Original Research

Integrated Nutrient Management for Wheat by Municipal Solid Waste Manure in Rice-Wheat and Cotton-Wheat Cropping Systems

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Abstract

The effects of integrated nutrient management (INM) by municipal solid waste manure (MSWM) on wheat yield were studied in rice-wheat and cotton-wheat systems. Each site was used as an independent experimental unit. Two fertilizer doses (conventional and site-specific) were applied in each of three improved techniques: chemical fertilizers, and MSWM plus chemical fertilizers with and without pesticides/herbicides. The results of three years field trials portrayed the role of INM with MSWM treatment by 9% increased wheat grain and straw yields over unique fertilizer application in cotton-wheat system only. However, INM technique helped in sustaining soil-test P status near to sufficiency levels during 3 years of experimentation in both systems.

Keywords: Integrated Nutrient Management (INM); Municipal Solid Waste Manure (MSWM); conventional and site-specific fertilizer application; rice-wheat and cotton-wheat cropping systems; Pakistan.

Introduction

Among established cropping systems, rice-wheat and cotton-wheat cover a major part of the irrigated area of Punjab, Pakistan. Yields of wheat, rice and cotton crops have been considerably improved with increased use of fertilizer and improved management techniques. Various improved management practices/techniques are part of these systems and they have been introduced to increase yields. However, the impact evaluation of improved techniques has not been evaluated systematically in these systems for wise use of resources and development of an environment-friendly and economically sound agricultural production system. The technique of soil fertility management is one of the critical components of any cropping system designed to enhance and sustain productivity. Therefore, the technology adaptation for correct dose of fertilizer that can assure economic optimum crop yield as well as sustain soil nutrient reserve, yet not environmentally degrading in the long run is the need of time. Various workers have suggested that it can be achieved only by incorporating soil test in fertilizer prediction procedures because soil test has the capability to forecast the fertilizer need for succeeding crops [1-3].

Once the fertilizer need has been evaluated, then soil nutrient status can be maintained by adding organic or inorganic fertilizers or a combination of both. Long-term inorganic fertilizer applications may lead to poor levels of soil organic matter and lower yield. However, available information is conflicting and uncertainties still remain about the influences of inorganic fertilizers on soil quality and productive capacity. Some studies have shown that continued

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use of inorganic fertilizers may result in diminishing soil quality and productive capacity [4-7]. Others have indicated both positive and negative effects [8, 9] and no noticeable changes [10] in soil quality and productive capacity. These conflicting reports emphasize the need for research on the effects of inorganic and organic fertilizers and combinations of both nutrients sources on soil quality and productivity.

However, organic sources of nutrients have low nutrient contents and are usually not abundantly available. An enormous amount of organic fertilizer would be required to maintain soil fertility levels. Therefore, a combination of both inorganic and organic fertilizers is the answer for sustainability [11]. It was reported by some researchers [12] that a combination of organic sources (FYM / green manure) with chemical fertilizers (25:75) produced more grains compared to fertilizers alone in the rice-wheat system in India. It was suggested that the option of bio-solids that can complement chemical fertilizers for sustainability escaping from environmental degradation threat in the long run [13]. In Pakistan, locally available organic sources are animal manure (farm yard manure), straw and crop residues. The scarcity of these products and use of straw as animal feed and burning of crop residues limited the scope for use as organic supplements to sustain crop yield by increasing soil organic matter (SOM). It was found that a rate of 10 Mg ha^{-1} of organic waste increased soil organic matter without risk of N leaching [14]. Other options include green manuring that is not popular because it does not offer any ready cash return. However, large amounts of municipal solid wastes are produced in cities of Pakistan for which disposal is unsatisfactory. These city solid wastes can be used effectively as organic manure for agriculture after proper management [15, 16].

