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Diversification of Crops in Rice-wheat Cropping System for Higher Productivity and Profitability of Farmers in Eastern Uttar Pradesh

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ABSTRACT: The continuous cultivation of rice has resulted in a decline in soil quality, posing a serious threat to agricultural sustainability. In response, efforts are being made to promote crop diversification by introducing a variety of crop types to restore soil health. A field experiment spanning from 2017 to 2019 at the Agronomy Research Farm in Ayodhya evaluated ten cropping systems for their productivity, sustainability, soil fertility and economic viability. The tested crop sequences included rice-wheat-fallow, rice-wheat-greengram, rice-frenchbean-greengram, rice-gram-cowpea (veg), rice-mustard-greengram, rice-linseed-black gram, rice-berseem-sudanchari, rice- oat- maize+cowpea, rice-cauliflower-okra, and rice-potato-cowpea (veg). Among these, the rice-cauliflower-okra cropping system showed the highest rice equivalent yield 18.63 t/ha/annum, followed by rice-potato-cowpea (veg) and rice-french bean-greengram. The rice-cauliflower-okra system also recorded the highest net return of Rs. 160443 per year. The study revealed significant effects of different cropping sequences on soil parameters such as available nitrogen, phosphorus, potassium, and organic carbon content.

Keywords: Rice based cropping system, Rice Equivalent Yield, Diversification, System Productivity and Profitability.

INTRODUCTION

Rice (*Oryza sativa*) is a part of diverse cropping systems with varying practices adopted by farmers. The cultivation of intensive rice-based cropping systems, which includes the use of high-yielding varieties for rice and other crops, has contributed to nutrient depletion in the soil. Unfortunately, the unregulated and imbalanced application of chemical fertilizers has further aggravated the decline in soil health (John *et al.*, 2001). Diversification of Rice-Wheat Cropping Systems (RWCS) is imperative for achieving enhanced yields, improved returns, and the preservation of soil fertility. This objective is not solely contingent upon the number of crops but also relies on the inclusion of diverse crop types within the cropping sequences, as highlighted by the All India Coordinated Research Project (AICRP). The strategic selection of crops should be carefully planned to harness synergies among them, optimizing resource utilization and bolstering overall productivity (Anderson *et al.*, 2005).

Incorporating pulses, oilseeds, vegetables, and fodder crops into agricultural practices holds the potential to uplift the economic conditions of small and marginal farmers by generating higher income. This diversification strategy not only contributes to economic well-being but also optimizes the utilization of resources, such as irrigation water and labor, during the post-rainy season. This approach ensures increased productivity, profitability, and food security (Raskar and Bhoi 2001). During the post-rainy season, cultivating pulses, oilseeds, vegetables, and fodder crops proves beneficial, not only economically but also in terms of resource efficiency. Efficient utilization of irrigation water and other inputs results in a sustainable and profitable farming system. This diversification strategy enhances the overall economic situation of farmers, particularly those with limited resources. Legumes as a third crop during the summer season in the rice-wheat sequence significantly improved the system's rice equivalent yield. This suggests that integrating legumes into cropping systems during the summer season can enhance overall productivity (Soni and Kaur 1984). While the substitution of winter cereals with legumes in the Rice-Wheat Cropping System (RWCS) has proven beneficial, replacing rice with legume crops during the rainy season resulted in monetary losses. Therefore, cropping strategies need to be carefully devised to ensure a high degree of complementarity among different enterprises. The importance of planning cropping systems where the output of one component serves as input for other enterprises. This approach maximizes the complementary effects among different crops, leading to a more sustainable and economically viable agricultural system, (Naresh *et al.*, 2017).

