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Influence of residual silicon and phosphorus on growth, productivity, lodging and grain quality of succeeding wheat under rice-wheat cropping system

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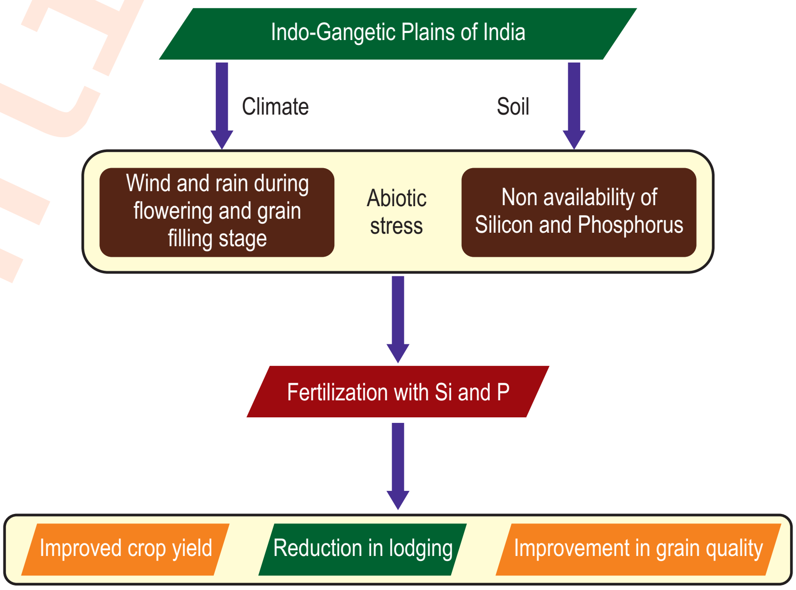
Abstract

Aim: To assess the residual effect of silicon (Si) and phosphorus (P_2O_5) application on the growth, productivity, lodging resistance and grain quality of wheat in Indo-Gangetic Plains of India.

Methodology: A field experiment was conducted with four levels each of silicon (0, 40, 80 and 120 kg Si ha^{-1}) and phosphorus (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) in a factorial randomized block design (FRBD) replicated three times at research farm of the ICAR-Indian Agricultural Research Institute, New Delhi during 2015-16 and 2016-17 to study the residual effect of Si and P_2O_5 on wheat. Growth, yield, yield attributes, lodging and grain quality parameters were analyzed using standard procedures. Both the nutrients were applied in aerobic rice crop and their residual effect was studied in wheat crop.

Results: Application of Si and P_2O_5 in preceding rice crop significantly improved the growth, yield, grain quality of succeeding wheat crop. Grain yield of wheat was increased by 21% due to application of Si and P_2O_5. Significant improvement was observed when P_2O_5 and Si were applied at 60 and 80 kg ha^{-1}, respectively. Lodging was reduced by 100% with P_2O_5 and Si application at 90 and 120 kg ha^{-1}, respectively.

Interpretation: Application of Si and P_2O_5 has potential to enhance productivity by improving growth, yield attributes and reduction in abiotic stress like lodging. Fertilization with P_2O_5 and Si can reduce lodging and improve wheat grain quality through enhanced sturdiness and protein content.



Key words: Growth, Lodging, Phosphorus, Silicon, Residual effect, Wheat

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Introduction

The rice–wheat cropping system (RWCS) has been in practice in Asia for more than 1000 years. However, the productivity of rice–wheat system remains below the potential yield, the major cause being nutrient depletion from the soil (Dawe *et al.,* 2000; Shah *et al.,* 2011). The continuous RWCS for several decades has been reported to result in nutrients depletion and decline in yields (Zia *et al.,* 1996; Dawe *et al.,* 2000; Duxbury *et al.,* 2000; Shah *et al.,* 2011). Silicon fertilization has the potential to mitigate environmental stresses and soil nutrient depletion, and as a consequence is an alternative to the extensive use of nitrogen (N) fertilizers for maintaining sustainable agriculture (Guntzer *et al.,* 2012). Silicon application can play a great role in increasing the productivity, quality besides mitigating the abiotic and biotic stresses (Liang *et al.,* 2007; Meena *et al.,* 2014; Jinger *et al.,* 2017). It has been reported that the application of Si fertilizer (slag) in Colombia increased upland rice yield by 100% due to residual effect (Correa-Victoria *et al*., 2001). Residual Si applied in previous crop also helps to enhance the growth and yield of succeeding crop like wheat (Patel *et al.,* 2019). Further, phosphorus (P_2O_5) is used by plants in much lower quantities. Unlike N, soil P_2O_5 readily forms weakly soluble mineral compounds in the soil, thus resulting in poor mobility and remain in soil as residual P_2O_5 (Nichols *et al.,* 2012). The residual soil P_2O_5 after rice harvest increased the grain yield and yield components of wheat significantly under low yielding fine genotype as compared to high yielding coarse genotypes (Amanullah and Inamullah, 2016). It has been studied that Si and P_2O_5 both have positive role in terms of growth, yield, quality and abiotic stress of rice crop (Liang *et al*., 2007; Jinger *et al.,* 2018; Wang *et al.,* 2019; Li *et al.,* 2020). Research on Si and P_2O_5 management under RWCS is lacking. For sustainable rice and wheat production, research on Si and P_2O_5 on rice crop and their residual effect on the succeeding wheat crop is needed. This study was, therefore, conducted to find whether Si and P_2O_5, applied to rice have any significant effect on the productivity of subsequent wheat crop.

