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Integrated phosphorus nutrient sources improve wheat yield and phosphorus use efficiency under sub humid conditions

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Abstract

Majority of Pakistani soils are deficient in phosphorus. Phosphorus is usually applied in form of synthetic fertilizer. However integrated use of P from synthetic and organic sources can be more profitable and beneficial on sustainable basis. Field trials were conducted at research farm University of Poonch, Rawalakot, AJK, Pakistan for two consecutive years to check the comparative effects of synthetic fertilizer and organic manures applied alone and in combinations on the phosphorus use efficiency (PUE), wheat yield and yield components. Shafaq-06 cultivar of wheat was used as test cultivar. Ten treatments were included: (I) Control (P_0) without application of fertilizer; (II) SSP @ 60 kg/ha (P_{60SSP}); (III) SSP @ 90 kg/ha (P_{90SSP}); (IV) SSP @ 120 kg/ha (P_{120SSP}); (V) PM @60 kg/ha (P_{60PM}); (VI) PM @90 kg/ha (P_{90PM}); (VII) PM @120 kg/ha (P_{120PM}); (VIII) SSP @30 kg/ha + PM @30 kg/ha ($P_{30SSP+30PM}$); (IX) SSP @45 kg/ha + PM @45 kg/ha ($P_{45SSP+45PM}$); (X) SSP @60 kg/ha + PM @60 kg/ha ($P_{60SSP+60PM}$) which were laid out under the Randomized Complete Block Design. Significantly higher values for yield of grain (2397 kg/ha) was recorded with PM + SSP @ 60 kg P_2O_5 ha^{-1} each. Likewise, FPUE, PIR of wheat and AFPUE was quite higher with combined use of PM and SSP i.e. $P_{60SSP+60PM}$ treatment. Additionally, increase in PUE, wheat yield and yield components associated with combined treated plot would help to minimize the use of high cost synthetic mineral fertilizers and represents an environmentally and agronomically sound management strategy.

1. Introduction

Wheat crop growth and yield is significantly influenced by phosphorus [1]. Early stages of wheat crop required phosphorus for proper growth and good yield of wheat crop [2]. Adequate amount of phosphorus enhances the root growth and seedling establishment of wheat crop [3]. Phosphorus as a basic nutrient plays a vital role from seedling to maturity stage of plant. Besides, all phonological, physiological and morphological processes improvement it also helps to enhance quality and as well as number of seeds on a plant [4].

So, sufficient supply of P is necessary particularly at early crop growth stage. Insufficient supply will be resulted in irreversible way, even P supply is started to apply in a sufficient amount [5]. Furthermore, phosphorus improves wheat crop tillering stage and brings uniformity at heading stage. It also increases the WUE of crop plant which ultimately increases the wheat potential of GY [6]. Synthetic fertilizer of phosphorus includes SSP, TSP, DAP, DCP etc. While organic sources include FYM (farmyard manure), PL (poultry litter), PM (poultry manure), compost and vermi-compost etc. Balanced use of fertilizer particularly NPK perform a fundamental role in enhancing yield and quality of wheat crop [7]. No doubt, inorganic sources enhances crop yield very quickly but their unwise use is very hazardous for the environment [8]. While, natural sources not just supply adequate N.P.K but also show good effect on the plant growth and development, water holding capacity (WHC), improving the fertility of the soil and also enhancing the biological characteristics of the soil [9].

Poultry manure is a cheap and excellent source of phosphorus among all organic fertilizer sources. Poultry manure is the farm fowl's excreta which gradually decompose and contain high percentage of P as compared to any other organic nutrient sources. It contains around 3.03% nitrogen, 2.63% phosphorus and 1.4% potash [10]. Under conditions of higher fertilizer rates, shortage at planting time and insufficient availability of inorganic fertilizers source [11] crop grower may be motivated to apply low cost and readily accessible natural waste as fertilizer of phosphorus (P) and all essential macro-nutrients. This practice may enhance the N: P, organic matter of the soil, availability of the necessary micronutrient [12].

However, only organic manure application is insufficient to obtain higher yield. Organic manures are applied in larger amount to meet-up the crop requirement due to relatively less nutrient percentage [13]. Organic manure helps the crop plant in multiple ways by providing balanced nutrient. This could be due to improve in increased soil microbial activity which improves soil nutrient availability and decomposition of harmful elements [14]. That's why combined use of synthetic and natural fertilizers enhances the fertilizer PUE and yield of crop [15]. Complementary use of inorganic and organic fertilizers is very important for increasing the FUE and decreasing the hazards produced by the unwise use of synthetic fertilizers, respectively [16].

It is commonly agreed that for assessment of high-potential new cultivar, application of higher rate of phosphorus fertilizer is pre-requisite [17]. Rice genotype with higher PUE adapted in those soils where low P availability in cultivated soils would help to improve the grains yield [18] because it encourages the root development and assist for the nitrogen uptake which ultimately enhances the protein content in the grain [19]. More effective utilization of phosphorus is required to increase the beneficial life of phosphorus in globe, for producing more food at low cost and to enhance the value of economic yield of the crop [20]. As developing countries are facing poverty and food security they are facing largely low P level in soils. Many efforts are done at global to quantify the P reserve in soil [21]. Hence, the significance of phosphorus (P) fertilizer as a major crop nutrient in this experiment was set to check relative impact of sources of phosphorus (P) fertilizer (synthetic and organic) which is used sole or in several combinations on PUE (phosphorus use efficiency) and the wheat yield under the sub humid environment.

2. Materials and methods

2.1 Site

The field study was performed at farm area of University of Poonch, Rawalakot, AJK for two consecutive growing seasons of 2011 and 2012.

2.2 Treatments and crop husbandry

Wheat cultivar Shafaq-06 was cultivated as a test wheat cultivar. Treatments included: (I) Control (P_0) No application of fertilizer; (II) SSP @ 60kg/ha (P_{60SSP}); (III) SSP @ 90kg/ha (P_{90SSP}); (IV) SSP @ 120kg/ha (P_{120SSP}); (V) PM @60 kg/ha (P_{60PM}); (VI) PM @90 kg/ha (P_{90PM}); (VII) PM @120 kg/ha (P_{120PM}); (VIII) SSP @30 kg/ha + PM @30 kg/ha ($P_{30SSP+30PM}$); (IX) SSP @45 kg/ha + PM @45 kg/ha ($P_{45SSP+45PM}$); (X) SSP @60 kg/ha + PM @60 kg/ha ($P_{60SSP+60PM}$) which were laid out under Randomized Complete Block Design having three replications. Wheat seed was used at the rate of 120 kg/ha and the sowing was done by using hand drill under rain fed sub humid conditions.

2.3 Soil and plant analyses

Prior to sowing, soil sample was collected and dried in the air. Pestle and mortar was used to grind the soil then screened out from 2mm sieve [22]. Nelson and Sommers's proposed method was used to determine the total carbon and P in soil [23]. Hydrometer-method was used to check the distribution of the soil-particle size [24]. While the pH was determined by the Mclean's method by the saturated soil solution with 1:1 proportion of soil and water [25]. Similarly, Kjeldahl method was used to extract total nitrogen content in soil [26]. Total extractable K (potassium) was measured by Richards's procedure [27].