Various indicators are employed to assess soil quality, considering factors such as sensitivity, required time, and pertinent properties, with soil physical, chemical, and biological attributes traditionally serving as proxies (Andrews and Carroll 2001). The notion of soil quality encompasses intrinsic soil characteristics, ecosystem interactions, and land use or management, introducing subjectivity in defining "good quality" (Blanco and Lal 2008). Recently, attention has shifted to "soil health," predominantly emphasizing biological properties. Both concepts aim to evaluate soil functions in the landscape, yet lack an explicit reference state within their frameworks. The selection of soil quality indicators typically aligns with specific research objectives, contributing to the nuanced nature of soil assessment.

METHOD AND MATERIALS

A field trial was conducted within the All India Coordinated Research Project (AICRP) on Integrated Farming Systems (IFS) at the Agronomy Farm of Acharya Narendra Deva University of Agriculture and Technology in Ayodhya, U.P., India, from 2017 to 2019, utilizing consistent site and layout parameters. The experimental soil showed alkaline characteristics with a pH of 8.20, low available nitrogen content (180 kg/ha), medium levels of available phosphorus (16.7 kg/ha) and medium available potassium (252 kg/ha). The experimental site, located in the subtropical zone of the Indo-Gangetic plains, featured alluvial soil and geographical coordinates between 24.4° and 26.5° North and 82.12° and 83.98° East, with an elevation of approximately 113 meters above sea level. The climate in this region is categorized as tropical to subtropical, characterized by minimal seasonal temperature variations.

A randomized block design (RBD) with three replications was employed to evaluate ten different cropping sequences. These sequences, denoted as T1 to T10, included diverse combinations such as rice-wheat-fallow, rice-wheat-green gram, rice-french bean-green gram, rice-gram-cowpea, rice-mustard-green gram, rice-linseed-black gram, rice-berseem-sudan chari, rice-cowpea-oat-maize + cowpea, rice-cauliflower-okra, and rice-potato-cowpea (veg). Various crop varieties were selected for the experiment, such as rice 'NDR-359,' wheat 'PBW-343,' green gram 'NDM-1,' gram 'Aurodhi,' black gram 'NDU-1,' mustard 'NDR-8501,' linseed 'Garima,' Sudan Chari 'MP Chari,' berseem 'Vardan,' maize 'Jaunpuri Safedi,' okra 'VRO-5,' cauliflower 'Pusa Himjyoti,' potato 'Kufri Safed,' and cowpea (veg) 'Kashi Kanchan.' The experimental plot size was 6 m × 5 m each.

25-day-old rice seedlings were manually transplanted in the field in the first week of July during the rainy season, with harvesting taking place in the third week of October. Subsequent post-rainy season crops were hand-sown in the second half of November, while summer-season crops were manually sown in March after the harvest of the preceding post-rainy season crops. After the rice harvest, plots were irrigated and prepared for the ensuing post-rainy season crops using two cross-cultivation and two harrowing operations, followed by planking with a wooden beam attached behind the tractor to reduce clod size. For summer season crops, field preparation included one deep plowing using a moldboard plough, followed by two harrowing operations and planking.

Fertilization followed recommended doses of N, P_2O_5, and K_2O (kg ha^{-1}) for various crops. For instance, rice received (150:60:60), wheat (150:60:60), mustard (100:60:40), chickpea (20:60:0), French bean (120:60:60), green gram (20:40:20), black gram (15:40:20), gram (20–60–0), cowpea (veg) (20–50:50), cowpea (fodder) (60:40:00), okra (150:60:60), potato (150:60:90), maize (150:60:60), oat (100:40:0), Sudan chari (80:40:0), cauliflower (120:60:40), linseed (100:60:40), and berseem (40:60:00). P and K, along with a basal dose of N, were drilled in rows 5–6 cm below seeds before sowing or planting, with the remaining N applied in split doses according to recommendations. In rice, P and K, along with a basal dose of N, were provided before puddling and incorporated into the soil. Urea (46.0% N), single superphosphate (16.99% P_2O_5), and muriate of potash (KCl) (49.6% K_2O) served as sources for N, P, and K, respectively.