An increase in soil organic matter certainly improves soil quality by acting as revolving nutrient bank account and also as an agent to improve soil structure, maintain tilth and retain moisture. But maintenance of organic matter by bulk use of wastes is not a practical approach to farming as was assessed in the region [17]. It is more realistic to use a management system that will incorporate municipal solid waste (MSW) in suitable ratio in a specific fertilizer program to realize sustained results. Keeping these facts in view, a study was planned and initiated in 2002 for impact evaluation of the use of municipal solid waste manure as part of an integrated nutrient management system so that a sustained and improved yield, SOM, phosphorus (P) and potassium (K) status can be assured in two renowned cropping systems of Punjab (Pakistan), i.e. rice-wheat and cotton- wheat in addition to overcoming the dilemma of municipal solid waste management.

Experimental Procedure

The investigation included monitoring of soil quality during 3 years (2002-03 to 2004-05) of study comprised of field trials with municipal solid waste manure (MSWM) and chemical fertilizer application in two cropping systems by recording grain and straw yields of wheat, soil organic matter, soil test phosphorus and potassium at harvesting time in each winter (Rabi) season.

Field Trial Sites

Two field sites in the Punjab province of Pakistan were used for this field study: a loam soil at Adoptive Research Farm, Gujranwala situated 80 km north of Lahore for rice–wheat cropping system (32.17^o N, 73.83^o E) and a sandy loam soil located at 30 km south of Lahore in Cotton Research Sub-Station, Raiwind for cotton–wheat system (31.25^o N, 74.22^o E). Selected characteristics of two soils are given in Table 1. The average annual precipitation was 800 mm at Gujranwala and 600 mm at Raiwind. The average normal temperature was 24^{0}C at both sites (Pakistan Meteorological Department). Canal and tube well irrigation facilities were available at both sites.

Site-Specific Phosphorus Fertilizer Prediction

The procedure for site-specific fertilizer prediction [18] was adopted following the equation "P required = P fixation factor (soil P sufficiency level – existing P level)". The fixation factor was calculated as reciprocal of recovered P of that added in to a soil. The assumed P sufficiency soil test level was kept at 21 mg P kg^{-1} soil in rice-wheat and 16 mg P kg^{-1} in cotton-wheat system.

Municipal Solid Waste Manure (MSWM) and Application Rates

The manure was obtained from "M/s Waste Busters" for which they performed sorting / clean up operation firstly for unwanted materials and then introduced microbes

Table 1. Selected site characteristics.

Parameter	Gujranwala (rice–wheat)	Raiwind (cotton–wheat)
Soil type	Loam	Sandy loam
Clay (g kg^{-1})	192	142
Silt (g kg^{-1})	372	212
Sand (g kg^{-1})	436	644
OM (%)	0.92	0.50
P ($NaHCO_3$) (mg kg^{-1})	8.7	1.7
K (NH_4 acetate) (mg kg^{-1})	119	129
pH (paste)	7.9	8.0
EC_e (dSm^{-1})	1.3	0.9
P fixation factor*	2.5	3.0

*Reciprocal of recovered P of that added for decomposition followed to drying and packing into bags of 35 kg weight. The application rates were based on P analysis of material in a ratio of 20:80 (MSWM: Chemical Fertilizer) of respective fertilizer doses. Table 2 presents information about nutrient composition of MSWM.

Treatments and Experimental Design

The impact evaluation of 2 fertilizer doses and 3 improved management techniques / practices i.e. unique fertilizer application, integrated use of MSWM along with chemical fertilizer in ratio of 20:80 (P based) with and without application of pesticides/herbicides was explored in this field study. The treatment combinations (Tables 3 and 4) were replicated three times at both sites and were applied to the same plots in every season for a period of 3 years. The plot size was 5m x 20m at Gujranwala and 9m x 11m at Raiwind. MSWM was incorporated in upper 15 cm soil. Each site was used as an experimental unit with 6 combinations of treatments (2 x 3) of 2 factors in randomized complete block design (RCBD). The factor-1 included two fertilizer doses, i.e. conventional and site-specific that carried in all three improved techniques/practices of factor-2.

