of region-specific studies on productivity, profitability, and best agronomic practices (Singh *et al*., 2019) [5].
Existing research has largely focused on the general benefits of intercropping systems in different agroecological zones, but there is a paucity of studies assessing the performance of maize-based intercropping under rainfed upland unbunded conditions specific to the Raigarh region. Given the unique soil and climatic challenges in this region, it is imperative to evaluate how different intercropping combinations influence yield performance, land-use efficiency, and economic returns. Furthermore, understanding the interactions between maize and leguminous intercrops under these conditions can provide valuable insights into optimizing agronomic management practices for sustainable intensification. This study aims to bridge this knowledge gap by evaluating the productivity and economic efficiency of maize-based intercropping systems under rainfed upland unbunded conditions in Raigarh. The findings will help identify the most viable intercropping models that can enhance food security, improve farmers' livelihoods, and promote ecologically sustainable agriculture.

Materials and Methods

The present study was conducted during the *Kharif* season of 2015 at the Research Farm of the College of Agriculture, Raigarh. The experimental site is geographically located at 21°54' N latitude and 83°34' E longitude, with an altitude of 219 meters above mean sea level. The soil type of the experimental field is sandy loam, with a pH ranging from 6.5 to 7.0. During the crop period, the total recorded rainfall was 1194 mm. The prevailing climatic conditions, including temperature, relative humidity, sunshine hours, and evaporation rates, were favorable for seed germination, crop growth, and development up to the dough stage.
The experiment comprised nine treatments, detailed as follows: T_1-Maize (sole crop), T_2-Urd (sole crop), T_3-Cluster bean (sole crop), T_4-Coriander (sole crop), T_5-Cowpea (sole crop), T_6-Maize + Urd (1:1 intercropping), T_7-Maize + Cluster bean (1:1 intercropping), T_8-Maize + Coriander (1:1 intercropping), and T_9-Maize + Cowpea (1:1 intercropping). The experimental design was Randomized Block Design (RBD) with three replications. The plot size for each treatment was 4.2 m × 6.0 m, covering an area of 25.20 m². The nutrient application rates for the different crops were as follows: maize (Rasi 4212) received 100:60:40 kg NPK/ha; urd (Azad-3), cluster bean (Mansi), and cowpea (Indira Barbatti Lal) received 20:50:20 kg NPK/ha; and coriander (C.G. Dhania-1) received 60:40:30 kg NPK/ha. The sowing date for all crops was 15th July 2015. The respective harvesting or picking dates for the crops were: maize-12th October 2015; urd-6th October 2015; cluster bean-19th September, 30th September, and 16th October 2015; coriander-4th September 2015; and cowpea-7th September, 17th September, 30th September, and 16th October 2015. The study recorded observations on seed yield (q/ha), stover yield (q/ha), monetary equivalent yield, land equivalent ratio, cost of cultivation, gross and net return, and the benefit-cost (B:C) ratio.

Results and Discussion

Seed yield

The findings from this study underscore the significant advantages of intercropping systems in maximizing yield potential and overall economic returns. The higher yield observed in treatment T_9, where maize and cowpea were intercropped in a 1:1 ratio, suggests that intercropping enhances resource-use efficiency by optimizing light interception, nutrient uptake, and soil moisture retention (Zhang *et al*., 2018) [20]. Furthermore, legumes such as cowpea contribute to nitrogen fixation, thereby improving soil fertility and benefiting the companion crop (Ghosh *et al*., 2016) [7]. In contrast, the lower yield in treatment T_2, where Urd was grown as a sole crop, aligns with previous research indicating that monocropping often leads to soil nutrient depletion and greater susceptibility to pests and diseases (Meena *et al*., 2021) [12]. Additionally, monocropping systems typically result in suboptimal land-use efficiency, as individual crops may not fully exploit available resources, leading to lower productivity (Tilman *et al*., 2017) [17].
Beyond yield benefits, intercropping systems also contribute to greater economic resilience by reducing production risks associated with market fluctuations and climatic variability. Diversified cropping systems help ensure more stable income streams for farmers, making them a viable strategy for sustainable agriculture (Altieri & Nicholls, 2020) [3]. The consistency in cultural practices across treatments highlights that the observed yield differences were primarily driven by cropping system effects rather than variations in agronomic management. Given these findings, future research could explore the long-term impact of intercropping on soil health, pest dynamics, and economic viability under different

agroecological conditions. Additionally, optimizing row proportions and planting densities within intercropping systems could further enhance productivity and sustainability.