Alongside soil analysis, poultry-manure analysis was additionally done in the same institute's laboratory after collecting the composite sample from the grower's field. After drying in the air, grinding and screening through the 2mm sieve to get homogenize manure sample free from undesired particles was obtained. To determine total P in the plant hot-plate digestion strategy was practiced and absorbance of total plant P was measured by using Spectrophotometer at λ of 410 nm [28]. While phosphorus (P) % in plants body was determined according to following formula:

$$\text{Phosphorus \% in plant} = \frac{\text{Total phosphorus in plant} \times \text{Volume of Digest}}{\text{Total weight of crop} \times 1000}$$

2.4 Observations

Observations of wheat plant on Leaf area (cm^2), Leaf moisture content (%), PH (PH cm), spike length (SL cm), no. of grains ($spike^{-1}$), 1000-grain weight (TGW g) and GY (GY k/ha) were recorded. While FPUE (fertilizer phosphorus use efficiency), AFPUE (applied fertilizer phosphorus uptake efficiency) and Phosphorus-index ratio (PIR) were measured according to the following formulae [29].

$$FPUE = \frac{(\text{Yield of fertilized plot}) - (\text{Yield of control plot})}{(\text{Phosphorus applied})}$$

$$AFPUE = \frac{(\text{Phosphorus in fertilized plants ha}^{-1}) - (\text{Phosphorus in control plants ha}^{-1})}{(\text{P applied})}$$

$$PIR = \frac{\text{P economic use efficiency}}{\text{P biological use efficiency}}$$

Statistical analysis was carried out by utilizing the LSD at 5% level of probability [30].

3. Results

The data for two years showed non-significant variation hence the pooled data over years has been presented and discussed below.

3.1 Nutrient status in soil and in organic sources

The soil of the field study was silt loam having pH 7.2 and 7.1. The pH of poultry manure was 6.82 and 6.55 (Mclean method) in 2011 and 2012, respectively. Soil organic carbon 1.31% and 1.12% (Nelson and Sommers method), total N 0.041% and 0.029% in soil. Olsen's available P was 6.9 mg/kg and 6.5 mg/kg in soil and Richard's total extractable K was 177 mg kg^{-1} and 170 mg/kg in soil (Table 1). Total N in poultry manure was 2.21% and 2.33% (Kjeldahl method) in 2011 and 2012, respectively. Total P 1.87% and 1.91% in poultry manure and total extractable K 2.24% and 2.39% during both the years under study, respectively as shown in Fig 1.

3.2 Applied fertilizer phosphorus use efficiency (AFPUE)

The maximum applied fertilizer phosphorus use efficiency (AFPUE) (0.25) was observed in the plots provided with phosphorus SSP+PM@ 60 each kg/ha (Fig 2). While minimum (0.14) AFPUE was observed in P_{60SSP} treatment however plots supplied with P60PM and P90PM also could not reveal significant variation.

3.3 Fertilizer phosphorus use efficiency

Significant influence of different P sources on FPUE (Fig 3). The maximum fertilizer use efficiency of phosphorus (23.79) was observed under treatment $P_{60SSP+60PM}$ in which natural and synthetic sources were used in combination at equal doses. It was statistically similar with the $P_{30SSP+30P}$, $P_{45SSP+45PM}$ and P_{60SSP}. Minimum FPUE was observed in the control treatment

Table 1. Physico-chemical analysis of the soil samples from experimental site.

Parameters	2011	2012
Organic matter	1.31%	1.12%
Total N	0.041%	0.029%
Available P	6.9 mg/kg	6.5 mg/kg
Extractable K	177 mg/kg	170 mg/kg
pH	7.3	7.1
Textural class	Silt loam	Silt loam
EC	0.56	0.58

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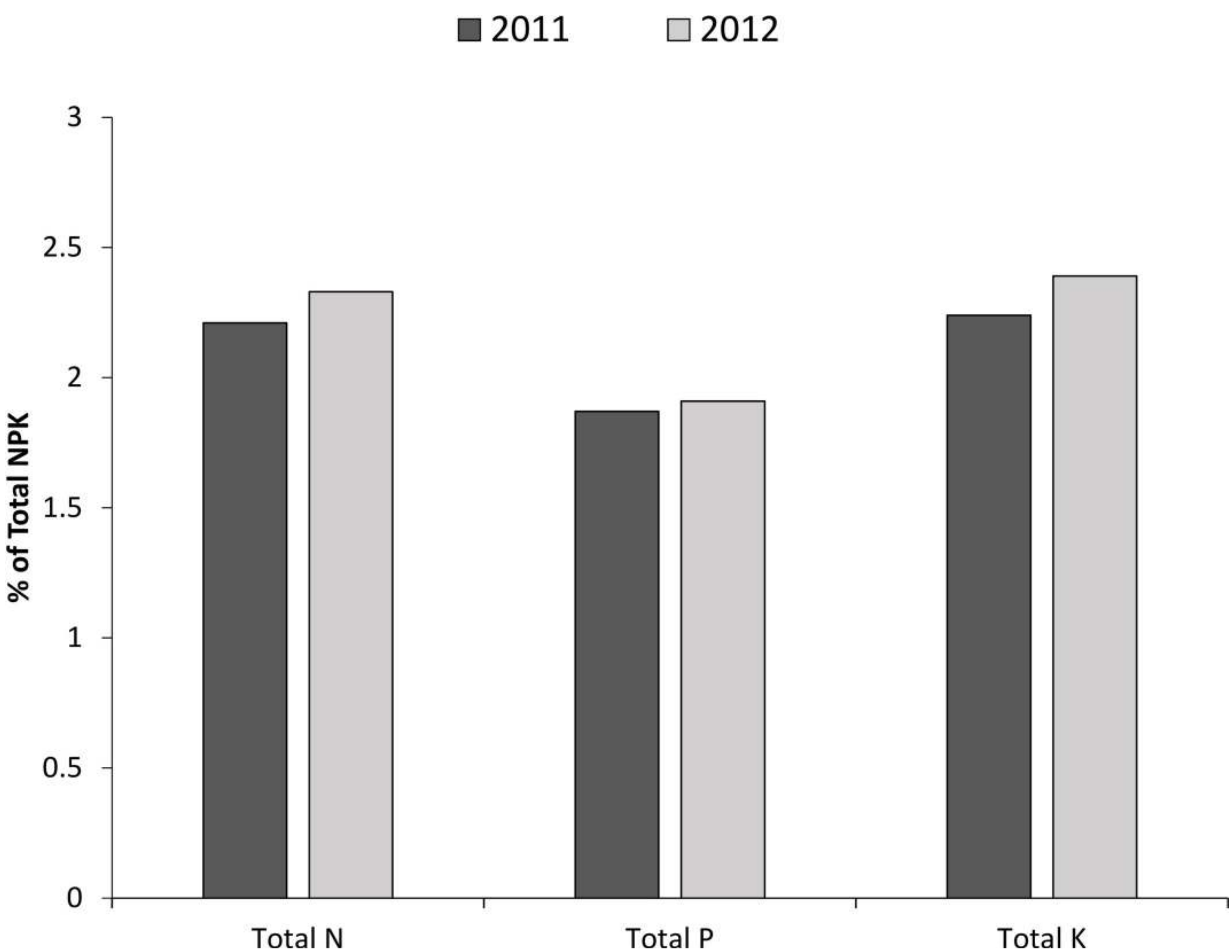

Fig 1. Percentage of total NPK in poultry manure.

