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Efficiency of different cropping systems for sustaining productivity in middle Indo-Gangetic Plains

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ABSTRACT

There is an urgent need for identification of eco-friendly and cleaner production systems that are more productive, profitable, efficiently use energy/water/carbon input and are environmentally safer. Under that context, a long-term experiment was conducted during 2019–21 at the farmers' fields of Krishi Vigyan Kendra (KVK), Gaya, Bihar. The main objective of the study was to evaluate the productivity of diverse cropping systems for irrigated and rainfed conditions. Nine cropping system, viz. transplanted puddled rice (TPR)–wheat (conventional-till)-fallow (farmers practices) [CS1],TPR-wheat(zero-till)-mung (ZT) [CS2], Conventional-till direct seeded rice (CTDSR)-mustard (ZT)-mung (ZT) [CS3], ZTDSR-lentil (ZT)-fallow [CS4], Maize (CT)-lentil (ZT)-mung (ZT) [CS5], Bajra (CT)-lentil (ZT)-mung (ZT) [CS6], Bajra (CT)-wheat (ZT)-mung (ZT) [CS7], TPR-chickpea (ZT)-fallow [CS8] and TPR-maize (CT)-fallow [CS9] were used for the present study. Maximum system productivity was recorded with maize (CT)-lentil (ZT)-mung (ZT) (13.2 t/ha), which was 46, 3.9, 13.8, 94.7, 22.2, 15.8, 39.5, 11.9% higher compared to CS1, CS2, CS3, CS4, CS6, CS7, CS8 and CS9, respectively. Net returns (₹211677/ha) and Benefit cost (B:C) ratio (3.59) were recorded maximum with maize (CT)-lentil (ZT)-mung (ZT). Land use efficiency was the maximum with TPR-wheat (ZT)-mung (ZT) (92.6%). Carbohydrate equivalent yield was also maximum with TPR-wheat (ZT)-mung (ZT). Diversification of rice-wheat system with millets i.e. Bajra (CT)-lentil (ZT)-mung (ZT)/Bajra (CT)-wheat (ZT)-mung (ZT) improves the system productivity by 19.5–26.1% compared to TPR-wheat (CT)-fallow. Thus, the present study could be important to identify an alternate cropping systems for enhancing the overall system productivity and profitability sustainably through adoption of environment-friendly technologies.

Keywords: Cropping system, Eastern India, Economics, Land use efficiency, System productivity

Climate change is threatening the agriculture, making farmers more vulnerable; posing challenges to sustaining productivity of farmers who constitute >50% population of country (Kumar *et al.* 2021a). Considering that new approach is needed; development and deployment of technologies and capacity building have important role to play not only in building the farmer capability but also in changing the mindset (Kumar *et al.* 2021b). Bihar is only state in the country that experiences drought and floods on a recurring basis. Floods in north Bihar are a regular feature with 74% of state being flood-prone, while south Bihar suffers from drought (Roy *et al.* 2011). Weather trend analysis in Bihar revealed signs of climate change-induced variability in intensity, frequency, duration of temperature and rainfall (Haris *et al.* 2010). Temperature in the region has risen over last few decades, extreme maximum temperature event showed decreasing trends. Rainy days showed a significant increasing trend for zone III, though decreasing trend in I & II (Chhabra and Haris 2015). Increasing trends of rainfall and minimum temperature in IGPs were reported by Haris *et al.* (2010). Trends in annual air temperature over 100 years revealed increase of 0.5°C in future, having alarming consequences on agriculture (Jat *et al.* 2016). Climate projection for 2050 revealed an increasing trend in maximum and minimum temperature (2–4°C) in every month coupled with more variability (-25 to +30%) in monthly rainfall patterns which are bound to have large implication on food security and livelihood of rural mass (IPCC 2015). Increase in minimum temperature up to 1–3°C above normal led to decline in productivity of rice & wheat by 3 and 10% (Joshi *et al.* 2013). Being a populous state, predominantly agrarian economy with good water and soil endowment, Bihar has potential to become "Future Food Bowl". Though, varying production system and farm typologies that are vulnerable to climate change need to be understood and addressed

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through scientific efforts. Keeping these things in view, we hypothesized diversified cropping rotation resulting in reduction of energy input and C-footprints. Thus, the present investigation was undertaken at the selected farmers' field of KVK Gaya, Bihar.

