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Viable alternatives to cotton-wheat crop rotation for semi-arid climatic conditions

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A study was conducted in the research area of Agronomy Department, University of Agriculture, Faisalabad during 2014-2015 to evaluate a sustainable and economical wheat-based rotation system under agro-climatic conditions of Faisalabad, Pakistan. Guar, maize, mash bean, mung bean, soybean, millet and some fodders (maize, millet and sorghum) were grown in Kharif season while wheat was the main crop in Rabi season. Wheat-fodder millet-grain maize gave the highest net benefits of Rs. 272062 ha^{-1} but exhausted the soil. The maximum value of BCR (2.25:1) was achieved in the same rotation that is, wheat-fodder millet-grain maize followed by wheat-fodder maize-mash bean with BCR of 1.86:1. Keeping in view the soil fertility plus economy, the wheat-fodder maize-mash bean cropping system is not only economical for small landholders but also improve soil fertility status as compare to others.

Key words: Crop rotations, cropping patterns, economics, semi-arid and subtropical climate.

INTRODUCTION

Farmers generally follow the conventional and nutrient-exhaustive cropping systems that show a negative trend in crop efficiency. These may include rice-wheat, cotton-wheat and mixed-wheat. The traditional mixed cropping system has failed to provide its financial potential in kharif/summer season (Rasul and Mahmood, 2009). In cotton-wheat system, cotton is planted in summer and is followed by winter wheat. Cotton occupies a large area of land because it is considered as more profitable crop than wheat. Many efforts have been made to assist the farmers in making thoughtful management choices to stay sustainable in continuously changing climatic conditions in agriculture, but, the best tactic is always a dynamic cropping system approach (Tanaka et al., 2002). Many cropping patterns implemented by the growers are generally exhaustive and non-productive that not merely leads towards lower revenues but cause continuous drop in the soil productivity too. The cropping systems in areas with limited precipitation are subjected to a wide range of variations in production and profitability (Sharma et al., 2007). In dry land cropping systems, we can effectively enhance cropping frequency using guidelines for selection of crops (Nielsen et al., 2010). The inclusion of crops such as oilseeds, legumes, fodders and pulses can

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enhance the soil fertility and productivity of cereals (Ahmad et al., 2001; Reddy and Suresh, 2009). The significant changes in cropping systems may be induced due to the relative prices rather than productivity (Vivekananda and Satyapriya, 1994; Vyas, 1996). Present cropping system has become obsolete and local farmers gain minor returns from it. The need of the hour is a revised set of cropping system comprising on advanced and systematic practices of agriculture which will necessarily be cost-effective, feasible, sustainable and suitable to growers in that region (Gill and Ahlawat, 2006). A cropping system having such qualities is anticipated to enhance the farm productivity with regards to improved farm production, higher water use efficiency and improved utilization of farm labor, farm machinery and all other available resources (Dogan et al., 2008; Ghosh, 1987). The current research plan was intended to discover economically effective cropping systems in semi-arid climatic conditions of Faisalabad region on sustainable basis concerning the fertility status of the soil. In other words, the current study was planned to propose some feasible alternative crops as a substitute of cotton during kharif/summer season to attain highest agronomic efficiency on sustainable basis from the existing resources.

MATERIALS AND METHODS

This study was conducted on sandy clay loam soil at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan under prevailing semi-arid climatic conditions of this sub-tropical area during 2014-2015. The experimental area was located at 73° East longitude, 31° North latitude and at an altitude of 135 m above sea level. Soil of experimental area was quite uniform, so a composite and representative soil sample to a depth of 30 cm was obtained with soil auger, before sowing the crops and after the final harvesting. The experiment was laid out with a net plot size of 9.5 m × 6 m in randomized complete block design (RCBD) having four replications. The following crop rotations were tested during the study: T_1= cotton-wheat, T_2= wheat-guar, T_3= wheat-fodder maize-mashbean, T_4= wheat-fodder sorghum-mungbean, T_5= wheat-fodder maize-soybean, T_6= wheat-fodder millet-grain maize, T_7= wheat-mashbean-soybean, T_8= wheat-mungbean-grain millet. Cultivars/Varieties used during this experiment was Wheat (Lasani-2006), Cotton (FH-142), Mungbean (AZRI mung-2006), Mashbean (Mash Arooj), Guar (BR-99), Soybean (PSC-60), Sorghum fodder+grain (Sandal Bar Sorghum), Millet fodder (FB-786), Millet grain (HP-50), Maize fodder (Sadaf) and Maize grain (DK-6789 Hybrid). Wheat crop was sown after the harvesting of kharif and other summer crops in various combinations of rotations. Recommended doses of N-P-K fertilizers and all cultural practices were done for each crop according to the recommendations by Punjab Agriculture Department. Crops were harvested at maturity for grain purpose. However, the cutting of fodder crops was done on recommended time to get good quality forage. Soil chemical analysis was done before and after conducting the experiment to record the following chemical characteristics: Organic matter (%), Total nitrogen (%), available Potassium (ppm) and available phosphorus (ppm) using standard methods (Homer and Pratt, 1961). Following crop growth parameters was taken for all the crops: Total dry matter production (kg ha^{-1}), 1000-grain weight (g) and grain yield (t ha^{-1}). The mean economical values were calculated for each rotation using the mean market prices of the produces while marginal analysis, dominance analysis and marginal rate of return were calculated using methodology described in CIMMYT training manual (Cimmyt, 1988). Treatment means were compared using Tukey's honest significance difference (HSD) procedure (TUKEY, 1953).