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which was followed by plots supplied with P_{60SSP}. The lowest fertilizer phosphorus use efficiency (FPUE) was observed in the P_0 treatment which was followed by the treatment P_{60SSP}.

3.4 Phosphorus index ratio (PIR)

Phosphorus index ratio (PIR) illustrated in Fig 3 showed that highest PIR (43.30) was observed in treatment $P_{60SSP+60PM}$ where phosphorus at rate of 60 kg/ha was applied from natural (poultry manure) and synthetic sources of nutrients which was statistically at par with the plot having P_{60SSP} solely. Whereas, the plots P_{60PM} resulted lowest PIR which was followed by plots having $P_{30SSP + 30PM}$ and P_{90PM}.

3.5 Leaf area (cm)

Natural and synthetic sources of P put a substantial influence on leaf area of wheat crop at tillering and heading stages (Fig 4). The maximum leaf area (28.76 cm^2) at tillering was observed in the treatment $P_{60SSP+60PM}$. While the minimum leaf area (21.44 cm^2) was observed in P_0

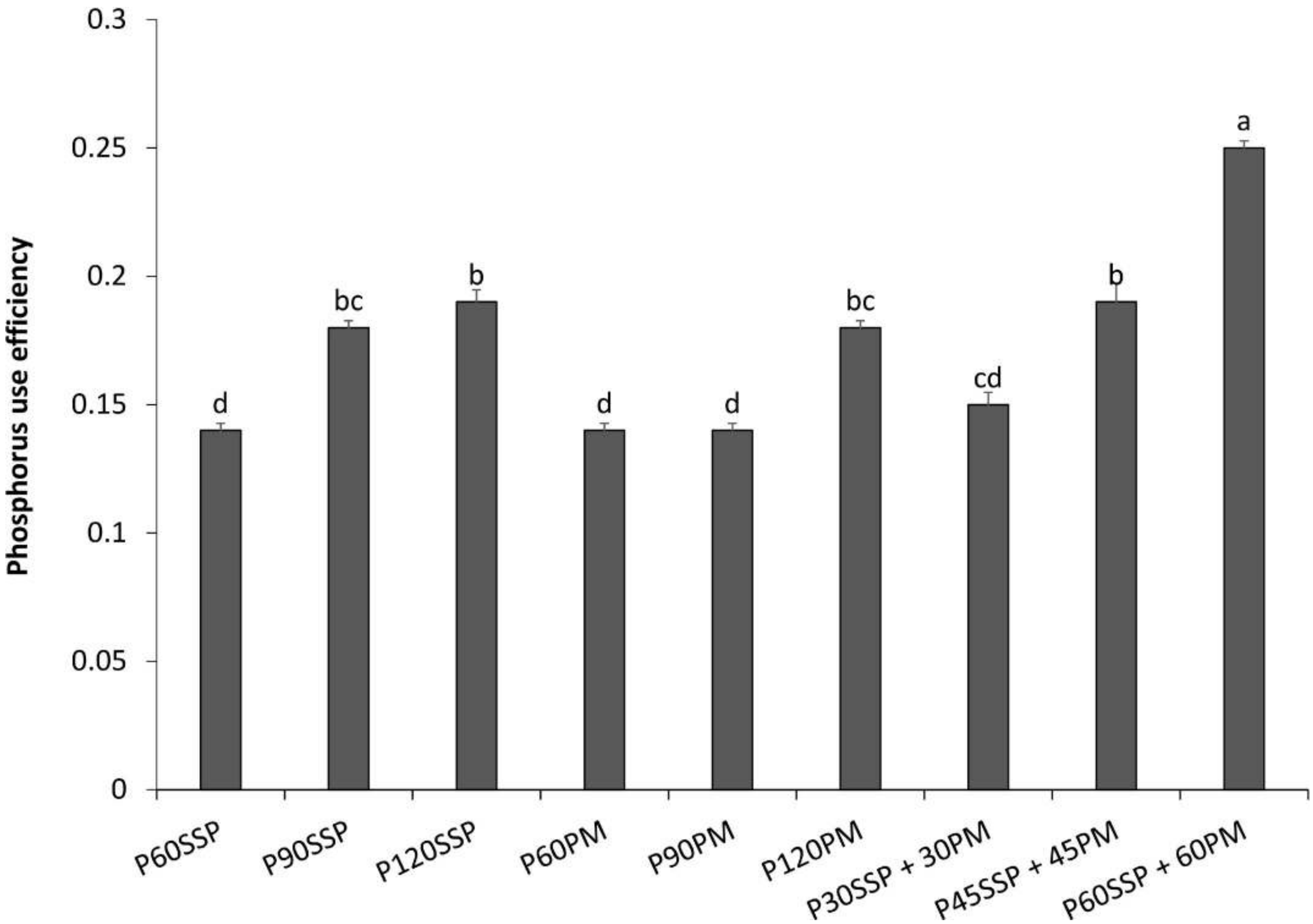

Fig 2. Effect of various organic and inorganic amendments on applied fertilizer P use efficiency.

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where, fertilizer was not used. Similarly, the outcomes related to leaf area (cm^2) at the heading stage demonstrated that the treatment P_{120PM} gave maximum leaf area (31.80 cm^2).

3.6 Leaf moisture percentage at heading stage

The data related to the percentage leaf moisture content at heading stage are shown in the Fig 5. Usage of SSP and PM in combination @ 45, 60 kg/ha and PM @ 120 gave highest leaf moisture content at the heading stage which was at par with SSP $_+$ PM @ 30, PM@ 90, SSP @ 90 and 120 kg/ha. While the minimum (54.3%) moisture content of leaf was recorded in P_0 treatment, where no fertilizers were used. During this present study, combined application of synthetic and organic sources of fertilizer improves leaf moisture content significantly. Combination of $P_{60SSP+60PM}$ kg/ha showed maximum (81.9%) moisture content of leaf at the heading stage which attributed to better soil moisture conservation by Poultry manure (PM).

3.7 PH (cm)

The data regarding PH revealed significant differences among various fertilizer sources treated plots (Table 2). Maximum (56.59 cm) PH was observed in plot having P_{90SSP} which was

