Environmentally Sound Alternative Cropping Systems For Rice-Wheat Systems In North West India

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Abstract

Continuous cultivation of Rice-Wheat Cropping System (RWCS) in Indo-Gangetic Plains of India is showing declining factor productivity coupled with many environmental problems. Diversifying the RWCS is one of the environmental friendly options for sustaining food production. Four crop rotations involving maize and sorghum in summer, wheat/ potato/ mustard in winter followed by short duration green gram in late spring were studied to identify the most productive and economic combination from 2017 to 2020. Ranking of treatments by Tukey's test of significance indicated that the maize-potato-wheat (16.49 t ha⁻¹) combination was best in terms of system productivity calculated in terms of wheat equivalent yield (WEY). Maize-wheat-green gram crop sequence was most profitable by having higher Land Use Efficiency (LUE=87.67%) and net return (NR=1577.1 \$ha⁻¹). The gross margin comparison revealed that maize-based crop sequences earned higher gross returns (23.17%), net return (93.66%), and B: C ratio (23.7%) than sorghum-based crop sequences. Soil health parameters were improved under the maize-mustard-green gram system, which increased the organic carbon content by 28.65% and available N by 34.91%. Adoption of alternate cropping sequences instead of rice-wheat, in the Indo-Gangetic Plains of India could be more sustainable, profitable, and environment friendly.

Introduction

The rice-wheat cropping system is the principal crop production system in South Asia and occupies approximately 13.5 million hectares' area including 10.3 million hectares in India (Ladha et al. 2000; Timsina & Connor 2001). India's approximately 23 % of rice and 34 % of wheat are grown in Indo Gangetic plains in a cropping sequence and both crops required contrast field conditions. Rice crop is grown in puddled fields whereas, wheat is grown in upland well-drained field conditions. Continuous cultivation of RWCS for decades has shown stagnation in productivity of RWCS along with depletion of natural resources in northwest (NW) India (Ladha et al. 2003; Pathak et al. 2003; Rodell et al. 2009). Rice a water-guzzling crop having an evapotranspiration requirement of more than 800–1000 mm (Meena et al. 2015, 2019b; Tripathi et al. 2019) and having very low irrigation efficiency. India is withdrawing maximum amount of groundwater (Mukherjee et al. 2015) and consumes 25% of the global use which is more than China and the USA combined (Margat and van der Gun 2013). The present rate of ground water decline in India is fastest in the world (Aeschbach-Hertig and Gleeson 2012). In North-West India underground water levels have fallen from 8 to 16m below ground level (mbgl) and in the rest of India, it has declined from 1 to 8 mbgl (Sekhri 2013). Another estimate reports a decline in the water table by 0.2-1.0 m per year, which is a major cause of concerns (Sinha et al. 2018). Continuous pumping from groundwater forced farmers to go deeper for submersible pumps, which raises production costs and also reduced the pumping efficiency and frequent malfunctioning of the tube wells (Meena, et al. 2019). Such a rapid rate of decline in groundwater raises serious concerns about the sustainability of RWCS. Results of long-term experiments on RWCS displayed a declining trend of rice yield at 0.02 t ha⁻¹ yr⁻¹ or 0.5 % yr⁻¹ (Yadav et al. 1998; Dawe et al. 2000).

High yielding, water use efficient genotypes provide opportunities for saving at least 20% of depleting water resources, thereby directly contributing to the reduced cost of cultivation, which gets reflected in farm profit (Meena, et al. 2019). Despite production gain, this RWCS favored the proliferation of weeds like *Phalaris minor*. Anaerobic condition due to puddling in rice creates favorable and congenial conditions for the RWCS associated weeds like *Phalaris minor* (Franke et al. 2007). Favorable agricultural practices, weather conditions, and the ineffectiveness of herbicides led to the development of resistance biotypes of *Phalaris minor* (Singh 2007; Kumar et al. 2013; Sharma et al. 2015). Besides weeds, this cropping system also encourages the build-up of many plant diseases in rice and wheat mainly sheath blight in rice resulting in loss of rice yield up to 20% (Ref). Since the causal organism (*Rhizoctonia solani*) is pathogenic on both crops rice and wheat, the disease continues to build up, where continuous RWCS is followed. Among soil-borne pathogens, two genera of plant-parasitic nematodes (*Tylenchorhynchus spp.* and *Hirschmanniella oryzae*) appeared to

predominate in the rice-wheat growing belt. In wheat, the incidence of *Alternaria* and *Helminthosporium* leaf blight has been reported to increase with continuous rice-wheat cultivation. These pathogens jointly account for severe loss of system productivity.

