

Original Research

Effect of Site-Specific Integrated Nutrient Management on Soil Fertility under Cotton-Wheat Cropping System of Punjab Pakistan

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Abstract

Cotton-wheat rotation is one of the profitable cropping systems under arid climatic conditions in the agro-ecosystem of Punjab, Pakistan. The cropping system's productivity factor is decreasing and is considered primarily due to imbalanced and non-integrated use of nutrients without taking care of soil health measures. Exploring the role of integrated site-specific nutrient management plans, treatments containing 2 fertilizer doses, and 3 management techniques on soil organic matter (SOM), soil P & soil K were studied in the cotton-wheat system of Punjab Pakistan for six crop seasons on a permanent layout. Substantial increase of 54-70% in SOM over the initial level of 5.0 g Kg⁻¹ in sandy loam soil was observed by adapting integrated nutrients management (INM) techniques. Similarly, significantly improved level of soil test phosphorus STP was observed at the end of the sixth crop season and INM techniques resulted in a 429% to 453% increase in STP. However, statistical analysis revealed a non-significant effect of doses, and a significant declining effect on soil K was observed with the applied technique of only mineral fertilizer application. Highly negative K balance suggests that the system will not be able to sustain the long-term supply of K. Ranking of indices from the best to the least favorable was recorded as P>SOM>K.

Keywords: mineral fertilizer, INM, cotton-wheat cropping system, site-specific, MSWC

Introduction

Cotton-wheat rotation is one of the profitable cropping systems under arid climatic conditions in the agro-ecosystem of Punjab, Pakistan. Subsequently, the soils of this system have been subjected to conventional exploitative agriculture over a long period of time and as such cannot sustain soil fertility and fulfill the

nutritional requirements of improved crop varieties. To meet the demands of the quickly increasing population, it is enormously needed to produce more grains (food) and fiber. At the same time, agriculture of the country is facing fierce competition for land, water and other natural resources with other sectors, including industry and urbanization. Since more and more land is lost to non-agricultural purposes and to land degradation, the increase in food demand has to be met by increasing yields from the existing land resources. Crop intensification is the main vehicle for increasing food

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output [1]. However, intensive cultivation with high yielding crop varieties augmented with unscrupulous use of mineral fertilizers has led to the depletion of soil organic matter (SOM) contents and the degradation of soil quality [2]. It is reported [3, 4] that soils of a vast area of Pakistan is extremely poor in organic matter which has appeared to be the main cause of crop yield stagnation [5]. Chemical fertilizers in combination with organic manures can be effectively used to level off the yield stagnation [6]. Because organic amendments have the potential to ameliorate the threat of climate change and seasonal variation to food security [7]. The efficient use of chemical fertilizers requires an optimum level of organic matter in the soil that can be achieved by integrated use of chemical and organic fertilizers including composts [8-10]. Hence, to sustain a cropping system, an effective and efficient fertilizer application as per need is required [11]. Soil test based fertilizer application can play a pivotal role due to its ability to determine fertilizer need for sowing of a crop [12, 13]. Excessive application of organic manure should be avoided, particularly in soil, to reduce the risk of toxic effects from reduced metabolic intermediates [14]. A crucial productivity factor of continuous and imbalanced use of fertilizers, is adversely affecting the sustainability of a cropping system besides degrades the soil health and quality hence causing environmental pollution [15-18]. Soil organic matter (SOM) is well known to enhance the physical, chemical, and biological properties of soil and is widely regarded as a key indicator of soil health [19, 20]. Therefore, this is high time to realize that this crop production system is depleting our environment and ecosystem [6, 21]. The major issue is the rational use of inorganic and organic inputs because only organic sources cannot meet the total nutrient requirements of modern agriculture, hence integrated use of nutrients from inorganic and organic sources will be the need of the time [22, 23, 11].

Use of mineral fertilizers with organic matter in suitable ratios is known as integrated nutrient management (INM) [24]. The indexation technique can be efficiently and effectively used to evaluate the effects of INM in a cropping system on the quality of soil and crop yield [24, 25]. Cotton-wheat cropping system is considered a “grain plus cash” cropping system [26]. Cotton is sold as an industrial product and increases farmers’ income while wheat improves food security [27]. These crops contribute greatly to improve

the economic conditions of a large number of people engaged in farming, processing trade, and the textile industry [28]. This study is first of its kind in Pakistan and will provide appropriate ratio/plan of combined application of inorganic and organic fertilizer in cotton -wheat cropping system, data base for future research work and guidelines for policy makers.