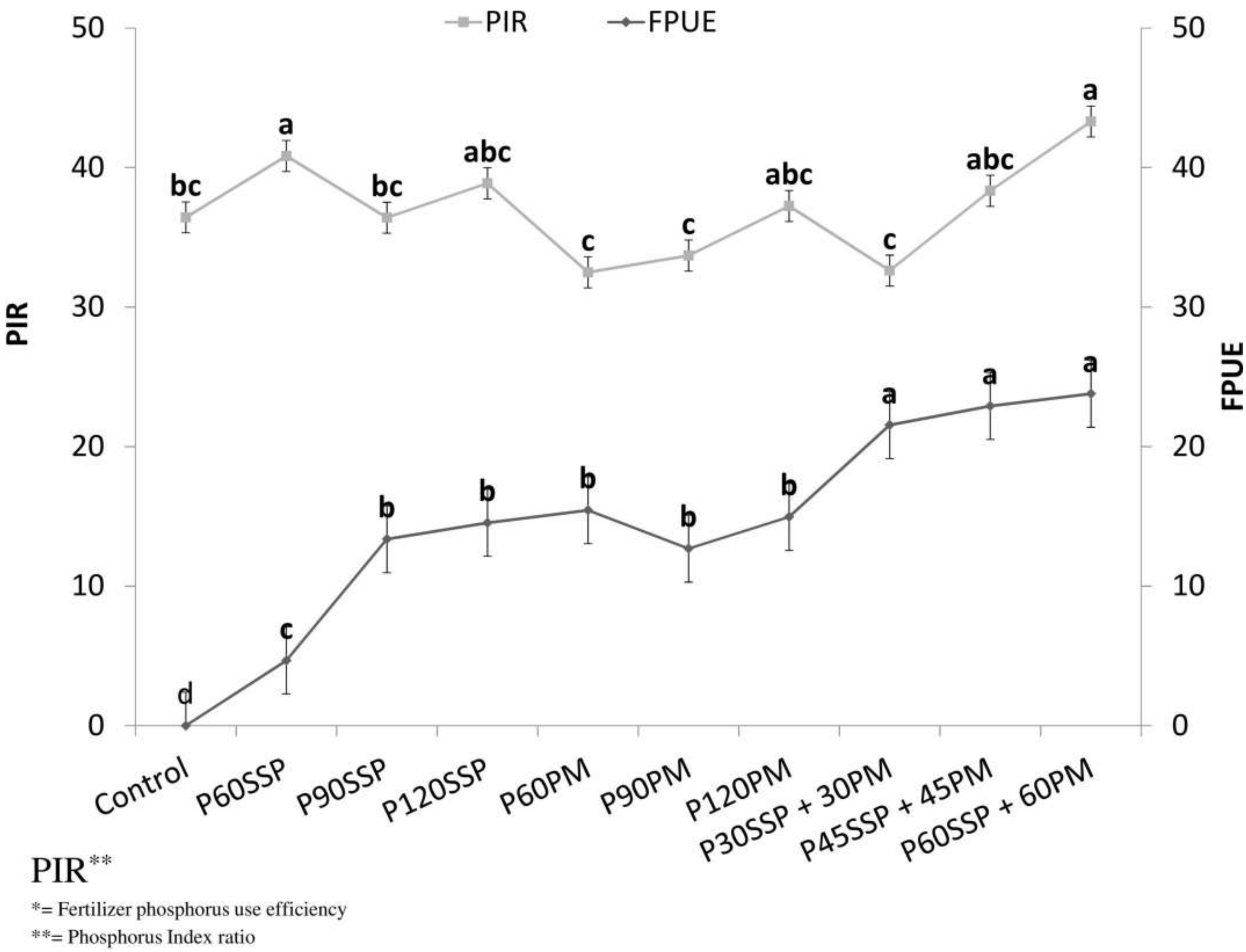

Fig 3. Effect of various organic and inorganic P nutrients sources on FPUE* and PIR*.

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statistically similar with plots having P_{120PM} and $P_{60SSP\ +\ 60PM}$. While minimum PH was recorded in control treatment where not a single source fertilizer was used. In fertilizer treated plot minimum (50.79 cm) PH was recorded in plot having $P_{30SSP\ +\ 30PM}$.

3.8 SL (cm)

Data regarding SL (Table 2) shown that highest (11.79 cm) SL was recorded in SSP @ 60 + PM @ 60 in combination, while minimum (8.78 cm) was recorded in plots which did not receive any P dose from either source.

3.9 Grains (spike^{-1})

Maximum number of grains spike^{-1} (53.67) was recorded in plot where integrated application of SSP and PM each @ 60 kg/ha was done. It seems statistically alike to plots $P_{45SSP+45PM}$ and P_{120SSP}, while the minimum grains spike^{-1} were observed in P_0 (control) treatment where no P was applied reflects the importance of P in wheat grains number.

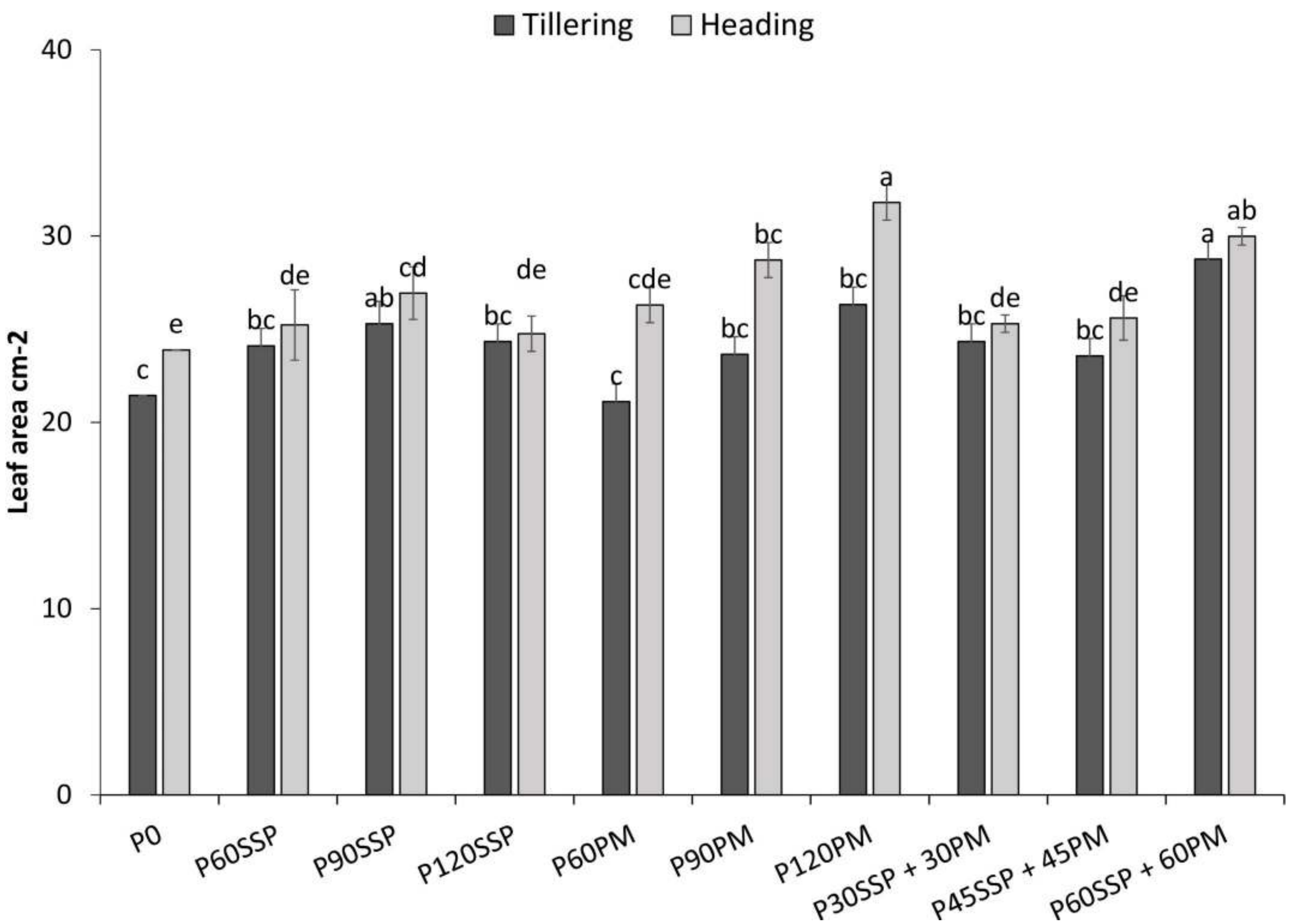

Fig 4. Effect of various organic and inorganic nutrient sources on leaf area of wheat.