Wheat-based cropping systems in India are rice-wheat, cotton-wheat, maize-wheat, pearl millet-wheat, sugarcane-wheat, soybean-wheat, and pigeon pea-wheat. Late sowing of wheat is a common problem due to delayed harvesting of rice in RWCS. These results in a decline in wheat productivity in India by 15.5, 32.0, 27.6, 32.9, and 26.8 kg ha⁻¹ day⁻¹ in the northern hill zone, northwestern plain zone, northeastern plain zone, central zone, and peninsular zone by switching from timely to late sowing, respectively (Tripathi et al. 2005).

Continuous following of the RWCS is reported to decline soil fertility particularly organic carbon content in Indo Gangetic plain (Nambiar and Abrol 1989; Ladha et al. 2000). To achieve the same yield level, farmers are applying higher doses of fertilizer (Singh et al. 2010; Coventry et al. 2011). In a nutrient budget prepared for Haryana state, K showed a negative balance (Pathak et al. 2003). Besides a decline in factor productivity and raising the cost of cultivation, it is also contributing towards environmental pollution. In the coarse-textured soils, and sandy soils high dose of nitrogen is resulting in NO₃ leaching to groundwater (Sunitha 2013; Sinha et al. 2015) which is very detrimental to human health. To overcome these problems there is an urgent need to diversify the RWCS so that different alternative crop in place of rice may be popularized in the Indo Gangetic plains of India. This prompted an investigation into alternate cropping sequence which could enhance yield with less water use and also play a catalytic role in the diversification of RWCS. This will also provide an opportunity for early wheat sowing (last week of October), which enhances spring wheat grain yield up to 10.06% due to conducive growth and additional one week gain in grain filling period (Tripathi et al. 2013). To cope with problems associated with RWCS, intensification and/or substitution of conventional crops with low water requiring crops is need of the hour. The proposed study focuses on replacing the rice crop with maize (grain) and sorghum (fodder) based cropping sequences to enhance productivity, profitability, and sustainability of the system.

Materials And Methods

Experimental site

Field experiments were conducted at the research farm of ICAR – Indian Institute of Wheat and Barley Research, Karnal, Haryana (Latitude 29° 43' N, longitude 76° 58' E and altitude 245 m) for four consecutive years commencing from 2016-17 to 2019-20.

Weather condition

This location represents a semiarid climate with long-term average annual precipitation of 600 mm, which is erratic. Most of the precipitation (70-80 %) received during the monsoon period i.e. July to September in each year. The temperature ranged from a minimum of 1-2 °C in December to a maximum of 44-45 °C in May-June. The maximum temperature during the study period was higher in February, March, and April in 2016 and 2017 and June in 2019 as compared to the long-term average. During the rest of the period, it was close to the long-term average or lower. Whereas, the minimum temperature was higher in March, April, May, and June in 2016, 2017, and 2018 and August, September, October, and November in 2019 as compared to the long-term average. Significant precipitation was recorded in January of all the years while, March 2020, recorded an exceptional higher rainfall than the long-term average (Figure 1).

Chemical analysis of soil

The soil samples (0-15 cm) were analysed for pH, EC, organic carbon (Walkley and Black 1934), available N (Jackson 1958), available P (Olsen 1954), and available K (Merwin and Peech 1951) at the start of the experiment and after

completion of 4 cropping cycles. The soil of the experimental plot was coarse sandy loam in texture having alkaline pH (8.3), low EC (0.14 dSm^{-1}), organic carbon (0.36 %) and available nitrogen (115.2 kg ha^{-1}) and medium in available phosphorous (12.0 kg ha^{-1}), and potassium (155.9 kg ha^{-1}) contents.

