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Maize Growth, Fodder Yield and Nutrient Uptake in relation to Phosphorus and Sulphur Nutrition

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ABSTRACT

Phosphorus (P) and Sulphur (S) are the most important plant nutrients which play significant roles in enhancing the early growth and development and increasing the fodder yield of maize. This important field study was planned to evaluate the P-S interaction effects on maize growth, fodder yield and nutrient (P and S) uptake. The soil used for study was clay loam, medium-alkaline (pH: 7.9), non-saline (EC: 0.85 dS m⁻¹), strongly calcareous (CaCO₃: 24 %), adequate in organic matter (1.6 %), low in ABDTPA-P (3.5 mg kg⁻¹), while medium in SO₄-S (21.5 mg kg⁻¹). Eight P and S treatments were involved in this study, i.e., single application of each 90 kg P₂O₅ (T1) and 20 kg S ha⁻¹ (T2); integration of 90 kg P₂O₅ with S @ 20, 40 and 60 kg ha⁻¹ (T3, T4 and T5, respectively), and integration of 120 kg P₂O₅ with S @ 20, 40 and 60 kg ha⁻¹ (T6, T7 and T8, respectively). The experiment followed an RCBD arrangement that was replicated thrice. Recommended seed rate of maize (95 kg ha⁻¹) was used for sowing. The results revealed that shoot biomass production was maximum when maize plants received higher doses of P and S in an integrated manner (120-60 kg P₂O₅-S ha⁻¹). At 30 DAS, shoot fresh biomass was found maximum, and statistically alike, when 90 or 120 kg P₂O₅ was integrated with S @ 60 kg ha⁻¹. Shoot fresh biomass was maximum, at 40 DAS when 120-60 kg P₂O₅-S ha⁻¹ was applied to maize. Shoot dry biomass after 30 days of sowing was highest when 90 kg P₂O₅ was applied with S @ 60 kg ha⁻¹ or when, 120 kg P₂O₅ was used with S @ 40 and 60 kg ha⁻¹. Shoot length was maximum, both at 30 and 40 DAS, in case of using 120-60 kg P₂O₅-S ha⁻¹. Chlorophyll content of maize was maximum, both at 30 and 40 DAS, when 90 kg P₂O₅ was applied with S @ 60 kg ha⁻¹. Maximum fodder yield of maize was noted when 120 kg P₂O₅ was applied with 60 kg S ha⁻¹. Highest P-uptake, both at 30 and 40 DAS was noted when 120 kg P₂O₅ was applied with S @ 60 kg ha⁻¹. At the first stage of growth, S-uptake was highest when 60 kg S was integrated with 90 kg P₂O₅ ha⁻¹. The study advocated integrated application of 120-60 kg P₂O₅-S ha⁻¹ for obtaining economically maximum fodder yield of maize.

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INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops of world (Saeed *et al.*, 2010). The USA is leading

country for area under maize (33079 thousand ha) and its production (392451 thousand tons) followed by China and Brazil. Pakistan produces 6826 thousand tons of

maize on 1374 thousand hectares with an average yield 4968 kg ha⁻¹ (MNFSR, 2021). Maize crop requires plant nutrients in big amounts during different growth stages because of higher biomass, especially that of phosphorus (P) and sulphur (S) (Kovar, 2021; Bekele *et al.*, 2022) which greatly affects yield components and total production (Ye *et al.*, 2011). Phosphorus (P) is vital for the plants owing to its number of essential roles during both the vegetative and reproductive stages. It is mainly absorbed during vegetative stage to support especially root growth and development (Wahid *et al.*, 2015). Later, it is re-translocated to the seeds for reproductive growth (Sharif *et al.*, 2014). Majority (85-90 %) of Pakistani soils are, however, reported P-deficient (Shaheen *et al.*, 2011) and, hence, P fertilization has been considered indispensable to obtain good crop yields and economic returns, including maize (Amanullah *et al.*, 2009). Similarly, sulphur (S) is also as essential as P for crop production (Wani *et al.*, 2010). It is considered essential for protein synthesis and chlorophyll formation, and hence, necessary for attaining the economically optimum yield (Khan *et al.*, 2017). Sulphur acidification is known to enhance P availability under its deficiency (Irum *et al.*, 2019) in alkaline soils. Although S is not frequently used as a fertilizer in Pakistan, high amount of S is required for rapid growth of crops because S is slowly released from soil organic matter (Johnson *et al.*, 1999). Hence, P and S interaction depends on soil fertility status, crop species and the rate of plant nutrients due to their interaction with all essential plant nutrients (Abdin *et al.*, 2003). Strong sulphate bonding has also been noticed due to the interaction of S with P as phosphate ion (Hedge and Murthy, 2005). P fertilization increases phosphate adsorption sites which results in elevated discharge of sulphate ions to soil solution (Tiwari and Gupta, 2006). Soil S deficiency may have bad impacts on the efficiency of applied fertilizers and, therefore, on crop yield (Ahmad, 1994). This study was aimed at understanding the effect of integrated P-S fertilization on the biomass production, fodder yield, and P and S uptake of maize.

