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Effect of phosphorus and Sulphur on the yield and quality of wheat (*Triticum aestivum* L.) crop

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Abstract
The field experiment conducted in a silty loam soil with a slightly alkaline pH (8.10) and an EC of 0.36 dS m^{-1} revealed noteworthy outcomes. It identified lower nitrogen (242 kg ha^{-1}), medium phosphorus (39.20 kg ha^{-1}), high potash (292 kg ha^{-1}), and medium sulphur (19.05 ppm) levels. Utilizing a Factorial Randomized Block Design with three replications, the experiment assessed four phosphorus (P_0-0, P_1-30, P_2-60, P_3-90 kg $P_2O_5ha^{-1}$ and three sulphur (S_0-0, S_1-20, S_2-40 $kgha^{-1}$) levels. The results exhibited substantial improvements with 90 kg P_2O_5 ha^{-1} in various yield attributes: tillers per meter row (89.9), effective tillers (85.7), spike length (8.7 cm), spikelets per spike (15.9), grains per spike (44.8), grain yield (4451 kg ha^{-1}), straw yield (6886 kg ha^{-1}), and test weight (46.18 g). The highest protein content (12.69%) was achieved with 90 kg P_2O_5 ha^{-1}, akin to 60 kg P_2O_5 ha^{-1}. Similarly, 40 kg S ha^{-1} exhibited akin results to 20 kg S ha^{-1}. Notably, the interaction effect of 90 kg P_2O_5 ha^{-1} + 40 kg S ha^{-1} significantly increased grain per spike, grain yield, and test weight. These findings underscore the pivotal role of phosphorus and sulphur in augmenting wheat productivity within this soil and agro-climatic zone.

Keywords: Wheat, phosphorus, sulphur, yield, economics

Introduction

Wheat (*Triticum aestivum* L.), the world's leading cereal crop, holds a position of paramount importance in the Indian diet. Ranking as the third most-produced cereal globally, following maize and rice, wheat has witnessed remarkable production advancements in India over the past four decades, making the country the second largest wheat producer worldwide. In India, wheat is second only to rice in terms of cultivation area and production. The predominant variety cultivated in India is the Mexican Dwarf Wheat (*Triticum aestivum* L.), commonly known as common bread wheat. Developed by Dr. N. E. Borlaug at CIMMYT in Mexico, its origins trace back to South West Asia. Characterized as a thermo-sensitive, cool-season crop and a long-day plant (LDP), wheat thrives optimally in regions between 30º and 60º N latitude and 27º and 40º S latitude. Being a self-pollinated, annual, C_3, and hexaploid plant, wheat is highly adaptable and known for its high yield potential.

One of wheat's notable features is its high protein content, ranging from 10 to 12%, primarily in the form of gluten, which is crucial for bakery applications. The gluten protein fraction, particularly the glutenins and gliadins, is integral to the bread-making quality, as it provides the viscoelastic properties necessary for processing dough into various products like bread, pasta, noodles, and more. The unique viscoelastic gluten protein complex in bread wheat is particularly significant for leavened bread production. In addition to its use in the bakery industry, wheat is a staple in temperate countries for both human consumption and livestock feed. It contributes essential amino acids, minerals, vitamins, beneficial phytochemicals, and dietary fiber, especially in whole-grain products.

In the Saurashtra region of Gujarat, the predominantly medium black calcareous soil presents challenges such as poor nitrogen (N) and sulfur (S) levels. Enhancing wheat productivity and protein content can be achieved through strategic fertilizer application. However, productivity in Gujarat faces hurdles like inadequate irrigation, unbalanced fertilizer use, and a lack of modern agricultural techniques.

Phosphorus, the second most essential plant nutrient, is crucial for various physiological processes, including photosynthesis, respiration, energy storage, and cell division. However, its availability in soluble forms is often limited in soils, with about 80% of applied phosphorus being immobilized, forming complexes with elements like Al or Fe in acidic soils or Ca in calcareous soils.

Sulfur, another vital nutrient, is critical for the synthesis of amino acids and the establishment of protein structures through disulphide bonds. Its deficiency in wheat can significantly affect production and grain quality, including reduced grain size and impaired baking quality due to affected disulfide bond formation. Despite its importance, the availability of sulfur for crop production is declining due to factors like improved air quality standards and the use of modern fertilizers with lower sulfur content.