Experimental design, treatments and crop management

Eight crop sequences were studied in a randomized block design with three replications and each crop used in the cropping system is mentioned as under.

No	Treatments	Crops grown
1.	SW	Sorghum-wheat
2.	SWG	Sorghum-wheat- green gram
3.	SMuG	Sorghum-mustard- green gram
4.	SPW	Sorghum-potato- wheat
5.	MPW	Maize-potato- wheat
6.	MMuG	Maize-mustard- green gram
7.	MWG	Maize-wheat- green gram
8.	MW	Maize-wheat

Varieties, seed rates, and fertilizer doses applied to different crops were given in table 1. All the crops received phosphorous and potash through DAP (diammonium phosphate) and murate of potash as basal, respectively. 150 kg N ha^{-1} was applied in sorghum fodder and maize crop with two split applications i.e. 50% N basal and 50% N in sorghum at 45 DAS (days after sowing), whereas in maize crop N was applied in three equal split doses i.e. $1/3 \text{ N}$ basal, $1/3 \text{ N}$ at 30 DAS and $1/3 \text{ N}$ at 60 DAS. The wheat crop also received N fertilizer in three splits i.e. $1/3^{\text{rd}}$ of nitrogen was applied at the time of sowing as basal dose, $1/3^{\text{rd}}$ N was applied at the first node stage i.e. DC 31 (Zadoks et al. 1974), and the remaining $1/3^{\text{rd}}$ N was applied at late jointing (DC37). Mustard and potato received N in two equal splits i.e. first 50% basal in both cases and second 50 % at flowering in mustard and at earthing in potato, respectively. Green gram cultivation didn't receive any fertilizer. For weed control in wheat two herbicides were sprayed i.e. sulfosulfuron @ 25 g ha^{-1} and metsulfuron @ 4 g ha^{-1} , respectively in 400 liters of water at 30 DAS. Weeds in maize were controlled by the application of atrazine 1.0 kg ha^{-1} at 20 DAS. Weeds in crops like potato, mustard, and green gram were controlled manually with the help of hand hoe. Irrigation in all the crops was applied as per the recommendation of the region. Aphids in mustard were controlled by application of Rogor 30 EC @ 1 litre ha^{-1} in 500 liters of water. Sorghum crop was cut at 50% flowering stage and sold in the local market for fodder use.

Table 1. Varieties, seed rates and fertilizer doses applied to different crops

Crops	Varieties	Seed rate (kg/ha)	Nutrients* applied (kg/ha)		
			N	P ₂ O ₅	K ₂ O
Sorghum	Manak	40	150	60	40
Maize	X-92	20	150	60	40
Wheat (TS)	HD 3086	100	150	60	40
Wheat (LS)	DBW 71	125	120	60	40
Mustard	Pusa bold	3	90	60	40
Potato	KufriPokhraj	2500	90	80	100
Green gram	SML-668	25			

*Applied through urea, diammonium phosphate and murate of potash.

Observations

The net plot of each crop was harvested for recording the yield data on a plot basis. The duration taken by each crop from sowing to harvesting was added to calculate the total duration of each crop rotation. Land use efficiency was calculated as the duration of crop sequence divided by 365 days. Production efficiency was calculated as wheat equivalent yield in a cropping sequence divided by the duration of that cropping sequence (Tomar and Tiwari 1990).

System productivity

System productivity in terms of wheat equivalent yield (WEY) was calculated by multiplying yield with minimum support price/market price of each crop in a cropping sequence and subsequently adding and thereafter divided by the price of one-ton wheat.

WEY= (Yield of intercrops x market price of intercrops)/ Market price of wheat

Sustainability value index (SVI)

$$SVI = (\mu - \delta) / Y_{\max}$$

where, μ = mean of a particular treatment in monetary terms, δ = standard deviation of a particular treatment in monetary terms, and $Y_{\max}$ = potential maximum monetary returns (by converting potential maximum yield in monetary terms) over the years. The sustainable value index was calculated as per the procedure described by Singh & others (1990)

Gross returns and margins

Cost of cultivation was calculated by taking into account the prevailing price of inputs like fertilizer, seed, herbicides, irrigations, tillage operations, transportation charges, management charges, rental value of land and depreciation cost of implements. Total returns (TR) were calculated by taking minimum support price of maize, mustard, wheat and green gram and market price of sorghum (fodder), potato tuber and wheat straw on pooled yield basis. Net return (NR) was calculated by subtracting cost of cultivation from TR whereas benefit cost ratio (B:C) was calculated by dividing TR with cost of cultivation.

