Indian Journal of Agricultural Sciences **87** (10): 1277–82, October 2017/Article
https://doi.org/10.56093/ijas.v87i10.74793

Research Articles

Rice (*Oryza sativa*) – potato (*Solanum tuberosum*) based cropping sequences in relation to production potential and economic returns under irrigated ecosystem of central plains

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Received: 15 April 2017; Accepted: 05 July 2017

ABSTRACT

Rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) is the most important cropping system in India. It occupies 10.5 m ha productive lands in Indo-Gangetic plains and contributes about 25% of the national food production which accounts for 25% and 40% of the total area under rice and wheat, respectively. In some part of Indo-Gangetic plains, potato is being used as sandwich crop in rice-wheat cropping system by small and marginal farmers to increase the cropping intensity and net profits. Introduction of potato (*Solanum tuberosum* L.) into cropping system increased the productivity of the cropping system in many areas due to higher yield. To further increase the sustainability and profitability of the system, other high value crops can also be included in the system. Results showed that rice-potato-onion (534.08 q/ha), rice-potato-Japanese mint (501.46 q/ha), rice-potato-bitter gourd (484.38 q/ha) and rice-potato-bottle gourd (461.68 q/ha) crop sequences were statistically at par, however, produced significantly higher potato equivalent yield than rice-wheat (224.46 q/ha), rice-potato-wheat (325.50 q/ha) and rice-potato-greengram (399.75 q/ha) crop sequences. The present study indicated that the rice-potato-Japanese mint and rice-potato-onion crop sequences were more productive and economically viable as they fetched more net returns and can be a better option for the farmers of the Central Plains zone of India, and the same cropping sequences were also adjudged as most sustainable by the farmers in their agricultural production system.

Key words: Economic returns, Potato-based cropping systems, Production efficiency, Productivity potential, Sustainability

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) is the most important cropping system in India (Prasad 2005). It occupies 10.5 m ha productive lands in Indo-Gangetic plains and contributes about 25% of the national food production (Ladha *et al*. 2000). Because of high productivity, stability and less risk, the wide adoption of this system will also play a major role in future planning to sustain self sufficiency of food grains in the years to come (Singh *et al.* 2012). The role of balanced fertilization in rice-wheat cropping system has been well documented (Rattan and Singh 1997). Also factor productivity trends have been worked out in a rice-wheat cropping system under long-term use of chemical fertilizers (Yadav 1998). However, now sustainability of rice-wheat cropping system has been questioned with yield stagnation (Busari *et al.* 2015).

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The main reason behind yield stagnation and declining soil productivity of the rice-wheat system is attributed to the monotony of the system as well as the over exhaustive nature of the cereal–cereal crop sequence and huge exploitation of the soil resource base coupled with imbalanced use of inputs. India faces the challenge of a burgeoning population and increasing demand for food, fibre and fuel. Crop intensification is a well-recognized solution for increasing productivity in a system (Gangwar and Katyal 2001). Food of the future, potato (*Solanum tuberosum* L.) holds a potential for higher quantity and quality produce per unit area besides spanning over a short duration of 60-80 days (Rawal *et al.* 2003). Introduction of potato in rice–wheat cropping system signifies the sequence of crops grown over a specific piece of cultivated land and also to increase the benefits from the available physical resources. Therefore, the basic approach in an efficient cropping system is to increase production and economic returns (Yadav *et al.* 1998). However, more than 80% of the potato crop is raised in the Indo-Gangetic plains during winter season from October to March. Potato is a unique crop and can be cultivated early or late depending upon market prices and requirement of field for subsequent crop. Potato produces almost 2-3 times more dry matter and edible energy per unit area and time than cereal crops like wheat and rice and thus augments the productivity of any potato-based cropping system. In some part of Indo-Gangatic plains, potato is being used as sandwich crop in rice-wheat cropping system by small and marginal farmers as cash crop for increasing cropping intensity. Introduction of potato into cropping system increased the productivity of the cropping system in many areas due to higher yield of potato. Hence, it is need of the hour for crop intensification and diversification to make farming sustainable and economically viable. Therefore, the present study was attempted to evaluate existing rice-potato based crop sequences versus rice-wheat cropping systems in Lucknow district of India's Central Uttar Pradesh.