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3.10 TGW (g)

Data regarding TGW revealed that heavier 1000-grains were observed in the integrated treatment of $P_{60SSP + 60PM}$ (43.33 g). However, SSP or PM application either at 90 and 120 kg/ha also revealed statistically similar grains on weight basis. While the lighter grains (29.33 g) were observed in P_0 (control) where fertilizer application was not practiced.

3.11 GY (kg/ha)

Results showed maximum GY (2397 kg/ha) in plots where phosphorus was used @ 60 kg/ha from integrated sources (PM and SSP). It was followed by GY 1863 kg/ha by the treatment $P_{SSP45+PM45}$ in which synthetic and organic sources were applied in combination. It could not vary significantly from the wheat plants in plots supplied with P 120 kg/ha from PM. The results show that, there was back to back improvement in the wheat yield of grain with increase in supply of phosphorus by the integrated use of natural (PM) and synthetic (SSP) nutrient sources. Whereas, minimum (1119 kg/ha) GY was observed in the control (P_0) treatment which was statistically similar with P_{60SSP} and P_{60PM} treated plots. Moreover, P_{120SSP} performed intermediate (1773 kg/ha) which was statistically similar to plots nourished with

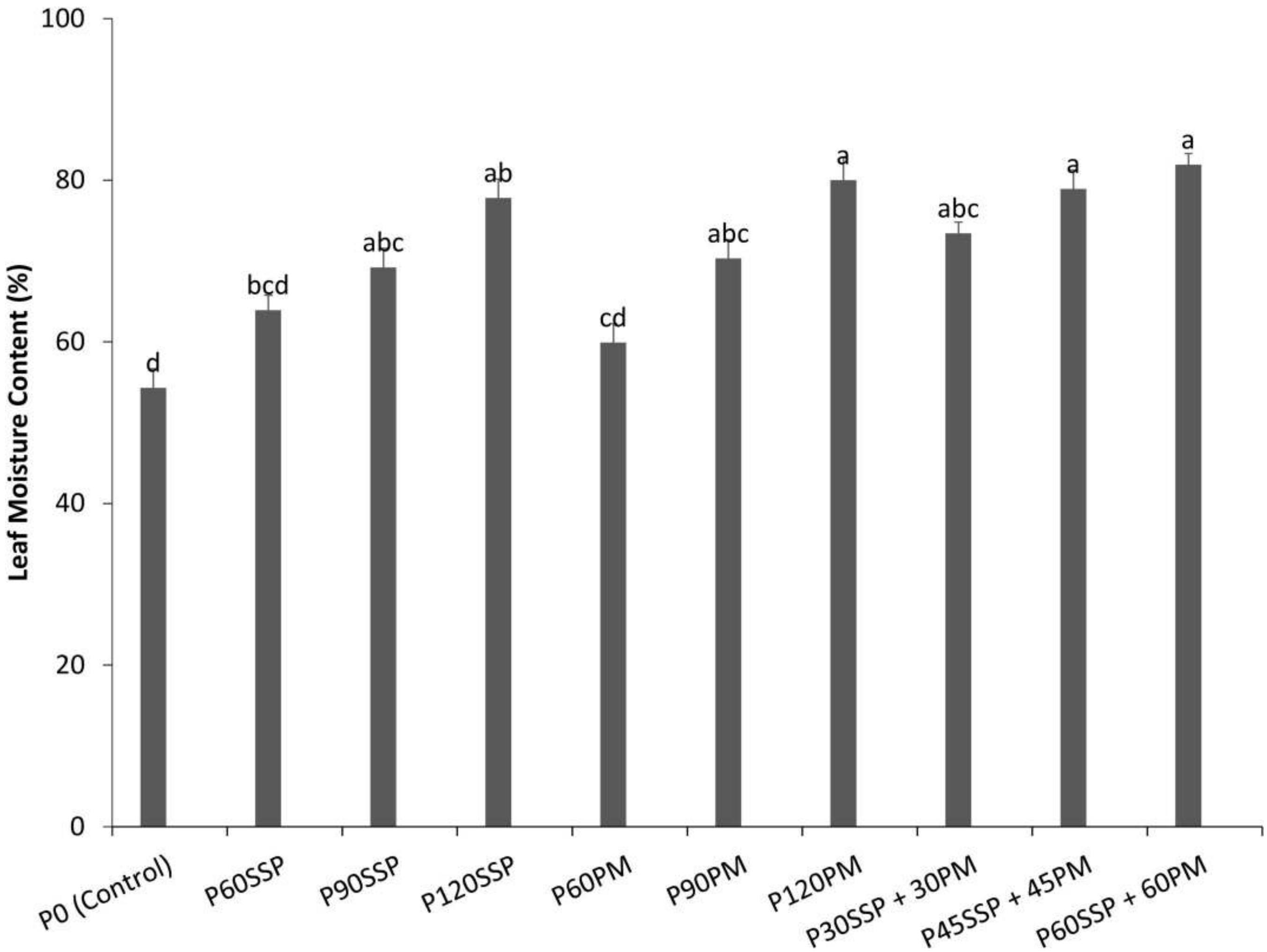

Fig 5. Effect of various organic and inorganic P nutrient sources on wheat leaf moisture content at heading stage.

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P_{120PM} showing GY of 1720 kg/ha. It was followed by $P_{30SSP+30PM}$ treated plots (1409 kg/ha) which is statistically different from the P_{120SSP} applied plots.

4. Discussion

Presented data showed that maximum AFPUE and PUE was observed plot $P_{60SSP+60PM}$ having natural and synthetic sources at equal doses. The significant difference for AFPUE can be attributed to various responses of different treatments for the uptake of phosphorus in sub-humid environment. The enhancement of AFPUE in $P_{60SSP+60PM}$ could be attributed to the improvement in moisture retention which might have occurred due to better organic matter in soil. Moreover, soil moisture content influence on growth pattern of crop determines the demand of phosphorus for the crop. Application of phosphorus through combined organic and inorganic sources makes the nutrient in that form which was not fixed and was more available owing to improved microbial activity. Roots of crop take up accumulated P in soil as residues from where combined organic and inorganic fertilizers were applied. Combined application of P sources helps them to utilize more nutrients for growth and development [31]. Furthermore, over the period addition of phosphorus and potassium sources in soils, the

Table 2. Effect of various organic and inorganic P nutrient sources on yield and yield components of wheat.

