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CONTENTS

Diversification and intensification in rice–wheat cropping system for enhancing productivity under *Tarai* zone of Uttarakhand

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ABSTRACT: The field experiment was conducted during 2021-2022 at Norman E. Borlaug Crop Research Centre, G.B Pant University of Agriculture and Technology, Pantnagar, U.S Nagar, Uttarakhand, India to evaluate the impact of diversification and intensification in rice-wheat cropping system (RWCS) on productivity and profitability. The experimental field soil was loam in texture, high in organic carbon, low in available nitrogen, high in phosphorus and medium in potassium with neutral pH. Ten cropping sequences were evaluated in a randomized block design with three replications. The study formed part of a long-term trial initiated in 2017–18 under AICRP–IFS. Results revealed that the rice–vegetable pea–mentha cropping sequence recorded the highest system productivity (239.7 q REY/ha), production efficiency (66.4 kg REY/ha/day) and relative production efficiency (148.1%), outperforming the conventional rice–wheat–fallow sequence. Napier grass + fodder cowpea–napier grass + berseem–napier grass + fodder cowpea cropping recorded the highest land use efficiency (99.4%), where as nutrient productivity was recorded highest in rice–vegetable pea–black gram and rice–vegetable pea–mentha cropping systems mainly due to higher productivity of vegetable pea (133.4 and 121.5 q REY/ha, respectively The presence of high-value crops (mentha and vegetable pea) contributed to the superior performance of diversified systems. Overall, diversification of conventional RWCS with legumes, vegetables and fodder crops substantially enhanced productivity, system efficiency, resource-use efficiency and economic profitability. Under the *Tarai* conditions of Uttarakhand, the rice–vegetable pea–mentha sequence proved to be the most productive and remunerative option among the tested cropping systems.

Keywords: Equivalent yield, Land use efficiency, Nutrient productivity, Production efficiency, System productivity

The rice–wheat cropping system (RWCS) is one of the world's largest agricultural production systems, covering nearly 26 million ha across the Indo-Gangetic Plains (IGP) of South Asia (Shweta and Malik, 2017). In India, RWCS occupies about 40% of the IGP's cultivated area and plays a major role in national food security. However, the system faces several sustainability challenges, including declining groundwater levels, nutrient imbalance, soil degradation, salinity, pest and disease resurgence, environmental pollution and reduced farm profitability (Parihar *et al*., 2016).

Crop diversification has emerged as an effective strategy to address these challenges by improving food and nutritional security, enhancing income, promoting efficient use of land and water resources. Integrating legumes into the rice–wheat system enhances productivity per unit resources, conserves groundwater and soil moisture and reduces input costs through biological nitrogen fixation. Diversification with maize, pulses, oilseeds and high-value cash crops such as potato, mentha and broccoli helps to reduce climatic and market risks while improving system productivity and profitability.

Inclusion of fodder crops such as sorghum and Napier grass can further strengthen integrated farming systems by providing nutrient-rich green fodder with high dry matter yield. Overall, diversification offers a viable approach to overcome the limitations of cereal–cereal rotations and enhance the productivity, profitability and sustainability of RWCS, particularly under irrigated conditions such as the *Tarai* region.

MATERIALS AND METHODS

A long-term experiment on diversification and intensification of cropping systems was conducted from 2017–18 to 2021–22 under the All India Coordinated Research Programme on Integrated Farming Systems (AICRP–IFS). The present study reports results from the 2021–22 cropping cycle, carried out at E-2 block of the Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand, India. The site is located at 29° N latitude and 79.3° E longitude, at an altitude of 243.83 m above mean sea level, within the *Tarai* belt of the Shivalik foothills. This region has a subtropical climate characterized by hot summers (up to 40°C) and cold winters (occasionally below 0°C), with an average annual rainfall of about 1450 mm, of which 80–90% is received during June to September. The soils are calcareous, medium to moderately coarse-textured and classified under the Mollisol order.

The experiment was laid out to evaluate the effects of diversification and intensification within the rice–wheat cropping system. During the rainy (*kharif*) season, crops such as rice, black gram, maize and sorghum were sown in the first week of July according to monsoon onset. Field preparation for both *kharif* and *rabi* crops consisted of one deep ploughing with a mouldboard plough followed by two cross harrowings and planking. Post-rainy (*rabi*) crops were sown during the first fortnight of November.

Details of the experimental treatments and the cultural practices adopted during the study are presented in Table 1 and Table 2. Standard agronomic practices were followed for each crop as per recommended packages.

Rice equivalent yield (REY), production efficiency, relative production efficiency, land-use efficiency and nutrient productivity were computed using standard formulae. Data were analyzed using ANOVA for randomized block design. Treatment means were compared using LSD at 5% significance.