RESULTS AND DISCUSSION

Total dry matter

Data showed significant effect of wheat based cropping rotations on the total dry matter of wheat crop. The maximum (14893.50 kg ha^{-1}) total dry matter of wheat was observed in wheat - mashbean - soybean cropping system followed by wheat - guar cropping system (14214.03 kg ha^{-1}). The cropping system viz. wheat - fodder maize-mashbean, wheat - fodder sorghum-mungbean, wheat-fodder maize-soybean and wheat-mungbean-grain millet produced 13661.43, 13631.21, 13607.68 and 13534.56 kg ha^{-1} wheat dry matter and these were statistically similar with each other. The conventional cotton-wheat system produced 12686.33 kg ha^{-1} dry matter and it was the least one from other cropping systems. Wheat - mashbean - soybean, wheat - guar, wheat - fodder maize - mashbean, wheat - fodder sorghum - mungbean, wheat - fodder maize - soybean, wheat - mungbean - grain millet and wheat - fodder millet - grain maize cropping systems produced 15, 11, 7, 7, 7, 6 and 4% higher wheat total dry matter over conventional cotton - wheat system. Increase in total dry matter and yield of crops with the inclusion of legume and other restorative crops were also observed by Ahmad et al. (2001) and Reddy and Suresh (2009).

Grain yield

Data showed significant effect of wheat based cropping rotations on the productivity of wheat crop. The result indicates the achievement of better yield in different wheat-based rotations. The maximum (4.60 t ha^{-1}) wheat yield was observed in wheat-mashbean-soybean cropping system followed by wheat-guar cropping system (4.39 t ha^{-1}). The cropping system viz. wheat-fodder maize-mashbean, wheat - fodder sorghum - mungbean, wheat - fodder maize - soybean and wheat - mungbean - grain millet produced 4.22, 4.21, 4.21 and 4.18 t ha^{-1} wheat and these were statistically at par with each other. The conventional cotton - wheat system produced 3.91 t ha^{-1} of wheat. The possible reason of higher yield may be due to inclusion of legumes in these wheat-based rotations. The current wheat was sown after the harvesting of spring and autumn crops resultantly the better crop as well as soil productivity. It was mainly due to incorporation of legumes crops in rotations. Wheat - mashbean - soybean, wheat - guar, wheat - fodder maize

Table 1. Total dry matter and yield of different wheat-based rotations.

Cropping Systems	TDM (kg ha^{-1})			Yield (t ha^{-1})		
	Wheat	Spring	Autumn	Wheat	Spring	Autumn
Cotton – Wheat	12686.33^{e}	12125.00^{a}	--	3.92^{e}	3.20^{d}	--
Wheat – Guar	14214.03^{b}	3405.13^{c}	--	4.39^{b}	1.31^{d}	--
Wheat-Fodder Maize-Mash bean	13661.43^{c}	9300.00^{ab}	2826.76	4.22^{c}	58.73^{a}	0.69^{b}
Wheat-Fodder Sorghum-Mung bean	13631.38^{c}	9826.67^{ab}	2967.66	4.21^{c}	41.45^{c}	0.64^{b}
Wheat-Fodder Maize-Soybean	13607.68^{c}	8989.00^{bc}	1855.11	4.21^{c}	55.73^{a}	0.63^{b}
Wheat-Fodder Millet-Grain Maize	13196.46^{d}	14300.00^{a}	1459.33	4.08^{d}	50.60^{b}	7.07^{b}
Wheat-Mash bean-Soybean	14893.50^{a}	3791.99^{c}	2116.56	4.60^{a}	0.79^{d}	0.69^{b}
Wheat-Mung bean-Grain Millet	13534.56^{cd}	3672.26^{bc}	6496.49	4.18^{c}	0.68^{d}	2.32^{a}

Mean in the same column having different letters differs significantly at P≤ 0.05).