Statistical analysis

The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) techniques for randomized block design using SAS (Statistical Analysis Software) version 10.3. Yearly as well as combined over the years analysis was performed for all the parameters under study. The least significant difference (LSD) test was used to compare mean differences between treatments at $P = 0.05$.

Results

Analysis of variance

Highly significant differences were observed for WEY, TR, NR, BC Ratio, and PE at a 5% level of significance. The main effects of year and treatments were found to be significant ($P = < 0.001$) (Table 2). One-way interaction involving Year x treatments was also found significant ($P = < 0.001$). Comparing the years, 2018 was significantly ($P = < 0.001$) superior for WEY (14.4 t ha^{-1}), TR ($3222 \$ \text{ ha}^{-1}$), NR ($1168 \$ \text{ ha}^{-1}$), BC Ratio (1.59), and PE ($51.3 \text{ kg ha}^{-1} \text{ day}^{-1}$) compared to that other three years. The years 2016 and 2017 were statistically at par ($P = > 0.05$) while, 2020 recorded significantly ($P = < 0.001$) lowest values concerning all the studied parameters among the years (Fig. 2).

Table 2
ANOVA on productivity, profitability and soil health parameters

		Productivity and profitability					Soil health parameters					
Source	DF	WEY	PE	TR	NR	B:C	pH	EC	OC	N	P	K
Year (Y)	3	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	-	-	-	-	-	-
Treatment (T)	7	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.017	0.535	< 0.001	< 0.001	0.021	< 0.001
Y*T	21	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	-	-	-	-	-	-

WEY: Wheat equivalent yield (t ha^{-1}); PE: production efficiency (%), TR: Total returns ($\$ \text{ ha}^{-1}$); NR: Net returns ($\$ \text{ ha}^{-1}$); BC ratio: Benefit to cost ratio; EC: Electrical conductivity dSm^{-1} ; OC: organic carbon (%); N: Nitrogen (kg ha^{-1}); P: Phosphorus (kg ha^{-1}); K: Potassium (kg ha^{-1})

Yield of different crops

The study revealed that the yield produced by different component crops varied among the different cropping sequences (Table 3). Maize yields were maximum under MWG (7.6 t ha^{-1}) sequence while wheat recorded maximum yield under SW (6.1 t ha^{-1}), sequence. The lowest maize yield (6.6 t ha^{-1}) was achieved when the potato was grown in between maize and wheat. Late sown wheat variety sown after potato produced lower grain yield (3.2 and 3.7 t ha^{-1}) as compared to timely sown variety taken after sorghum (6.1 and 5.7 t ha^{-1}) and maize (5.4 and 5.7 t ha^{-1}) based crop sequences. The average mustard (1.9 t ha^{-1}) and potato (20.3 t ha^{-1}) yields were numerically higher when maize was as a preceding crop compared to sorghum. In contrast, green gram (1.4 t ha^{-1}) yield was higher when sorghum was the preceding crop compared to maize (1.2 t ha^{-1}).

Table 3

Mean yield (t ha^{-1}) of different crops in various cropping systems (average of 4 years)

Crop Sequences	Maize	Sorghum (F)	Wheat	Mustard	Potato	Green gram
SW		48.82	6.09	0.00	0.00	0.00
SWG		41.31	5.69	0.00	0.00	1.18
SMuG		50.29	0.00	1.84	0.00	1.59
SPW		49.52	3.24	0.00	19.97	0.00
MPW	6.69		3.66	0.00	20.26	0.00
MMuG	7.00		0.00	1.91	0.00	1.55
MWG	7.66		5.36	0.00	0.00	0.93
MW	7.55		5.67	0.00	0.00	0.00
F = Fodder						