Materials and Methods

Six field experiments on a permanent layout were conducted for six crop seasons in the cotton-wheat cropping system in order to assess the effect of various applied treatments. Detail of the work plan is briefly given below.

Site for Study and Initial Soil Characteristics

Field experiments were conducted for three years at Cotton Research Sub-Station, Raiwind, Lahore (31.23886°N and 74.21686°E) to investigate the effects of integrated organic and inorganic fertilizers in a cropping system on SOM, P and K. Crops were irrigated with both canal as well as tube well water as per requirement. The experimental site was under continuous cotton-wheat cropping system for long and was 228 meters above mean sea level and initial soil characteristics are given in Table 1.

Management Techniques and Fertilizer Doses

Three management techniques (T_I : Only use of mineral fertilizer, T_{II} : INM of organic and mineral fertilizer in 1:4 with application of pesticides and herbicides and T_{III} : INM of organic and mineral fertilizer in 1:4 without application of pesticides and herbicides) and two mineral fertilizer doses (D_I : Conventional mineral fertilizer P application according to the current recommendation of the extension service without caring soil test value and D_{II} : Site-specific mineral fertilizer P application on the soil test basis) were evaluated in the form of following combinations.

Table 1. Initial soil characteristics.

Depth	EC	pH	OM	P	K	Sand	Silt	Clay	Textural Class
Cm	dS m ⁻¹	-	%	ppm		%			
0-15	0.9	8.0	0.50	1.70	129.0	64.4	21.2	14.4	Sandy loam
15-30	0.9	7.9	0.35	1.00	122.0	59.6	28.2	12.2	Sandy Loam

P fixation factor = 3.0

Treatment	Treatment Type	Description
$T_{-I} \times D_{-I}$	Conventional	Conventional mineral fertilizer P application according to the current recommendation of the extension service without caring soil test value
$T_{-I} \times D_{-II}$	Site-specific	Site-specific mineral fertilizer P application on soil test P basis
$T_{-II} \times D_{-I}$	Conventional Organic	Conventional way of integrated fertilizer use (INM of organic and mineral fertilizer in 1:4 on soil test P basis) with pesticides and herbicides.
$T_{-II} \times D_{-II}$	Site-specific Organic	Site-specific way of integrated fertilizer use (INM of organic and mineral fertilizer in 1:4 on soil test P basis) with pesticides and herbicides.
$T_{-III} \times D_{-I}$	Conventional Organic without pesticides	Conventional way of integrated fertilizer use (INM of organic and mineral fertilizer in 1:4 on soil test P basis) without pesticides and herbicides.
$T_{-III} \times D_{-II}$	Site-specific Organic without pesticide use	Site-specific way of integrated fertilizer use (INM of organic and mineral fertilizer in 1:4 on soil test P basis) without pesticides and herbicides.

Mineral Fertilizer Application Rates

The detail of mineral fertilizers applied in permanent field during three years in six crop seasons are given in Table 2.

Application Rates of Organic Fertilizer (MSWC)

The MSWC was prepared aerobically by M/S Waste Busters Pvt Ltd. Lahore, Punjab, Pakistan. MSWC application was made on the basis of P requirement of a crop in each treatment. A computed quantity of MSWC was integrated in a respective fertilizer dose in 1:4 (MSWC: Mineral fertilizer) on soil test P basis. Singer et al., 2004 [29]. emphasized phosphorus based application rather than nitrogen based application of compost in order to avoid loading of contaminants particularly phosphorus. In Punjab, Pakistan, the P sufficiency soil level (Olsen sodium bicarbonate extractable) was recommended as 21 ppm [30]. The MSWC analysis depicted that it contained organic matter 40%, nitrogen & phosphorus 0.50% and potassium 1.00%, zinc 2.0 ppm, copper 0.5 ppm, Iron 20.0 ppm, manganese 1.0 ppm, lead 0.1 ppm, Nickle 0.05 ppm, cobalt

0.05 ppm, cadmium 0.05 ppm and chromium 0.05 ppm on dry-weight basis. The MSWC application to each treatment in every season is presented in Table 3. McLean prediction model for site-specific P application was followed [31].