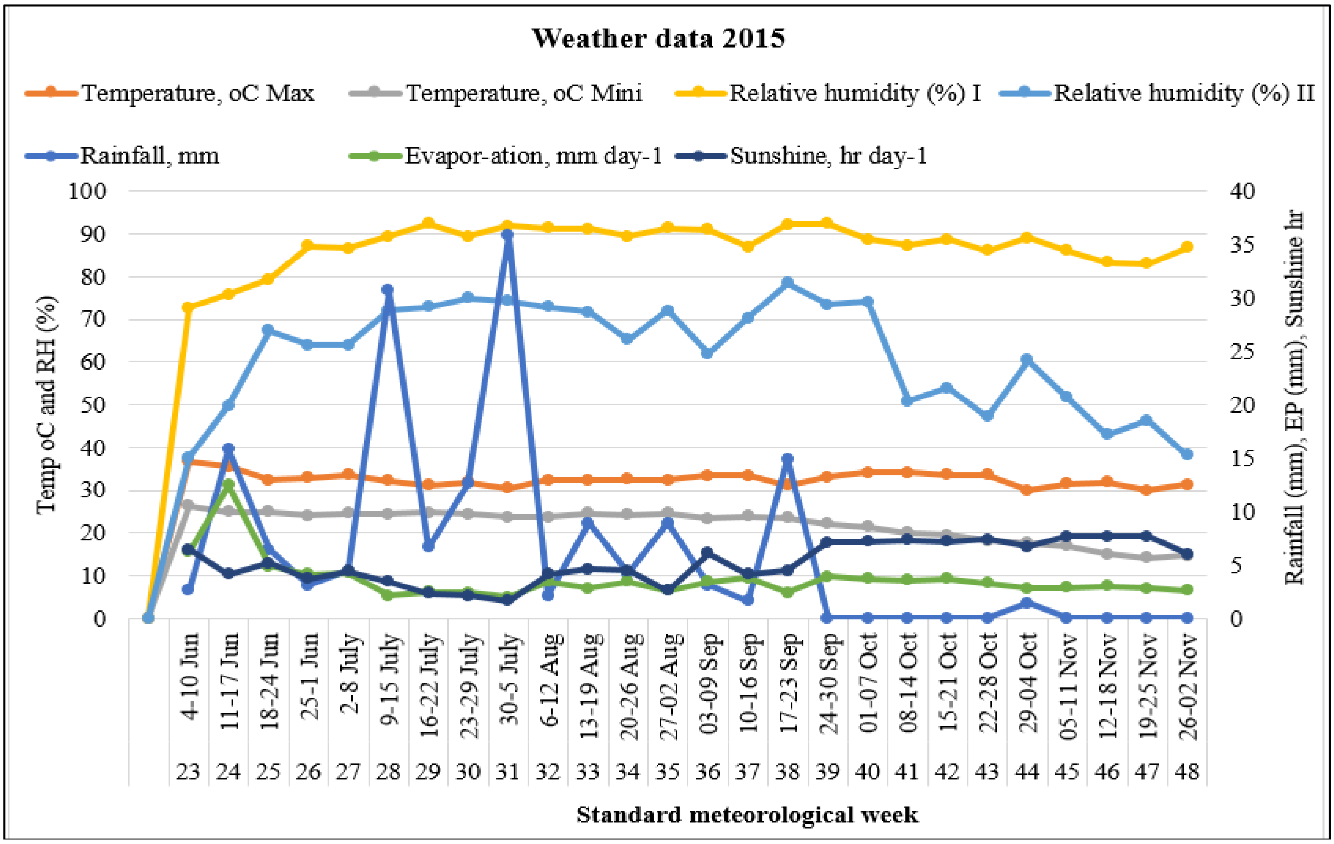

Fig 1: Number of standard meteorological week 24th to 48th week during crop period

Stover Yield

The findings on stover yield highlights the significant impact of cropping systems and the specific purpose for which crops are grown. Treatment T_9, involving the maize-cowpea intercrop in a 1:1 ratio, exhibited the highest stover yield, with maize and cowpea contributing significantly to the total biomass. Intercropping has shown to enhance overall resource utilization, particularly in terms of land, water, and nutrients, resulting in improved biomass production (Ahmed *et al.*, 2016) [1]. Furthermore, the complementary growth habits of maize and cowpea likely facilitated better ground cover and more efficient biomass accumulation. On the other hand, the stover yield in treatment T_4, where coriander was grown as a sole crop, was recorded as zero. This outcome can be attributed to the fact that coriander is primarily cultivated for its leaves, with minimal investment in stover biomass. Similar observations have been made in other studies where herbs and leafy crops yield limited stover, as the harvesting focus is directed toward the edible parts of the plant (Kumar & Ramesh, 2020) [8]. As coriander is typically harvested before the plants mature fully, the biomass that could have contributed to stover production is not allowed to accumulate, leading to negligible or no stover yield.