MATERIALS AND METHODS

Potentially existing rice-potato based cropping sequences were evaluated for the two consecutive seasons of 2012–13 and 2013–14 using a participatory approach on farmers' fields in the five villages, viz. Ahamadpurkhera, Digoi, Bhagwatipur, Bikamau in the Lucknow district of India's Central Uttar Pradesh. The objective was to identify the biologically and economically most efficient and sustainable crop sequence(s) for the farmers of this region. In an interactive session, farmers of the village were informed about the objective of on-farm trials and 5 farmers mutually agreed to make their land available and participate in activities of the experiment. The soil of the experimental site had been under rice-wheat cropping system, and was classified as loamy sand to sandy loam, having pH between 7.2 to 7.4, organic carbon 0.40 to 0.46%, and N, P_2O_5 and K_2O were 225–260, 60–84 and 238–260 kg/ha, respectively. The experimental site was located at 26° 56′ N longitude, 80°52′ E latitude, and 111 m above mean sea level with a semi-arid and sub-tropical climate with dry hot summers and cold winter. Before the planting of experimental crops, soil samples were collected from 0 to 15 cm depth with a core sampler of 8 mm diameter from 5 plots in the field. The samples were pooled together and represented a homogenized sample drawn for determination of organic carbon (Walkley and Black method), available N ($KMnO_4$ method), 0.5 m sodium bicarbonate-extractable P, and 1 N NH_4OAC- extractable K following the method as advocated by Jackson (1973). This process was carried out before the start of the experiment in June, 2012-2013 and at the end of experiment in June, 2013-2014 after completion of crop cycles. The treatments comprised seven rice-potato based cropping sequences, viz. T_1, rice (Arize 6444)-wheat (PBW 550); T_2 , rice (cv. NDR-97)- potato (Kufri Ashoka)– wheat (Unnat Halana); T_3, rice (NDR 97)–potato (Kufri Anand)-Japanese mint (Koshi); T_4, rice (NDR 97)–potato (Kufri Anand)-bitter gourd (Priya); T_5, rice (NDR 97)–potato (Kufri Anand)-green gram (PDM 11); T_6, ri ce (NDR 97)–potato (Kufri Anand)–bottle gourd (Narendra Rashmi) and T_7: rice (NDR 97)–potato (Kufri Anand)–onion (Agrifound dark red). All the crops under the above seven rice-potato based cropping sequences were chosen on the basis of their prevalence in the region. The rice–potato system is the major cropping sequence in the *Bakshi ka talab* tehsil while the other crops, viz. greengram, cucurbits, onion and mentha, are also taken by the farmers after harvesting of potato in summer season (*zaid*). The fitness of these crops in rice-potato based cropping system in the region is situation specific and also on the basis of choice and need of the farmers. Some of the farmers take only rice-wheat annually; there is need to diversify by including potato and vegetables in this existing system. The potato, a popular crop of the region, is taken after rice crop in succession in rice-wheat cropping system. Thus, there were seven rice-based cropping sequences formulated in the present study. However, a focus group discussion was also done with the farmers of the village to list important and prevalent rice-potato based cropping sequences. As a result, three cropping sequences, namely, T_1, T_2, T_3, emerged as most practiced systems in the village. At the same time, group consensus took place for the evaluation of existing cropping sequences including bottle gourd and bitter gourd, green gram and onion as *zaid* crop in rice-potato based cropping sequences and accordingly farmers agreed upon to record data after conducting participatory on-farm trials for assessing productivity, profitability, and sustainability of these seven crop sequences in the system.

