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Alternate cropping systems to rice (*Oryza sativa*)-wheat (*Triticum aestivum*) for Punjab

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ABSTRACT

A field experiment was conducted from 2006-07 to 2008-09 at Punjab Agriculture University, Ludhiana, centre of AICRP on Cropping Systems to evaluate the effect of 10 crop sequences on productivity, profitability, weed population and soil fertility. Maximum rice (*Oryza sativa* L.) equivalent yield was recorded by maize (*Zea mays* L.)-potato (*Solanum tuberosum* L.)-onion (*Allium cepa* L.) (32.0 t/ha) followed by summer groundnut (*Arachis hypogaea* L.)-potato-bajra (*Pennisetum glaucum* L.) (fodder), and maize-potato-summer moongbean (*Vigna radiata* L. Wilczek) cropping systems. These cropping systems produced an additional rice equivalent yield of 10.0 to 19.1 t/ha and saved 75.6 to 122.3 cm irrigation water over the rice-wheat system. The highest energy production was with maize-wheat (*Triticum aestivum* (L.) Fiori & Paol]-moonngbean (43.7 X 10^6 K.cal) whereas the production efficiency (98.8 kg/day/ha) and net returns (₹1.65 × 10^5) were highest in maize-potato-onion cropping system. The population of *Phalaris minor* was lower in all the cropping systems when compared with the rice–wheat system. The maize based cropping system showed positive influx of N, P and K over initial values.

Key words : Cropping systems, Productivity, Soil fertility, Soil micro-fauna

Rice-wheat cropping system occupies an area of 10.5 m ha in the Indo-Gangetic Plains of India, out of which 2.6 m ha area is in Punjab. The over exploitation of the underground water resources to meet the water requirement of the rice has resulted in the declining watertable (74 cm/ year in Central Punjab) which has become the serious concern during these days. Growing of crops in a sequence and to study their interaction effects with the available resources and technology on the farm is the common feature of cropping system research. Inclusion of pulses, oilseeds and vegetables in the system is more beneficial than cereals after cereals, and such inclusion in a sequence changes the economics of the crop sequences. (Gangwar *et al.,* 2004). The continuous cropping of rice-wheat system during last four decades has been causing many second generation problems, *viz.* emergence of multi-nutrient deficiencies, formation of hard pan, declining factor productivity and build up of problematic weeds like *Phalaris minor* in wheat. Moreover, stagnation in system productivity and profitability and decline in soil productivity have been experienced in recent years. The new policies of open economy have also paved the way for export of some quality food materials including vegetables. Higher productivity with sustainability remains the major concern of any crop planning. Any system which requires less input and contributes more is considered to be the efficient. Therefore, the present experiment was conducted to find out the possibility of diversification in traditional rice-wheat cropping system in view of sustainability, soil health and economics.

MATERIALS AND METHODS

The study was conducted at Punjab Agricultural University, Ludhiana centre of All India Co-ordinated Research Project on Cropping Systems from 2006-07 to 2008-09. The soil was sandy loam in texture and classified as Typic Ustrochrept having pH 7.2, EC 0.40 dS/m, organic C 0.53 % and available N 186 kg/ha, P 44 kg/ha and K 132 kg/ha, respectively. Ten cropping systems were evaluated for their production potential and economics, *viz.,* S_1, rice ‘PR 114’ wheat ‘PBW 343’; S_2, maize ‘Paras’ wheat; S_3, maize-wheat-summer moongbean ‘SML 668’; S_4, maize-potato ‘Kufri Chandermukhi’-summer moongbean; S_5, maize-potato-onion ‘Punjab Naroya’; S_6, Cotton ‘LH 1556’ (*Gossypium hirsutum* L.)-wheat ‘PBW 373’; S_7, Cotton-African sarson ‘PC 5’ (*Brassica carinata* A. Braun); S_8, Cotton-*Gobhi sarson* transplanted ‘GSL 1’ (*Brassica napus* sub sp. *Oleifera* var. *annua*); S_9, Summer groundnut ‘M 522’ Toria ‘TL 15’ (*Brassica rapa* var.