Materials and Methods

Experimental site: A field experiment was conducted during 2015-16 and 2016-17 at ICAR-Indian Agricultural Research Institute (IARI), New Delhi, situated at a latitude of 28º38' 23'' N and longitude of 77º09' 27'' E, and at an altitude of 228.6 m above mean sea level. The climate of New Delhi is sub-tropical and semi-arid type with hot and dry summer and cold winter and falls under the 'Trans-Gangetic plains zone'. Summer months (May-June) are hottest with maximum temperature ranging between 41-46°C, while drop in temperature is generally observed from September onward. January is the coldest month of the year with a minimum temperature ranges from 5-7ºC. The soil of experimental site was sandy clay loam in texture (sand 51.6%, silt 22.1% and clay 26.3%) with pH of 7.7, bulk density of 1.42 gcm^{-3} and electrical conductivity 0.42 dS m^{-1} at top 15 cm of soil. Soil had low organic carbon (0.45%) and available N (205 kg ha^{-1}), medium P_2O_5 (37.7 kg ha^{-1}) and K_2O (312 kg ha^{-1}).

Experimental setup: The experiment consisted of four levels each of P_2O_5 (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) and Si (0, 40, 80 and 120 kg Si ha^{-1}) replicated thrice in a FRBD. Phosphorus and Si were supplied as basal dose through di-ammonium phosphate (DAP) and calcium silicate, respectively, in the preceding aerobic rice crop. As per treatments, entire dose of Si and P_2O_5 was applied as basal just before sowing in the rice crop. Recommended dose of N (120 kg ha^{-1}) and K_2O (60 kg ha^{-1}) were applied to the wheat. Subsequently, it was incorporated into the soil while sowing by seed drill. Both N and P_2O_5 through urea and DAP was applied by broadcasting. Sowing was done through seed drill on 15th and 16th November during 2015 and 2016, in rows, 22.5 cm apart. The timely sown wheat variety HD 3086 was sown with at seed rate of 100 kg ha^{-1}. The crop was harvested on 15th and 16th April during 2016 and 2017, respectively.

Growth, yield and yield attributes: Five plants were randomly selected and collected by cutting from the ground level in each treatment at different stages of growth. These plants were selected from the middle of the plot to avoid border effect by leaving two rows on all the sides. These samples were shade dried for 5-7 days and then oven-dried at 70°C for 24 hrs. Total dry matter production was expressed in g m^{-2} at 30, 60, 90, 120 DAS and at harvest. Relevant yield parameters were recorded using standard procedure. Five plants were selected randomly and tagged for taking various yield attributing observations from each net plot (12 m^2). After threshing, cleaning and drying, the grain yield was recorded and reported at 14% moisture content. The straw yield was obtained by deducting grain yield from the total biological yield. Yields were expressed in tonnes per hectare (t ha^{-1}). Harvest index was calculated by the following equation.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (t ha}^{-1}\text{)}}{\text{Biological yield (t ha}^{-1}\text{)}} \times 100$$

Lodging force: The primary wheat tillers at their lower 3rd and upper 3rd nodes of heading stage were collected. Leaf blades and sheaths were removed and 200 mm stem sample prepared prior to measurement. *TA.XT plus Texture Analyser* from Stable Micro Systems was used for shear test of wheat samples. It had force capacity of 500 N with force resolution: 0.1 g. The test speed of loading varied in the range 1 mms^{-1}. During calibration and setting of the instrument, the contact and trigger forces were 0.2 kg each for a target distance of 8 mm. During the test, the data on force and extension at failure were generated automatically and forces versus displacement curves were obtained. The data was exported using exponent software within the system. Each wheat sample was tested under 5 mm sec^{-1} loading speed. The applied force required for breaking the lower 3rd and upper 3rd stem nodes was measured.