Crop and Soil Sampling

Yields were recorded within a net plot size of 3m x 3m. Soil samples were drawn from 0-15 cm soil depth at each harvest time from both sites.

Soil Analysis

Part of each soil sample was air dried and passed through 2 mm sieve before running the following analysis.

1. Organic Matter [19]
2. Sodium Bicarbonate extractable P [20]
3. Ammonium Acetate extractable K [21]
4. Soil reaction (pH) and salinity (EC_e)

Table 2. Selected characteristics of MSWM product.

Organic C (g kg^{-1} DM *)	400
N (g kg^{-1} DM)	5
P_2O_5 (g kg^{-1} DM)	5
K_2O (g kg^{-1} DM)	10
Zn (mg kg^{-1} DM)	2000
Cu (mg kg^{-1} DM)	500

*Dry Matter

Statistical Analysis

After the harvest of each year's field trials, treatments within each cropping system were compared by ANOVA followed by Duncan's multiple range tests [22]. For monitoring purposes, year-wise results were presented in graphs (Figs. 1 to 5).

Table 3. Treatments in a Cropping Unit.

Treatment	Fertilizer N-P-K	Pesticide / Herbicide
1. CON.[a]	Conventional Recommendation	General Recommendation
2. SITE [b]	Site-Specific	As Required
3. CON. ORG.[c]	Chemical fertilizer (80%) + MSWM (20%) @ Conventional	General Recommendation
4. IPNS [d]	Chemical fertilizer (80%) + MSWM (20%) @ Site-specific	As Required
5. CON. ORG – PEST.[e]	Chemical fertilizer (80%) + MSWM (20%) @ Conventional	Nil
6. IPNS – PEST [f]	Chemical fertilizer (80%) + MSWM (20%) @ Site-Specific	Nil

[a] Conventional crop production (unique fertilizer application) according to current recommendation by the Agriculture Department.

[b] Site-specific (unique) fertilizer recommendation based on soil test values to a sufficiency level of 21 mg P kg^{-1} soil (rice-wheat) or 16 mg P kg^{-1} soil (cotton-wheat)

[c] Conventional crop production with inclusion of MSWM in fertilizer program

[d] Integrated plant nutrient management with inclusion of MSWM in fertilizer program and pesticide use according to observed requirement

[e] Conventional crop production with inclusion of MSWM in fertilizer program without pesticide use

[f] Integrated plant nutrient management with inclusion of MSWM in fertilizer program without pesticide use

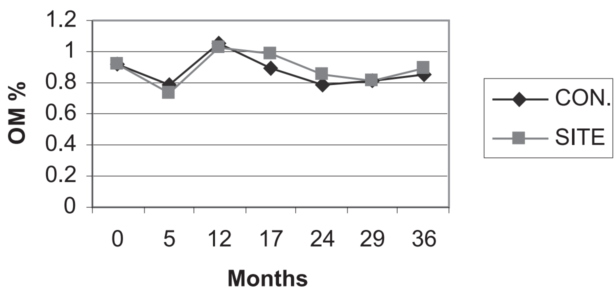

Fig. 1. Effect of fertilizer doses on soil organic matter (rice-wheat).

Table 4. Detail of fertilizer and MSWM application from 2002-03 to 2005.