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toria) + *gobhi sarson*; S_{10}-, Summer groundnut-potato-pearlmillet 'PCB 15' (*Pennisetum glaucum* L.). A randomized-block design was followed with four replications. For comparison between crop sequences, the yields of all the crops were converted into rice equivalent yield on price basis. The mean data of three years were analysed for computing stability indices as per the Katyal *et al.* (1999). Mean of prevailing market rates from 2006-07 to 2008-09 were used for computing economic viability. The profitability of cropping systems was calculated by dividing net returns ha^{-1} in a sequence by 365 days. The benefit: cost ratios for different cropping sequences were calculated by dividing the net returns by the cost of cultivation in a system. The energies of various crops and cropping systems were calculated as described by Gopalan *et al.* (1978). The water use productivity of different cropping systems was calculated by dividing the rice grain-equivalent yield of the system by the total of average water use by different crops in the cropping system. Similarly, the nutrient use productivity was calculated by dividing the grain equivalent yield of the system with the total quantity of nutrients (N-P-K) used in different crops in the system. The detailed agronomic study followed for raising crops are given as under:

The farmyard manure @ 10 t/ha on air dry weight basis was applied to potato and onion crops. The farmyard manure contains 0.75 % N, 0.34 % P, 0.71 % K, 56 ppm Zn, 14 ppm Cu, 478 ppm Fe and 116 ppm Mn. The soil

Agronomic practices followed in different crops

Crops	Sowing/ Transplanting time	Harvesting	Herbicide application	Nutrition (kg/ha) N	P	K
Rice	4th week of June	1st week October	Pre-emergence application of Butachlor 50 EC @ 3 litres/ha	120	13	25
Maize	2-3 week of June	3-4 week of September	Pre-emergence application of Atrataf 50 WP @ 2 kg/ha in 500 litres of water	120	26	25
Groundnut	3-4 week of May	2-3 week of September	Pre-emergence application of Lasso 50 EC @ 5 litres/ha in 500 litres of water	15	9	20
Wheat	1-2 week of November (timely sown) last week of November (late sowing)	2-3 week of April	Application of Clodinafop 15 WP @ 400 g/ha in 500 litres of water, 30 to 35 days after sowing	120	26	25
Potato	2-3 week of October	1-2 week of January (in Maize-Potato-Onion); 1 week of March	Pre-emergence application of Atrataf 50 WP @ 500 g/ha in 500 litres of water	188	27	51
Onion	2-3 week of January	Mid-May	Pre-emergence application of Stomp 30 EC @ 1.8750 litres/ha in 500 litres water	100	22	41
Cotton	Last week of April	3-4 week of November	Pre-emergence application of Stomp 30 EC @ 2.5 litres/ha	75	5	-
Toria+ *Gobhi sarson* (1:1)	Mid-September	Toria: End December; Gobhi sarson: Mid April	Two hand hoeing s	138	11	5
Gobhi *sarson* (T)	Last week of November	Mid-April	Post-emergence application of Isoproturon @ 750 g/ha before first irrigation	100	11	5
African sarson	3-4 week of November	Mid-April	Pre-plant application of Trifluralin @ 1.56 litres/ha	100	11	5
Bajra (fodder)	2-3 week of March	1st week of May	Pre-emergence application of Atrataf 50 WP @ 1.250 kg/ha in 500 litres of water	50	-	-
Summer moong	4th week of March (after Potato); Mid-April (after Wheat)	Last week of June; 2nd week of June	Pre-emergence application of Basalin 45 EC @ 1.5 litres/ha	13	9	-

samples, taken for analysis from 0 to 15 cm soil layer after summer of 2008-09, were analyzed in the laboratory using standard procedures. Rapid titration method (wet digestion method) was used for organic carbon determination (Walkley and Black, 1934). Available nitrogen, phosphorus and potassium were determined by the methods described by Subbiah and Asija (1956), Olsen *et al.* (1954) and Merwin and Peech (1950) respectively. The micronutrients from soil samples were determined from 1:2, soil-extractant ratio using DTPA-TEA buffer (0.005 M DTPA + 0.001 M $CaCl_2$ + 0.1 M TEA, pH 7.3) as per Lindsay and Norvell (1978). The N, P and K content in plants was determined by the procedures given by Jackson (1973). Serial dilution plates count method was followed for determining bacterial and fungal population using soil extract agar (Lochhaed and Chase, 1943) and Rose Bengal streptomycin agar medium (Martin, 1950), respectively.