- mashbean, wheat - fodder sorghum - mungbean, wheat - fodder maize - soybean, wheat - mungbean - grain millet and wheat - fodder millet - grain maize cropping systems produced 15, 11, 7, 7, 7, 6 and 4% higher wheat grain yield over conventional cotton-wheat system.

In case of fodder production of the existing cropping systems, the maximum fodder yield (58.73 t ha^{-1}) was recorded in wheat - fodder maize - mashbean cropping system followed by wheat-fodder maize-soybean cropping system and both were statistically at par. It is concluded that with the exhaustive crops, restorative crops must be incorporated in the existing wheat based cropping systems in order to attain higher productivity of wheat crop and maintain soil health. The results are quite similar to the findings of Ahmad et al., (2001) and Reddy and Suresh (2009) (Table 1).

Soil fertility

The data on different soil parameters recorded before planting of crop and at end of year after harvesting of second crop revealed that maximum organic matter (0.86%) was left in the soil by wheat - mashbean - soybean cropping system followed by wheat-fodder maize - mashbean. The possible reason of increment in organic matter is due to consecutive sowing of two pulses as well leguminous crop in this system. The maximum nitrogen (0.055%) was left in the soil by wheat - mashbean - soybean cropping system followed by wheat-fodder, maize - mashbean (0.05%) and wheat-mungbean- grain millet (0.05%).

Depletion in nitrogen was recorded by cotton-wheat and wheat- fodder millet-grain maize cropping systems. The maximum available phosphorus (8.45 ppm) was noted in the soil by wheat - mashbean - soybean cropping system followed by wheat-guar (8.24 ppm) and wheat-mungbean- grain millet (8.15 ppm). However, reduction in available phosphorus was recorded by cotton-wheat (7.43 ppm) and wheat- fodder millet-grain maize (7.62 ppm) cropping systems. The maximum potash (166 ppm) was recorded in the soil by wheat - mashbean - soybean cropping system followed by wheat-guar (165 ppm) and wheat-fodder maize-soybean (162 ppm). The minimum amount of potash (147 ppm) was noticed in wheat- fodder millet-grain maize cropping system. Ghosh, (1987) also reported that addition of legumes and pulses into existing cropping systems can enhance soil fertility (Table 2).

Economic analysis

Benefit-cost ratio (BCR)

Benefit-Cost Ratio (BCR) is informal approach for making decisions of any kind. A ratio of greater than one shows that the system is a viable one. The maximum value of BCR (2.39: 1) was achieved in wheat - fodder millet - grain maize followed by wheat - fodder maize - mashbean with BCR of 1.87: 1. It was due to less cost of production of grain maize crop and it gave the maximum net return due to high grain yield and market price. The minimum value of BCR (1.47:1) was achieved in wheat - guar cropping system. The reason for low BCR is the less production of guar crop. Wheat - fodder maize - soybean and

Table 2. Effect of different wheat-based crop rotations on soil fertility.

Cropping systems	Organic matter (%)		Nitrogen (%)		Available Phosphorus (ppm)		Potash (ppm)	
	Initial level	Final level	Initial level	Final level	Initial level	Final level	Initial level	Final level
Cotton – Wheat	0.84[a]	0.8[d]	0.047[a]	0.044e	8[a]	7.43f	144[a]	154[d]
Wheat – Guar	0.84[a]	0.83[c]	0.047[a]	0.049[c]	8[a]	8.24[b]	144[a]	165[ab]
Wheat-Fodder Maize-Mash bean	0.84[a]	0.85[ab]	0.047[a]	0.050[b]	8[a]	8.12[c]	144[a]	150e
Wheat-Fodder Sorghum-Mung bean	0.84[a]	0.84[b]	0.047[a]	0.048[d]	8[a]	8.13[c]	144[a]	159[c]
Wheat-Fodder Maize-Soybean	0.84[a]	0.83[c]	0.047[a]	0.049[c]	8[a]	8.09[d]	144[a]	162[b]
Wheat-Fodder Millet-Grain Maize	0.84[a]	0.79e	0.047[a]	0.042f	8[a]	7.62e	144[a]	147f
Wheat-Mash bean-Soybean	0.84[a]	0.86[a]	0.047[a]	0.055[a]	8[a]	8.45[a]	144[a]	166[a]
Wheat-Mung bean-Grain Millet	0.84[a]	0.82[cd]	0.047[a]	0.050[b]	8[a]	8.15[bc]	144[a]	155[cd]

Table 3. Economic analysis of different wheat-based crop rotation.