Treatments	PH (cm)	SL (cm)	Grain (spike^{-1})	TGW (g)	GY (kg/ha)
$P_{0\ (Control)}$	49.5 c	8.7 c	43.0 c	29.3 e	1119 f
P_{60SSP}	53.6 ab	9.5 bc	47.4 bc	35.3 d	1259 ef
P_{90SSP}	56.5 a	10.4 abc	50.0 ab	40.3 abcd	1459 cde
P_{120SSP}	54.8 a	11.0 ab	53.2 a	42.0 ab	1773 bc
P_{60PM}	54.6 ab	9.6 bc	48.5 ab	37.6 bcd	1277 ef
P_{90PM}	53.4 ab	9.8 bc	51.4 ab	40.3 abcd	1428 de
P_{120PM}	54.7 a	11.0 ab	50.0 ab	43.3 a	1720 bcd
$P_{30SSP\ +\ 30PM}$	50.7 bc	9.1 c	49.4 ab	36.0 cd	1409 de
$P_{45SSP\ +\ 45PM}$	54.1 ab	10.9 ab	53.3 a	40.6 abc	1863 b
$P_{60SSP\ +\ 60PM}$	54.9 a	11.7 a	53.6 a	43.3 a	2397 a
LSD ($p \leq 0.05$)	3.88	1.79	5.25	5.26	338.39

Means sharing same letter could not differ significantly at 5% probability level.

(I) Control (P_0) without application of fertilizer; (II) SSP @ 60kg/ha (P_{60SSP}); (III) SSP @ 90kg/ha (P_{90SSP}); (IV) SSP @ 120kg/ha (P_{120SSP}); (V)PM @60 kg/ha (P_{60PM}); (VI) PM @90 kg/ha (P_{90PM}); (VII) PM @120 kg/ha (P_{120PM}); (VIII) SSP @30 kg/ha + PM @ 30 kg/ha ($P_{30SSP+30PM}$); (IX) SSP @45 kg/ha + PM @45 kg/ha ($P_{45SSP+45PM}$); (X) SSP @60 kg/ha + PM @60 kg/ha ($P_{60SSP+60PM}$).

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concentration of these nutrient increases over the time [32, 33]. Application of integrated phosphorus improved nutrient supply, soil health and crop growth. It promoted availability of N and P [34] and improved biomass as well as yield of crop [35]. Grain production per unit use of nutrient (FUE) is an index for effective usage of fertilizers. Better FPUE of treatment $P_{60SSP+60PM}$ could be resulted in improvement in GY yield per unit supply of P nutrients. Moreover, the application of phosphorus @ 60 kg/ha from both natural (PM) and synthetic (SSP) source could be an appropriate prescription that can improve the soil productivity and fertility which leads to maximize the FPUE. Furthermore, improved fertilizer use efficiency of phosphorus in $P_{60SSP+60PM}$ can be attributed in to the increase in the yield of wheat crop per unit use of phosphorus nutrient. FPUE enhanced with appropriate dose application [36].

Phosphorus index ratio presented data showed that substantial increase in the responsiveness of phosphorus for PIR in higher-regimes phosphorus can be attributed to the enhancement in GY of. Probably, wheat plant at high phosphorus doses accumulates and utilizes more phosphorus that increase the economic production leading to higher PIR in the $P_{60SSP+60PM}$ treatment. Phosphorus applied by external sources in appropriate doses can increase yield of crops significantly [37, 38].

In the present study, combined use of natural and synthetic nutrient sources improves the leaf area considerably as compared to P_0 (control). Results showed that PM sole and integrated form with synthetic P sources significantly improve the growth and yield parameters as compared to control treatment, which revealed the importance of these sources fertilizers to improve productivity. Sole and integrated application of organic and inorganic fertilizer sources could increase the growth parameters [39, 40].

Significant higher leaf moisture percentage in plot where natural and synthetic sources of fertilizer was applied in combination resulted in improved soil physical properties that help to retain the highest leaf-moisture content. Integrated application of synthetic and natural nutrient sources resulted in increased soil moisture conservation, nutrient availability and enhanced biological and economic yield of the crops [41]. Combined use of nutrient sources can help improve soil health by making an improvement in soil physiochemical traits, nutrient cycling, speed up the soil enzyme activities and as well as bioactivities of soils [42] making soluble phosphorus available readily ultimately helping to improve the crop yield. Organic and inorganic P sources have a direct influence on leaf area, moisture contents, growth and development of wheat.

Varying doses of P as sole application either synthetic or natural source could not vary significantly for plant stature as compared to the plots applied with combined application of P from SSP and PM each at 60 kg/ha. The highest plant-height observed can be attributed to the improved vigor of plant, growth of root and the WUE of the crop that could have helped the wheat plant to get maximum height. An improvement in the level of P supply resulted in improvement in the height of the plant [43]. Moreover, application of phosphorus sole or in integration in various ratios can be beneficial, because it helps in mobilizing inherent phosphorus that affect the uptake and usage of phosphorus which helped crop plant in the growth and development [44]. However, reduction in P dose to 30 kg SSP and PM each per hectare reduced the growth of plants reflected in reduced height of wheat plants. The plots not received any P source or dose showed smaller plants. PH is controlled by the environmental conditions [4] as well as genetic properties of crop plant [45].

It was interesting to note that single source of P either SSP or PM each at 60 and 90 kg/ha could not differ significantly from zero applied P source showing similar length of spike. Enhancement in the length of spike could be due to the sufficient availability of moisture and nutrient. Organic sources improve crop productivity by increasing the soil health. So, instead of using sole dose of organic manure and inorganic chemical fertilizers, use of these sources in combination can attain more effective and suitable environment for growth and yield of crop. Application in combined form of fertilizer sources increase the spike-length [46].

Significant higher number grains spike^{-1} in plot where combined dose of organic and SSP were applied at 60 kg ha^{-1}. This showed the importance of optimum rate of phosphorus in cereal crop to get potential of grains spike^{-1}. Maximum grains s pike^{-1}was achieved by the application of higher dose phosphorus [47]. The integrated application of P fertilizer showed higher grains per ear in cereal (maize) field as compared to plot where sole fertilizer treated plots [48].

TGW of wheat plants was high significantly where fertilizers were applied in integrated form. Use of combined 50:50 of P organic and inorganic sources helps to improve grain yield as compared to control treatment [48]. Moreover, optimum dose of phosphorus application helped in achieving maximum 1000 grain weight [47]. This was probably due to improvement in water holding capacity (WHC), uptake and usage of phosphorus increase the rate of photosynthesis and also provide extra opportunity for the transportation of carbohydrates from source to sink (grains). It would have ultimately resulted in increased grain-size and weight of 1000 grains.

Presented data related GY showed that among the sources, SSP fertilized plots @120 kg/ha revealed relatively more GY than the sole PM fertilized plots at the same dose i.e. 120 kg/ha. Application of fertilizer in combined form from organic and inorganic sources resulted to significantly positive influence on crop health as well as on the crop yield. Integrated use of organic manures (irrespective of its kind) and inorganic fertilizer sources enhances the crop yield substantially [49, 50]. The mixture of organic and inorganic sources of fertilizers produces higher yield in wheat crop [51]. Improvement in the size of grains was observed with the combined application of phosphorus fertilizers [52]. GY basically depends on various components particularly moisture, nutrient and 1000-grain weight. So the plot $P_{SSP60+PM60}$ showed maximum yield which could be attributed to the interaction between these yields components. Whereas, the minimum GY observed in P_0 and P_{60SSP} could be due to reduced P supply which ultimately reflected by the poor plant establishment and low TGW. The results showed the consecutive increase in yield of grains with the increase in the supply of phosphorus in integrated organic and synthetic form. Pre-mixing of SSP with PM enhanced the phosphorus availability in soil and uptake by the plants leading to improvement in GY of crop. Mixing of rock-phosphate with organic manure increase yield of wheat crop [53].