RESULTS AND DISCUSSION

Cropping systems productivity

The results revealed that there is sufficient scope to replace rice-wheat cropping system with other cropping systems without any decline in economic yield rather it improved substantially. The maize–potato-onion; summer groundnut-potato-*bajra* (fodder) and maize-potato-summer moongbean gave 32.0, 24.7 and 22.9 t/ha/annum rice equivalent yield, respectively as against 12.9 t/ha/annum (Table 2) in rice-wheat system that showed superiority of these systems over rice-wheat system. The higher rice equivalent yield in these cropping systems may be due to high yield of potato and onion crops. The addition of short duration potato crop between two crops increased the cropping system productivity. These results corroborate with Khaurb *et al.,* (2003). The maize-wheat-summer moongbean cropping system produced 3.1 t/ha/annum more rice equivalent yield when compared with maize-wheat system. The rice equivalent yields of maize-wheat, cotton-wheat, cotton-African mustard, cotton-*gobhi sarson* (transplanted) sequences were statistically at par with the prevalent rice-wheat cropping system. Cropping system groundnut-*toria* + *gobhi sarson* excelled the rice equivalent yield by 29.2% over rice-wheat system. To diversify rice-wheat system, several options are available which not only give more productivity than rice-wheat system but also ensure the rational use of resources and result in substantial saving of irrigation water. Gill and Ahlawat (2006) reported that in Punjab crops like soybean, maize, basmati rice, cotton and summer groundnut in rainy season are viable and remunerative alternatives to the nutrient and water exhaustive rice crop while crops like potato, Indian mustard, vegetable pea, grain pea, sunflower and onion, as regularly or intermittently, can substitute wheat. In *kharif*, rice was highly stable (0.97) when grown in sequence with wheat, followed by cotton when raised in sequence with *gobhi sarson* (0.92) and wheat (0.90), respectively (Table 3). The maize based cropping systems showed stability index of 0.84 to 0.90, while it was least 0.82 to 0.86 in groundnut based cropping systems. Amongst *rabi* crops, the potato was more stable with the highest stability index of 1.00 when grown after maize and groundnut and closely followed by wheat after rice (0. 98), after cotton (0.92) and after maize (0.90). Oilseed crops showed sustainability index of 0.84 to 0.96. In summer, the summer moongbean was found more stable (0.97-0.98) followed by pearlmillet fodder (0.95) and onion (0.92).

Maize-potato-onion showed the highest production efficiency (98.8 kg/day/ha), followed by summer groundnut-potato-*bajra* (fodder) system (73.8 kg/day/ha) and maize-potato-summer mungbean (73.7 kg/day/ha) (Table 2). The production efficiency for rice-wheat cropping system was 43.2 kg/day/ha and it varied from 49.0 to 98.8 in maize based cropping system; 50.3 to 73.8 in groundnut based cropping system and 34.6 to 37.0 kg/day/ha in cotton based cropping system.

The maize-potato-onion system gave the highest productivity (32.0 t/ha/annum) and energy (2329 X 10^4 K. Cal) and used 75.6 cm less water than rice-wheat system with a productivity margin of 19.1 t/ha/annum. Maize-potato-summer moongbean cropping system gave 22.9 t/ha/annum productivity and 2638 X 10^4 K. Cal energy with total irrigation water used as 105 cm; thereby indicating the net saving of irrigation water to the extent of 119.3 cm (Tables 2 and 3). The summer groundnut-potato-*bajra* (fodder) system gave 24.7 t/ha/annum productivity with 102 cm irrigation water leading to 122.3 cm saving of water.

There was a marked effect of the preceding crops on the performance of wheat (Tables 1 and 2). The wheat after maize which received 10 t FYM/ha showed improvement in grain yield of wheat by more than 1.0 t/ha as compared to that after rice. The wheat grain yield following cotton was less due to delayed sowing. The maize grain yield in potato-based cropping systems showed an edge as FYM was applied to both maize and potato crops. However, the cotton and groundnut yields were not influenced by the preceding crop irrespective of cereal, vegetable or oilseed crop.