MATERIALS AND METHODS

An experiment was conducted at the selected farmers' fields at Rupaspur, Rasalpur (Manpur block) and Rasalpur Nagar (Gaya block) during 2019–21 under the KVK, Gaya, Bihar. This region received annual precipitation of 1003 mm, of which 75% was achieved during July–September. Soil was clay loam in texture (50.1, 35.3 and 14.6% of sand, silt and clay, respectively), having *p*H of 7.5, electrical conductivity (EC) of 0.17 dS/m, organic carbon of 2.56 g/kg, $KMnO_4$ oxidizable N of 164.7 kg/ha, Olsen P of 15.4 kg/ha, NH_4OAc exchangeable K of 308.3 mg/kg (0–15 cm soil depth). Total annual rainfall at experimental site varied between 980 (Manpur block) to 1026 mm (Gaya block) during 2019–20 and 2020–21. Weather data were collected from Manpur and Gaya meteorological observatory during cropping periods.

Experimental treatments: Nine cropping system, viz. transplanted puddled rice (TPR)-wheat (conventional-till)-fallow (farmers practices) [CS1], TPR-wheat (zero-till)-mung (ZT) [CS2], Conventional-till-direct seeded rice (CTDSR)-mustard (ZT)-mung (ZT) [CS3], ZTDSR-lentil (ZT)-fallow [CS4], Maize (CT)-lentil (ZT)-mung (ZT) [CS5], Bajra (CT)-lentil (ZT)-mung (ZT) [CS6], Bajra (CT)-wheat (ZT)-mung (ZT) [CS7], TPR-chickpea (ZT)-fallow [CS8] and TPR-maize (CT)-fallow [CS9] were used to evaluate their productivity and profitability. TPR-chickpea (ZT)-fallow and TPR-maize (CT)-fallow were taken as dummy check. Rice cv. Rajendra Sweta, pearlmillet cv. Proagro 9450, maize cv. P 3377, wheat cv. HD 2967, Lentil cv. HUL 57, chickpea cv. Pusa 256, mustard cv. Rajendra Suflam, maize cv. S2 945 and mung cv. IPM 2-3 have been used for cropping along with standard package of practices. All the crops were raised during rainy (*kharif*) season in CT, while all winter/summer crops were grown in ZT, except CT-wheat and maize. In TPR-wheat (ZT)-mung (ZT), CTDSR-mustard (ZT)-mung (ZT), ZTDSR-lentil (ZT)-fallow, ~30% residues of rice and wheat were retained, whereas other crop was harvested close to ground. After 2/3 picking of summer mung, entire biomass was incorporated into the soil.

Crop establishment and management: Before introduction of climate-resilient production technologies i.e. residues management, land-laser levelling, ZT, minimum/reduced tillage, precision nutrient and irrigation management, CTDSR and nutri-cereals/millets, training and awareness programmes were organized for farmers at adopted villages. Before experimentation, land was levelled properly through laser land leveller. Weed control was done by use of glyphosate (41% EC) at 1.5 l/ha before sowing. Selective pre-and post-emergence (PE/POE) herbicides were used to manage the weeds. Atrazine (PE) for maize, pretilachlor (PE) for PTR [2–3 days after transplanting (DAT)], pendimethalin (PE) followed by bispyribac-sodium (POE) for CTDSR [20 days after sowing (DAS)], pendimethalin (PE) for mung and mustard (2–3 DAS) and clodinafop propargyl (POE) for wheat (30 DAS) was used. All rainy crops were planted in 3rd week of June and harvested by 2nd week of October. All winter crops (wheat, oilseed, pulses) were sown in 3rd week of October, harvested in March/April. Mung was sown and harvested in 1st week of April and June, respectively.

System equivalent yield measurements: System productivity of different cropping sequences was converted into rice equivalent yield (REY) as:

$$\text{REY (t/ha)} = \frac{\text{Grain yield of the winter/summer crops} \times \text{MSP of winter/summer crops}}{\text{Price of rice}}$$

where MSP, minimum support price as fixed by the Government of India in the respective years.

System rice equivalent yield (SREY) or system productivity and system production efficiency (SPE) was computed as:

$$\text{SREY (t/ha)} = \text{Grain yield of rice} + \text{REY of winter crops} + \text{REY of summer crops}$$

$$\text{System production efficiency (SPE) (kg/ha/d)} = \frac{\text{SREY}}{\text{Total duration of the cropping period}}$$

Land use efficiency (LUE): LUE was obtained by dividing total number of days occupied by different crops by 365 days and multiplying with 100.