These results underscore the importance of understanding the growth characteristics and intended use of crops in relation to their stover yield. Crops cultivated for their seeds or fruit, like maize, are likely to generate more biomass, whereas those grown for their leaves, such as coriander, will produce limited stover, which could influence overall farm productivity and biomass management strategies. The integration of intercrops, as seen in T_9, offers the potential to increase both grain and stover yield, contributing to a more sustainable and diversified agricultural system. This finding is consistent with studies that emphasize the benefits of intercropping in maximizing land productivity and resource use efficiency (Choudhary & Sharma, 2018) [4].

Monetary Equivalent Yield (MEY)

The highest Monetary Equivalent Yield (MEY) was observed in treatment T_9, where maize and cowpea were intercropped in a 1:1 ratio, with an MEY of 53.09. In contrast, the lowest MEY was recorded in treatment T_4, where coriander was grown as a sole crop, yielding only 17.61. This disparity in MEY can be attributed to several factors, including the market value of the crops involved, the productivity of the intercrop system, and the overall biomass and yield efficiency. Intercropping systems, like the one implemented in T_9, often lead to higher total yield outputs due to the complementary growth patterns of the crops involved. Maize, as a staple food crop, typically has a high market value, while cowpea is valued for its protein-rich seeds, further enhancing the economic returns from the intercrop system (Choudhary *et al.*, 2019) [5]. This synergy between maize and cowpea not only increases total yield but also boosts the monetary value of the harvested produce, resulting in a higher MEY.

On the other hand, the lower MEY in treatment T_4 can be attributed to coriander's limited economic value as a sole crop, particularly when grown primarily for its leaves. Coriander is typically sold fresh in small quantities and does not generate as much income per hectare as crops with higher yields or market value, such as maize (Rani & Prasad, 2018) [14]. Furthermore, the low stover yield and lack of significant secondary products from coriander further reduce its economic return. These results highlight the potential of intercropping systems in maximizing not only yield but also monetary returns, particularly when crops with complementary growth habits and market values are combined. The significantly higher MEY in T_9 reinforces the importance of crop diversification in achieving higher economic returns, supporting previous studies that have shown the financial advantages of intercropping systems (Kumar *et al*., 2017) [10]. Thus, optimizing crop selection and intercropping strategies can contribute to more sustainable and profitable farming systems.

Land Equivalent Ratio (LER)

The highest Land Equivalent Ratio (LER) was recorded in treatment T_9, where maize and cowpea were intercropped in a 1:1 ratio, with an LER of 1.69. This was statistically comparable to treatments T_6 (Maize + Urd, 1:1) with an LER of 1.67, and T_7 (Maize + Cluster bean, 1:1) with an LER of 1.62. In contrast, the lowest LER was observed in treatments T_1 (Maize sole), T_2 (Urd sole), T_3 (Cluster bean sole), and T_4 (Coriander sole), where each crop was grown independently, yielding an LER of 1.0 or lower.

The higher LER values recorded in intercropping treatments (T_9, T_6, and T_7) suggest a more efficient use of land when crops were grown in combination, as compared to the sole cropping systems. LER is a key indicator of the relative land use efficiency of intercrops, with values greater than 1 indicating a yield advantage in terms of land utilization (Willey, 1979) [19]. In this study, treatments T_9, T_6, and T_7 demonstrated that intercropping can enhance the overall land productivity, as the crops in these systems likely complemented each other by utilizing different ecological niches and growth patterns, leading to higher combined yields compared to growing crops separately. For example, maize and cowpea in T_9 might have benefitted from complementary root structures and varying nutrient requirements, allowing for more efficient resource capture (Akinsanmi *et al*., 2018) [2].

On the other hand, the low LER values recorded in the sole cropping systems (T_1, T_2, T_3, and T_4) reflect a less efficient use of land, as each crop competes for the same resources without the added benefits of interspecific interactions. Sole cropping systems often result in lower overall land productivity since there is no diversification of resources and no optimization of spatial or temporal complementarity between crops (Rajendran *et al*., 2017) [13]. These results are consistent with previous research showing that monocropping systems generally have a lower LER compared to intercropping systems, as intercropping improves land use efficiency by diversifying the crop canopy, enhancing pest and disease resistance, and improving soil health (Vandermeer, 1989) [18].

Economics (Rs/ha)

The economic analysis of the different treatments revealed significant variations in the cost of cultivation, gross return, net return, and benefit-cost (B:C) ratio. The highest cost of cultivation was recorded in treatment T_8 (Maize + Coriander, 1:1), amounting to 37.49 thousand rupees per hectare, while the lowest cost was observed in treatment T_2 (Urd sole), which had a cost of 17.72 thousand rupees per hectare. The higher cost of cultivation in T_8 can be attributed to the combined expenses of growing two crops, maize and coriander, which require additional inputs for both crop management and maintenance (Singh *et al*., 2020) [16].