1. Rice Equivalent Yield (REY)

$$REY = \frac{Y_i \times P_i}{P_r}$$

Where,
Y_I= Yield of ith crop (kg ha^{-1});
P_I= Price of ith crop (Rs kg^{-1});
P_r= Price of rice (Rs kg^{-1})

2. Production Efficiency (PE)

$$PE = \frac{REY}{D}$$

Where,
REY$_t$ = Rice equivalent yield (kg ha^{-1});
D= Duration of cropping system (days)

3. Relative Production Efficiency (RPE)

$$RPE(\%) = \frac{REY_t - REY_c}{REY_c} \times 100$$

Where,
REY_t = REY of treatment;
REY_c = REY of control (rice–wheat)

4. Land Use Efficiency (LUE)

$$LUE(\%) = \frac{DO}{365} \times 100$$

Where, DO = Days land occupied

5. Nutrient Productivity (NP)

$$NP = \frac{REY}{N + P + K}$$

Where, N, P, K = Total nutrients applied (kg ha^{-1})

RESULTS AND DISCUSSION

System Productivity

Significant variation in system productivity was observed among the treatments. The rice–vegetable pea–mentha cropping sequence recorded the highest productivity (239.7 q REY/ha), followed by rice–vegetable pea–black gram (223.7 q REY/ha) and basmati rice–potato–maize (cob) (218.8 q REY/ha). The above cropping systems produced 2.47, 2.31 and 2.26 times higher system productivity respectively than the traditional rice–wheat cropping system (96.7 q REY/ha). The lowest productivity (29.0 q REY/ha) was noted in the fodder-based napier grass + fodder cowpea – napier grass + berseem – napier grass + fodder cowpea cropping system.

Higher productivity in rice–vegetable pea–mentha, rice–vegetable pea–black gram and basmati rice–potato–maize (cob) resulted primarily from the inclusion of short-duration and high-yielding crops such as vegetable in rice–vegetable pea–mentha (121.5 q REY/ha) and rice–vegetable pea–black gram (133.4 q REY/ha) and potato in basmati rice–potato–maize (cob) cropping system (89.4 q REY/ha). These findings corroborate the results of Singh *et al.* (2013), who reported that inclusion of vegetables enhances system productivity due to their higher production potential. The lower values observed in fodder-based systems across productivity parameters are primarily due to the lower economic conversion efficiency of fodder crops, which produce high biomass but comparatively low marketable yield and price, thereby reducing rice equivalent yield and overall system productivity, as also reported by Li *et al.* (2024).

Production Efficiency

Production efficiency followed a similar pattern, rice–vegetable pea–mentha cropping sequence recorded the highest value (66.4 kg REY/ha/day), followed by rice–vegetable pea–black gram (61.8 kg REY/ha/day) and basmati rice–potato–maize (cob) (59.8 kg REY/ha/day). These systems achieved 2.51, 2.34 and 2.26 times greater production efficiency than the rice–wheat system (26.4 kg REY/ha/day). The lowest value (7.9 kg REY/ha/day) occurred in napier grass + fodder cowpea – napier grass + berseem – napier grass + fodder cowpea.

The superior performance of rice–vegetable pea–mentha, rice–vegetable pea–black gram and basmati rice–potato–maize (cob) can be attributed to higher daily productivity from vegetable pea and potato, which yield substantially within a shorter duration, thereby increasing output per unit time. Similar conclusions were drawn by Prasad *et al.* (2013), who noted that vegetable-based sequences showed higher production efficiency due to their high yield potential within a short growth period.

Relative Production Efficiency

Relative production efficiency (RPE) was highest (148.1%) in rice–vegetable pea–mentha, followed by rice–vegetable pea–black gram (131.6%). The lowest values (–70%) occurred in fodder-based system such as napier grass + fodder cowpea – napier grass + berseem – napier grass + fodder cowpea and black gram – wheat – vegetable cowpea (–11.1%). The higher RPE in rice–vegetable pea–mentha and rice–vegetable pea–black gram resulted from the inclusion of vegetables and legumes during the zaid season, leading to substantially higher system productivity compared with the fallow period of the

Table 1: Treatment details of experiment

Treatments	Kharif	Rabi	Zaid
T_1	Rice	Wheat	Fallow
T_2	Rice	Vegetable pea	Mentha
T_3	Blackgram	Wheat	Vegetable cowpea
T_4	Rice	Vegetable pea	Blackgram
T_5	Maize	Yellow sarson	Blackgram
T_6	Rice	Yellow sarson	Grain Cowpea
T_7	Multicut sorghum	Berseem+ oat	Maize+ Cowpea
T_8	Napiergrass+ Fodder cowpea	Napiergrass+ Berseem	Napiergrass+ Fodder cowpea
T_9	Basmati Rice	Potato	Maize (Cobs)
T_{10}	Maize (Cobs)	Broccoli	Okra