System productivity

System productivity measured as wheat equivalent yield (WEY) was significantly ($P = < 0.001$) higher under MPW sequence (16.49 t ha^{-1}) and MWG (16.17 t ha^{-1}) rotations than others (Fig. 3). This was followed by the MMuG sequence (14.42 t ha^{-1}) at second rank, SPW (13.53 t ha^{-1}), and SWG (13.39 t ha^{-1}) which were at third and fourth position, respectively along with MW (13.73 t ha^{-1}) on the Tukey ranking. The crop sequences, SMuG (11.59 t ha^{-1}) and SW (10.85 t ha^{-1}) were the lowest ranking crop sequences for WEY. Maize-based crop sequences recorded higher WEY ($13.73\text{--}16.49 \text{ t ha}^{-1}$) than sorghum-based crop sequences ($10.85\text{--}13.53 \text{ t ha}^{-1}$). This clearly showed that maize-based cropping system was a more efficient production system.

Land use efficiency (LUE)

Land use efficiency determines the percent of time land was cultivated with crops so that barren percent area can be reduced. Low LUE refers to that, crop can be taken in a short period whereas high LUE indicates coverage of land most of the time and thereby reducing the erosion losses. In this study, MWG showed maximum LUE (87.67%) followed by MMuG (83.56%) whereas the lowest was recorded in SW (63.56%). As sorghum was harvested as fodder at 50 % flowering, sorghum-based crop sequences showed lower LUE (63.56–82.74%) as compared to maize-based rotations (68.41–87.67%).

Production efficiency (PE)

MPW ($56.87 \text{ kg ha}^{-1} \text{ day}^{-1}$) and MW ($54.90 \text{ kg ha}^{-1} \text{ day}^{-1}$) exhibited similar PE values but were significantly ($P = < 0.001$) higher than other crop sequences. MWG also showed significantly lower PE than earlier mentioned rotations but was higher ($P = < 0.001$) than all other crops sequences except SPW. The lowest PE was obtained by SMuG ($40.39 \text{ kg ha}^{-1} \text{ day}^{-1}$) crop sequence, which was significantly lower ($P = < 0.001$) than all other crop sequences. Maize-based crop sequences exhibited higher PE ($47.3\text{--}56.9 \text{ kg ha}^{-1} \text{ day}^{-1}$) than sorghum-based crop sequences ($40.4\text{--}49.8 \text{ kg ha}^{-1} \text{ day}^{-1}$) which clearly indicated an efficient production system with Maize (Fig. 3).

Sustainable value Index (SVI)

The sustainable value index determines returns available with minimum fluctuations over the period. Crop sequence SMG (0.96) and MWG (0.95) showed maximum SVI as compared to other crop rotations. In contrast, the lowest SVI was

obtained with MW rotations (0.89). All the sorghum and maize-based crop sequences produced better SVI indicating that these cropping sequences can be good alternative options in place of rice for the farmers.

Gross returns and margins

MPW (3671.7 \$ha⁻¹) and MWG (3598.9 \$ha⁻¹) recorded significantly ($P = < 0.001$) higher total returns, compared to all other crop rotations. Whereas, lowest total returns were earned in SW (2415 \$ha⁻¹) and SMuG (2580\$ha⁻¹) crop sequences, which were significantly ($P = < 0.001$) lower than all other sequences. The maximum cost of cultivation (SPW = 2590 \$ ha⁻¹ and MPW = 2582 \$ ha⁻¹) was incurred in crop sequences where potato crop was a component and minimum in SW (1684 \$ ha⁻¹) and MW (1676 \$ ha⁻¹) crop sequences, which showed only 200% crop intensity. MWG recorded maximum net return (1577.1 \$ ha⁻¹), which was significantly ($P = < 0.001$) higher than all other crop rotations and 115.59 % higher than SW crop sequence. The next best-earning crop rotations were MW (1379.4 \$ha⁻¹) and MMuG (1287.7 \$ha⁻¹), which were statistically at par. On the other hand, significantly ($P = < 0.001$) lowest net return of 422.6 \$ ha⁻¹ was obtained in SPW rotation. Maximum benefit: cost ratio was obtained for MW (1.82) and MWG (1.78), which was significantly ($P = < 0.001$) higher than other crop sequences. In contrast, the lowest B: C ratio was obtained for SPW (1.16) rotation, which was significantly ($P = < 0.001$) lower than all other crop sequences in this study. In general, maize-based crop sequences have shown higher total return, net return, and B: C ratio than sorghum-based crop sequences owing to their higher productivity (Fig. 3).