While the water requirement for rice was met through a combination of rainfall and irrigation, post-rainy and summer crops were cultivated under irrigated conditions using tube well water. No significant rainfall occurred during the post-rainy and summer cropping seasons, consistent with the climatic conditions in this region of India. Recommended interculturing practices were adhered to as necessary for the successful cultivation of various crops, contributing to the overall water-efficient and sustainable agricultural practices adopted during the experiment.

The economic evaluation of the cropping systems involved the conversion of individual crop yields into rice-equivalent yield (REY), considering the Minimum Support Price (MSP) of various crops, except for those sold at prevailing market prices. The land use efficiency (LUE) was expressed as the total field duration as a percentage of 365 days (Tomar and Tiwari 1990). Averaged data from four crop cycles were utilized for economic analyses of diverse rice-based cropping systems. Cost of cultivation for each crop was computed based on various operations and materials involved. For rice and cauliflower, this included seed, nursery raising, field preparation, transplanting, fertilizers, weeding, herbicide application, irrigation, and harvesting. Other crops involved operations like seed bed preparation, sowing, fertilizers, weeding, irrigation, harvesting, and threshing. Gross returns encompassed income from the sale of main products and straw or haul in selected crops. Net returns, the difference between gross return and total cultivation cost, provided a measure of the system's profitability.

After completing each cropping sequence, soil sampling and analysis were conducted to assess the physical and chemical properties. Soil samples, collected randomly from five locations within each 30 m^2 plot at a 0–15 cm depth, were combined to form a composite sample of 500 g. This sample was then divided into two parts, with one part air-dried, ground, and sieved (through a 2-mm mesh) for physicochemical analysis. The gathered data underwent statistical testing using the 'Analysis of Variance Technique' as recommended by Gomez and Gomez (1984). The profitability of the system was computed employing the formula specified by Kumar *et al*. (2019).

System profitability (Rs. ha/ day) = Net return (Rs. ha)/365 days

REY (t ha^{-1}) = [Yield of first crop (t ha^{-1}) × Price of first crop (Rs/t)/Price of paddy (Rs/t)] + [Yield of second crop (t ha^{-1}) × Price of second crop (Rs/t)/Price of paddy (Rs/t)] + [Yield of third crop (t ha^{-1}) × Price of third crop (Rs/t)/Price of paddy (Rs/t).

RESULT AND DISCUSSION

Rice Equivalent of different rice based cropping system. Crop diversification within the rice-based cropping system had a notable impact on rice equivalent yield (Table 1). The highest recorded rice equivalent yield (18.63 t ha^{-1}) occurred in the rice-cauliflower-okra cropping system, significantly surpassing other systems. Interestingly, this was statistically comparable to the rice-potato-cowpea (veg) cropping system (18.53 t ha^{-1}), possibly attributed to the elevated yield and value of potato and okra. Singh *et al.* (2012) also found that vegetable-dominated cropping systems demonstrated notably higher productivity, aligning with our results. Integrating vegetables and pulses into rice-based cropping systems enhances overall productivity. These findings underscore the positive influence of crop diversification, particularly with high-value crops, on the productivity and sustainability of rice-based cropping systems (Mishra *et al*., 2007).

System Productivity, System profitability, Land Use Efficiency and Energy production of various rice based cropping system. Diversified cropping systems significantly influenced system production efficiency (system productivity), with notable variations observed (Table 1). Among the different rice-based cropping systems, the rice-potato-cowpea (vegetable) system showed that the highest production efficiency in terms of Kg/ha/day. This outcome was attributed to the substantial total productivity, particularly the significant contribution of potatoes to the rice equivalent yield (REY) in this sequence. The rice-cauliflower-okra cropping system exhibited the highest profitability in terms of Rs/ha/day, surpassing other sequences. Conversely, the rice-berseem-sudanchari system showed the lowest profitability, likely due to lower productivity and net returns.