The recommended doses of fertilizers, viz. N, P_2O_5 and K_2O was applied to all the crops in different crop sequences as well as details of planting/sowing and harvesting dates are given in Table 1. The plot size was 1000 m^2 and the experiment of each individual farmer field constituted one replication of a randomized block design laid out at five farmers' fields for each cropping sequence. The experiment was laid out at the same site each year. All recommended packages of practices were followed to raise the crops in different cropping sequences. Economic yields of component crops were converted into potato equivalent yield (PEY), taking into account the prevailing market prices of different crops. The above values were computed as per the formula given by Verma and Modgal (1983).

Production-efficiency values (kg/ha/day) were worked out for the total production by means of potato equivalent yield in a crop rotation divided by total duration of crop in that rotation. Land-use efficiency was obtained by taking total duration of crops in an individual crop rotation divided by 365 days. The values of production efficiency in terms of income net return (₹/ha/day) were calculated by net monetary returns of the rotation divided by total duration of the crop in that rotation (Tomar and Tiwari 1990). The oil of mentha (the above ground part of herb) was obtained by steam distillation at the experimental site itself. The data of each crop season were statistically analyzed separately. The homogeneity of error variance was tested using Bartlett's test. As the error variance was homogeneous, pooled analysis was done according to Cocharan and Cox (1957). Since the variation between the two seasons was not significant, the mean data of the two crop seasons are presented here

Table 1 Details of potato-based cropping sequences

Cropping sequences*	Nutrient (kg/ha)			Transplanting/planting/sowing date						Harvesting date						Mean duration (days)
	Kharif	*Rabi*	*Zaid*	*Kharif*		*Rabi*		*Zaid*		*Kharif*		*Rabi*		*Zaid*		
	$N:P_2O_5:K_2O$	$N:P_2O_5:K_2O$	$N:P_2O_5:K_2O$	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	
T_1	150:60:60	150:60:60		01:07:13	05.07.14	20.11.13	20.11.14			25.10.13	29.10.14	03.04.14	04.04.15			271
T_2	120:60:60	175:80:100	120:60:60	01:07:13	30.06.14	10.10.13	10.10.14	25.12.11	26.11.12	30.09.13	30.09.14	25.12.14	25.12.15	15.04.14	15.04.15	285
T_3	120:60:60	175:80:100	100:50:50	01.07.13	01.07.14	05.11.13	05.11.14	28.02.12	28.02.13	30.10.13	30.10.14	15.02.14	15.02.15	15.06.14	15.06.15	344
T_4	120:60:60	175:80:100		01.07.13	03.07.14	10.11.13	10.11.14	0.3.03.11	03.03.11	02.11.13	02.11.14	20.02.14	20.02.15	15.05.14	15.05.15	315
T_5	120:60:60	175:80:100	100:50:50	01.07.13	03.07.14	05.11.13	05.11.14	14.01.12	14.01.13	31.10.13	31.10.14	15.02.14	15.02.15	20.06.14	20.06.15	349
T_6	120:60:60	175:80:100	100:50:50	01.07.13	03.07.14	05.11.13	05.11.14	14.01.12	14.01.13	31.10.13	31.10.14	15.02.14	15.02.15	20.06.14	20.06.15	349
T_7	120:60:60	175:80:100	150:100:50	01.07.13	03.07.143	05.11.13	05.11.14	10.02.11	10.02.12	31.10.13	31.10.14	09.02.14	09.02.15	15.06.14	16.06.15	345

*T1, Rice-Wheat; T2, Rice-Potato-Wheat; T3, Rice-Potato- Japanese mint; T4, Rice-Potato-Greengram; T5, Rice-Potato-Bottlegourd; T6, Rice-Potato-Bittergourd; T7, Rice-Potato-Onion

for discussion. Various treatments were compared under a randomized block design. The critical difference (CD) was computed to determine statistically significant treatment differences.