Lodging score: Lodging is often not distributed uniformly throughout unaffected field but may be scattered over certain sections or spots. There are several indicators to measure the lodging, among them lodging score is used frequently.

$$\text{Lodging score} = \frac{(\text{Lodged area/Net plot area}) \times 100 \times \text{Angle of lodging}}{90}$$

Quality parameters: Crude protein content of wheat grain was calculated by multiplying the determined nitrogen content in grain with a conversion factor of 5.70 (A.O.A.C. 1995). Nitrogen content in grain was estimated by Kjeldahl method. This conversion factor is due to the fact that nitrogen content of isolated chemical substance, *i.e.*, protein is 17.54 in wheat. Hectolitre weight was estimated by hectolitre weight measuring apparatus developed by the Indian Institute of Wheat and Barley Research, Karnal. Hectolitre weight (hl), expresses weight in kg hl^{-1} (100 l). Grain hardiness index was measured by Single Kernel Characterization System (SKCS)-4100', Perten Instruments (Osborne and Anderssen, 2003). Sodium Dodecyl Sulphate (SDS)-sedimentation volume test was performed by the method of Dick and Quick (1983).

Statistical analyses: Data collected from the experiments were analyzed by analysis of variance (ANOVA) and means for significant treatment effects were compared using Fisher's Least Significant Difference (LSD) at 5% probability level (Gomez and Gomez, 1984). Thereafter, pooled analysis of data for two years was carried out by ANOVA. Statistical package SAS @ version 9.3 was used for data analysis.

Results and Discussion

Dry matter accumulation (DMA): Residual P_2O_5 and Si application significantly influenced DMA at 60, 90, 120 DAS and at harvest in pooled analysis (Table 1). Among the P_2O_5 fertilization, at growth stages (60, 90, 120 DAS and at harvest), significantly higher DMA was obtained with 90 kg P_2O_5 ha^{-1} than other treatments, except it was found on par with 60 kg P_2O_5 ha^{-1} in pooled analysis. It might be due to higher residual P_2O_5 availability from applied treatment in rice which reduced the immobilization of P_2O_5 and in turn wheat crop received more P_2O_5 from that particular treatment. Sufficient availability of P_2O_5 led to vigorous and taller plants with larger leaf area, which increased the photosythate production, resulting in enhanced dry matter production. Amanullah and Inamullah (2016) reported that increase in P_2O_5 levels to the preceding rice crop increased the residual soil P_2O_5 that had positive impact on the growth and growth components of subsequent wheat crop. This indicates strong carry over effect of P_2O_5 for subsequent wheat crop under rice–wheat cropping system. Majeed *et al*. (2014) reported significant effect of different phosphorus rates on plant height of wheat. This phenomenon was also confirmed by Aulakh *et al.* (2003). Among Si levels, at 60, 90, 120 DAS at harvest, significantly higher DMA was obtained with 120 kg Si ha^{-1} than other levels. However, this treatment was at par with 80 kg Si ha^{-1}. The DMA of wheat increased progressively with advancement of crop stages. At early phase of growth, difference was not significant. However, at 60, 90, 120 DAS and harvest, DMA were significantly influenced. It might be due to higher availability of Si from calcium silicate and its other beneficial effect like effective utilization of nutrients through extensive root system developed by crop plants which resulted in higher growth of wheat crop. Patel *et al.* (2019) reported that residual effect of Si significantly affected the plant height of succeeding wheat crop, which might be due to increase in Si status after harvest of rice during both the years, as it was involved in stimulation of cell division, photosynthetic process as well as formation of chlorophyll.