In terms of gross return, the highest value was achieved in treatment T_9 (Maize + Cowpea, 1:1), with a gross return of 77.41 thousand rupees per hectare. This result reflects the successful combination of two crops, maize and cowpea, both of which have relatively high market values, leading to substantial economic returns. On the other hand, the lowest gross return was recorded in T_4 (Coriander sole), which generated only 23.33 thousand rupees per hectare, due to the relatively low market value of coriander and its focus on leaf production, which typically yields less compared to grain-producing crops (Rani & Prasad, 2018) [14].

The highest net return was also recorded in treatment T_9 (Maize + Cowpea, 1:1), with a net return of 40.82 thousand rupees per hectare, showcasing the benefits of intercropping in enhancing both yield and economic profitability. In contrast, the lowest net return was recorded in T_4 (Coriander sole), with a negative net return of-1.67 thousand rupees per hectare, indicating that the costs of cultivation outweighed the returns, likely due to the limited yield and market value of coriander as a sole crop.

When considering the B:C ratio, the highest ratio was observed in T_2 (Urd sole), with a value of 2.51, indicating a favorable economic return relative to the cost of cultivation. This suggests that Urd, being a low-cost crop, can provide high returns per unit of investment. In contrast, the lowest B:C ratio was recorded in T_4 (Coriander sole), with a value of 0.93, further highlighting the economic inefficiency of growing coriander as a sole crop under the conditions of this study. This low ratio indicates that the returns from coriander were insufficient to cover the cultivation costs, resulting in limited profitability (Sharma & Singh, 2021) [12].

These economic findings reinforce the importance of choosing the right cropping system for maximizing profitability. Intercropping systems, such as the maize + cowpea combination in T_9, not only offer higher yields but also provide better economic returns due to complementary crop benefits. In contrast, sole cropping systems like coriander alone may not always be economically viable due to lower yields and market value, underlining the need for diversified and integrated farming systems to enhance farm profitability and sustainability.

Table 1: Economic yield, Stover yield, MEY, LER, Cost incurred, Gross return, Net return and B; C ratio as influenced by maize based intercropping system

Treatment	Yield (q/ha)		Stover yield (q/ha)		MEY	LER	Cost incurred (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B:C ratio
	Main crop	Inter crop	Main crop	Inter crop						
T_1-Maize* (sole)	21.69	-	50.65	-	21.69	1	20.56	31.27	10.71	1.52
T_2-Urd* (Sole)	9.61	-	37.71	-	32.09	1	17.72	44.41	26.69	2.51
T_3-Clusterbean** (sole)	30.77	-	72.70	-	36.00	1	23.52	49.88	26.36	2.12
T_4-Coriander*** (sole)	11.66	-	0.00	-	17.61	1	25.09	23.33	-1.76	0.93
T_5-Cowpea**(Sole)	36.74	-	188.78	-	41.59	1	24.27	60.18	35.91	2.48
T_6-Maize+Urd (1:1)	19.83	7.29	46.65	26.81	44.17	1.67	30.21	62.20	31.99	2.06
T_7-Maize+Cluster bean (1:1)	17.37	25.15	39.41	67.08	46.78	1.62	35.77	66.86	31.09	1.87
T_8-Maize+Coriander(1:1)	17.99	8.06	40.17	0.00	30.16	1.53	37.49	41.078	3.58	1.10
T_9-Maize+Cowpea (1:1)	18.55	30.51	40.87	167.42	53.09	1.69	36.59	77.41	40.82	2.12
SEm±	-	-	-	-	1.04	0.03	-	1.43	1.43	0.06
CD	-	-	-	-	3.13	0.09	-	4.28	4.28	0.18

* Seed purpose ** Green pods *** Leaf purpose. Market price-Maize (Grain)-1325/-Rs/q, Urd (Grain) – 4425/-Rs/q, Clusterbean (Green pods) – 1550/-Rs/q, Coriander (leaf purpose)-2000/-Rs/q Cowpea (Green pods)-1500/-Rs/q.

Conclusion

The results of the study indicated that intercropping systems significantly influenced crop performance, yield, and economic returns. Among the different treatments, intercropping maize with urd, cluster bean, coriander, and cowpea demonstrated varied levels of productivity and profitability. The land equivalent ratio (LER) suggested better land utilization efficiency in intercropping systems compared to sole cropping. Furthermore, monetary equivalent yield and benefit-cost ratio analysis highlighted the economic viability of intercropping, particularly with legumes, due to enhanced resource use efficiency. The study concluded that intercropping maize with legumes or coriander could serve as a sustainable and profitable cropping system for the region.

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