Economic analysis

The highest cost of cultivation (₹82,284/ha/annum) was incurred on maize-potato-onion followed by groundnut-potato-pearlmillet (₹70,283/ha/annum), (Table 2). The inclusion of potato and onion in the cropping systems in-

Table 1. Economic yield under different cropping systems

Cropping system	Economic yield (t/ha)								
	2006-07			2007-08			2008-09		
	Rainy	Winter	Summer	Rainy	Winter	Summer	Rainy	Winter	Summer
Rice-Wheat	6.23	5.06	-	6.47	5.16	-	6.63	5.06	-
Maize-Wheat	5.18	6.21	-	5.92	6.38	-	5.72	5.70	-
Maize-Wheat-Mungbean	4.93	6.06	1.28	5.97	6.17	1.17	5.79	5.65	1.17
Maize-Potato-Mungbean	5.12	32.97	1.38	5.78	32.37	1.25	5.67	32.84	1.25
Maize-Potato-Onion	5.21	31.00	22.04	5.84	30.20	24.14	5.71	31.29	25.78
Cotton-Wheat	2.06	4.89	-	2.24	5.00	-	2.05	4.58	-
Cotton-African Sarson	2.09	2.38	-	2.33	2.29	-	2.09	1.89	-
Cotton-*Gobhi sarson* (T)	2.12	1.94	-	2.26	1.88	-	2.13	1.80	-
G.nut-*Toria*+ *Gobhi sarson*	2.78	0.86 + 2.19	-	3.25	0.93 +2.04		3.01	0.82 + 1.75	
G.nut-Potato-Bajra(F)	2.61	33.44	34.70	3.19	33.16	36.59	2.96	33.67	38.19

Table 2. Rice equivalent yield (t/ha), net returns, irrigation water applied and production efficiency of different cropping systems.

Cropping systems	Economic yield (t/ha)			Rice equivalent yield (t/ha)	Total calories (K × 1000)	Total variable cost (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	Production efficiency (kg/ha/ day)	B: C ratio
	Rainy	Winter	Summer							
Rice-Wheat	6.44	5.09	-	12.87	39,918	40,649	99,707	59,058	46.2	1.453
Maize-Wheat	5.61	6.10	-	13.04	40,268	39,726	101,047	61,321	49.0	1.544
Maize-Wheat-Mungbean	5.57	5.96	1.21	16.12	43,682	52,131	124,959	72,828	52.1	1.397
Maize-Potato-Mungbean	5.52	32.73	1.29	22.86	26,378	71,340	177,196	105,856	73.4	1.484
Maize-Potato-Onion	5.59	30.83	23.99	31.98	23,294	82,284	247,860	165,576	98.8	2.012
Cotton-Wheat	2.12	4.82	-	12.19	16,677	41,688	94,472	52,784	37.0	1.266
Cotton-African Sarson	2.17	2.18	-	12.36	11,815	35,484	95,826	60,342	36.6	1.701
Cotton-*Gobhi sarson* (T)	2.17	1.88	-	11.50	10,144	35,484	89,153	53,669	34.6	1.512
G.nut-*Toria*+ *Gobhi sarson*	3.02	0.87 + 2.00	-	16.63	32,606	34,607	128,844	94,237	50.3	2.723
G.nut-Potato-Bajra(F)	2.92	33.42	36.49	24.65	37,026	70,283	191,064	120,781	73.8	1.718
SEM ±				0.51				2,352	2.49	
CD (P=0.05)				1.16				7,085	7.27	

Price : (Rs t^{-1})/K.Cal. (per 100 gram) : Wheat, 9770(346); Rice, 775(346); Maize, 7400(342); Potato, 3330(97); Onion, 4330(50); Oilseed, 21620(541); Toria, 21100 (541); Mungbean, 21170(334); Cotton, 22400; G.nut, 20000 (567); urea; 4780; DAP, 9350; MOP, 4450; FYM, 90. Mean of 3 years.