Relative system productivity efficiency (RSPE) and relative system economic efficiency (RSEE): RSPE and RSEE were calculated as:

$$\text{RSPE} = \frac{\text{Total productivity (TP) of diversified cropping system (CS)–TP of existing cropping system}}{\text{TP of existing cropping system}} \times 100$$

$$\text{RSEE} = \frac{\text{Net returns (NR) of diversified CS–NR of existing cropping system}}{\text{NR of existing cropping system}} \times 100$$

Carbohydrate equivalent yield and carbon output: Economic yield of rice and other crops in different cropping sequences was converted into an equivalent value of carbohydrate as suggested by Gopalan *et al.* (2004). Carbon output was calculated based on plant biomass production in different sequences as suggested by Lal (2004).

Economics: Economics was worked out by considering all the incurred variable cost. Labour cost was computed by multiplying wage rate. Gross returns (GR) were computed by multiplying marketable output (grains and straw/stover yield of individual crops) with their market price. Net returns (NR) were computed by taking the difference between gross returns (GR) and total costs.

Statistical analysis: Mean data for two years were pooled and analysed statistically following randomised block design using the F-test (Panse and Sukhatme 1978). Farmers trails were taken as replications during statistical analysis. Significance of differences among means was compared by using the DMR test when F-values were significant.

RESULTS AND DISCUSSION

Crop yield: Rice yield in different sequences ranged from 3.11–4.89 t/ha (Table 1). Pooled yield of bajra ranged from 2.75–2.95 t/ha. Among rainy crops, maximum yield was recorded by maize (6.08 t/ha). This might be due to the genetic potential of respective crops (Bohra and Kumar 2015). In winter, ranges of crop yield of wheat, lentil, chickpea and mustard were 4.3–4.81, 1.43–1.52, 1.75 and 1.91 t/ha, respectively. During winter, maximum crop yield was recorded in maize (7.12 t/ha). During summer, yield of mung ranges from 0.79–0.93 t/ha. It was noted that crops grown in resource conservation technologies had better yields in comparison to conventional tillage in winter (Samal *et al.* 2017). Among the rainy season, maximum rice equivalent yield (REY) was recorded by maize (6.08 t/ha) followed by TPR (4.89 t/ha). Similarly, wheat had the highest REY of 5.02 t/ha among winter crops. In summer, mung in climate-resilient system had the highest REY of 3.58 t/ha. REY was directly related to crop productivity and minimum support price.

System productivity: Rotation of crop/cultivars within cropping systems, is a widely adopted management practice to resolve the issues of adverse effects of climate change. Crop diversification through climate-resilient systems is one of the main approaches for improving productivity and resolving issues of ecological sustainability. Crop sequences having 300% cropping intensity had higher system productivity. Maximum system productivity was recorded with maize (CT)-lentil (ZT)-mung (ZT) (13.2 t/ha), which was 46, 3.9, 13.8, 94.7, 22.2, 15.8, 39.5, 11.9% higher compared to CS1, CS2, CS3, CS4, CS6, CS7, CS8 and CS9, respectively (Table 1). This might be due to higher production of maize along with better market price of lentil causing higher returns. Kumar *et al.* (2021b) also reported that maize (CT)-pigeonpea (ZT) had recorded maximum system productivity in rice-based cropping sequences.

Highest SPE was noted in maize (CT)-lentil (ZT)-mung (ZT) (44 kg/ha/day) and significantly higher than rest of rice-based sequences (Table 2). ZTDSR-lentil (ZT)-fallow had lowest SPE (27.7 kg/ha/day). SPE of maize (CT)-lentil-mung (ZT) was recorded 29, 17, 2.3, 58.8,14, 15.5, 29.4 and 4% higher as compared to CS1, CS2, CS3, CS4, CS6, CS7, CS8 and CS9. Higher SPE was noted with respective treatments due to inclusion of better crop yields i.e. maize in rainy and inclusion of pulses (lentil) in winter, which fetched better monetary returns (Kumar *et al.* 2021a).

Land use efficiency (LUE): LUE is directly related to total duration of main and component crops. Highest

Table 1 Crop yields, rice equivalent yield (REY) and system productivity (SREY) of diverse cropping systems (mean of 2 years)