In a focus group discussion with farmers of the village, 10 dimensions of sustainability for agricultural practices were discussed (Yadav *et al*. 2007), viz. technological appropriation, economic viability, environmental soundness, socio-cultural compatibility, stability, resource-use-efficiency, productivity, local adaptability, equity and Government policy, and thereafter six dimensions (technological appropriateness, economic viability, environmental soundness, socio-cultural compatibility, productivity and local adaptability) were agreed upon by the farmers to assess the sustainability of the seven potato based cropping sequences on which participatory on-farm trials were undertaken. A matrix ranking exercise with seven selected farmers was done. In this exercise, each farmer was asked to weigh using a scale of 1 to 5 every sustainability dimension for all the seven cropping sequences under study. The total sustainability score for the respective cropping sequence was calculated by adding scores obtained against the components of sustainability dimension. Finally on the basis of the sustainability score, cropping sequences were ranked.

RESULTS AND DISCUSSION

System productivity

Two years (2011 and 2012) data showed that all cropping sequences under the study were significantly different from the general practice of the farmers as a control (T_1: rice-wheat). Among them, four emerging cropping sequences namely rice-potato-Japanese mint (T_3), rice-potato-bottle gourd (T_5), rice-potato-bitter gourd (T_6) and rice-potato-onion (T_7) were performed statistically at par in relation to mean potato equivalent yield. Of which rice-potato-onion (T_7) produced significantly highest potato equivalent yield (534.08 q/ha) followed by the treatments T_3, T_6, T_5, T_4, T_3 and the lowest in T_2 (rice-potato-wheat). Diversification and intensification of cropping systems led to increase in potato equivalent yield by 45% (T_2) - 138% (T_7) in the tested cropping sequences (Table 2) compared with conventional rice-wheat cropping system (T_1) used by majority of farmers in the region. Production efficiency (kg/ha/day) also exhibited almost similar trends as that of potato equivalent yield, and observed maximum in cropping sequence rice-potato-onion (155, T_7) closely followed by T_3 (146), T_6 (139), T_5 (133), T_4 (127), T_2 (114) and the lowest under rice-wheat (83, T_1, control) cropping sequences. Land use efficiency (%) was observed as T_5 (96%), T_6 (96%), T_3 (95%), T_7 (95%), T_4 (87%) and T_2 (78.1%) in comparison with control (T_1, 75%). Inclusion of potato in any of the above crop sequences proved beneficial for enhancing the productivity and profitability of the system. This may be attributed due to deep hoeing of the field because of ridge planting and hilling up, as well as the digging of potato

Table 2 Yield, production efficiency and land utilization efficiency of potato-based cropping sequence

Cropping sequence*	Yield (q/ha)						PEY (t/ha)		Mean potato equivalent yield (q/ha)	Production efficiency (kg/ha/ day)	Land- use efficiency (%)	Increase over rice-wheat system (%)
	Kharif		*Rabi*		*Zaid*							
	2011	2012	2011	2012	2011	2012	2011	2012				
T_1	60.6	65.4	48.5	49.6			223.30	225.62	224.46	83.0	75.0	
T_2	45.6	44.2	165.6	170.6	34.5	36.0	442.64	328.29	325.50	114.0	78.1	45.0
T_3	44.6	43.6	268.5	270.6	1.22	1.32	499.33	503.58	501.46	146.0	95.0	124.0
T_4	45.2	46.5	278.5	265.3	08.00	07.00	408.17	391.33	399.75	127.0	87.0	78.0
T_5	43.6	42.6	259.5	248.4	152.5	145.3	471.28	452.07	461.68	133.0	96.0	106.0
T_6	47.2	43.2	265.4	274.2	126.5	135.6	478.56	490.03	484.38	139.0	96.0	116.0
T_7	44.5	47.8	274.5	265.3	208.40	210.60	535.78	532.37	534.08	155.0	95.0	138.0
CD (P=0.05)	NS	NS	35.6	39.4			46.50	54.60	61.20	11.23	7.80	8.6