creased the total variable cost due to more fertilization and human labour requirement. However, the gross returns were also higher in these systems because of higher value of produce. The maize-potato-onion cropping system fetched a gross return of ₹2,47,860/ha/annum and proved to be the most remunerative cropping system. Groundnut-potato-pearlmillet with a gross returns of ₹1,91,064/ha/annum was second and maize-potato-summer moongbean with a gross return of ₹1,77,196/ha/annum was third in order. The net profitability was highest in maize-potato-onion cropping system (₹1,65,576) followed by groundnut-potato-pearlmillet (fodder) (₹1,20,781) and groundnut – *toria+ gobhi sarson* (₹1,28,844). The inclusion of vegetables in crop sequences can boost the profitability of the sequences. These results confirm the findings of Samui *et al.* (2004). The maize based cropping systems showed net profit in range of ₹61,321 to ₹1,65,576 cotton based cropping systems ₹52,784 to ₹60,342 and groundnut based cropping systems ₹94,237 to ₹1,20,781 and rice-based cropping system showed ₹59,058 as net profit. The B:C ratio of cotton based cropping systems was more ranging from 1.266 to 1.701; groundnut based 1.718 to 2.723, maize based 1.397-2.012 and predominant rice-wheat system showed B:C of 1.453. The lower B:C ratio was noted with maize-wheat -summer moongbean (1.397) which may be due to lower market price of produce.

Water and nutrient use productivity

The maize–potato-onion; summer groundnut-potato-*bajra* (fodder) and maize-potato-summer moongbean cropping systems helped to save 75.6 to 122.3 cm of irrigation water over rice-wheat system (Table 3). It is, therefore, pertinent that shifting of small area under these systems may help to conserve the resources and a boon for making the productivity level intact.

The groundnut-potato-bajra (fodder) cropping system showed highest water productivity (2.417 kg grain cm^{-3} irrigation water) followed by groundnut-*Gobhi sarson*+Toria (2.298 kg grain cm^{-3} irrigation water) maize-potato-summer moongbean (2.178 kg grain cm^{-3} irrigation water) and maize-potato-onion (2.151 kg grain cm^{-3} irrigation water). The lowest water productivity (0.573 kg grain cm^{-3} irrigation water) was observed with rice-wheat cropping system (Table 3).

The groundnut-*Gobhi sarson* + *Toria* cropping system showed highest nutrient use productivity of 83.99 kg grain/kg nutrient applied followed by groundnut-potato-*bajra* (fodder) cropping system (68.47 kg grain/kg nutrient applied) which may be due to higher yield potential and price of these crops and groundnut being leguminous crop required less nutrients (15-9-20; N-P-K; kg/ha) (Table 3). The maize-potato-onion and maize-potato-summer mungbean cropping system showed nutrient use productivity of 53.30 and 49.80 kg grain/kg nutrient applied, respectively. The nutrient use productivity for cotton-wheat, rice-wheat and maize-wheat cropping systems were 48.57, 39.12 and 38.13 kg grain/kg nutrient applied, respectively.

Weed population

In rice-wheat system, the population of grassy weeds was 74 m^{-2}, which decreased drastically in maize-wheat-moongbean, summer groundnut- *toria*+ *gobhi sarson* and in the other cropping systems. But surprisingly, the *Phalaris minor* infestation was reduced discernibly which varied from 3 to 12 only as against 36 as in rice-wheat rotation. Likewise, change in broadleaf weeds was also noticed. Summer groundnut- *toria*+ *gobhi sarson* recorded lowest broadleaf weed population (10) where as in rice-wheat system it was maximum (25). The results further revealed that *Phalaris minor* population is increasing in rice-wheat system where as in all other cropping systems it has reduced. It may be attributed due to the change in the physical conditions of the soils on account of puddling.