Inorganic fertilizer is also not highly soluble and not easily available to plant roots that's why phosphorus use efficiency significantly affects the production of wheat crop. Application of synthetic fertilizer increase the PUE that resulted in significantly increase GY [54]. Inorganic P nutrient source always influence GY of wheat because its agronomic nutrient use efficiency is always greater than any other nutrient source [55]. So, significant difference for the GY of wheat can be attributed to higher FPUE of P_{120SSP} treatment in sub-humid environmental conditions. Phosphorus uptake and its usage are controlled by the storage of moisture in the root zone of crop plant [56]. All yield parameters showed significantly different response to different source of P fertilizers which revealed that PM or other synthetic fertilizer to enhance wheat crop growth. Under controlled environment cotton crop growth and development showed similar response when PM was applied [57]. The increase in yield could be attributed to the improvement in phenological parameters which could be attributed to application of organic fertilizers that regulate the growth and physiological processes by regulating the growth chemicals [58]. The organic fertilizers were used in agriculture from ancient days but in recent decades due to low organic matter content and harmful effect of synthetic fertilizer help to understand the importance of sustainable and organic farming [59].

5. Conclusion

The present investigations amplified the importance of applying phosphate fertilizers and organic manures in combination for increased wheat grain yields. $P_{60SSP+60PM}$ application makes phosphorus nutrients readily available from the fertilizers used and manure improve the soil properties. Hence it may be concluded that farmers in sub humid areas should apply P in soil in an integrated way with 60 kg/ha each from SSP and PM not only to improve the AFPU, FPUE and PIR but also to obtain higher and sustainable wheat productivity. It will also ensure less reliance on chemical fertilizers and will reduce the subsequent potent risks associated with continuous and heavy use of synthetic fertilizers on aerial and soil environment.

Supporting information

S1 Data.
(ZIP)

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References

1. Havlin JL, Tisdale SL, Nelson WL, Beaton JD. Soil fertility and fertilizers. An introduction to nutrient management. 7th Ed. Prentice Hall of India; 2016.
2. Grant C, Bittman S, Montreal M, Plenchette C, Morel C. Soil and fertilizer phosphorus: Effects on plant P supply and mycorrhizal development. Can J Plant Sci. 2005; 85: 3–14.
3. Blue EN, Mason SC, Sander DH. Influence of planting date, seeding rate, and phosphorus rate on wheat yield. Agron J. 1990; 82(4): 762–768.
4. Crop Quest. The importance of phosphorus fertilizer in wheat. 2019. [Cited: 18 November 2019]. Available from: Crop Quest, Inc. https://www.cropquest.com/phosphorus-fertilizer-wheat/.
5. Grant CA, Flaten DN, Tomasiewicz DJ, Sheppard SC. The importance of early season phosphorus nutrition. Can J Plant Sci. 2001; 81(2): 211–224.
6. Gupta PK. Major plant nutrient. In: Guptak PK, editor. Soil, Fertilizer and Manure. 2nd Edn ed. Jodhpur: Agrobios India; 2003.
7. Ahmed N, Rashid M. Fertilizer use in Pakistan. NFDC. Planning and development division, Islamabad; 2003. pp. 94–95.
8. Tiwary DK, Hasan MA, Chattopadhyay PK. Studies on the effect of inoculation with Azotobacter and Azospirillum on growth, yield and quality of banana. Ind J Agric. 1998; 42(4): 235–240.
9. Cooke GW. Fertilizing for maximum yield. 3rd Ed. Collins professional and technical books, Agricultural Research Council, London; 1982.
10. Babu SD, Ibraham T. Sustainable nutrient management in rice cropping system. Agrobios Newsletter. 2006; 4(12): 48–49.
11. Nisar A. Integrated plant nutrition management in Pakistan: status and opportunities. In: Proceeding of symposium on integrated plant nutrition management, NFDC, Islamabad. 2000; pp. 18–39.
12. Timsina J, Connor DJ. Productivity and management of rice–wheat cropping systems: issues and challenges. Field Crops Res. 2001; 69(2): 93–132.
13. Palm CA, Myers RJ, Nandwa SM. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. Replenishing soil fertility in Africa. 1997; 51: 193–217.
14. Han SH, An JY, Hwang J, Kim SB, Park BB. The effects of organic manure and chemical fertilizer on the growth and nutrient concentrations of yellow poplar (Liriodendron tulipifera Lin.) in a nursery system. Forest Sci Tech. 2016; 12 (3): 137–143.
15. Yamoah CF, Bationo A, Shapiro B, Koala S. Trend and stability analyses of millet yields treated with fertilizer and crop residues in the Sahel. Field Crops Res. 2002; 75(1): 53–62.
16. Bayu W, Rethman NFG, Hammes PS, Alemu G. Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. J Plant Nutr. 2006; 29(2): 391–407.
17. Clark RB. Physiology of cereals for mineral nutrient uptake, use, and efficiency. Crops as enhancers of nutrient use. 1990; pp.131–209.
18. Rose TJ, Wissuwa M. Rethinking internal phosphorus utilization efficiency: a new approach is needed to improve PUE in grain crops. In Adv Agron. 2012; 16: 185–217.
19. Government of Pakistan. Agricultural statistics of Pakistan, Govt. of Pakistan. Ministry of Food, Agriculture and Livestock, Economic Wing, Islamabad. 2003; pp. 13–38.