MATERIALS AND METHODS

Characteristics of soil under study

The soil under study was clay loam, medium-alkaline (pH: 7.9), non-saline (EC: 0.85 dS m⁻¹), strongly calcareous in reaction (CaCO₃: 24%), adequate in organic matter (1.06 %), low in ABDTPA-P (3.5 mg kg⁻¹), while medium in SO₄-S (21.5 mg kg⁻¹).

Experimental design, treatment details and fertilization

A total of eight varying P and S treatments were involved in this study, i.e., single application of each 90 kg P₂O₅ (T1) and 20 kg S ha⁻¹ (T2); integration of 90 kg P₂O₅ with S @ 20, 40 and 60 kg ha⁻¹ (T3, T4 and T5, respectively), and integration of 120 kg P₂O₅ with S @ 20, 40 and 60 kg ha⁻¹ (T6, T7 and T8, respectively). The experiment followed an RCBD arrangement that was replicated thrice. Half of the nitrogen (N) fertilizer was applied with full P and S fertilizers at sowing. The leftover N fertilizer was given after 15 days of sowing at first irrigation. Nitrogen was applied as urea (46 % N), P as DAP (18 % N, 46 % P₂O₅) and S as sulphuric acid (97 % S).

Sowing and harvesting of maize

The maize (*Cv.* Akbar) was grown in small plots (6m × 4m = 24 m²) @ 95 kg ha⁻¹. Recommended production technology was followed throughout the course of this field experiment, conducted at the Agriculture Research Institute, Tandojam. At day 30 and 40, ten randomly tagged plants were harvested from each experimental unit to record maize growth, biomass production and to determine maize P and S uptake. At day 50, the sub-plots were harvested to record maize fodder yield on kg per square meter basis, multiplied by 10,000 and again divided by 1000 to report yield to ton per hectare.

Soil sampling, processing and analysis

Before the sowing of maize crop, surface (0-15 cm) and sub-surface (15-30 cm) soil samples were collected for physico-chemical analyses. The representative soil layers were dried, ground and stored in the laboratory. Soil analyses of selected parameters were done by following the standard methods suggested by Ryan *et al.* (2001).

Plant sampling, processing and analysis

After 30 and 40 days of maize germination, five plants were collected from each sub-plot for P and S analyses, through acid digestion method by using 1:2 HNO₃:HClO₄ mixture. Shoot P concentration was determined by Vanadomolybdate yellow colour method (Ryan *et al.*, 2001) while shoot S concentration was analyzed by following turbidimetric method (Tabatabai and Bremner, 1970). P and S uptake were calculated by multiplying P and S concentration with dry matter yield, respectively.

Statistical analysis

The data were statistically analyzed by using Statistix ver. 8.1 (Analytical Software, 2020). Treatment means were differentiated using HSD_{0.05}.

RESULTS

Soil physio-chemical properties

The soil under study was clay loam, with medium alkaline pH (7.9) and medium saline (EC: 0.85 dS m⁻¹), strongly calcareous in reaction (CaCO₃: 24 %), adequate in organic matter content (1.6 %), low in ABDTPA-P (3.5 mg kg⁻¹) while medium in SO₄-S (21.5 mg kg⁻¹) content at the upper 0-15 cm layer. It was a silt clay with medium alkaline pH (8.0), medium saline (EC: 1.1 dS m⁻¹), lime content (CaCO₃: 18 %), low ABDTPA-P (2.5 mg kg⁻¹) and medium SO₄-S (13.5 mg kg⁻¹) status, however the organic matter content was medium (1.04 %) at sub-surface layer (15-30 cm).