Soil fertility

Maximum pH was recorded in MPW (8.42) rotation alone after four cycles of crop sequence, which was higher while most of the rotations reduced the pH compared to the initial level. There was no significant difference in EC level and available P among the cropping sequences. Organic carbon and available N were significantly ($P = < 0.001$) higher in the crop sequences where green gram was included as one of the components crops either in sorghum or in maize-based crop sequences. After four crop cycles, the MMuG crop sequence recorded 28.65% and 34.91% higher organic carbon and available N as compared to the initial soil level, respectively. MMuG and SWG recorded significantly ($P = < 0.001$) higher available K as compared to other crop sequences. The former one recorded almost 25.16 % higher available K in soil than the initial level (Fig. 4).

Discussion

System productivity plays an important role in the comparison of various cropping sequences. MPW and MWG cropping systems recorded 51.99% and 48.98% higher WEY, respectively as compared to the lowest SW treatment. Generally, when cropping intensity increased from 200–300% by taking three crops in a year this increases WEY. Earlier, in a study, (Chauhan et al. 2001) reported that the inclusion of potato as one of the component crop in between the rice and late wheat enhances the system productivity significantly. In a similar kind of study, (Bhargavi and Behera 2019) observed that diversified cropping systems like maize–pea–okra, maize–mustard–green gram, and cotton–wheat under marginal farmer's situations produced higher system productivity. Diversified cropping systems enhanced crop productivity across rotation as compared to the less diversified systems. A meta-analysis of 45 studies in China, (Zhao et al. 2020) found that rotations increase crop productivity up to 20% as compared to continuous monoculture. Growing of pulse crop cowpea after wheat increased the crop productivity of rice up to 8.35 % (Tripathi et al. 2019). In a study of cereal and legume intercropping by using ¹⁵N isotopes authors (Jensen et al. 2020) reported that cereal benefits more when grown in association with legumes and N requirement can be reduced by 26% on a global scale basis.

Increasing cropping intensity from 200–300% also enhances land use efficiency. MWG and MMuG are having 300% cropping intensity and showed up to 87.67% LUE, which was the maximum under the study. Even, 200% cropping

intensity rotation like sorghum - berseem showed 78.35% LUE due to the long duration of berseem owing to repeated cutting for fodder (Singh et al. 2008). Four crops i.e. rice-vegetable pea-wheat-green gram grown in a year showed more than 96% LUE (Tripathi and Singh 2007). Therefore, this whole system depends upon the number of crops grown in a calendar year and their duration.

Production efficiency i.e. yield per unit area and per unit time of MPW crop sequence was maximum. The inclusion of potato in the cropping system enhances the PE (Singh et al. 2011). Differences in PE among rotations was reported by (Tripathi 2008) where authors elaborated that it is not governed by the number of crops grown in a calendar year but an efficient production system for the economic yield. The sustainability of the cropping system can be determined by SVI and in this study higher SVI was obtained by SMuG and MWG cropping sequences. Intensification of the rice-wheat system by inclusion of green gram leading to enhanced sustainability and PE was also reported previously (Chauhan et al. 2001; Tripathi et al. 2004).

Maize-based crop sequences recorded a higher total return, net return, and B: C ratio than sorghum-based crop sequences. This showed that maize is more productive and profitable than sorghum, which was taken as a fodder crop. In a study of maize-based crop sequences, it was observed by various authors (Gangwar and Singh 2011; Meena et al. 2015; Bhargavi and Behera 2019) that maize-based systems resulted in higher net return as compared to rice-wheat system. Another way to enhance the economic return is to intensify the rice-wheat system by the inclusion of pulses so that 300 % cropping intensity could be maintained (Tripathi 2008; Jat et al. 2012; Tripathi et al. 2019). In another study, the inclusion of green gram in the MWG crop sequence enhanced the net return by 14.33% as compared to MW rotation while Choudhary et al. (2018) also observed that the inclusion of green gram in cereal systems contributed to a 15% increase in profitability. Inclusion of potato in the crop rotation increases the cost of cultivation due to its tuber cost and thereby net return and B: C ratio is lower as compared to other maize-based crop sequences. This finding is in agreement with earlier observation (Chauhan et al. 2001).