Analysis of Soil Characteristics

The following methods were used for analysis.

Sr. No.	Parameter	Method Followed
1.	SOM	[32] (Walkley and Black, 1934)
2.	Soil Phosphorus	[33] (Olsen et al., 1954)
3.	Soil Potassium	[34] (Brown and Warncke, 1988)
4.	Phosphorus and potassium balance in kg ha^{-1}	$\text{P or K balance} = \sum (\text{Fertilizer P or K, municipal solid waste manure P or K, irrigation water P or K}) - \text{Plant P or K (P or K removal by grain and straw)}$

Table 2. Mineral fertilizer application rates.

Crop detail	Soil P (ppm)	Mineral Fertilizer Application Rate (kg ha^{-1})					
		D_{-I} (Conventional)			D_{-II} (Site-Specific)		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
Wheat, 1 st Crop	1.7	135	100	40	135	196	40
Cotton, 1 st Crop	9.4	115	85	35	115	91	35
Wheat, 2 nd Crop	14.6	135	100	40	135	91	40
Cotton, 2 nd Crop	17.8	115	85	35	115	82	35
Wheat, 3 rd Crop	16.7	135	100	40	135	59	40
Cotton, 3 rd Crop	14.7	115	85	35	115	19	35
Total		750	555	225	750	538	225

Table 3. Detail of MSWC application to soil.

Combination of Techniques and Doses	MSWC Applied (kg ha ⁻¹)						Cumulative Amount
	Wheat-1 Soil test P at sowing = 1.70 mg kg ⁻¹	Cotton-1 Soil test P at sowing = 9.40 mg kg ⁻¹	Wheat-2 Soil test P at sowing = 9.40 mg kg ⁻¹	Cotton-2 Soil test P at sowing = 10.0 mg kg ⁻¹	Wheat-3 Soil test P at sowing = 11.70 mg kg ⁻¹	Cotton-3 Soil test P at sowing = 14.60 mg kg ⁻¹	
$T_{-I} \times D_{-I}$ and $T_{-I} \times D_{-II}$	0	0	0	0	0	0	0
$T_{-II} \times D_{-I}$ and $T_{-III} \times D_{-I}$	4000	3400	4000	3400	4000	3400	22200
$T_{-II} \times D_{-II}$ and $T_{-III} \times D_{-II}$	7800	3600	3600	3400	2400	800	21600

Indexation

Indices were calculated in respect of SOM, P and K. The index value of each characteristic of a cropping system was determined as the ratio the improved characteristic to that of conventional characteristic. For example, the index of SOM was determined as “SOM

because of INM/SOM due to only mineral fertilizer application”.

If the value of index is more than one indicates positive role/effect, if the value of index is less than one indicates negative role/effect and if the value of index is equal to one indicates no change as described by Eltun et al., (2002) [35].

Table 4. Soil OM, P and K status after three years of experimentation.

Treatments	SOM (%)	% Increase over initial SOM level (0.50%)	P ₂ O ₅ (ppm)	% Increase over initial STP level (1.7 ppm)	K ₂ O (ppm)	% Increase over initial soil K level (129.0 ppm)
Fertilizer doses						
D_{-I} Conventional	0.77 b	54	8.4 b	394	121 a	-6.2
D_{-II} Site-specific	0.85 a	70	9.5 a	459	124 a	-3.87
LSD .05	0.063		0.82		6.2	
% increase over D_{-I}	10.38		13.09		2.48	
Management Techniques						
T_{-I} Only Mineral fertilizer	0.74 b	48	8.5 a	400	116 b	-10.1
T_{-II} INM with pesticides	0.82 a	64	9.0 a	429	123ab	-4.70
T_{-III} INM without pesticides	0.88 a	76	9.4 a	453	129 a	0
LSD .05	0.077		0.99		7.6	
% increase in T_{-II} over T_{-I}	18.92		10.59		11.21	
% increase in T_{-III} over T_{-I}	10.81		5.88		6.03	
Season						
Wheat, 1 st Crop	0.93 a	86	7.1 e	318	114 c	-11.63
Cotton, 1 st Crop	0.82 b	64	8.8 d	417	103 d	-20.16
Wheat, 2 nd Crop	0.68 c	36	9.7 cd	470	131 b	1.55
Cotton, 2 nd Crop	1.01 a	102	11.1 bc	552	158 a	22.48
Wheat, 3 rd Crop	0.68 c	36	14.8 a	770	133 b	3.10
Cotton, 3 rd Crop	0.75 bc	50	12.1 b	611	94 d	-27.13
LSD .05	0.085		1.41		8.2	
Last % increase over Initial status	50.00		611.76		-27.13	

Figures sharing same alphabet are not significantly different from each other

Design and Analysis

The data were subjected to analysis of variance. A combination of techniques and doses effect was studied on SOM, P & K in cotton-wheat system by considering as one unit and unit was replicated thrice in a split plot design by using statistical software “CoStat 6.451”.