Nutrient uptake

Rainy season crops: Rice in rice-wheat cropping system recorded maximum N- uptake (185.65 kg/ha) as compared to maize in maize-based cropping systems (S_2, S_3, S_4 and S_5) ranging from 150.71-161.94 kg/ha, (Table 3). The lowest N-uptake was recorded in cotton (134.01 kg/ha) in cotton-African mustard (S_7). The groundnut removed 166.88 to 168.99 kg N/ha in different cropping systems. Rice in rice-wheat cropping system removed maximum

Table 3. Water productivity, nutrient use productivity, sustainability index and nutrient uptake by crops in different cropping systems

Cropping systems	Irrigation water applied (cm)	Water productivity (kg grain /m^{-3} irrigation water)	Nutrient use productivity (kg grain/ kg nutrient applied)	Sustainability index			Nutrient uptake (kg/ha)						
				Rainy	Winter	Summer	Rainy			Winter			System total
							N	P	K	N	P	K	
Rice-Wheat	224.3	0.573	39.12	0.97	0.98	-	185.65	41.01	134.55	126.61	24.48	84.13	596.43
Maize-Wheat	73.7	1.770	38.13	0.88	0.90	-	179.39	42.16	129.05	138.54	34.21	95.59	618.94
Maize-Wheat-Mungbean	98.3	1.640	47.13	0.84	0.92	0.98	150.71	32.75	119.07	135.38 (50.11)	34.11 (14.80)	97.42 (43.83)	678.18
Maize-Potato-Mungbean	105.0	2.178	49.80	0.89	1.00	0.97	148.92	38.38	118.20	123.55 (59.06)	30.54 (15.43)	89.65 (47.53)	671.26
Maize-Potato-Onion	148.7	2.151	53.30	0.90	1.00	0.92	161.94	31.61	127.00	136.09 (123.33)	32.81 (32.97)	90.48 (94.50)	830.71
Cotton-Wheat	77.0	1.583	48.57	0.90	0.92	-	140.23	31.31	75.42	127.03	30.74	81.13	485.86
Cotton-African Sarson	71.0	1.742	63.06	0.87	0.84	-	134.01	31.53	72.50	118.80	31.82	118.14	506.81
Cotton-*Gobhi sarson* (T))	66.0	1.743	58.67	0.92	0.96	-	153.38	32.39	67.65	113.60	30.86	113.79	511.68
G.nut-*Toria*+ *Gobhi sarson*	72.3	2.298	83.99	0.86	0.87 + 0.87	-	168.99	21.42	76.50	132.01	34.28	126.23	559.43
G.nut-Potato-Bajra(F)	102.0	2.417	68.47	0.82	1.00	0.95	166.88	25.17	65.58	136.50 (18.73)	27.22 (10.57)	81.42 (60.23)	592.29

Figures in parenthesis denote the nutrient uptake by summer crops phosphorus (41.01 kg/ha) from the soil as compared to maize-based cropping systems (31.61 to 42.16 kg/ha). However, P-uptake in cotton and groundnut based cropping systems ranged from 31.31 to 32.39 kg/ha and 21.42-25.17 kg/ha, respectively. Rice removed the maximum potassium (134.55 kg K/ha) where as maize removed 118.20 to 129.05 kg K/ha followed by cotton (67.65 to 75.42 kg K/ha) and groundnut (65.58 to 76.50 kg K/ha). These results were supported by Imas and Bansal (1999), Saidou *et al.* (2003) and Sharma *et al.* (2003) for maize, potato and onion crops grown under different conditions.

Winter crops: Maximum N-uptake (138.54 kg/ha) was recorded by wheat grains in maize-wheat cropping system when compared with wheat grown in rice-based cropping system (126.61 kg/ha). However, different cropping systems removed N from soil in the range of 113.60 to 138.54 kg/ha, Table 3. Amongst the oilseeds, *gobhi sarson +Toria* removed 132.01 kg N/ha followed by *African* mustard (118.80 kg N/ha) and *gobhi sarson* (transplanted) (113.60 kg N/ha). The nitrogen uptake in potato varied from 123.55 to 136.50 kg N/ha. Maximum P uptake was recorded in wheat in maize-wheat cropping systems (34.21 kg/ha). The P-uptake in wheat and potato in maize-based cropping systems in S_2, S_3, S_4 and S_5 varied from 30.54 to 34.21 kg/ha as compared to wheat and oilseeds after cotton in S_6, S_7 and S_8 (30.74 to 31.82 kg/ha) followed by *toria* + gobhi sarson and potato after groundnut in S_9 and S_{10} (27.22 to 34.28 kg/ha). Maximum K was removed by African mustard in cotton- African mustard cropping system (118.14 kg/ha) followed by wheat (97.42 kg N/ha) in maize-wheat-summer moongbean cropping system. The oilseeds after cotton removed 113.79 to 118.14 kg K/ha as compared to oilseeds and potato after groundnut based cropping systems ranged from 81.42 to 126.23 kg K/ha. The wheat in rice-wheat cropping system removed 84.13 kg K/ha.

