Introduction

Rice (Oryza sativa L.) - wheat (Triticum aestivum L.) is one of the world’s largest agricultural production systems. Intensive farming techniques, unbalanced application of chemical fertilizers without proper review of soil nutrient status, poor soil management and high-yielding crop varieties have resulted in a substantial decrease in soil organic matter (SOM) and crop productivity over the past decades. [1, 2]. A useful strategy to feed the rapidly growing population is to increase the unit area production by using existing agricultural area and resources [3]. This can be accomplished by growing improved crop varieties [4], site specific way of fertilizer application [5], integrated...
nutrient management [6] and modified cropping systems [7]. But improved crop varieties require higher fertilizer doses as compared to conventional varieties, hence having an inherent disadvantage to degrade the quality of soil and cause eutrophication by phosphorus enrichment due to surface runoff [8-10]. [11] has described that use of mineral fertilizers continuously deteriorates the quality of soil and causing the soil pollution. Hence, to sustain a sustainable a cropping system, an effective and efficient fertilizer application as per need is required [12]. Soil test based fertilizer application can play a pivotal role due to its ability to determine fertilizer need for growing a crop [13]. The use of organic matter in the form of green manures [14], crop residues [15] and farmyard manure [16] has been conventionally used to maintain soil quality and to meet the requirements for crop nutrients. These Conventional sources are diminishing day by day due to their use in other purposes, mainly in energy [17]. Green manuring is also limited due to change of cropping pattern and intensive cultivation [18]. Other sources such as municipal solid waste compost (MSWC) application also attracted farmers and researchers by its high carbon content and ability to improve soil chemical and physical properties [19]. The idea of mixing organic, inorganic, and biological nutrient sources through Integrated Nutrient Management (INM) is being promoted as a way to increase the efficiency of nutrient use to meet crop demand [20, 21, 22]. To minimize the risk of harmful accumulations of heavy metals and phosphorus, it is not desirable to use compost as the sole nutrient for crop production [23]. Developing a well-balanced and integrated nutrient management plan that uses MSWC in conjunction with mineral fertilizers is therefore needed to enhance and maintain soil fertility [24] while reducing harmful environmental impacts. 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 [25]. The present study in the rice-wheat cropping system of Punjab, Pakistan worked out to assess the cumulative effect of INM and site-specific application of fertilizer with and without use of pesticides and herbicides.

**Materials and Methods**

Field experiments on a permanent layout were conducted for six crop seasons in the rice-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 on Rice-Wheat Cropping System**

Depending upon soil type and climate, different agricultural farming systems were established. The rice - wheat system is being practiced in the North Eastern areas of Punjab because the climate and soil type are favorable for cultivation of rice. To monitor and concede the system’s effects on SOM, P and K, three years experimentation was conducted at Acre No. 8 of Adaptive Research Farm, Gujranwala, Punjab, Pakistan. Crops were irrigated with both canal as well as tube well water as per requirement. The experimental site (32.19057°N and 74.18077°E) was under an ongoing rice-wheat cropping system.

**Treatments and Management Practices**

Three management techniques ($T_i$; Only mineral fertilizer, $T_{ij}$, INM of organic and mineral fertilizer in 1:4 along with application of pesticides and herbicides and $T_{ij}$, INM of organic and mineral fertilizer in 1:4 without application of pesticides and herbicides) and two mineral fertilizer doses ($D_s$; Conventional mineral fertilizer P application according to the current recommendation of the extension service without caring soil test value and $D_{ss}$; Site specific mineral fertilizer P application on soil test basis) were evaluated in the form of following combinations. Fertilizer doses were either based on standard N, P and K recommendations or on measured site-specific soil plant available phosphorus (PAP) levels. To understand, treatments are briefly detailed below:

| Treatment   | Type                     | Description                                                                 |
|-------------|--------------------------|-----------------------------------------------------------------------------|
| T-I X D-I   | Conventional             | Conventional mineral fertilizer P application according to the current recommendation of the extension service without caring soil test value |
| T-I X D-II  | Site specific            | Site specific mineral fertilizer P application on soil test basis            |
| T-II X D-I  | Conventional Organic     | Conventional crop production with INM technique.                             |
| T-II X D-II | INM                      | INM of organic and mineral fertilizer in 1:4 on soil test basis along with application of pesticides and herbicides. |
| T-III X D-I | Conventional Organic     | Conventional crop production with INM technique without application of pesticides and herbicides. |
| T-III X D-II| INM without pesticide use | INM of organic and mineral fertilizer in 1:4 on soil test basis without application of pesticides and herbicides. |
The MSWC was prepared aerobically by M/S Waste Busters Pvt Ltd, Lahore, Punjab, Pakistan. MSWC application was made on the basis of the P requirement of a crop in a treatment. A computed quantity of MSWC was integrated in respective fertilizer dose in 1:4 (MSWC: Mineral fertilizer) on the soil test P basis. [26] 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 [27]. The MSWC analysis depicted that it contained organic matter 40%, nitrogen & phosphorus 5.0 ppm and potassium 10.0 ppm, 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. The MSWC application to each treatment in every season is presented in Table 1. and Initial soil characteristics is given in Table 2. A McLean prediction model for site specific P application was followed by McLean, et al., 1982 [28].

### Table 1. Detail of MSWC application to soil.

| Combination of Techniques and Doses | MSWC Applied (kg ha⁻¹) | Cumulative Amount |
|------------------------------------|------------------------|------------------|
|                                     | Wheat-1 | Rice-1 | Wheat-2 | Rice-2 | Wheat-3 | Rice-3 |                  |
| Soil test P at sowing = 8.2 mg kg⁻¹ | 0       | 0      | 0       | 0      | 0       | 0      | 0                 |
| Soil test P at transplanting = 18.4 mg kg⁻¹ | 0       | 0      | 0       | 0      | 0       | 0      | 24000             |
| Soil test P at sowing = 14.6 mg kg⁻¹ | 4000    | 4000   | 4000    | 4000   | 4000    | 4000   |                  |
| Soil test P at transplanting = 17.8 mg kg⁻¹ | 2800    | 1600   | 2000    | 2800   | 13600   | 13600  |                  |
| Soil test P at transplanting = 14.7 mg kg⁻¹ | 0       | 0      | 0       | 0      | 0       | 0      |                  |

### Table 2. Mineral fertilizer application rates.

| Crop detail | Soil P (ppm) | Mineral Fertilizer Application Rate (kg ha⁻¹) | D₁ (Conventional) | D₂ (Site Specific) |
|-------------|--------------|-----------------------------------------------|-------------------|--------------------|
|             |              |                                               | N | P₂O₅ | K₂O | N | P₂O₅ | K₂O |
| Wheat, 1st Crop | 8.7  | 135   | 100 | 40  | 135 | 80  | 40  |
| Rice, 1st Crop | 18.4 | 115   | 100 | 40  | 115 | 30  | 40  |
| Wheat, 2nd Crop | 14.6 | 135   | 100 | 40  | 135 | 73  | 40  |
| Rice, 2nd Crop | 17.8 | 115   | 100 | 40  | 115 | 37  | 40  |
| Wheat, 3rd Crop | 16.7 | 135   | 100 | 40  | 135 | 49  | 40  |
| Rice, 3rd Crop | 14.7 | 115   | 100 | 40  | 115 | 72  | 40  |
| Total        | 750 | 750   | 240 | 750 | 341 | 240 |      |

### Application Rates of MSWC

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

### Mineral Fertilizer Application Rates

The following methods were used for analysis of SOM, P and K.

### Analysis of Soil Characteristics

| Sr. No. | Parameter | Method Followed |
|---------|-----------|-----------------|
| 1.      | SOM       | [29]            |
| 2.      | Soil Phosphorus | [30]        |
| 3.      | Soil Potassium | [31]      |
| 4.      | Phosphorus and Potassium balance in kg ha⁻¹ | P or K balance = Σ (Fertilizer P or K, municipal solid waste manure P or K, irrigation water P or K) – Plant P or K (P or K removal by grain and straw) |
Indexation

The 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 the SOM was determined as “SOM because of INM/SOM due to only mineral fertilizer application”.

If the value of the index is more than one indicates positive role/effect, if the value of the index is less than one indicates a negative role/effect and if the value of the index is equal to one indicates no change as described by Eltun et al., 2002 [32].