Yield attributes: Data revealed that Si and P_2O_5 application had a positive effect on different yield attributing parameters *viz.* effective tillers; spike length, spike weight and grains per spike (Table 2). There was significant effect of P_2O_5 application on effective tillers and their higher number were recorded with 90 kg P_2O_5 ha^{-1} than other treatments and found at par with 60 kg P_2O_5 ha^{-1} in pooled analysis. Similar trends were also observed with respect to spike length, spike weight and grain $spike^{-1}$. This could be attributed to sufficient, balance and continuous supply of P_2O_5 which increased accumulation of photosynthates from source and enhanced translocation to sink with increased levels of P_2O_5 application. Phosphorus fertilization at the beginning of experiment increased dry matter of wheat and this suggests that wheat can utilize residual P_2O_5 fertilizer in soil (Takahashi, 2007). Similarly, in wheat crop number of spike m^{-2} and spike length were also affected significantly due to residual P_2O_5 over check. The maximum number of spike m^{-2} (23) and spike length (25.33 cm) were recorded with application of 90 kg P_2O_5 ha^{-1} in the preceding rice crop. Rahim *et al*. (2010) reported that increasing P_2O_5 levels up to 81 kg P_2O_5 ha^{-1} resulted in significantly more number of tiller m^{-2}, grains $spike^{-1}$, 1000-grain weight (36.3 g) and grain yield (3.94 t ha^{-1}) as compared to lower levels. Silicon application also influenced the yield attributes. The maximum effective tillers, spike weight, grain $spike^{-1}$ and spike length were recorded with 120 kg Si ha^{-1} and found at par with 80 kg Si ha^{-1} application in pooled analysis. This happened in plots receiving full Si dose at sowing might be due to vigorous growth on account of maximum availability of nutrients. Silicon increases the number and weight of grains of wheat by stimulating shoot and root biomasses (Filho *et al*., 2005) and ultimately enhances the wheat growth and yield attributes (Gong *et al*., 2003). Further, Soratto (2012) stated that Si played a favorable role in plant growth, mineral nutrition, and mechanical strength. The increase in plant growth may be attributed to changes in physiological and morphological properties which are facilitated by the presence of Si.

Table 1 : Residual effect of P_2O_5 and Si on periodic DMA of succeeding wheat crop at different growth stages (pooled data of 2 years)

Treatment	Dry matter accumulation (g m^{-2})				
	30 DAS	60 DAS	90 DAS	120 DAS	Harvest
Phosphorus levels (kg P_2O_5 ha^{-1})					
0	21.9	212.6	477.7	871.0	990.5
30	22.9	221.8	530.3	932.5	1134.6
60	23.2	229.1	549.8	953.9	1169.6
90	25.5	239.3	578.2	1001.0	1226.0
SEm±	1.28	5.17	13.9	17.6	25.9
LSD (P=0.05)	NS	14.9	40.1	51.0	74.9
Silicon levels (kg Si ha^{-1})					
0	22.5	213.5	488.4	885.2	1005.7
40	22.6	223.8	536.6	943.2	1146.2
80	22.8	228.3	545.4	950.0	1166.1
120	25.5	237.2	565.7	979.8	1202.7
SEm±	1.28	5.17	13.9	17.6	25.9
LSD (P=0.05)	NS	14.9	40.1	51.0	74.9

Table 2 : Residual effect of P_2O_5 and Si on yield attributes of succeeding wheat crop (pooled data of 2 years)

Treatment	Effective tillers m^{-2}	Spike weight (g)	Grain per spike	Spike length (cm)	1000-Grain weight (g)
Phosphorus levels (kg P_2O_5 ha^{-1})					
0	313	3.07	45.8	9.6	41.3
30	351	3.25	53.3	10.7	42.1
60	396	3.51	58.9	11.5	42.8
90	403	3.74	64.8	11.9	43.5
SEm±	7	0.13	2.3	0.4	0.7
LSD (P=0.05)	22	0.36	6.7	1.1	NS
Silicon levels (kg Si ha^{-1})					
0	333	3.12	46.8	9.6	41.4
40	356	3.22	54.6	10.7	41.8
80	376	3.59	59.8	11.5	43.1
120	398	3.65	61.7	12.0	43.2
SEm±	7	0.13	2.3	0.4	0.7
LSD (P=0.05)	22	0.36	6.7	1.1	NS