20. Batten GD. A review of phosphorus efficiency in wheat. Kluwer Academic Publishers. Netherlands. Plant Soil. 1992; 146(1–2): 163–168.
21. MacDonald GK, Bennett EM, Potter PA, Ramankutty N. Agronomic phosphorus imbalances across the world's croplands. Proc Natl Acad Sci USA. 2011; 108(7): 3086–3091. https://doi.org/10.1073/pnas.1010808108 PMID: 21282605
22. Klute A, Dirksen C. Hydraulic conductivity and diffusivity: Laboratory methods. Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods. 1986; pp. 687–734.
23. Nelson DW, Sommers L. Total carbon, organic carbon, and organic matter. Methods of soil analysis: Part 2 chemical and microbiological properties. 1983; 9: 539–579.
24. Gee GW, Bauder JW. In: Methods of soil analysis, Part-1: Physical and minerological methods. American Society of Agronomy. No. 9. Madison, Wisconsin. 1986; pp. 383–411.
25. McLean EO. Soil pH and lime requirement. Methods of soil analysis: Part 2 Chemical and microbiological properties. 1983; 9: 199–224.
26. Bremner JM, Mulvaney CS. Nitrogen-Total. Methods of Soil Analysis. Part 2. Chemical and Microbial properties. No. 9. (AL Page. RH Miller and DR Keeney Eds), American Society of Agronomy and Soil Science Society of America. Inc., Madison, Wisconsin; 1982.
27. Richards LA. Diagnosis and improvement of saline and alkali soils. Washington: United States Department of Agriculture. Agriculture handbook. 1954; 78(2): 154.
28. Cottenie A. Soil and plant testing as a basis of fertilizer recommendations. FAO Soil Bulletin 38/2; 1980.
29. Shah P, Kakar KM, Zada K. Phosphorus use-efficiency of soybean as affected by phosphorus application and inoculation. In: Horst WJ. et al., editors. Plant nutrition- Food security and sustainability of Agroecosystem. Kluwer Academic Publishers, Netherland. 2001; pp. 670–671.
30. Steel RGD, Torrie JH, Dickey DA. Principles and procedures of statistics: A biometrical approach. 3rd Ed. McGraw hill, Inc. Book Co. New York. 1997; pp. 352–358.
31. Syers JK, Johnston AE, Curtin D. Efficiency of soil and fertilizer phosphorus use. FAO Fertilizer and plant nutrition bulletin. 2008; 18(108): 3–109. Available at http://www.fao.org/3/a1595e/a1595e00.pdf/ (accessed 30 November 2020).
32. Bilkis S, Abedin MMJ, Rafiqul IM, Mahmood MAZ. Fractionation of potassium in soil amended with organic and inorganic fertilizers. Bangladesh J Progress Sci Technol. 2014; 12(1): 71–74.
33. Zhan X, Zhang L, Zhou B, Zhu P, Zhang S, Xu M. Changes in Olsen phosphorus concentration and its response to phosphorus balance in black soils under different long-term fertilization patterns. PLoS One. 2015; 10(7): p.e0131713. https://doi.org/10.1371/journal.pone.0131713 PMID: 26177293
34. Liu L, Li C, Zhu S, Xu Y, Li H, Zheng X, et al. Combined Application of Organic and Inorganic Nitrogen Fertilizers Affects Soil Prokaryotic Communities Compositions. Agron. 2020; 10(1): p.132.
35. Endris S. Combined application of phosphorus fertilizer with Tithonia biomass improves grain yield and agronomic phosphorus use efficiency of hybrid maize. Int J Agron. 2019; 1–9.
36. Iqtidar AK. Crops and cropping in Pakistan. Higher Education Commission Islamabad, Pakistan. 2008; pp. 231–234.
37. Fohse D, Claassen N, Jungk A. Phosphorus efficiency of plants. Plant Soil. 1988; 110(1): 101–109.
38. Jamal A, Fawad M. Effectiveness of Phosphorous Fertilizers in Wheat Crop Production in Pakistan. J Hort Plant Res. 2019; 5: 25–29.
39. Sadur R, Khalil SK, Fida M, Abdur R, Khan AZ, Saljoki AR, et al. Phenology, leaf area index and grain yield of rainfed wheat influenced by organic and inorganic fertilizer. Pak J Bot. 2010; 42(5): 3671–3685.
40. Zhang M, Sun D, Niu Z, Yan J, Zhou X, Kang X. Effects of combined organic/inorganic fertilizer application on growth, photosynthetic characteristics, yield and fruit quality of Actinidia chinesis cv 'Hongyang'. Glob Ecol Conserv. 2020; p.e00997. Available at: https://doi.org/10.1016/j.gecco.2020.e00997
41. Reddy GR, Malewar GU, Sharma KL, Sudhakar N, Karle BG. Effect of organic recycling on soil improvement and rainfed crop production in Vertisol. Ind J Dryland Agric Res Division. 2001; 16(2): 91–96.
42. Ali W, Nadeem M, Ashiq W, Zaeem M, Gilani SSM, Rajabi-Khamseh S, et al. The effects of organic and inorganic phosphorus amendments on the biochemical attributes and active microbial population of agriculture podzols following silage corn cultivation in boreal climate. Sci Rep. 2019a; 9(1): 1–17.
43. Hussain NAZIM, Khan MB, Ahmad RIAZ. Influence of phosphorus application and sowing time on performance of wheat in calcareous soils. Int J Agric Biol. 2008; 10(4): 399–404.
44. Toor GS, Bahl GS. Effect of solitary and integrated use of poultry manure and fertilizer phosphorus on the dynamics of P availability in different soils. Biores Tech. 1997; 62(1–2): 25–28.

45. Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y, et al. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. Plants. 2019; 8(2): p.34. https://doi.org/10.3390/plants8020034 PMID: 30704089

46. Ibrahim M, Hassan A, Iqbal M, Valeem EE. Response of wheat growth and yield to various levels of compost and organic manure. Pak J Bot. 2008; 40(5): 2135–2141.

47. Kaleem S, Ansar M, Ali MA, Rashid M. Effect of phosphorus on the yield and yield components of wheat variety "Inquilab-91" under rainfed conditions. Sarhad J Agric. 2009; 25(1): 21–24.

48. Ali W, Ali M, Kamal A, Uzair M, Ullah N, Khan MD, et al. Maize Yield Response under Various Phosphorus Sources and their Ratios. Eur J Exp Biol. 2019b; 9: 1–6.

49. Bodruzzaman M, Meisner CA, Sadat MA, Hossain MI. August. Long-term effects of applied organic manures and inorganic fertilizers on yield and soil fertility in a wheat-rice cropping pattern. Proc 19th World Cong Soil Sci. 2010; pp. 10–15.

50. Subhan A, Khan QU, Mansoor M, Khan MJ. Effect of organic and inorganic fertilizer on the water use efficiency and yield attributes of wheat under heavy textured soil. Sarhad J Agric. 2017; 33(4): 582–590.

51. Rehman S, Khalil SK, Rehman A, Saljoqi AUR. Organic and inorganic fertilizers increase wheat yield components and biomass under rainfed condition. Sarhad J Agric. 2008; 24(1): 12–18.

52. Zhang J, Sui X, Li B, Su B, Li J, Zhou D. An improved water-use efficiency for winter wheat grown under reduced irrigation. Field Crop Res. 1998; 59(2): 91–98.

53. Yagi R, Quadros TCF, Martins BH, Andrade DS. Maize yields and carbon pools in response to poultry litter, rock phosphate and P-solubilizing microorganisms. Scientia Agricola. 2020; 77(3): e20180141. Available at https://doi.org/10.1590/1678-992X-2018-0141

54. Sandana P, Pinochet D. Grain yield and phosphorus use efficiency of wheat and pea in a high yielding environment. J Soil Sci Plant Nutr. 2014; 14(4): 973–986.

55. Dhillon J, Torres G, Driver E, Figueiredo B, Raun WR. World phosphorus use efficiency in cereal crops. Agron J. 2017; 109(4): 1670–1677.

56. Manske GGB, Ortiz-Monasterio JI, Van Ginkel M, Gonzalez RM, Fischer RA, Rajaram S, et al. Importance of P uptake efficiency versus P utilization for wheat yield in acid and calcareous soils in Mexico. Euro J Agron. 2001; 14(4): 261–274.

57. Tewolde H, Sistani KR, Rowe DE. Broiler litter as a sole nutrient source for cotton: Nitrogen, phosphorus, potassium, calcium, and magnesium concentrations in plant parts. J Plant Nutr. 2005; 28(4): 605–619.

58. Sharma AR, Mittra BN. Effect of combinations of organic materials and nitrogen fertilizer on growth, yield and nitrogen uptake of rice. J Agric Sci. 1988; 111(3): 495–501.

59. Gryndler M, Larsen J, Hrselova H, Rezacva V, Gryndlerova H, Kubat J. Organic and mineral fertilization, respectively, increase and decrease the development of external mycelium of arbuscular mycorrhizal fungi in a long-term field experiment. Mycorrhiza. 2006; 16(3): 159–166. https://doi.org/10.1007/s00572-005-0027-4 PMID: 16341895