Results and Discussion

The results of field experiments for six seasons are discussed hereafter according to treatments effect on SOM, Phosphorus, and Potassium.

Changes in Soil Organic Matter (SOM)

Total application of MSWC was 22.0 tons ha⁻¹ (Table 3) during three years in applied treatments resulted in 64% to 76% increase in SOM over an initial level of 0.5 % to a level of 0.82 to 0.88% by both management techniques (T_{II} and T_{III}) of INM with and without pesticide use (Table 4). The only mineral fertilizer application in T_I increased 48% SOM. The performance of T_{II} and T_{III} over T_I is 18.92% and 10.81% respectively in enhancing SOM level, while, conventional (D_I) and site-specific (D_{II}) doses enhanced SOM level 54% and 70% respectively. Site-specific (D_{II}) dose performed 10.38% better in enhancing SOM level as compared to conventional (D_I). By season's interpretation, 50% increase in SOM was observed after the harvest of final cotton crop. It is important to note that season's effect is significantly different in different crop seasons. It was also noticed that initial improvement in SOM was up till second cotton harvest, afterward status decreased or sustained. But in all seasons, values were higher than initial status. It counts as high attainment that the increase in SOM was taken place in an exhaustive cropping system of semi-arid to arid climate especially through INM. Rate of increase of SOM over initial level in six crop seasons after crop harvest is depicted in Fig. 1.

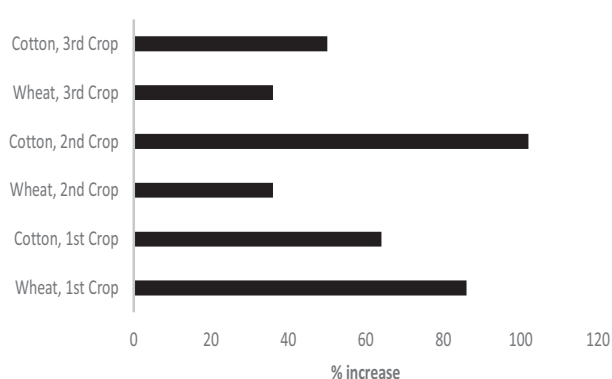


Fig. 1. % Increase of SOM over initial level in six crop seasons.

Changes in Soil Phosphorus

The marked beneficial effects of MSWC application on STP level were observed in this system. Statistical significant improved soil test phosphorus (STP) level was observed by the site-specific way of fertilizer application (D_{II}) over conventional fertilizer application (D_I) after three years. The conventional (D_I) and site-specific (D_{II}) doses enhanced soil test phosphorus (STP) level 394% and 459% respectively over initial level. Comparison of two doses revealed that 13.00% increase was due to site-specific way of fertilizer application over conventional fertilizer application (Table 4) in spite of the fact site-specific way of fertilizer application received less i.e. P_2O_5 i.e. 538 kg ha⁻¹ as compared to conventional fertilizer application which received P_2O_5 i.e. 555 kg ha⁻¹ in three years (Table 2). Total application of MSWC was 21.6-22.0 tons ha⁻¹ (Table 3) during three years in INM techniques resulted in 429% to 453% increase in STP over an initial level of 1.70 % to a level of 9.0 ppm and 9.40 ppm by both management techniques (T_{II} and T_{III}) of INM with and without pesticide use (Table 4). The only mineral fertilizer application in T_I also increased 400% STP level. By season's interpretation, 612% increase in STP level was observed after the harvest of final cotton crop (Table 4). It was also noticed that gradual improvement in STP level was up till third wheat crop harvest, the afterward status was found decreased. But in all seasons, values were much higher than initial status. It counts as significant attainment that the increase in STP level was taken place in an exhaustive cropping system of arid to semiarid climate especially through site-specific way of fertilizer application and INM. Zvomuya et al. (2007) [36] claimed that application of compost rates more than 20.0 tons ha⁻¹ resulted in high P buildup of phosphorus in the soil i.e. 95.7 ppm. The rate of increase of STP level over the initial level in six crop seasons after crop harvest is depicted in Fig 2.