Design and Analysis

A combination of techniques and doses effect was studied on SOM, P & K in the rice-wheat system by considering as one unit and the 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 treatment effect on SOM, Phosphorus, and Potassium.

Changes in Soil Organic Matter (SOM)

Total application of MSWC was 14.0 tons ha⁻¹ and 24.0 tons ha⁻¹ (Table 1) during three years in applied treatments resulted in 7.3 to 9.8 percent increase in SOM over an initial level of 0.82 % to a level of 0.90% by management techniques (T-II and T-III) through inclusion of MSWC with and without pesticide use (Table 4). The only mineral fertilizer application in T-I also increased 3.7% SOM. The performance of T-II and T-III over T-I is 5.9% and 3.5% respectively in enhancing SOM level. While, conventional (D-I) and Site-specific (D-II) doses enhanced SOM level 6.1% and 8.5% respectively. Site-specific (D-II) dose performed 2.3% better in enhancing SOM level as compared to conventional (D-I). By season’s interpretation, maximum increase of 26.8% in SOM was observed after the harvest of the first rice crop and 6.1% at the harvest of final rice crop.

The impact of the season is substantially different in different crop seasons. It was also found that initial significant improvement in SOM was first rice harvest, then decreased or sustained status. But in all seasons, values were higher than initial (Table 4). It counts 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 the initial level in six crop seasons after crop harvest is depicted in (Table 4).

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 the conventional fertilizer application (D-I) after three years (Table 4). The conventional (D-I) and site-specific (D-II) doses enhanced soil test phosphorus (STP) level 85.1% and 96.6% respectively over initial level. Comparison of two doses revealed that 6.20% 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. P₂O₅ i.e. 341 kg ha⁻¹ as compared to conventional fertilizer application which received P₂O₅ i.e. 600 kg ha⁻¹ in three years (Table 2). Total application of MSWC was 14-24.0 tons ha⁻¹ (Table 3) during three years in INM techniques resulted in 88.5% to 97.7% increase in STP over an initial level of 8.70 % to a level of 16.40 ppm and 17.2 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 86.2% STP level. By season’s interpretation, 86.2% increase in STP level was observed after the harvest of the final rice crop (Table 4). It is important to note that season’s effect is significantly different in different crop seasons. It was also noticed that initial significant improvement in STP level was at first wheat harvest, afterwards status was almost remained sustained. It counts 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. [33] claimed that Soil available P concentration and P uptake were

Table 3. Initial soil characteristics.

| Depth  | EC   | pH | OM | P  | K   | Sand | Silt | Clay | Textural Class |
|--------|------|----|----|----|-----|------|------|------|----------------|
| Cm     | dS m⁻¹ | -  | %  | ppm|     | %    | %    |      |                |
| 0-15   | 1.3  | 7.9| 0.82| 8.7| 119 | 43.6 | 37.2 | 19.2 | Loam          |
| 15-30  | 1.4  | 8.0| 9.3 | 115| 47.6| 34.0 | 18.4 |      | Loam          |

P fixation factor = 2.5
affected significantly by the addition of P-enriched compost. Rate of increase of STP level over initial level in six crop seasons after crop harvest is depicted in Table 4.

Changes in Soil Potassium

No beneficial effects of MSWC application regarding the soil K level were observed in the rice-wheat system. Statistically non-significant decrease in the soil K level was observed by the site-specific way of fertilizer application ($D_{II}$) over the conventional fertilizer application ($D_{I}$) after three years. The conventional ($D_{I}$) and site-specific ($D_{II}$) doses decreased soil K level by 10.1% over the initial level (Table 4). Total application of MSWC was 14-24.0 tons ha$^{-1}$ during three years in INM techniques resulted in decrease soil K level by 12.6% and 7.6% over an initial level of 119 ppm. A decrease of 10.9% in soil K level was observed by technique of only mineral fertilizer application ($T_{I}$). A significant declining trend is noted in the seasons after 2nd wheat crop harvest (Table 4).