Table 2: Agronomic practices followed in different crops

Crop	Seedrate (kg/ha)	Fertilizer rate (NPK kg/ha)	Spacing (cmxcm)	Cultivar/ Variety
Rice	35 (50)	150:60:40	20 x10	HKR-47
Wheat	100 (125)	150:60:40	22.5	UP-2784
Maize	10	120:60:40	60 x15	Suvarna
Mentha	400 kg suckers	120:60:40	60	Him Kranti
Potato	2000	200:100:100	60 x15	Kufri Himsona
Veg. pea	100	20:60:40	30 x5	Arkel
Black Gram	20	20:40:20	30 x10	Pant Urd-31
Yellow sarson	5	60:30:30	30 x 15	PPS-1
Cowpea	10	20:40:0	35 x5	Kashi Kanchan
Broccoli	28000 seedlings	120:60:40	60 x60	Perasio (Hybrid)
Okra	12	120:60:40	60 x15	Kashi Pragati
Sorghum	25	120:60:40	Broadcasting	PC-5
Berseem	25	20:60:40	30 x5	Mescavi
Oat	100	120:60:40	23	UPO-212
Basmati Rice	15	150:60:40	20 x10	PUSA-1509

Table 3: Effect of diversification and intensification of cropping system on system productivity, production efficiency relative production efficiency, land use efficiency (LUE) and nutrient productivity

Treatments	System Productivity (qREY/ha)	Production efficiency (kgREY/ha/day)	Relative production efficiency(%)	Crop growing periods (days)	LUE (%)	Nutrient productivity (kgREY/ kgNPK)
T1	96.7	26.4	--	259	70.9	19.3
T2	239.7	66.4	148.1	315	86.3	40.6
T3	85.9	23.5	-11.1	325	89.0	20.9
T4	223.7	61.8	131.6	293	80.2	49.7
T5	114.4	31.5	18.4	324	88.7	27.2
T6	121.3	33.2	25.5	341	93.4	28.2
T7	154.3	42.5	59.7	353	96.7	29.1
T8	29.0	7.90	-70.0	363	99.4	5.7
T9	218.8	59.8	126.4	305	83.5	24.3
T10	170.2	46.4	76.1	291	79.7	25.8
SEm±	2.06	0.35	27.8	-	-	0.39
CD (p=0.05)	6.12	1.03	82.8	-	-	1.16

traditional rice–wheat system. These observations align with Mishra *et al*. (2007), who reported that addition of short-duration legumes, vegetables and medicinal crops during the summer season improves overall system productivity.

Land-Use Efficiency

Among the different systems, napier grass + fodder cowpea – napier grass + berseem – napier grass + fodder cowpea recorded the highest (99.4%) land-use efficiency followed by multicut sorghum – berseem – oat – maize + fodder cowpea (96.7%). In contrast, the rice–wheat–fallow system exhibited the lowest land-use efficiency (70.9%). Higher LUE in fodder-based systems was mainly due to continuous land occupancy (363 days in napier grass + fodder cowpea – napier grass + berseem – napier grass + fodder cowpea and 353 days in multicut sorghum – berseem – oat – maize + fodder cowpea). The higher land-use efficiency observed in fodder-based systems was primarily due to continuous land occupancy throughout the year, as these systems involve perennial and multi-cut fodder crops with negligible fallow period, resulting in maximum temporal utilization of land resources, in line with the findings of Li *et al.* (2024).

Nutrient Productivity

Similarly, variation was also observed in nutrient productivity across systems. Nutrient productivity was highest (49.7 kg REY/ kg NPK) in rice–vegetable pea–black gram cropping sequence followed by rice–vegetable pea–mentha, mainly due to higher productivity of vegetable pea (133.4 and 121.5 q REY/ha, respectively) at a relatively low nutrient application rate (20:40:0 NPK). Legumes, being nutrient-efficient and capable of biological nitrogen fixation, provided higher yield per unit nutrient applied compared with nutrient-exhaustive cereals. Similar findings were reported by Kumar *et al*. (2023), who observed higher nutrient productivity in legume-based cropping sequences.

CONCLUSION

The study demonstrates that diversification and intensification of the rice–wheat system significantly improves productivity and economic returns. Among the evaluated systems, the rice–vegetable pea–mentha cropping sequence emerged as the most efficient and profitable. Therefore, inclusion of high-value vegetable crops in the rice-based system is recommended as a viable strategy to enhance farm profitability and resource-use efficiency under *Tarai* conditions.

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