Changes in Soil Potassium

No beneficial effects of MSWC application regarding soil K level were observed in cotton-wheat

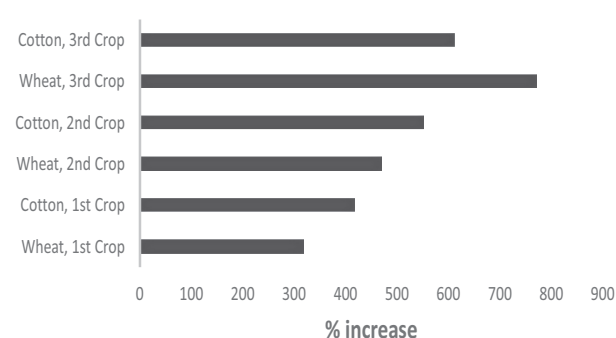


Fig. 2. % Increase of STP level over initial level in six crop seasons.

Table 5. Mean indices of soil fertility indicators.

Technique / Dose	SOM	P ₂ O ₅	K ₂ O	Mean
T _{-I}	1.311	1.221	0.956	1.163
T _{-II}	1.151	1.333	0.992	1.159
T _{-III}	0.989	1.106	1.132	1.076
D _{-II}	1.107	1.193	1.023	1.108
Mean	1.140	1.213	1.026	1.126

system. Statistical non-significant decrease in soil K level was observed by the site-specific way of fertilizer application (D_{-II}) over conventional fertilizer application (D_{-I}) after three years. The conventional (D_{-I}) and site-specific (D_{-II}) doses decreased soil K level by 6.2% and 3.87% respectively over initial level (Table 4). Total application of MSWC was 21.6-22.0 tons ha⁻¹ during three years in INM techniques resulted in decrease soil K level by 4.70% to 0.00% over an initial level of 129 ppm. A significant decrease of 10.1% in soil K level was observed by the technique of only mineral fertilizer application T_{-I} . By season's interpretation, overall 27.13% decrease in soil K level was observed after the harvest of the final cotton crop. A significant declining trend is visible in seasons. Probably the K additions were not adequate to meet the enhanced crops requirement. Mian and Akram (2002) [37] also reported continuous mining of K in the soils of Punjab, Pakistan.

Indexation of Soil Organic Matter, Phosphorus, and Potassium

Soil fertility characteristics play a vital role in the sustainability of a farming system. Values of SOM and soil nutrients status were recorded with improved practices as well as with conventional practices over the

whole study period are used as indices of soil fertility and these indices are listed in Table 5. Indices ranking from the best to least favorable were recorded as P>SOM>K. No negative impact was noticed. Favorable mean indices were achieved by applying techniques T_{-I} followed by T_{-II} as compared to T_{-III} . Mean index 1.163, 1.159 and 1.076 of T_{-I} , T_{-II} and T_{-III} respectively was based on favorable values of P, SOM and K incorporation of MSWC in fertilizer recipes contributed in enhancing their status. Summing up, all treatments were found advantageous by the indexation with an overall mean index of 1.126 in this cropping system. The enrichment of SOM seems to be the residual effect of the flourished roots due to availability of nutrients applied through mineral fertilizers. The extractable phosphorus, and the SOM increased in twenty years of intensive cultivation by 61.0% and 51.0% respectively but potassium decreased by 31.0% due to use of mineral N&P fertilizers in Quzhou County [38]. The degrading effects of a cropping system due to soil fertility depletion cannot be mitigated without introduction of new improved technique like INM with cost-effective organic sources and lower herbicides/pesticide use to protect/sustain SOM. Positive site-specific P dose (D_{-II}) index (improved practice over conventional routine) i.e. 1.108 was noticed primarily due to favorable indices of all fertility parameters.

Nutrients Balance of Phosphorus and Potassium

Apparent Balance of Phosphorus

The apparent balance of phosphorus in a cropping system remained positive in all applied treatments including doses (D_{-I} and D_{-II}) and management techniques (T_{-I} , T_{-II} and T_{-III}) at harvest of first and last crop (Table 6). The doses were enough to gain STP

Table 6. Apparent phosphorus balances.