Biomass accumulation

In general, shoot biomass production was found to be maximum when maize plants received integrated doses of P and S at the higher rates, i.e. 120-60 kg P₂O₅-S ha⁻¹. At 30 DAS, shoot fresh biomass was found maximum, and statistically alike, when 90 or 120 kg P₂O₅ was integrated

with 60 kg S ha⁻¹, followed by the shoot fresh biomass noted when 40 kg S was integrated with 120 kg P₂O₅ ha⁻¹ (Table 1). All other treatments produced lowest shoot fresh biomass and were statistically alike (Table 1). Shoot fresh biomass was highest, at 40 DAS, when 120-60 kg P₂O₅-S ha⁻¹ was applied to maize, followed by the treatment where only 20 kg S was applied without any P₂O₅ integration (Table 1). All other treatments produced lowest and statistically similar shoot fresh biomass at 40 DAS (Table 1). Shoot dry biomass at 30 DAS was highest when 90 kg P₂O₅ was applied with 60 kg S or when 120 kg P₂O₅ was used with 40 and 60 kg S ha⁻¹. It was followed by the treatment receiving only 20 kg S ha⁻¹ without any P₂O₅ integration. All other treatments produced statistically alike and lowest shoot dry weight (Table 1). Shoot dry biomass at 40 DAS was highest when 120 kg P₂O₅ was applied with 60 kg S. All other treatments produced statistically alike and lowest shoot dry weight (Table 1).

Table 1. Phosphorus-sulphur interaction effects on shoot biomass and length of maize shoot.

P ₂ O ₅ - S (kg ha ⁻¹)	Shoot fresh biomass		Shoot dry biomass		shoot length	
	(g plant ⁻¹)		(g plant ⁻¹)		(cm plant ⁻¹)	
	30 DAS	40 DAS	30 DAS	40 DAS	30 DAS	40 DAS
90-00	9.15 bc	15.70 ab	1.96 ab	3.08 ab	41.97 bc	53.27 ab
00-20	8.41c	14.78 b	1.52 b	2.83 b	40.90 c	49.63 b
90-20	9.50 abc	28.14 ab	1.97 ab	5.51 ab	42.43 bc	56.67 ab
90-40	9.33 bc	22.98 ab	2.00 ab	3.79 ab	44.60 ab	55.90 ab
90-60	11.30 a	23.37 ab	2.54 a	4.18 ab	46.20 a	56.27 ab
120-20	9.55 abc	21.51 ab	2.01 ab	4.08 ab	42.00 bc	57.83 ab
120-40	10.42 ab	24.09 ab	2.50 a	4.62 ab	44.60 ab	57.07 ab
120-60	11.28 a	34.59 a	2.52 a	6.20 a	46.23 a	59.90 a

Note: Means followed by same letters are statistically alike at alpha 0.05.

Shoot length of maize

Shoot length was highest, at 30 DAS, in case of using 120-60 kg P₂O₅-S ha⁻¹ followed by the treatments when 90 and 120 kg P₂O₅ each was used with 40 kg S ha⁻¹ (Table 1). Shoot length in case of all other treatments was lowest and statistically similar for all other treatments (Table 1). At 40 DAS, shoot length was maximum in case of same treatment, i.e. 120-60 kg P₂O₅-S ha⁻¹, followed by the treatment when only 20 kg S was applied without

integrating phosphorus while all other treatment produced lowest statistically similar shoot length of maize.

Number of leaves of maize

The analysis of variance revealed that the treatments were non-significantly different for producing number of leaves of maize. None the less, maximum numbers of leaves were recorded in case of 120 kg P₂O₅ integrated with S @ 60 kg ha⁻¹ (Table 2).

Table 2. Phosphorus-sulphur interaction effects on number of leaves, chlorophyll content and fodder yield of maize.

P ₂ O ₅ – S (kg ha ⁻¹)	Number of leave		chlorophyll content		Maize fodder yield (t ha ⁻¹)
	(g plant ⁻¹)		(SPAD)		
	30 DAS	40 DAS	30 DAS	40 DAS	50 DAS
90-00	8.07	5.33	41.97 bc	53.27 ab	5.0 ab
00-20	8.10	5.43	40.90 c	49.63 b	4.3 b
90-20	8.33	6.43	42.43 bc	56.67 ab	6.0 ab
90-40	8.93	6.00	44.60 ab	55.90 ab	5.3 ab
90-60	8.87	6.67	46.20 a	56.27 ab	5.7 ab
120-20	8.33	6.63	42.00 bc	57.83 ab	4.7 ab
120-40	8.13	6.30	44.60 ab	57.07 ab	7.0 a
120-60	9.07	6.77	46.23 a	59.90 a	7.7 a

Note: Means followed by same letters are statistically alike at alpha 0.05.