Land use efficiency, expressed as a percentage, was highest in the rice-frenchbean-greengram (95.88%) cropping system, likely owing to the continuous standing of the crop in the field. Additionally, the rice-wheat and green gram cropping sequence recorded maximum land use efficiency of 95.88%, emphasizing the positive impact of crop diversification on efficient land resource utilization. Kumar *et al.* (2019); Kumar (2015) also observed the notion that longer sequences and diversification, especially with vegetables, pulses, and oilseeds, enhance land use efficiency, profitability, and employment generation during lean periods. While higher energy productivity was observed in green manure-rice, oat-maize, and rice-berseem-sudanchari cropping systems, attributed to the inclusion of fodder crops requiring fewer inputs. The total specific energy of these systems, encompassing crops with lower energy requirements, was lower compared to other crops. This suggests that the energy utilized to produce unit output was more efficient in these cropping systems, aligning with findings by Walia *et al*. (2011).

pH and soil organic carbon of different rice based cropping system. The influence of crop diversification on post-harvest soil status was evident in the present experiment, particularly when compared to the conventional farmer's practice of a rice-wheat cropping system. While pH remained unaffected, organic carbon content significantly varied across cropping systems.

The mean data of soil presented indicated that the inclusion of legumes led to an increase in organic carbon content. The highest organic carbon content was observed in the rice-gram-cowpea system (5.35 mg/kg), significantly outperforming other systems but comparable to rice-french bean-green gram (5.28 mg/kg). Legumes, known for enhancing biological nitrogen fixation, contribute to increased primary productivity, thereby elevating soil organic carbon content (Wu *et al.*, 2017). Positive effects on soil organic carbon can be attributed to legume residues' low C/N ratios, facilitating microbial nitrogen acquisition and efficient decomposition into organic matter (Spohn *et al.*, 2016). The rice-french bean-green gram system recorded a minimum pH of 7.90, potentially linked to legume incorporation releasing organic acids during decomposition, thereby reducing the crop rhizosphere pH. The continuous growth of leguminous crops in the system further contributes organic acids, acting as soil pH reducers. This observation highlights the multifaceted impact of crop diversification, not only on organic carbon content but also on soil pH dynamics, demonstrating the potential for sustainable agricultural practices through strategic crop choices.

Available Macronutrients under the various rice based cropping system. The availability of essential nutrients, nitrogen (N), phosphorus (P), and potassium (K), showed significant variations different cropping systems. Nitrogen content increased with the incorporation of legumes, reaching the highest level in the rice-frenchbean-greengram cropping system (224.54 kg ha^{-1}), significantly outperforming other systems, yet comparable to rice-gram-cowpea (223.58 kg ha^{-1}) and rice-wheat-greengram (223.00 kg ha^{-1}) systems. In term of phosphorous content, the rice-wheat-green gram system exhibited the highest level (22.65 kg ha^{-1}), significantly surpassing other systems but aligning with rice-oat-maize+cowpea (22.05 $kgha^{-1}$). The incorporation of legumes in the cropping system, with their decomposition releasing organic acids, likely contributed to the conversion of fixed phosphorous into an available form, consistent with findings by Ali *et al.* (2012). For potassium content, the rice-wheat-green gram system recorded the highest level (270.00 kg ha^{-1}), significantly superior to other systems but on par with rice-french bean-green gram (267.50 kg ha^{-1}). These results emphasize the positive impact of legume inclusion in enhancing soil nutrient availability, particularly for N, P, and K. Legumes, through nitrogen fixation and subsequent release during decomposition, contribute substantial quantities of N, P, and K to the soil (Kumar *et al.*, 2019).

Economic. The economic performance of various rice-based cropping systems, encompassing the cost of cultivation, gross return, net return per hectare, and the benefit-cost (B:C) ratio, was subjected to statistical analysis, as illustrated in Table 3. Notably, the rice-potato-cowpea (veg) system exhibited a significantly higher gross return (Rs 2, 66, 660/ha), while the rice-cauliflower-okra cropping system recorded the highest net return (Rs 1,60,443) and a B: C ratio of 1.77. While, rice-potato-cowpea (veg) displayed the highest cost of cultivation, whereas rice-wheat-green gram had the lowest cost. Rice-based cropping systems often yield the highest gross return, net return, and economic efficiency (Tiwari *et al.*, 2002). Similarly reported favorable economic outcomes for rice-based cropping systems incorporating field peas, attributing it to the crop's higher yields and better market prices compared to other crops (Subimal *et al.*, 2003; Bastia *et al.*, 2008).