Technique / Dose	Application through mineral fertilizer plus MSWC	Addition through irrigational water	Total addition	Uptake by crop	Balance
	kg/ha				
	After 1 st wheat Crop				
D_{-I}	44	0.7	44.7	5.6	+39.1
D_{-II}	85	0.7	85.7	6.1	+79.6
T_{-I}	65	0.7	65.7	5.2	+60.5
T_{-II}	65	0.7	65.7	6.3	+59.4
T_{-III}	65	0.7	65.7	6.1	+59.6
	After last wheat crop				
D_{-I}	44	0.7	44.7	9.9	+34.8
D_{-II}	26	0.7	26.7	11.5	+15.2
T_{-I}	35	0.7	35.7	9.6	+26.1
T_{-II}	35	0.7	35.7	11.7	+24.0
T_{-III}	35	0.7	35.7	10.8	+24.9

Table 7. Apparent potassium balances.

Technique / Dose	Application through mineral fertilizer+MSWC	Addition through irrigational water	Total addition	Uptake by crop	Balance
	kg/ha				
	Wheat 1 st Crop				
D_{-I}	58	11	69	71	-2
D_{-II}	58	11	69	71	-2
T_{-I}	58	11	69	73	+4
T_{-II}	58	11	69	72	-3
T_{-III}	58	11	69	73	-4
Wheat last crop					
D_{-I}	58	11	69	92	-23
D_{-II}	58	11	69	111	-32
T_{-I}	58	11	69	68	+1
T_{-II}	58	11	69	106	-37
T_{-III}	58	11	69	113	-44

sufficiency level to fulfill the crop requirement and also besides comparatively lower uptake of the crop. At the time of last wheat harvest, the residual P effect was found minimized in all the treatments except for D_{-I} where sustained residual effect was recorded. Phosphorus balance in site-specific fertilizer application (D_{-II}) appeared less i.e. +15.2 because of residual application of phosphorus recommendations were quite adequate and capable to sustain nutrients soil P supplying capacity on a long term basis.

Apparent Balance of Potassium

The apparent K balance was negative in all treatments except in T_{-I} at harvest of wheat, 1st crop, whereas in D_{-I} nearly sustained situation was observed. The average K balance ranged from +1 kg in T_{-I} of the only use of mineral fertilizers technique to -37 and -44 kg K ha⁻¹ in T_{-II} & T_{-III} techniques of INM respectively after harvest of last wheat crop. When MSWC integrated in fertilizer recipe, the K balance was highly negative as compared to nearly zero balance achieved through only use of mineral fertilizers (Table 7). Despite substantial inputs from irrigation water, the K balance was remained negative. The total K uptake by wheat was variable with varied treatments. However, the highly negative K balance suggests that the system will not be able to sustain the K supply in the long run. The major fraction of K uptake, however, remained in straw; thus, recycling of straw can dramatically change the K balance and would keep it within reasonable limits. However, Eltun et al. (2002) [35] summarized that there were considerable deficits in ecological (organic) systems on the basis of nutrient balance calculations, a fact which must be taken into

consideration in the development of the sustainable ecological cropping systems with or without FYM.

Conclusions

Total application of 22 tons MSWC ha⁻¹ during three years in applied treatments resulted in 64% to 76% increase in SOM over an initial level of 0.5% to a level of 0.82 -0.88% by both management techniques of INM with and without pesticide use while conventional and Site-specific doses enhanced SOM level 54% and 70% respectively. Statistical significant improved soil test phosphorus (STP) level was observed by the site-specific way of fertilizer application over conventional fertilizer application after three years. The conventional and site-specific doses enhanced soil test phosphorus (STP) level 394% and 459% respectively over initial level. No beneficial effects of MSWC application regarding soil K level were observed. The conventional and site-specific doses decreased soil K level by 6.2% and 3.87% respectively over initial level. Indices ranking from the best to least favorable are recorded as P>SOM>K. All applied treatments were found advantageous by the indexation with an overall mean index of 1.126 in cotton-wheat cropping system. The apparent balance of phosphorus in a cropping system remained positive in all applied treatments including doses and management techniques at harvest of first and last crop but apparent K balance was found negative in INM techniques.

Conflict of Interest

The authors declare no conflict of interest.

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