Yield: The grain, straw and biological yield of succeeding wheat crop was significantly influenced by the residual effect of P_2O_5 applied to aerobic rice (Fig. 1). Grain yield ranges from 4.19 t ha^{-1} to 6.11 t ha^{-1} in different treatment. The higher grain yield (6.01 t ha^{-1}), straw yield (8.70 t ha^{-1}) and biological yield (15.06 t ha^{-1}) were obtained with 90 kg P_2O_5 ha^{-1} than other treatments except it was found on par with 60 kg P_2O_5 ha^{-1} in pooled analysis. P_2O_5 application had non-significant effect on harvest index. Residual P_2O_5 release gradually and continuously during whole crop growth period which resulted in better performance of crop. Baraich *et al.* (2012) indicated that application of 90 kg P_2O_5 ha^{-1} significantly increased spike length (10.85 cm), grains spike^{-1} (66.33), seed index (48.38 g) and grain yield (4.5 t ha^{-1}) of wheat as compared to control. The highest yield and yield components for subsequent wheat crop was due to higher P_2O_5 levels applied to the preceding rice crop. According to Cooke (1982), the recovery of applied phosphatic fertilizer by plants is very low as compared with other nutrients, and only 10–20% of applied phosphatic fertilizer is available to the current crop, and the residual P_2O_5 is available to subsequent crops (Wild, 1988). Phosphate fertilizers can have long lasting residual effects on succeeding crops and due to accumulated residues, the level of soil P_2O_5 gradually raises contributing more to P_2O_5 pool available to growing plants (Harapiak and Beaton, 1986). According to Karamanos *et al.* (2007), P_2O_5 recovery by crops in the year of fertilizer application was very low (10 to 30%) which depends on soil, crop and management factors. They reported negligible benefits to the residual soil P_2O_5, so continuous P_2O_5 fertilize was required to increase crop yield. Among Si fertilization, maximum grain yield (6.11 t ha^{-1}), straw yield (8.35 t ha^{-1}) and biological yield

Table 3 : Residual effect of P_2O_5 and Si on grain quality parameters of succeeding wheat crop (pooled data of 2 years)

Treatment	Protein content (%)	Protein yield (kg ha^{-1})	Hectolitre weight (kg ha^{-1})	Grain hardness index	Sedimentation volume (ml)
Phosphorus levels (kg P_2O_5 ha^{-1})					
0	10.7	520	78.0	89.5	49.6
30	10.9	572	78.0	86.6	50.7
60	11.9	700	78.9	84.0	53.3
90	11.9	735	79.5	83.8	55.0
SEm±	0.3	32	0.5	0.7	0.9
LSD (P=0.05)	1.0	93	1.4	2.1	2.5
Silicon levels (kg Si ha^{-1})					
0	10.5	441	77.8	88.5	51.0
40	11.0	599	78.3	87.4	51.4
80	11.8	732	79.1	84.4	52.2
120	12.1	754	79.2	83.7	53.9
SEm±	0.3	32	0.5	0.7	0.9
LSD (P=0.05)	1.0	93	1.4	2.1	2.5

(15.06 t ha^{-1}) were recorded with 120 kg Si ha^{-1}. However, this treatment was found at par with 80 kg Si ha^{-1}. Silicon application had non-significant effect on harvest index. Soratto *et al*. (2012) found increase in 34% yield, compared to the treatment with no Si application. The result is mainly justified by higher number of spike m^{-2} and filled grains $spike^{-1}$. The significantly higher wheat grain (4438 kg ha^{-1}) and straw yield (6701 kg ha^{-1}) was recorded due to residual effect of Si applied in rice crop under central Gujarat region (Patel *et al.,* 2019). This increase in grain and straw yield might be attributed to increase in growth and yield related attributes by increased photosynthetic efficiency upon Si addition and/or might be due to increase in root growth and enhanced P_2O_5 availability with Si application (Buck *et al.,* 2008; Gholami and Falah, 2013).