Cropping system	Crop yield (t/ha)						REY			SREY (t/ha)	SPE (kg/ha/day)	LUE (%)
	Rainy		Winter		Summer							
	Grain yield	Straw yield	Grain yield	Straw yield	Seed yield	Straw yield	Rainy	Winter	Summer			
TPR-wheat (CT)-fallow: (FP)	4.67	5.78	4.24	5.73	-	-	4.67^{bcde}	4.37^{def}	-	9.04^{gh}	34.1^{g}	72.6^{efgh}
TPR-wheat (ZT)-mung (ZT)	4.85	5.89	4.67	5.81	0.79	2.11	4.85^{bc}	4.81^{bc}	3.04^{cde}	12.7^{b}	37.6^{def}	92.6^{a}
CTDSR-mustard (ZT)-mung (ZT)	3.60	4.37	1.91	3.74	0.89	2.18	3.60^{f}	4.52^{de}	3.43^{ab}	11.6^{cd}	43.0^{ab}	74.0^{efg}
ZTDSR-lentil (ZT)-fallow	3.11	3.96	1.43	2.47	-	-	3.11^{ghi}	3.67^{i}	-	6.78^{i}	27.7^{i}	67.1^{hi}
Maize (CT)-lentil (ZT)-mung (ZT)	6.14	8.46	1.52	2.53	0.84	2.38	6.08^{a}	3.91^{g}	3.24^{bc}	13.2^{a}	44.0^{a}	82.2^{b}
Bajra(CT)-lentil (ZT)-mung (ZT)	2.95	4.85	1.48	2.29	0.93	2.25	3.40^{efg}	3.80^{h}	3.58^{a}	10.8^{def}	38.6^{d}	76.7^{bcd}
Bajra (CT)-wheat (ZT)-mung (ZT)	2.75	4.52	4.87	6.23	0.83	2.17	3.17^{gh}	5.02^{b}	3.20^{bcd}	11.4^{cde}	38.1^{de}	81.9^{bc}
TPR-chickpea (ZT)-fallow:Dummy I	4.89	5.51	1.75	2.59	-	-	4.89^{b}	4.57^{cd}	-	9.46^{g}	34.0^{gh}	76.2^{bcdef}
TPR-maize (CT)-fallow:Dummy II	4.71	5.33	7.12	11.94	-	-	4.71^{bcd}	7.05^{a}	-	11.8^{c}	42.3^{abc}	76.4^{bcde}

TPR, transplanted puddle rice; FP, farmers practices; CT, conventional till; ZT, zero-till; DSR, direct seeded rice; RCT, resource conservation technology; SREY, system rice equivalent yield; LUE, land-use efficiency; SPE, system production efficiency; RSPE, relative system production efficiency; RSEE, relative system economic efficiency; SCOC, system cost of cultivation; SNR, system net returns; SGR: system gross returns; SBCR, system benefit:cost ratio; SEE, system economic efficiency. Mean values followed by different small letters within a row are significantly different at P=0.05 by Duncan's Multiple Range Test (DMRT).

Table 2 Carbohydrate equivalent yield (CEY), carbon output (CO) and economics as influenced by diverse cropping systems (mean of 2 years)

Cropping system	CEY (t/ha)	CO (CE t/ha)	SCOC (₹/ha)	SGR (₹/ha)	SNR (₹/ha)	SBCR	SEE (₹/ ha/day)	RSPE (%)	RSEE (%)
TPR-wheat (CT)-fallow:(FP)	6.67^{c}	8.98^{cdef}	89445^{defg}	226356^{fg}	136911^{fg}	2.53^{cdef}	265^{defgh}	-	-
TPR-wheat (ZT)-mung (ZT):RCT	7.57^{b}	10.61^{b}	117077^{ab}	308424^{a}	191347^{b}	2.63^{c}	338^{a}	10.3^{fg}	27.5^{a}
CTDSR-mustard (ZT)-mung (ZT)	3.77^{g}	7.34^{g}	101058^{c}	257590^{cde}	156532^{d}	2.55^{cde}	270^{defg}	26.1^{ab}	1.9^{g}
ZTDSR-lentil (ZT)-fallow	3.28^{hi}	4.83^{a}	72236^{i}	157395^{i}	85159^{i}	2.18^{i}	245^{gi}	23.1^{cd}	-7.55^{h}
Maize (CT)-lentil (ZT)-mung (ZT)	5.46^{de}	9.62^{c}	81699^{h}	293376^{ab}	211677^{a}	3.59^{a}	300^{b}	29.0^{a}	13.2^{b}
Bajra (CT)-lentil (ZT)-mung (ZT)	3.39^{h}	6.49^{cd}	92541de	238328^{ef}	145787^{def}	2.58^{cd}	280^{bcd}	13.2^{e}	5.7^{d}
Bajra (CT)-wheat (ZT)-mung (ZT)	5.79^{d}	9.40^{cde}	92745^{d}	272039^{c}	179294^{c}	2.93^{b}	299^{bc}	11.7^{ef}	12.8^{bc}
TPR-chickpea (ZT)-fallow:Dummy I	4.89^{f}	6.49^{h}	90541^{def}	214238^{gh}	123697^{h}	2.37^{defg}	278^{bcdef}	-0.3^{h}	4.9^{ef}
TPR-maize (CT)-fallow:Dummy II	8.43^{a}	12.80^{a}	111718^{a}	264903^{cd}	153185de	2.37^{defg}	279^{bcde}	24.0^{c}	5.3^{de}

Cropping system details has been given in footnote of Table 1.