MMuG crop sequence exhibited 28.65% and 34.91% higher organic carbon and available N as compared to pre-experiment levels which were 0.36 % OC and 115.22 kg ha⁻¹ available N. This revealed that continuous growing of pulses and incorporating their residue enriches the soil as well as brings pH towards neutrality. An increase in soil health in the form of higher organic carbon by the cultivation of a pulse crop was previously studied by different researchers (Beri et al. 1989; Kharub et al. 2003; Singh and Sidhu 2014; Tripathi et al. 2019; Singh et al. 2020). Growing green gram, cowpea, and vegetable pea increased the organic carbon content by 42.89%, 16.38%, and 4.57 %, respectively in a span of eight years (Tripathi et al. 2019). In the post rainy season, there is a demand for green fodder, which can be fulfilled with sorghum-based crop sequences like rice–sorghum–green gram. This will provide a nutritious diet to the family while maintaining soil fertility through the inclusion of legumes (Jat et al. 2012).

Conclusions

To bring out a sustainable and profitable solution for the challenges posed by the rice-wheat cropping system leading to air pollution and decline in soil health, diversification and/or intensification of the system was tested for four years. The results revealed that there is sufficient scope to replace the rice-wheat cropping system with other cropping systems without any decline in economic yield rather it improved substantially. System productivity in terms of wheat equivalent yield was maximum for the maize-potato-wheat (16.49 t ha⁻¹) and maize-wheat- green gram (16.17 t ha⁻¹) rotations. Maize-wheat- green gram (87.67%) showed maximum land use efficiency; maize-potato-wheat (56.87 kg ha⁻¹ day⁻¹) produced maximum production efficiency; sorghum-mustard green gram (0.96) and maize-wheat green gram (0.95) recorded maximum sustainable value index; maize-wheat green gram recorded maximum net return (1577.1 \$ha⁻¹), which was 115.59 % higher than sorghum-wheat. Comparison between maize and sorghum-based crop sequences showed that maize-based crop sequences recorded higher total return, cost of cultivation, net return, and B: C ratio than

sorghum-based. Maize-mustard green gram cropping system increased the organic carbon content by 28.65% and available N by 34.91% as compared to the initial soil level. Therefore, maize-based crop sequences can fit well in replacing the rice crop and simultaneously increasing productivity and profitability, and enhancing efficiency in a sustainable manner.

Declarations

Authors contribution

S C Tripathi- Conduction of experiment, data recording, drafting and editing of manuscript

Karnam Venkatesh- Data analysis and editing of manuscript

Raj Pal Meena- Review and literature, editing of manuscript

Availability of data and material

All the data will be available if request is made.

Code availability

Project No. CRSCIWBSIL201500800189

Ethics approval

All authors approve ethical responsibilities related with this manuscript.

Consent to participate

All authors give their consent to participate.

Consent for publication

All authors give their consent for publication in Theoretical and Applied Climatology.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Figures

Figure 1

Maximum and minimum temperature and rainfall during the crop years. LPA: Long period average (1972-2020)

Figure 2

Year effect on system productivity, efficiency and profitability. Note: Alphabet(s) following the mean values is based on Tukey's test of significance. Mean values followed by same letters are not significantly different at 0.001 probability level

Figure 3

Variation in wheat equivalent yield, land use efficiency, production efficiency and sustainable value index under different cropping systems Note: Alphabet(s) following the mean values is based on Tukey's test of significance. For each treatment mean values followed by same letters are not significantly different at 0.001 probability level

Figure 4

Soil fertility status after four crop cycles under different cropping systems Note: Alphabet(s) following the mean values is based on Tukey's test of significance. For each treatment mean values followed by same letters are not significantly different at 0.001 probability level