*T1, Rice- Wheat; T2, Rice-Potato-Wheat; T3, Rice-Potato- Japanese mint; T4, Rice-Potato-Greengram; T5, Rice-Potato-Bottle gourd; T6, Rice-Potato-Bitter gourd, T7, Rice-Potato-Onion

tubers, which caused better soil aeration and weed-free conditions for the bottle gourd, bitter gourd, Japanese mint, green gram and onion crops. Apart from this, it is also documented that being shallow rooted crop, potato is not able to use the full fertilizers dose and leaves sufficient portion for the subsequent crops. Verma and Yadav (1988) also indicated the favourable influence in having potato in the sequential cropping system. Further, long-term fertilizer experiments in India have been reviewed by Nambiar and Abrol (1992).

Economic analysis

A perusal of two years mean data as summarized in Table 3 revealed that the highest net returns (₹ 211 319/ha) was obtained with rice-potato-Japanese mint (T_3) followed by rice-potato-onion (T_7) (₹ 196 946/ha), T_6 (₹ 160 892 /ha), T_2 (₹ 159 848/ha), T_5 (₹ 156 796 /ha) and T_4 (155 919) compared with the control, rice-wheat (T_1) cropping sequence (₹ 94 622 /ha). The higher net returns as obtained from any cropping sequence with potato was apparently due to higher potato equivalent yields on account of improved production potential of the system, which fetched higher economic gains. However, the benefit to cost ratio was highest (2.52) in rice-potato-Japanese mint (T_3) followed by rice-wheat (T_1, 2.51), rice-potato-green gram (T_4, 2.20), rice-potato-onion (T_7, 2.10), rice-potato-wheat (T_2, 2.06), rice-potato-bitter gourd (T_6, 1.92) and rice-potato-bottle gourd (T_5, 1.90). This variation noticed may be due to different cost of cultivation in descending order such as T_1 (₹ 62 500/ha), T_4 (₹ 129 800/ha), T_3 (₹ 138 200/ha), T_2 (₹ 150 000/ha), T_5 (₹ 173 100/ha), T_6 (₹ 174 100/ha) and maximum in T_7 (₹ 178 100/ha). Production efficiency in terms of income net return (₹/ha/day) was the highest (₹ 579.0) under rice-wheat-Japanese mint (T_3) followed by the rice-potato-onion cropping sequence (₹ 539.57) (T_7) and the lowest in rice-wheat (T_1) cropping sequence.

Soil fertility status

The surface soil (0–15 cm) analysis after two crop cycles showed a decline in available N from 210 to 185 kg/ha except in rice-potato-wheat cropping sequence (245 kg/ha), while K declined from initial 259 to 216 kg/ha in all cropping sequences. However, increase in available P content in the surface soil ranged from 8.3-47.6 % in different cropping sequences (Table 4). The decline was higher in systems involving sequences, i.e. rice-wheat (18.5%), rice-potato-wheat (15.3%), rice–potato–Japanese mint (15.8%), rice–potato–bitter gourd (11.3%), rice–potato–

Table 3 Economics of potato based cropping sequences (Mean data of two years)

Cropping sequences*	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Benefit:cost ratio	Production efficiency (₹/ha/day)
T1: Rice-Wheat	62500	157122	94622	2.51	₹ 259.2
T2 : Rice-Potato-Wheat	150000	309848	159848	2.06	₹ 437.9
T3: Rice-Potato-Japanese mint	138200	349531	211331	2.52	₹ 579.0
T4: Rice-Potato-Greengram	129800	285719	155919	2.20	₹ 427.2
T5: Rice-Potato-Bottle gourd	173100	329896	156796	1.90	₹ 429.6
T6: Rice-Potato-Bitter gourd	174100	334992	160892	1.92	₹ 440.8
T7: Rice-Potato-Onion	178100	375046	196946	2.10	₹ 539.6

Table 4 Effect of potato based cropping sequences on soil fertility after two years