A survey in the Saurashtra region indicated a decline in soil sulfur levels over a decade, underscoring the need for addressing nutrient depletion for sustainable wheat production. Proper management of these nutrients is essential for optimizing wheat growth, yield, and quality, especially in regions with specific soil characteristics like those found in Saurashtra.

Materials and Methods

The experiment was carried out in the D-6 plot of the Instructional Farm at the Department of Agronomy, Junagadh Agricultural University, located at 21.50 N latitude and 70.50 E longitude, with an elevation of 60 meters above sea level. This site is situated within the South Saurashtra Agro-climatic region of Gujarat state. The study encompassed twelve treatments, systematically organized in a Factorial Randomized Block Design, and each was replicated three times. These treatments included four phosphorus levels (P_0-0, P_1-30, P_2-60, P_3-90 kg P_2O_5 ha^{-1}) and three sulfur levels (S_0-0, S_1-20, S_2-40 kg ha^{-1}). The experimental plot featured silty loam soil with a slightly alkaline reaction, indicated by a pH of 8.10 and an electrical conductivity (EC) of 0.36 dS m^{-1}. The soil's nutrient profile was characterized as low in available nitrogen (242 kg ha^{-1}), medium in available phosphorus (39.20 kg ha^{-1}), high in available potash (292 kg ha^{-1}), and medium in available sulfur (19.05 ppm).

Throughout the growing period, from germination to harvest, various plant growth parameters were meticulously recorded at regular intervals. Post-harvest, key yield parameters such as the number of grains per spike, grain yield, stover yield, and harvest index were also carefully documented. The statistical analysis of the data collected from these various characteristics was conducted in accordance with the Factorial Randomized Block Design (FRBD), using standard statistical procedures as outlined by Panse and Sukhatme (1985) [10]. For the interpretation of results, the standard error of the mean, critical difference (C.D.) at a 5% probability level, and coefficient of variance were calculated.

Results and Discussion

Yield attributes

The treatment with a phosphorus application rate of 90 kg P_2O_5 ha^{-1}resulted in significantly higher values for both the maximum number of tillers (89.9) and effective number of tillers (85.7) per meter row length. This finding was statistically similar to the effect observed with the application of 60 kg ha^{-1}of phosphorus. Moreover, the length of spike and the number of spikelets per spike exhibited significantly higher values when treated with 90 kg ha^{-1}of phosphorus, and these results were statistically comparable to the application of 60 kg ha^{-1}of phosphorus. When 40 kg ha^{-1}of sulfur was applied, it led to an increase in the number of spikelets per spike and the number of grains per spike, which were on par with the results obtained from the application of 20 kg ha^{-1}of sulfur. The interaction effect of the P_3S_2 treatment combination was found to be significant specifically in the case of the number of spikelets per spike. This interaction was also observed to be on par with treatments involving P_1S_0, P_2S_1, P_3S_1, and P_2S_2. However, the length of the spike did not yield statistically significant results in this context.

These findings align with the research conducted by Islam *et al*. (2017) [5], supporting the notion that specific combinations of phosphorus and sulfur application rates have notable impacts on the spike characteristics and grain development in wheat plants.

Test weight (g)

The application of phosphorus at a rate of 90 kg ha^{-1} (P_3) resulted in the significantly highest test weight recorded at 46.18 g among all treatments. Interestingly, treatment P_2 (phosphorus at 60 kg ha^{-1}) exhibited statistically similar test weights to treatment P_3. Similarly, the application of 40 kg ha^{-1}of sulfur displayed higher test weights and was on par with the test weights achieved by the application of 20 kg ha^{-1}of sulfur. Notably, the interaction effect was also found to be significant, particularly with treatments P_3S_2, which showed similarity with all combinations except P_0S_0, P_1S_0, and P_0S_1.

This observed increase in test weight might be attributed to the enhanced vigor and growth of plants resulting from sufficient nutrient absorption. This could lead to better performance in terms of test weight. Noonari *et al.* (2016) [9] noted that higher nutrient absorption contributes to improved growth, resulting in higher test weights. Additionally, the augmentation of yield-contributing traits with higher sulfur doses could be due to the availability of adequate sulfur throughout the wheat crop's growth cycle, promoting robust vegetative growth and overall development. Similar findings have been reported in the study conducted by Sharma *et al.* (2003) [17]. These findings collectively suggest that the application of specific doses of phosphorus and sulfur significantly influences wheat growth and yield-contributing characteristics, contributing to improved test weight and overall crop productivity.