Protein content and protein yield: Application of P_2O_5 and Si significantly influenced the protein content and protein yield in pooled analysis (Table 3). Among P_2O_5 application, higher protein content (11.9 %) and protein yield (735 kg ha^{-1}) was recorded with 90 kg P_2O_5 ha^{-1} and found at par with 60 kg P_2O_5 ha^{-1}. Grain protein is an important factor that influences the milling and baking quality of wheat. N and P_2O_5 are the major nutrient that influences grain protein content (Bly and Woodward, 2003). Singh and Ahlawat (2006) found that increasing rates of applied P_2O_5 in wheat resulted in significant increase in N (159.85 kg ha^{-1}) and P_2O_5 (43.7 kg ha^{-1}) uptake which was associated with increase in the protein content. Protein content of wheat grains increased with increase in application rate of P_2O_5. The rate of chemical fertilization has significant effects on the physico-chemical, mechanical, and thermal properties of seeds; it also has an important effect on the seed quality parameters. In addition, the result confirms that the dose of P_2O_5 fertilization has a significant effect on the chemical compositions of wheat grain. It is generally believed, that P_2O_5 slightly affects grain proteins in winter wheat (Gaj *et al.,* 2013). It has been pointed out that the influence of P_2O_5 fertilization on wheat quality characters largely depends on the N and P_2O_5 rates (Berecz, 2001). Among Si fertilization, the maximum protein content (12.1 %) and protein yield (754 kg ha^{-1}) was obtained with 120 kg Si ha^{-1} and found at par with 80 kg Si ha^{-1}. Yu and Gao (2012) observed the effects of Si on grain quality in two wheat cultivars (Longmai 26 and Kehan 16) and found that Si application influenced protein content of grain due to positive effect of Si on P_2O_5, which ultimately increased the protein content in two cultivars tested. Liu *et al.* (2017) reported that application of Si fertilizer also significantly enhanced the protein concentration in milled rice, with increase of 7.29% and 5.08% in 'Shengdao14' and 'Huaidao11', varieties, respectively relative to control treatment. Similar trend was observed in brown rice. Application of Si fertilizer markedly increased concentrations of most amino acids evaluated in milled rice for both cultivars, including non-essential and essential amino acids. In Poland, under laboratory conditions, the effect of Optysil (Si) growth stimulator was studied to reduce the negative impact of drought stress on wheat (Ciecierski, 2016). Laboratory tests on wheat showed 41% lower leakage of electrolytes and increase in protein production by 40% as compared to control combination.

Hectolitre weight, grain hardness index and sedimentation volume were significantly influenced due to residual effect of P_2O_5 and Si application in pooled analysis (Table 3). The highest hectolitre weight (79.5 kg hl^{-1}) and sedimentation volume (55.0 ml) was obtained with 90 kg P_2O_5 ha^{-1} and found at par with 60 kg P_2O_5 ha^{-1}. In case of Grain hardness index, the highest (89.5%) and lowest (83.8%) values were recorded with no application of phosphorus and 90 kg P_2O_5 ha^{-1}, respectively. Improvement in grain quality might be due to increase in boldness and hardness of grain due to P_2O_5 application. Hectolitre weight and grain hardness were not significantly affected by N rates, but