Treatment No.	Fertilizer N -P_2O_5-K_2O-MSWM (kg ha^{-1})	
	Rice-wheat	Cotton-wheat
2002-03	Soil test P at sowing = 8.7 mg kg^{-1}	Soil test P at sowing = 1.7 mg kg^{-1}
T-1	135-100-40-0	135-100-70-0
T-2	135-80-40-0	135-196-70-0
T-3	115-80-0-4000	115-80-30-4000
T-4	119-64-8-3200	96-157-0-7800
T-5	115-80-0-4000	115-80-30-4000
T-6	119-64-8-3200	96-157-0-7800
2003	Soil test P at sowing = 18.4 mg kg^{-1}	Soil test P at sowing = 9.4 mg kg^{-1}
T-1	115-100-40-0	115-85-35-0
T-2	115-30-40-0	115-91-35-0
T-3	95-80-0-4000	98-68-0-3400
T-4	109-24-28-1200	97-73-0-3600
T-5	95-80-0-4000	98-68-0-3400
T-6	109-24-28-1200	97-73-0-3600
2003-04	Soil test P at sowing = 14.6 mg kg^{-1}	Soil test P at sowing = 9.4 mg kg^{-1}
T-1	135-100-40-0	135-100-70-0
T-2	135-73-40-0	135-91-70-0
T-3	115-80-0-4000	115-80-30-4000
T-4	111-59-12-2800	117-73-34-3600
T-5	115-80-0-4000	115-80-30-4000
T-6	111-59-12-2800	117-73-34-3600
2004	Soil test P at sowing = 17.8 mg kg^{-1}	Soil test P at sowing = 10.0 mg kg^{-1}
T-1	115-100-40-0	115-85-35-0
T-2	115-37-40-0	115-82-35-0
T-3	95-80-0-4000	98-68-0-3400
T-4	107-29-24-1600	98-65-0-3400
T-5	95-80-0-4000	98-68-0-3400
T-6	107-29-24-1600	98-65-0-3400
2004-05	Soil test P at sowing = 16.7 mg kg^{-1}	Soil test P at sowing =11.7 mg kg^{-1}
T-1	135-100-40-0	135-100-70-0
T-2	135-49-40-0	135-59-70-0
T-3	115-80-0-4000	115-80-30-4000
T-4	125-39-20-2000	123-47-46-2400
T-5	115-80-0-4000	115-80-30-4000
T-6	125-39-20-2000	123-47-46-2400
2005	Soil test P at sowing = 14.7 mg kg^{-1}	Soil test P at sowing = 14.6 mg kg^{-1}
T-1	115-100-40-0	115-85-35-0
T-2	115-72-40-0	115-19-35-0
T-3	95-80-0-4000	98-68-0-3400
T-4	101-58-12-2800	115-15-35-800
T-5	95-80-0-4000	98-68-0-3400
T-6	101-58-12-2800	115-15-35-800

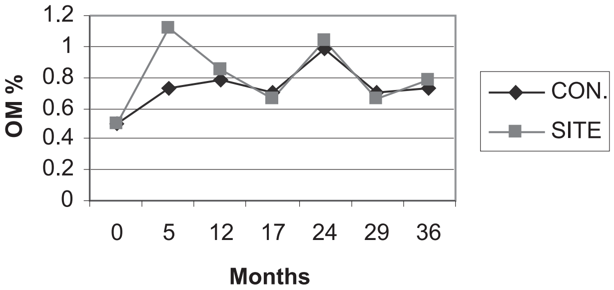

Fig. 2. Effect of fertilizer doses on soil organic matter (cotton-wheat).

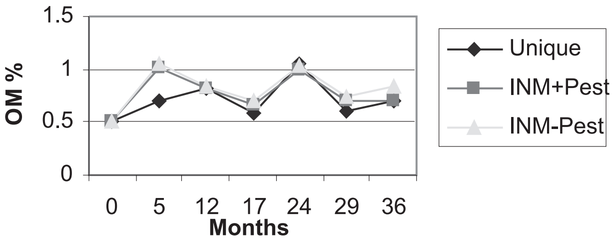

Fig. 3. Effect of techniques on soil organic matter (cotton-wheat).

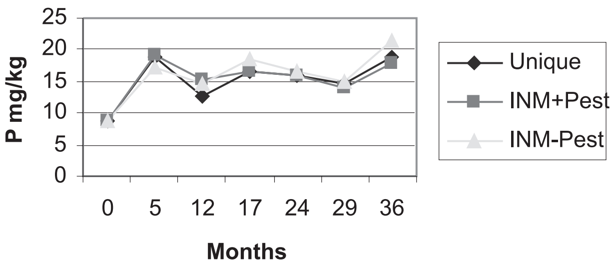

Fig. 4. Effect of techniques on soil test P (rice-wheat).