LUE noted with TPR-wheat (ZT)-mung (ZT) (92.6%) due to the longest duration of cropping sequences (283 days) followed by maize (CT)-lentil (ZT)-mung (ZT) (82.2%). However, lowest LUE (72.6%) was noted with TPR-wheat (CT)-fallow (Table 1). Crop diversification utilized land efficiently throughout year, which enhances profitability but generate more employment for farmers during lean period (Kumar *et al.* 2019a). Cropping system analysis not only illustrates current land use, but it also reflects how land pattern has been changed over time. Kumar *et al.* (2019b) also reported that intensification of pulses in cropping systems increased LUE. Highest RSPE (29%) was obtained with maize (CT)-lentil (ZT)-mung (ZT) followed by CTDSR-mustard (ZT)-mung (ZT) (26.1%). TPR-wheat (ZT)-mung (ZT) had the highest RSPE of 27.5% followed by maize (CT)-lentil (ZT)-mung (ZT) (13.1%).

Carbohydrate equivalent yields (CEY) and carbon output (CO): Maximum carbohydrate equivalent (CEY) was recorded in TPR-maize (CT)-fallow (8.43 t/ha) followed by TPR-wheat (ZT)-mung (ZT) (7.57 t/ha). TPR-maize (CT)-fallow increased in CEY by 26.4, 11.4, 123.6, 157, 54.4, 148.7, 45.6 and 72.4% in comparison to TPR-wheat (CT)-fallow, TPR-wheat (ZT)-mung (ZT), CTDSR-mustard (ZT)-mung (ZT), ZTDSR-lentil (ZT)-fallow, Maize (CT)-lentil (ZT)-mung (ZT), Bajra (CT) lentil (ZT)-mung (ZT), Bajra (CT)-wheat (ZT)-mung (ZT), TPR-chickpea (ZT)-fallow (Table 2). This was due to higher yield of maize and rice. Higher CEY in crop sequence is obtained mainly due to higher economic yield and per unit production of carbohydrate that is higher in cereal-based system (Kumar *et al.* 2021b).

Maximum carbon output was recorded in TPR-maize (CT)-fallow (12.8 t CE/ha) followed by TPR-wheat (ZT)-mung (ZT) (10.6 t CE/ha) (Table 2).TPR-maize (CT)-fallow was increased in carbon output by 42.5, 20.6, 74.4, 165, 33.1, 97.2, 36.2 and 97.2% compared to TPR-wheat (CT)-fallow, TPR-wheat (ZT)-mung (ZT), CTDSR-mustard (ZT)-mung (ZT), ZTDSR-lentil (ZT)-fallow, Maize (CT)-lentil (ZT)-mung (ZT), Bajra (CT)-lentil (ZT)-mung (ZT), Bajra (CT)-wheat (ZT)-mung (ZT), TPR-chickpea (ZT)-fallow. This might be due to more biomass production.

Production economics: Among diverse cropping systems, the maximum net returns of ₹211677/ha were recorded by maize (CT)-lentil (ZT)-mung (ZT) (Table 2). Minimum net returns were noted with ZTDSR-lentil (ZT)-fallow (₹85119/ha). Higher net returns of maize (CT)-lentil (ZT)-mung (ZT) was noted due to the maximum system productivity and inclusion of pulses in summer fetched higher net returns. Increase in net returns due to inclusion of pulses in cereal-based systems was reported by Mishra *et al.* (2021). Highest B:C ratio was noted with maize (CT)-lentil (ZT)-mung (ZT) (3.59). System economic efficiency (SEE) was maximum with TPR-wheat (ZT)-mung (ZT) (₹338/ha/day). Among millets-based system, Bajra (CT)-wheat (ZT)-mung (ZT) had the highest SEE (₹299/ha/day). This might be due to higher production of respective cropping systems with better monetary returns, especially from mung. Increase in net profit over rice-wheat system with inclusion of pulses in cropping sequences.

On the basis of above study, it can be concluded that most productive and profitable cropping system was maize (CT)-lentil (ZT)-mung (ZT). Among millet-based cropping, Bajra (CT)-wheat (ZT)-mung had highest system productivity. Thus, TPR-wheat (CT)-fallow system diversified with maize, bajra on rainy and maize, lentil, chickpea, and mustard during winter is the best option.

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