Summer crops: The maximum N uptake (123.33 kg/ha) was found in onion bulb in maize – potato – onion cropping system (Table 3). The phosphorus uptake was more in onion (32.97 kg P/ha) in maize-potato-onion cropping system followed by summer moongbean in maize based cropping systems (14.80 to 15.43 kg/ha). The *bajra* (fodder) removed 10.57 kg P/ha. The highest K uptake was in onion crop (94.50 kg/ha) and in summer moong it ranged between 43.83 to 47.53 kg K/ha. Bajra fodder mined 60.23 kg K/ha.

Amongst 200% cropping intensity, the maize-wheat cropping system removed maximum nutrients (618.94 kg/ha) > rice-wheat (596.43) > cotton- *gobhi sarson* (T) (511.68) > cotton-African *sarson* (506.81) > cotton-wheat (485.86), respectively. Amongst 300% cropping intensity, the maize-potato-onion cropping system removed 830.71 kg nutrients/ha which was 22.49, 23.75 and 40.25% higher over maize-wheat-summer moongbean, maize-potato-summer moongbean, groundnut-potato-*bajra* (fodder), respectively. Similar results were reported by Westermaan *et al.* (1994) and EL-Desuki *et al.* (2006) who reported that application of K fertilizers increased the uptake of NPK nutrients in onion crop for two successive seasons

Soil health

The organic carbon level in all the systems reduced over the initial status (0.53%) except in maize-potato-onion (0.53%) and groundnut-potato-*bajra* (fodder) (0.54%) cropping systems. The maximum reduction was accrued in rice-wheat system (S_1) (Table 4). The organic carbon was less influenced in cotton-based cropping systems (S_6, S_7 and S_8) and remained in the range of 0.47 to 0.49%. In maize-based cropping systems (S_2, S_3, S_4 and S_5), where FYM was applied @ 10 t/ha, the OC was also reduced but the magnitude of decline was less as compared to the rice-wheat (S_1) cropping system. The available N-status clearly indicated the improvement in N-status over its initial value (185.9 kg/ha). The lowest N-status was recorded in rice-wheat cropping system (218.97 kg/ha) and the N-status in S_4 and S_5 systems where potato crop was taken, a substantial improvement was observed over the rest of the systems. The maize-potato-moongbean (S_3) and maize-potato-onion (S_4) being input intensive high-yielding systems led to show comparatively better levels of nitrogen but these were also found in the low category. Similar results were reported by Sharma *et al.* (2003), Snapp *et al.* (2003) and Somasunderam *et al.* (2007).

The application of farmyard manure to potato and maize crops (S_2, S_3, S_4 and S_5) helped significantly in the buildup of phosphorus status over the remaining treatments. The maximum P status (48.95 kg/ha) was recorded in maize-potato-onion cropping system followed by maize-potato-moongbean cropping system (46.25 kg/ha). The P values in the summer groundnut-potato-*bajra* (fodder) (S_{10}) showed phosphorus status of 45.85 kg/ha, after maize-wheat (S_2) which led to improve the P status up to 42.64 kg/ha. There was slight decrease in P status in rice-wheat (S_1) system over its initial values (40.13 kg/ha). Cotton based cropping systems (S_6, S_7 and S_8) showed improvement in P-status than its initial values. The available K-status followed the similar trend as observed in available P status. The maximum build up of K was accrued in maize based cropping systems (140.62 to 161.28 kg/ha) where as it was lowest (128.86 kg/ha) in rice-wheat system (S_1) which was lower than maize-wheat, maize-potato-onion, maize-potato-moongbean and groundnut-potato-*bajra* (fodder) systems. Roy Bardhan *et al.* (1999)

Table 4. Weed population and soil health status as influenced by different cropping systems.