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

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

| Treatments | SOM (%) | % Increase over initial SOM level (0.82 %) | P$_2$O$_5$ (ppm) | % Increase over initial STP level (8.7 ppm) | K$_2$O (ppm) | % Increase over initial soil K level (119 ppm) |
|------------|---------|---------------------------------|----------------|---------------------------------|-------------|---------------------------------|
| Fertilizer doses |
| $D_{I}$, Conventional | 0.87a | 6.1 | 16.1b | 85.1 | 107a | -10.1 |
| $D_{II}$, Site-specific | 0.89a | 8.5 | 17.1a | 96.6 | 107a | -10.1 |
| LSD .05 | 0.043 | | 0.89 | | 4.7 | |
| % increase over $D_{I}$ | 2.3 | | 6.2 | | 0.0 | |
| Management Techniques |
| $T_{I}$, Only Mineral fertilizer | 0.85a | 3.7 | 16.2a | 86.2 | 106a | -10.9 |
| $T_{II}$, INM with pesticides | 0.90a | 9.8 | 16.4a | 88.5 | 104a | -12.6 |
| $T_{III}$, INM without pesticides | 0.88a | 7.3 | 17.2a | 97.7 | 110a | -7.6 |
| LSD .05 | 0.053 | | 1.09 | | 5.7 | |
| % increase in $T_{II}$ over $T_{I}$ | 5.9 | | 1.2 | | -1.9 | |
| % increase in $T_{III}$ over $T_{I}$ | 3.5 | | 6.2 | | 3.8 | |
| Season |
| Wheat, 1st Crop | 0.76d | -7.3 | 18.4ab | 111.5 | 105c | -11.7 |
| Rice, 1st Crop | 1.04a | 26.8 | 14.1d | 62.1 | 124b | 4.2 |
| Wheat, 2nd Crop | 0.95b | 15.9 | 17.1bc | 96.6 | 140a | 17.6 |
| Rice, 2nd Crop | 0.84cd | 2.4 | 16.2c | 86.2 | 105c | -11.8 |
| Wheat, 3rd Crop | 0.82cd | 0 | 14.5d | 66.7 | 91d | -23.5 |
| Rice, 3rd Crop | 0.87c | 6.1 | 19.3a | 121.8 | 76e | -36.1 |
| LSD .05 | 0.08 | | 1.45 | | 7.6 | |

Figures sharing same alphabet are not significantly different from each other.
and soil nutrients status are recorded with improved practices as well as with conventional practices over the whole study period as were used as indices of soil fertility and these indices are listed in Table 5. Indices ranking of the best to least favorable were recorded as P>SOM>K. Comprehensive mean soil fertility index was estimated as 1.040. No negative effect was found. Favorable mean indices were achieved using techniques T-I, followed by T-II and T-III respectively was based on favorable values of P and SOM and incorporation of MSWC in fertilizer recipes contributed in enhancing their status. In another technique (T-II), the SOM index was not promising. Here, SOM status seems to be suppressed may be due to the application of herbicides and non-target effect of herbicides used by the elimination of flora [37, 38, 39]. Enrichment of SOM seems to be the residual effect of the flourished roots due to the availability of nutrients applied through mineral fertilizers. The findings supported the conclusions of [40]. 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 less herbicides/pesticide use to protect/sustain SOM. Positive site specific P dose (D-II) index (improved practice over conventional routine) i.e. 1.034 was noticed primarily due to favorable indices of P and SOM. Indices of Potassium indicated no change and it lowered down the ultimate mean value of the index for improved fertilizer dose prediction.

**Conclusions**

Total application of MSWC was 14.0 tons ha\(^{-1}\) and 24.0 tons ha\(^{-1}\) during three years resulted in 7.3 to 9.8 percent increase in SOM over an initial level of 0.82% through INM in rice-wheat cropping system. The season’s effect was significantly different in different crop seasons. 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 85.1% and 96.6% respectively over initial level of 8.7 ppm. Both techniques of INM with and without pesticide use resulted in 88.5% to 97.7% increase in STP over an initial level. The target soil P level of 19.0 ppm is recorded by following a McLean’s model which is closed to recommended level of 21.0 ppm although some variations are recorded in different seasons. The K application either through INM or through mineral fertilizers did not increase the soil test K level and overall 36.1% decrease in the soil K level was observed after the harvest of final rice crop. Probably the K additions were not adequate to meet the enhanced crops requirement in rice-wheat cropping system. Indices ranking from the best to least favorable were recorded as P>SOM>K.

**Conflict of Interest**

The authors declare no conflict of interest.

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