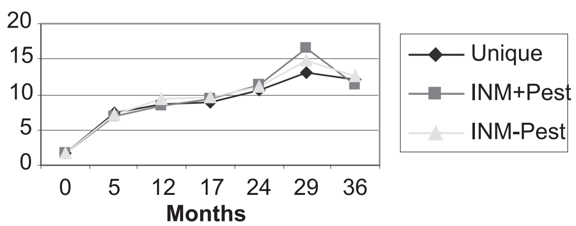

Fig. 5. Effect of techniques on soil test P (cotton-wheat).

Results and Discussion

Wheat grain and straw yields and respective statistical analysis are given in Tables 5 and 6. Effects of treatments on grain and straw yields of wheat, soil organic matter (SOM), soil test phosphorus (P) and potassium (K) after 3-years field trials are discussed hereafter:

Table 5. Mean grain yield (kg ha^{-1}) of wheat and statistical analysis.

	Rice-wheat	Cotton-wheat
Fertilizer Doses		
Conventional P	2914 a	3525 a
Site-specific P	2731 a	3655 a
Techniques		
Unique fertilizer	2803 a	3524 b
Fert + MSWM (80:20)+Pest	2831 a	3843 a
Fert + MSWM (80:20)-Pest	2833 a	3403 b
Year		
2002-03	2456 c	2854 c
2003-04	2813 b	3876 b
2004-05	3197 a	4040 a
Interaction		
Technique x dose	Non-significant	Significant
Technique x year	Non-significant	Significant
Dose x year	Non-significant	Highly significant
Technique x dose x year	Non-significant	Significant

Means sharing same alphabet in columns are non-significant to each other at 0.05% level

Table 6. Straw yield (kg ha^{-1}) of wheat and statistical analysis.

	Rice-wheat	Cotton-wheat
Fertilizer Doses		
Conventional P	4570 a	6148 a
Site-specific P	4225 a	6365 a
Techniques		
Unique fertilizer	4037 b	6038 b
Fert + MSWM (80:20)+Pest	4057 b	6567 a
Fert + MSWM (80:20)-Pest	5099 a	6165 ab
Year		
2002-03	2721 c	3872 b
2003-04	4687 b	7337 a
2004-05	5785 a	7561 a
Interaction		
Technique x dose	Non-significant	Non-significant
Technique x year	Highly significant	Non-significant
Dose x year	Non-significant	Non-significant
Technique x dose x year	Non-significant	Non-significant

Means sharing same alphabet in columns are non-significant to each other at 0.05% level

Table 7. Interactions between treatments in cotton-wheat system (mean grain yield, kg ha^{-1}) .

Interaction	Techniques x Year			
Technique	**Year-1**	**Year-2**	**Year-3**	
Unique Fertilizer	2865 c	3622 b	3667 b	
INM (MSWM)+Pesticides	2964 c	3919 b	4417 a	
INM (MSWM)-Pesticides	2736 c	3837 b	3938 b	
Interaction	**Dose x Year**			
Dose	**Year-1**	**Year-2**	**Year-3**	
Conventional	2887 c	3654 b	3750 b	
Site-specific	2823 c	3931 ab	4264 a	
Interaction	**Technique x Dose x Year**			
Technique	**Dose**	**Year-1**	**Year-2**	**Year-3**
Unique Fertilizer	Conventional	2847 ef	3200 ef	3333 cde
	Site-Specific	2882 ef	4044 b	4000 b
INM (MSWM)+Pesticides	Conventional	3078 ef	3911 b	4083 b
	Site-Specific	2850 ef	3926 b	4750 a
INM (MSWM)-Pesticides	Conventional	2736 f	3852 bc	3833 bc
	Site-Specific	2736 f	3822 bcd	4042 b
Interaction	**Technique x Dose**			
Technique	**Conventional**	**Site-specific**		
Unique Fertilizer	3127 b	3642 a		
INM (MSWM)+Pesticides	3691 a	3842 a		
INM (MSWM)-Pesticides	3474 ab	3533 ab		

Means sharing same alphabet in columns are non-significant to each other at 0.05% level

Table 8. Change in SOM, P and K status after 3 years experimentation.