Cropping sequences	Soil fertility (0-15 cm)						
	Organic carbon (%)	Nitrogen (N)		Phosphorus (P)		Potassium (K)	
		N (kg/ha)	% increase (↑) or decrease (↓)	P (kg/ha)	% increase	K (kg/ha)	% decrease
Initial (June 2012)	0.35	210		22		259	
T1: Rice-Wheat	0.28	185	13.51 ↓	24	8.3	216	18.5
T2 : Rice-Potato-Wheat	0.36	245	14.30 ↑	36	38.9	222	15.3
T3: Rice-Potato-Japanese mint	0.28	204	2.8 ↓	34	35.30	221	15.8
T4: Rice-Potato-Greengram	0.33	206	1.9 ↓	40	45.0	232	10.3
T5: Rice-Potato-Bottle gourd	0.32	208	0.96 ↓	39	43.6	234	09.4
T6: Rice-Potato-Bitter gourd	0.32	204	2.8 ↓	36	38.9	230	11.3
T7: Rice-Potato-Onion	0.34	202	3.8 ↓	42	47.6	231	10.8
CD (P=0.05)	NS	NS		9.9		NS	

Table 5 Sustainability score of potato-based cropping sequences

Sustainability dimension	Pooled score of five farmers on cropping sequences							Total score	Rank
	Rice-wheat	Rice-potato-wheat	Rice-potato-Japanese mint	Rice-Potato-Green gram	Rice-Potato-Bottle gourd	Rice-Potato-Bitter gourd	Rice-Potato-Onion		
Technical appropriateness	6	15	20	9	19	15	19	103	II
Economic viability	7	13	20	15	14	15	21	105	I
Environmental soundness	10	11	12	17	15	15	13	93	V
Socio-cultural compatibility	7	14	21	10	14	18	19	103	II
Productivity	6	13	14	11	16	13	21	94	IV
Adoptability	11	18	20	8	15	13	16	101	III
Total score	44	84	107	70	93	89	109		
Rank	VII	V	II	VI	III	IV	I		

onion (10.8%), rice-potato-green gram (10.3%) and rice–potato–bottle gourd (9.4%). Other cropping sequences involving rice, wheat and Japanese mint in the potato based cropping systems showed a higher decline as compared to pulses and vegetables (Table 4). Available N in soil tended to slightly decrease from the initial values in surface soil, however, this decrease was minimum where the crop of potato was included in different potato-based cropping systems (Table 4). Balloli *et al.* (2000) reported that increasing duration of continuous practicing of rice-wheat system from 5 to 15 years resulted in the depletion of organic carbon, N and K, however, it showed an increase in the amount of available P.

Sustainability of cropping sequences

Pooled scores of seven farmers for each of the sustainability dimensions against every cropping sequence are presented in Table 5. It is evident that the rice–potato–onion sequence was ranked first on the sustainability index with a total sustainable score of 109 followed by rice–potato–Japanese mint (107; T_3), rice–potato–bottle gourd (93; T_5), rice–potato-bitter gourd (89; T_6), rice-potato-wheat (84; T_2), rice-potato-green gram (70; T_4) and rice–wheat– (44; T_1) cropping sequences at II, III, IV, V, VI, and VII rank on the sustainability index, respectively. Farmers rated rice-potato-onion (T_7) and rice-potato-Japanese mint (T_3) as the most sustainable crop sequences in their system due to fitness in terms of economic viability, productivity, environment soundness, adaptability and technological appropriateness in local agricultural production systems (Table 5).

Thus, it may be concluded from the study that the rice-potato-Japanese mint (T_3) and the rice-potato-onion (T_7) crop sequences are more productive, economically viable and sustainable crop sequences in rice-potato-based cropping system.

ACKNOWLEDGEMENT

The authors are thankful to the Director, ICAR-Indian Institute of Sugarcane Research, Lucknow, India for providing necessary facilities, and also to Deepak Rai and Veenika Singh, from KVK-Indian Institute of Sugarcane Research, Lucknow, India for extending technical assistance during the course of study.

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