Cropping systems	Weed population m^{-2}		Organic Carbon	Available nutrients (kg/ha)			Micronutrient status in soil (ppm)				Microbial population (cfu/g)**		
	Grass*	BLW	(%)	N	P	K	Zn	Cu	Fe	Mn	Bacteria ($x10^6$)	Fungi ($\times10^3$)	Actinomycetes ($\times10^4$)
Rice-Wheat	74 (36)	25	0.42	218.97	40.13	128.86	2.95	0.52	9.65	8.81	22.4	20.9	29.2
Maize-Wheat	12 (7)	17	0.45	231.44	42.64	140.62	5.78	0.50	9.49	9.79	19.2	21.2	36.1
Maize-Wheat-Mungbean	10 (5)	11	0.48	233.85	46.25	143.03	3.19	0.42	10.52	8.43	23.6	23.4	26.1
Maize-Potato-Mungbean	17 (4)	19	0.52	241.08	45.35	150.35	6.66	0.70	9.71	10.84	18.6	18.4	20.4
Maize-Potato-Onion	22 (4)	17	0.53	253.23	48.95	161.28	6.14	0.67	10.63	12.33	19.2	19.2	20.8
Cotton-Wheat	19 (12)	21	0.45	240.64	45.65	131.86	3.88	0.44	6.72	8.95	20.9	16.2	23.4
Cotton-African Sarson	12 (5)	16	0.49	242.24	45.25	130.16	3.69	0.57	5.91	9.49	18.4	19.2	19.4
Cotton-*Gobhi sarson* (T)	14 (4)	13	0.49	241.74	44.64	135.57	3.54	0.48	6.04	8.89	23.4	18.2	21.2
G.nut-*Toria*+ *Gobhi sarson*	11 (3)	10	0.47	246.18	44.54	131.42	3.26	0.31	5.20	9.71	18.2	15.9	16.4
G.nut-Potato-Bajra(F)	10 (4)	17	0.54	230.52	45.85	137.25	2.88	0.72	7.74	10.47	16.4	16.4	13.8
SEM ±	1.7 (1.2)	1.0	0.01	3.81	0.73	3.16	0.17	0.03	0.30	0.33	0.45	0.52	0.30
CD (P=0.05)	5 (4)	3	0.02	11.24	2.31	9.64	0.57	0.08	0.93	0.86	1.25	1.73	0.96

*Figures in parentheses represent the *Phalaris minor* population; ** date of sampling 19.02.2009

reported that inclusion of legume increases soil fertility status.

Micronutrients status (zinc, copper, iron and manganese) in the soil under different cropping systems was determined after the *rabi* crop. The maize-based cropping systems especially maize–potato–summer moongbean and maize–potato–onion maintained the higher levels of zinc (3.19-6.66 ppm), copper (0.42-0.70 ppm), iron (9.71-10.63 ppm) and manganese (8.43-12.33 ppm) as compared to the other cropping systems (Table 4). However, all the values of micronutrients under different cropping systems are in sufficient range.

The soil microbial population of different cropping systems showed a varied trend both for the systems and the type of micro-organisms. The highest bacterial counts of 23.6 x 10^6 and 23.4 x 10^6 cfu g^{-1} were observed in Cotton-maize-wheat-summer moongbean system (S_3) and *gobhi sarson* system respectively (Table 4). The highest fungal counts of 23.4 x10^3 and 21.2 X 10^3 cfu/g were seen in wheat crop grown in maize-wheat-summer moongbean system (S_3) and maize-wheat (S_2) systems, respectively. The actinomycetes recorded the highest counts of 36.1 × 10^4 and 29.2 × 10^4 in wheat crop of maize/rice-wheat cropping systems, respectively. It may be inferred that factors like the type of crop, the cropping system, the soil and the nutrients contribute differently towards development of micro flora.

Consequently maize–potato-onion; summer groundnut-potato-pearlmillet (fodder) and maize-potato-summer mungbean are biologically efficient, resource conservative, highly profitable crop sequences. However, stability of rice-wheat sequence was more. Similar results were reported by Yadvinder Singh *et al.* (1988, 1991).

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