	Rice-wheat		Cotton-wheat	
	2002	2005	2002	2005
Soil OM (%)	0.92	0.85 – 0.90	0.50	0.74 – 0.88
Soil test P (mg kg^{-1})	8.7	16 – 17	1.7	8 – 10
Soil test K (mg kg^{-1})	119	104 – 110	129	116 – 129

Effects on Grain and Straw Yield

The treatment effects on yield as well as on soil test levels were different in various aspects in rice-wheat compared to cotton-wheat cropping system. Two fertilizer doses i.e. conventional and site-specific produced almost at par grain as well as straw yields in both cropping systems with an edge over superiority of site-specific (P) treatment in cotton-wheat system. As the N and K fertilizer levels were kept standard in the plan, the varied P dose explained the crop response in both systems. However, the experimental site of cotton-wheat system was very deficient in $NaHCO_3$-P (1.7 mg kg^{-1}) with a long history of under application of P & K fertilizers. Therefore, to manage the situation and to meet the soil sufficiency level of 16 mg kg^{-1}, total P recipe of 538 kg P_2O_5 ha^{-1} was applied during 3 years of cotton-wheat cropping in site-specific treatment. It was calculated on the basis of soil test P level attained at harvesting of each crop. The total P applied in site-specific treatment was nearly equal to total amount applied (555 kg P_2O_5 ha^{-1}) in treatment of conventional dose (Table 4). In rice-wheat system, total conventional dose (600 kg ha^{-1}) was much higher compared to site-specific (369 kg ha^{-1}) that expressed the reciprocal (but non-significant) responses of doses in systems. Nevertheless, site-specific predictions earned significance by producing statistically at par grain and straw yields to conventional dose though P application was 1.6 times less in site-specific prediction than the conventional dose. Here, conventional dose produced 10% higher mean grain yield whereas increase in mean straw yield was 8%.

When management techniques (implicated) in a system were compared, the treatment including MSWM with pesticides application was found effective to improve grain and straw yields significantly about 9% over unique fertilizer application in cotton-wheat system only. While working to determine whether modifications to currently recommended crop management practices could improve wheat yield at hot-environment, It was reported [23] that FYM (10 t ha^{-1}) gave the highest yield response (14%) and approximately equivalent levels of NPK gave the lowest (5.5%), suggesting that organic fertilizer provided growth factors in addition to nutrient content. The data obtained from semi-arid sub-tropical conditions in India suggested that, as compared to unbalanced and sub-optimum fertilizer application, the organic C status in soil was improved by balanced application of chemical fertilizer nutrients and manure. In the present study, ignoring pesticides application restricted response to MSWM treatment declining to none or 3.7% non-significant increase. Seemingly, weeds competed in nutrients uptake resulting into disturbed response. Significant year effect was noted in both systems because grain and straw yields increased in progression as soil test P in rice-wheat and P and SOM in cotton-wheat increased after each crop harvest. With manure fertilization, increase in SOM contents has been observed in many field trials [24] and higher SOM have been found to have positive effects on yield and yield components of cereals. In China, over 20 years of field experimentation with organic manure, SOM increased by 80% compared to only 10% with NPK alone, which explained yield increases of wheat about 1 t ha^{-1} [25].

Interactions

In rice-wheat cropping system, interactions between treatment means were not observed in grain as well as straw yield data except for interaction between management techniques and years and it was noted in case of straw yield. The results of Table 7 elucidated the leading role of years in predicting grain yield of wheat in cotton-wheat system. The interactions of Technique x Year, Dose x Year, Technique x Dose and interactive interaction of all three factors tested were found significant at 0.05 level after running Duncan's Multiple Range Test. In this system, clarity among treatments for crop response was observed with the passage of time as the continuous application of treatments altered the soil environment from a very poor fertility status to a moderate level. Overall superiority of site-specific fertilizer dose could not be ascertained in the first year; however, a significant increase in yield (14%) over conventional dose was obtained in the third year. The difference was pronounced in unique fertilizer doses with 17% increase in yield due to site-specific fertilizer application over conventional application. The order of response over years was none, 8 and 14% in the 1st, 2nd and 3rd years.