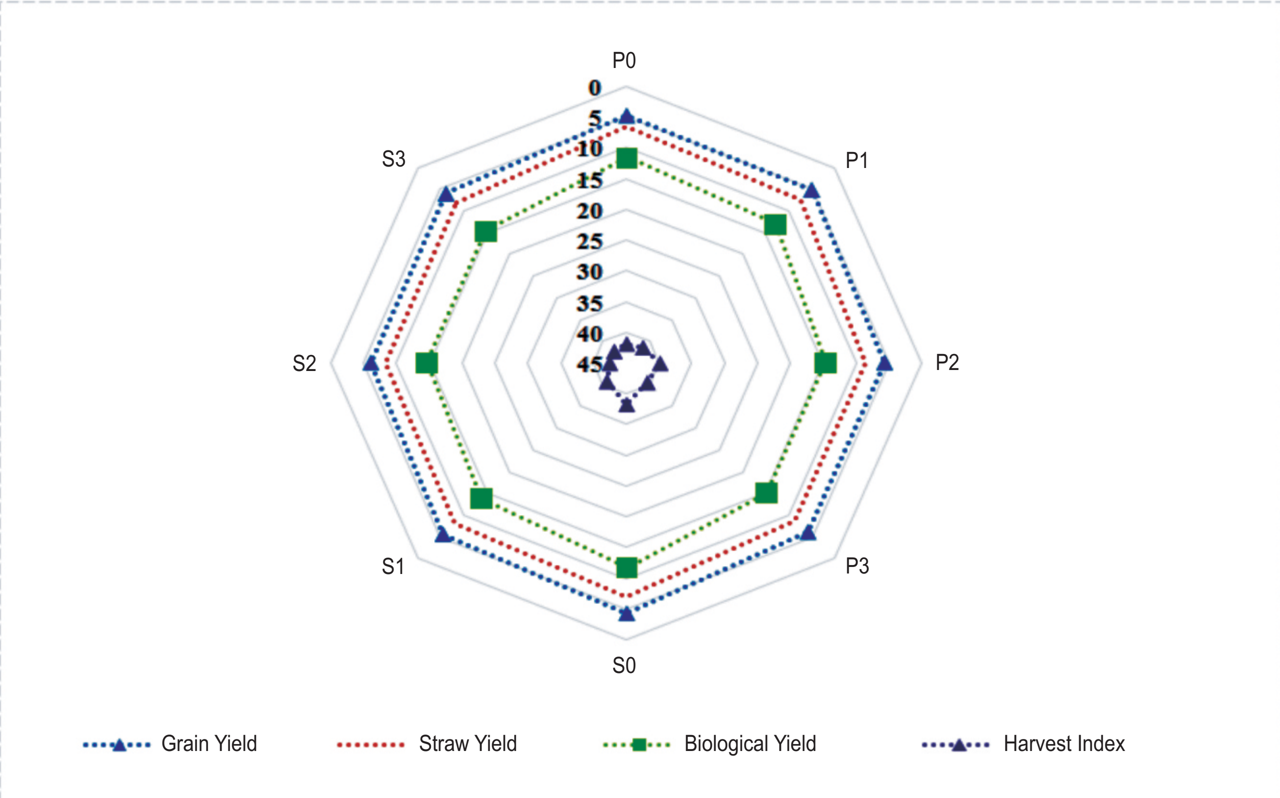

Fig. 1 : Residual effect of P_2O_5 and Si on pooled grain, straw, biological yields (t ha^{-1}) and harvest index (%) of succeeding wheat during experimental period (P0, P1, P2 and P3 are 0, 30, 60 and 90 kg P_2O_5 ha^{-1}; S0, S1, S2 and S3 are 0, 40, 80 and 120 kg Si ha^{-1}, respectively).

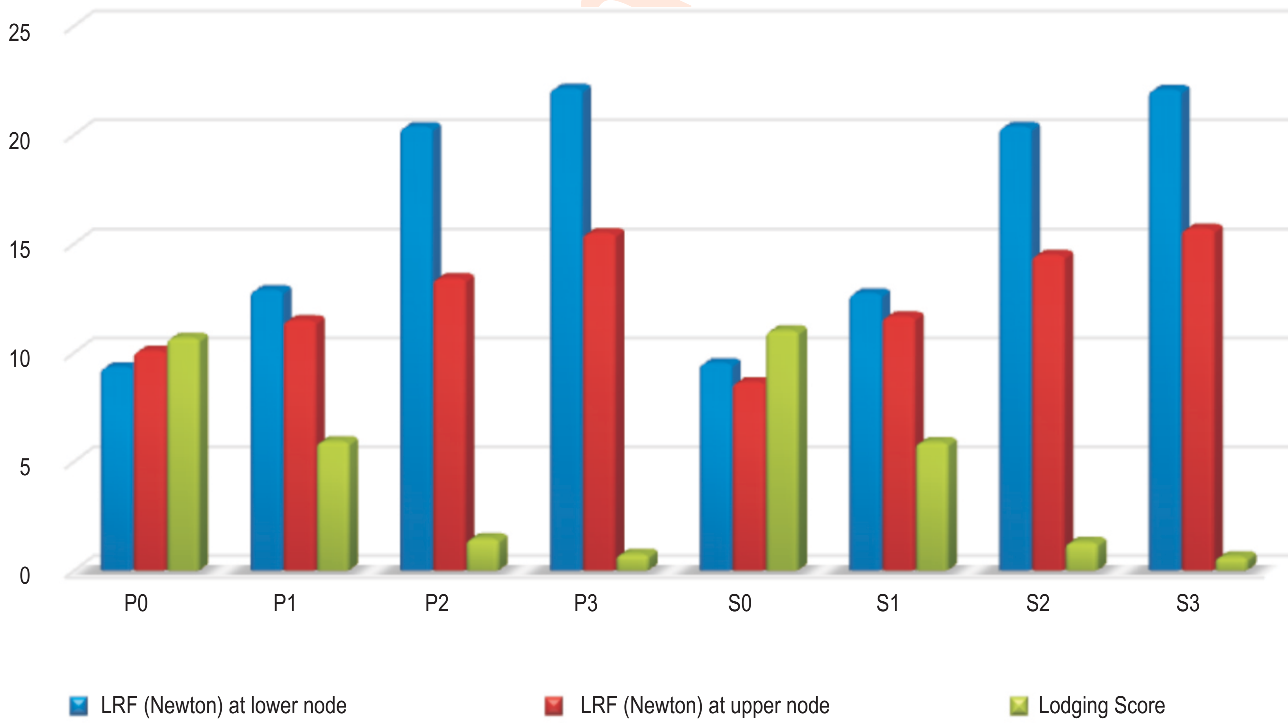

Fig. 2 : Residual effect of P_2O_5 and Si on LRF (Newton) and lodging score of succeeding wheat during experimental period (P0, P1, P2 and P3 are 0, 30, 60 and 90 kg P_2O_5 ha^{-1}; S0, S1, S2 and S3 are 0, 40, 80 and 120 kg Si ha^{-1}, respectively).