Protein content (%)

The application of phosphorus at a rate of 90 kg ha^{-1}resulted in a significantly higher protein content of 12.69% in the grain. However, treatment with 60 kg P_2O_5 ha^{-1} (P_2) exhibited a similar statistical outcome in comparison to treatment P3. This increased nutrient absorption capacity facilitated greater nutrient uptake by the grain and straw, subsequently leading to improved nutrient content in both. The presence of phosphorus seems to stimulate more efficient nutrient absorption, thereby enhancing the synthesis of protein and the formation of stable phospho-protein compounds. This phenomenon is responsible for the observed higher protein content in the grains. Furthermore, the elevated protein content associated with these phosphorus levels is attributed to the increased nitrogen uptake by the grains, ultimately resulting in higher protein synthesis.

These findings align with previous studies conducted by Laghari *et al*. (2010) [7], Paswan *et al*. (2014) [11], Saha *et al.* (2014) [15], and Chauhan *et al*. (2014) [2] in wheat crops. These studies also indicated a similar positive impact of phosphorus application on enhancing protein content in wheat grains, emphasizing the role of phosphorus in improving nutrient uptake and protein synthesis in crops.

Grain yield (kg/ha): The highest grain yield of 4451 t ha^{-1} was significantly recorded with the application of 90 kg/ha of phosphorus (P_3), surpassing all other treatments. However, treatment P_2 (60 kg ha^{-1}) exhibited statistically comparable results to the application of 90 kg ha^{-1} of phosphorus. The increased grain yield attributed to phosphorus application can be linked to the relationship between source and sink in the plant. There seems to be enhanced translocation of photosynthates from the source (plant) to the sink (developing seeds), potentially leading to a boost in seed yield. Phosphorus aids in elevating yield due to its role in fostering well-developed root systems, enhancing nitrogen fixation and its availability to plants, and creating favorable environments in the rhizosphere. These findings are consistent with the results reported by Sandana and Pinochet (2014) [13].

Furthermore, applying sulfur at a rate of 40 kg ha^{-1} (S_2) resulted in a significantly higher grain yield of 4354 kg ha^{-1} compared to plots without sulfur application (S_0). This yield was on par with applying sulfur at a rate of 20 kg ha^{-1}. The interaction between phosphorus and sulfur was found to be significant. Notably, treatment P_3S_2 exhibited the highest grain yield (4937 kg ha^{-1}) and was comparable to treatment combinations P_0S_2, P_2S_1, P_1S_2, and P_3S_1. The increased yield associated with higher doses of sulfur application may be attributed to its positive effects on root growth, cell multiplication, elongation, and cellular expansion within the plant, ultimately leading to increased grain yield. These results are in line with the findings reported by Yadav *et al.* (2004) [18].

In summary, the application of phosphorus and sulfur, particularly at specific rates, significantly influences grain yield by enhancing nutrient availability, root development, and essential physiological processes that contribute to improved crop productivity.

Straw yield (kg ha^{-1})

The highest straw yield, significantly recorded at 6886 kg/ha, was achieved with the application of 90 kg ha^{-1} of phosphorus (P_3), surpassing all other treatments. However, the treatment involving 60 kg ha^{-1} of phosphorus (P_2), which yielded 6549 kg ha^{-1} of straw, was statistically comparable to the P_3 treatment. The yield of straw is closely linked to vegetative growth, as the balanced and optimal use of fertilizers enhances plant height, the number of green leaves per plant, and overall dry matter production, all of which contribute to an increased straw yield. These results align with the findings presented by Sharma *et al*. (2011) [16], further emphasizing the critical role of appropriate fertilizer application in optimizing both grain and straw yields in agricultural practices.

Economics

Highest gross returns of Rs. 91,666 ha^{-1} gained with 90 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1}, where as lower gross return of Rs. 73,650 ha^{-1} gained without phosphorus and Rs. 71,720 ha^{-1} without sulphur. In case of net return and benefit cost ratio gained with 90 kg phosphorus ha^{-1} and 40 kg sulphur ha^{-1} and would be lower with no phosphorus or sulphur. These results demonstrate the economic advantage of using adequate phosphorus and sulphur, with higher doses enhancing returns and benefit-cost ratios. Lack of these nutrients leads to the least financial gains.