The INM (+Pesticides) technique with use of MSWM also performed well in the 2nd and 3rd year and maximum grain yield of 4417 kg ha^{-1}was obtained in the 3rd year with an increase of 20% grains over unique fertilizer application (3667 kg ha^{-1}). The order of response due to INM (+Pesticides) was 3, 8 and 20% in the 1st, 2nd and 3rd years over unique fertilizer. The overall highest grain yield (4750 kg ha^{-1}) was conferred by INM technique using MSWM with pesticides under site-specific fertilizer application. When treatment combinations were considered for comparison, the best combination was found as INM (+Pesticides) under site-specific fertilizer application. It yielded 4–5% higher grains than to INM (+Pesticides) under conventional fertilizer application or to unique site-specific fertilizer application on average. It was noted that mean yields of wheat for the 16 years of experimentation ranged from 1.29 t ha^{-1} for the unfertilized plot to 4.71 t ha^{-1} for the plots that received manure annually along with inorganic N P K fertilizers [26]. It also was quantified that the annual addition of organic manures may increase yields, even with the application of large amounts of fertilizer. However, it is unclear whether the benefit was due to the FYM or to increase in SOC per se or to an increase in some related property such as soil available water content or minor nutrients in the manure.

Effects on Soil Organic Matter, Soil Test P and K

In rice-wheat system, addition of MSWM from 14 t ha^{-1} to 24 t ha^{-1} during 3 years did not contribute to improve the soil organic matter in both treatments of INM and conventional organic from an initial level of 0.92%; however, that had almost been maintained during all study period with a little variation (Table 7, Figs. 1, 2). The beneficial effects of use of MSWM (Fig. 3) were found prominent in the cotton-wheat system where soil was sandy loam and was initially poor in OM. An addition of 22 t ha^{-1} manure (during 3 years) enhanced SOM significantly from 0.50% to 0.77–0.88% that cannot be over-looked. The data obtained from semi-arid sub-tropical conditions in India suggested that, as compared to unbalanced and sub-optimum fertilizer application, the organic C status in soil was improved by balanced application of chemical fertilizer nutrients and manure [27]. The soil test P status improved to a level of 16 – 17 mg kg^{-1} from an initial level of 8.7 mg kg^{-1} in rice-wheat system and to a level of 8 – 10 mg kg^{-1}from an initial of 1.7 mg kg^{-1} in cotton-wheat system (Figs. 4, 5).

The marked beneficial effects of MSWM application were obtained in cotton-wheat system. The notable increase in soil test P was observed to a level of about 9 mg kg^{-1} soil from an initial of 1.7 mg kg^{-1}(Fig. 5). The addition of K either through MSWM or through chemical fertilizer was found futile in increasing soil test K levels in both cropping systems during 2004-05. However, declining trend was noted which is understandable. It seems that K additions were not satisfactory to meet the enhanced requirement of improved yields. The continuous mining of K had already been noticed in the Punjab by the staff of the Soil Fertility department [28].

Conclusions

Municipal solid waste is an important component of organic nutrient sources in Pakistan, if regulated properly in the form of manure. However, an enormous amount of manure would be required to maintain the soil fertility levels. Therefore, integrated nutrient management is the answer for its use in agriculture. The results of three years field trials portrayed the role of integrated nutrient management with municipal solid waste manure by 9% increased wheat grain and straw yields over unique fertilizer application in cotton-wheat system. The technique helped in sustaining soil-test P status near to sufficiency levels in both cotton-wheat and rice-wheat systems. The addition of K either through municipal solid waste manure or through chemical fertilizer was found futile in maintaining soil test K.

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