Table 1: Rice yield equivalent, energy production, system profitability, system productivity, and land use efficiency as affected by the diversified cropping system.

Treatments	Rice yield equivalent (t/ha)	LUE (%)	Energy production (K x 10^3 cal.)	System profitability (Rs/ha/day)	System productivity (Kg/ha/day)
T_1	9.61	71.09	26183	221.71	28.79
T_2	13.35	93.42	27029	282.55	50.94
T_3	16.30	95.88	23889	405.74	54.43
T_4	15.29	90.13	16198	364.17	45.59
T_5	12.42	89.99	26127	256.12	35.42
T_6	12.06	86.71	21117	282.21	39.75
T_7	10.29	86.98	29335	170.02	36.69
T_8	9.78	92.19	29938	179.98	41.93
T_9	18.63	85.34	20640	439.57	56.45
T_{10}	18.55	87.67	25272	330.345	96.71
SEm ±	0.728	-	128.34	38.92	12.04
CD (P=0.05)	2.086	-	375.09	112.48	32.82

Table 2: Organic carbon, pH, Macro nutrient under different rice based cropping system.

Treatments	O.C (mg kg^{-1})	pH	Av. N	Av. P	Av. K
T_1	4.75	8.08	203.52	19.13	247.51
T_2	5.35	7.95	223.00	22.05	270.00
T_3	5.28	7.95	224.54	21.25	267.50
T_4	5.35	7.97	223.58	20.51	256.53
T_5	4.95	7.94	215.50	20.72	253.54
T_6	5.15	8.01	219.51	20.83	247.18
T_7	4.95	8.00	204.00	20.25	244.53
T_8	5.37	7.92	217.59	22.65	263.59
T_9	5.44	8.04	219.00	21.16	264.52
T_{10}	5.30	7.95	212.00	21.11	263.00
SEm ±	0.58	0.608	4.862	0.62	5.64
CD(P=0.05)	1.64	1.618	13.82	1.78	17.48

Table 3: Economic of different rice based cropping system.

Treatments	Cost of cultivation (Rs. /ha/ year)	Gross Income (Rs. /ha/ year)	Net return (Rs. /ha/ year)	B:C ratio
T1	73487	154410	80923	1.11
T2	95699	102665	102974	1.07
T3	95436	243533	148097	1.55
T4	84539	217461	132923	1.65
T5	89271	182754	93483	1.04
T6	78831	181837	103006	1.30
T7	80960	143019	62149	0.77
T8	75882	141875	65693	0.86
T9	93154	253597	160443	1.77
T10	146084	266660	72641	0.84

CONCLUSIONS

Introducing crop diversification, including legumes, fodder, vegetables, and oilseeds, into the conventional rice-wheat cropping system enhances productivity, profitability, rice equivalent yield (REY), land use efficiency, and energy. These improvements were statistically comparable to the rice-french bean-green gram system, with potato and fodder crops following closely. Significant enhancements in available nitrogen (N), phosphorus (P), and potassium (K) in the soil were observed in the rice-french bean-green gram and rice-wheat-green gram cropping systems. Notably, post-harvest soil organic carbon content was consistently highest when legumes were incorporated. While rice-potato-cowpea demonstrated the highest productivity and rice-french bean-green gram the highest profitability, the latter proved to be the most sustainable and profitable for farmers. The findings suggest that adopting diversified cropping practices, particularly incorporating legumes, offers a pathway for farmers in the Eastern Gangetic Plains of India to improve livelihoods, food security, and overall sustainability in agriculture.

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Conflict of Interest. The authors declare that they have no Conflict of interest.

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