Table 1: Effect of phosphorus and sulphur on number of tillers, number of effective tillers per meter row length, length of spike, number of spikelets per spike and number of grains per spike

Treatments	Number of tillers (Meter row length)	Number of effective tillers (Meter row length)	Length of spike (cm)	No. of spikelet $spike^{-1}$	Number of grains $spike^{-1}$
Phosphorus (P_2O_5 kg ha^{-1})					
P_0- 0	81.2	77.1	7.8	13.9	39.7
P_1- 30	83.0	78.6	8.0	14.3	40.8
P_2- 60	87.9	83.2	8.3	15.3	42.9
P_3- 90	89.9	85.7	8.7	15.9	44.8
S.Em. ±	2.32	2.28	0.21	0.52	1.13
C.D. at 5%	6.82	6.69	0.61	1.53	3.33
Sulphur (S kg ha^{-1})					
S_0- 0	81.1	77.0	7.8	13.7	39.9
S_1- 20	86.8	81.8	8.2	15.1	43.0
S_2- 40	88.6	84.6	8.6	15.8	43.1
S.Em. ±	2.01	1.98	0.18	0.45	0.98
C.D. at 5%	5.91	5.80	0.53	1.32	2.88
Interaction (P×S)					
S.Em. ±	4.03	3.95	0.36	0.90	1.96
C.D. at 5%	NS	NS	NS	NS	5.76
C.V.%	8.16	8.44	7.58	10.50	8.09

Table 2: Effect of phosphorus and sulphur on grain yield, straw yield, harvest index and protein content of grain

Treatments	Test weight (g)	Protein content (%)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Phosphorus (P_2O_5 kg ha^{-1})				
P_0- 0	42.14	10.62	3521	6016
P_1- 30	43.44	11.12	3623	6242
P_2- 60	44.33	11.97	3994	6549
P_3- 90	46.18	12.69	4451	6886
S.Em.±	0.76	0.30	163	216
C.D. at 5%	2.23	0.88	478	635
Sulphur (S kg ha^{-1})				
S_0- 0	42.44	11.03	3398	6127
S_1- 20	43.85	11.64	3940	6334
S_2- 40	45.78	12.08	4354	6809
S.Em.±	0.66	0.26	141	187
C.D. at 5%	1.93	0.77	414	550
Interaction (P×S)				
S.Em.±	1.32	0.52	282	375
C.D. at 5%	3.86	NS	828	NS
C.V.%	5.18	7.80	12.55	10.11

Table 3: Interaction effect of phosphorus and sulphur on number of grains per spike, test wight and grain yield of wheat

Levels of phosphorus	Number of grains spike^{-1}			Test weight (g)			Grain yield (kg/ha)		
	Levels of sulphur			Levels of sulphur			Levels of sulphur		
	S_0	S_1	S_2	S_0	S_1	S_2	S_0	S_1	S_2
P_0	39.33	41.33	38.33	38.08	42.47	45.87	2711	3574	4276
P_1	42.67	39.33	40.33	40.40	43.62	46.30	3287	3160	4422
P_2	37.33	44.67	46.67	45.60	43.20	44.20	3881	4321	3779
P_3	40.00	47.00	47.33	45.67	46.10	46.77	3711	4703	4937
S.Em.±		1.96			1.32			282	
C.D. at 5%		5.76			3.86			828	

Table 4: Economics of different treatments

Treatments	Gross return (₹ ha^{-1})	Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})	B: C ratio
Phosphorus (P_2O_5 kg ha^{-1})				
P_0- 0	73650	38418	35232	1.92
P_1- 30	75896	44289	35607	1.88
P_2- 60	82995	42159	40836	1.97
P_3- 90	91666	44029	47637	2.08
Sulphur (S kg ha^{-1})				
S_0- 0	71720	37429	34291	1.92
S_1- 20	81621	41224	40398	1.98
S_2- 40	89813	45018	44795	2.00

Conclusion

Based on the findings from the field investigation conducted in the clayey calcareous soil of the South Saurashtra agro-climatic zone, it is reasonable to conclude that achieving higher yields and better net realization from irrigated wheat requires a specific fertilization strategy. This strategy involves the application of 90 kg P_2O_5 ha^{-1} and 40 kg S ha^{-1} in conjunction with a nitrogen-based dose of 120 kg N ha^{-1}. This optimized fertilizer combination appears to be conducive to maximizing wheat yield and improving the overall net realization in this specific agricultural context.

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