was responsive to P_2O_5 fertilizers where the highest rates (46 and 69 kg P_2O_5 ha^{-1}) showed statistically similar and higher values than the control treatment. Although it has been suggested that higher P_2O_5 content in grain may provide safer or healthier products for humans, due to the ability of phytate to inhibit aflotoxin production and impart other benefits, this advantage of high P_2O_5 is unlikely to be of great importance in human nutrition (Fana *et al.,* 2012). Similar findings were also reported by Kumar *et al*. (2011). Among Si applications, the highest hectolitre weight (79.2 kg hl^{-1}) and sedimentation volume (53.9 ml) was recorded with 120 kg Si ha^{-1} and found at par with 80 kg Si ha^{-1}. In case of grain hardness index, the highest (88.5%) and the lowest (83.7%) value were obtained with no application of Si treatment and 120 kg Si ha^{-1}, respectively (Table 3), which might be due to increase in sturdiness and gluten content in wheat due to Si application. In India, during the years 2016–2017, a significant increase in corn grain yield and improvement of grain quality was observed when Si in the form of monosilicic acid was applied to the soil (Silixol granules) and foliar fertilization (Silixol plus) was applied (Jawahar *et al.,* 2017). Similar findings were reported by Gong *et al*. (2003).

Lodging resistance force (LRF) and lodging score: Data related to LRF and lodging score are given in Fig. 2. Application of 90 kg P_2O_5 ha^{-1} recorded the highest lodging resistance force at lower node (22.1 newton) and at upper node (15.5 newton), in pooled analysis. However, this treatment was found at par with 60 kg P_2O_5 ha^{-1}. In case of lodging score, the minimum (0.75) and maximum values (10.67) were recorded with 90 kg P_2O_5 ha^{-1} and control, respectively, which might be due to P_2O_5 that helped in formation of extensive root system and kept the plant intact and erect during windy situations. Among Si fertilization, the highest LRF at lower node (22.0 newton) and at upper node (15.7) were recorded with 120 kg Si ha^{-1}, respectively, and found at par with 80 kg Si ha^{-1}. In case of lodging score, the minimum (0.63) and maximum values (11.0) were obtained with 120 kg Si ha^{-1} and control treatment of Si application, respectively. Maximum lodging was recorded with no application of Si and P_2O_5. Lodging was reduced by 100% with application of 90 kg P_2O_5 and 120 kg Si kg ha^{-1} (Fig. 2). It might be due to the effect of Si on leaf erectness, mainly a function of Si deposition in the epidermal layers of leaf and also on stem, which provides strength to stem. Accumulation of Si element in shoots increased the cell wall thickness of stem and size of vascular bundles with reduced lodging index (Kim *et al.,* 2002). Moreover, this element also affects the architecture of plant leaves to increase the amount of light interception by leaves (Rehman, 2016), thereby improving sclerenchyma, vascular tissues and vascular sheaths (Tanaka and Park, 1966; Hernandez, 2014), and preventing lodging in wheat and rice. This micronutrient can be utilized to stimulate silicification and lignification in thick-walled cells, thicken collenchyma cells, and improve keratinocyte development and enhance cellulose content, as a result of increasing lodging resistance (Dorairaj *et al.,* 2017).

Conclusions: Nutrient management is important for improving crop productivity in cereal based system. The results confirmed that wheat grown on plots having more residual soil Si and P_2O_5 had positive impact on the growth, yield and grain quality of succeeding wheat crop under RWCS. The dose of 120 kg Si and 90 kg P_2O_5 ha^{-1} may be recommended in preceding aerobic rice crop for better growth, productivity and grain quality of both preceding rice and succeeding wheat crop. Both the nutrients have mitigated the lodging to a great extent, therefore, Si along with P_2O_5 should be recommended for regions where there is problem of heavy wind or lodging during grain filling stage.

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