Cropping systems	Cost (Rs. ha^{-1})				Income (Rs. ha^{-1})				Net profit	Benefit-Cost Ratio
	Wheat crop	Spring crops	Autumn crops	Total cost	Wheat crop	Spring crops	Autumn crops	Gross income		
Cotton – Wheat	138859	99877	----	**238736**	146069	223007	----	**369076**	**130340**	**1.55 : 1**
Wheat – Guar	138859	26514	----	**165373**	161164	81854	----	**243019**	**77646**	**1.47 : 1**
Wheat-Fodder Maize-Mash bean	138859	38477	29382	**206717**	154295	161508	69958	**385760**	**179043**	**1.87 : 1**
Wheat-Fodder Sorghum-Mung bean	138859	35437	36682	**210977**	153606	82900	62252	**298758**	**87781**	**1.42 : 1**
Wheat-Fodder Maize-Soybean	138859	38477	40923	**218259**	153965	153258	76726	**383949**	**165690**	**1.76 : 1**
Wheat-Fodder Millet-Grain Maize	138859	23057	48647	**210562**	149484	75895	278690	**504069**	**293507**	**2.39 : 1**
Wheat-Mash bean-Soybean	138859	29382	40923	**209164**	167287	74487	84545	**326319**	**117155**	**1.56 : 1**
Wheat-Mung bean-Grain Millet	138859	36682	29954	**205494**	153489	65929	91753	**311171**	**105677**	**1.51 : 1**

wheat-mashbean - soybean gave BCR of 1.76:1 and 1.56:1 respectively and were at 3rd and 4th position in the term BCR (Table 3).

Dominance analysis of wheat-based rotations:

A cropping system was dominated, denoted by "D" if its variable cost was higher but net benefit was lower than the preceding systems. The dominance analysis of wheat based rotations revealed that wheat- mashbean - soybean, wheat - fodder sorghum - mungbean and cotton - wheat cropping systems were dominated by rest of the cropping systems under study. The dominated cropping systems were actually less profitable than other cropping systems.

Marginal rate of return (MRR)

The data for the analysis of Marginal Rate of Return (MRR) revealed that if instead of wheat - guar, wheat - mungbean - grain millet rotations is recommended then MRR is 69.87%. This implied that for every 100 rupees invested in guar production, the farmers can expect to recover Rs.100 and obtain an additional amount of Rs. 69.00 in wheat - mungbean - grain millet cropping systems. The replacement of wheat - guar system with wheat - mungbean - grain millet cropping system is not a good option for farmers. This was due to high marginal cost along with low marginal

Table 4. Dominance analysis of different wheat-based rotations.

S/N	Cropping systems	TCV (Rs. ha^{-1})	NB (Rs. ha^{-1})
T_2	Cotton – Wheat	**165373**	77646
T_8	Wheat – Guar	**205494**	105677
T_3	Wheat-Fodder Maize-Mash bean	**206717**	179043
T_7	Wheat-Fodder Sorghum-Mung bean	**209164**	117155 D
T_6	Wheat-Fodder Maize-Soybean	**210562**	293507
T_4	Wheat-Fodder Millet-Grain Maize	**210977**	87781 D
T_5	Wheat-Mash bean-Soybean	**218259**	165690
T_1	Wheat-Mung bean-Grain Millet	**238736**	130340 D

TCV=Total variable cost, NB=Net benefit.

Table 5. Analysis of marginal rate of return of different wheat-based rotations.

S/N	Cropping systems	TCV (Rs. ha^{-1})	MC (Rs. ha^{-1})	NB (Rs. ha^{-1})	MNB (Rs. ha^{-1})	MRR (%)
T_2	Cotton – Wheat	**165373**	---	77646	---	---
T_8	Wheat – Guar	**205494**	40122	105677	28031	**69.87**
T_3	Wheat-Fodder Maize-Mash bean	**206717**	41345	179043	101397	**245.25**
T_7	Wheat-Fodder Sorghum-Mung bean	**209164**	43791	117155	39509	**90.22**
T_6	Wheat-Fodder Maize-Soybean	**210562**	45190	293507	215861	**477.68**
T_4	Wheat-Fodder Millet-Grain Maize	**210977**	45605	87781	10135	**22.22**
T_5	Wheat-Mash bean-Soybean	**218259**	52886	165690	88044	**166.48**
T_1	Wheat-Mung bean-Grain Millet	**238736**	73364	130340	52694	**71.83**

TCV=Total variable cost, NB=Net benefit, MC=Marginal cost, MNB=Marginal net benefit, MRR=Marginal rate of return, BCR=Benefit cost ratio

net benefit. The maximum MRR (477.68%) was calculated in wheat - fodder millet - grain maize cropping system followed by wheat - fodder maize - mashbean system with MRR of 245.25% (Tables 4 and 5).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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