Chlorophyll content of maize

At both the stages of growth, the chlorophyll content of maize was highest when 90 kg P₂O₅ was applied with S @ 60 kg ha⁻¹ (Table 2). This was followed by the chlorophyll content noted in case of applying 90 and 120 kg P₂O₅ with S @ 40 kg ha⁻¹ at 30 DAS and in case of applying 90 kg P₂O₅ with S @ 40 kg ha⁻¹ at 40 DAS (Table 2).

Fodder yield of maize at 50 days after sowing

Maximum fodder yield of maize was noted when 120 kg P₂O₅ was applied with S @ 60 kg ha⁻¹, followed by the fodder yield noted in case of 120 kg P₂O₅ with S @ 40 kg ha⁻¹, however, both the treatments were statistically alike. All other treatments had statistically similar and lowest fodder maize yield (Table 2).

P uptake of maize at 30 and 40 days after sowing

Highest P-uptake at 30 DAS was noted where 120 kg P₂O₅ was applied with S @ 60 kg ha⁻¹ followed by 120 kg P₂O₅, with S @ 40 kg ha⁻¹. P-uptake noted in case of applying 90 kg P₂O₅ along with 40 or 60 kg S ha⁻¹ was comparatively lower than the treatments, however, higher than all other treatments (Table 3). P-uptake at 40 DAS was highest when 120 kg P₂O₅ was added with S @ 60 kg ha⁻¹ while P-uptake of all other treatment was statistically similar (Table 3).

S uptake of maize after 30 and 40 days after sowing

At 30 DAS, S uptake was highest when 60 kg S was integrated with 90 kg P₂O₅ ha⁻¹, followed by the S uptake noted in case of applying 120 kg P₂O₅ with S @ 60 kg ha⁻¹, while all other treatments were statistically similar (Table 3).

Table 3. Phosphorus-sulphur interaction effects on P and S uptake by maize.

P ₂ O ₅ – S (kg ha ⁻¹)	P uptake		S uptake	
	(ug g ⁻¹)			
	30 DAS	40 DAS	30 DAS	40 DAS
90-00	0.43 bcd	0.50 b	0.58 c	0.41
00-20	0.28 d	0.34 b	0.58 c	0.53
90-20	0.37 cd	0.80 ab	0.68 bc	1.23
90-40	0.47 bc	0.51 b	0.81 bc	0.60
90-60	0.53 abc	0.59 b	1.21 a	1.27
120-20	0.38 bcd	0.48 b	0.73 bc	0.76
120-40	0.55 ab	0.68 b	0.88 abc	0.91
120-60	0.66 a	1.32 a	0.99 ab	0.83

Note: Means followed by same letters are statistically alike at alpha 0.05.

DISCUSSION

The results of this field study highlighted that shoot fresh biomass production at 30 DAS was found maximum when 90 or 120 kg P₂O₅ was integrated with S @ 60 kg ha⁻¹. The importance of S and P in maize nutrition and enhanced P uptake has been established in recently published literature (Irum *et al.*, 2019; Kovar, 2021; Bekele *et al.*, 2022). Shoot fresh biomass was highest, at 40 DAS, when 120-60 kg P₂O₅-S ha⁻¹ was applied. Earlier workers also reported such results, including Gurmani (2006), Imran, (2007), Irfan *et al.* (2015) and Dharwe *et al.* (2019). Likewise, shoot dry biomass after 30 days of sowing was highest when 90 kg P₂O₅ was applied with 60 kg S or when, 120 kg P₂O₅ was used with S @ 40 and 60 kg ha⁻¹. At 40 days of sowing, it was highest when 120 kg P₂O₅ was applied with S @ 60 kg ha⁻¹. This was comparable with the findings of Irfan *et al.* (2015). Likewise, Khan *et al.* (2006) reported increased shoot dry biomass in case of 60 kg S ha⁻¹; beyond 60 kg S ha⁻¹ had no effect on maize biomass. Shoot length was highest, at 30 DAS, in case of using 120-60 kg P₂O₅-S ha⁻¹ followed by the treatments when 90 and 120 kg P₂O₅ each was used with S @ 40 kg ha⁻¹. At 40 DAS, shoot length was maximum in case of same treatment, i.e. 120-60 kg P₂O₅-S ha⁻¹. The maximum chlorophyll content at both stages was found in case of 90 kg P₂O₅ integrated with 60 kg S ha⁻¹. Earlier, Khan *et al.* (2017) reported vitality of S to chlorophyll content. Highest P uptake at 30 DAS was noted where 120 kg P₂O₅ was applied with 60 kg S ha⁻¹ followed by the application of 120 kg P₂O₅, with 40 kg S ha⁻¹. P uptake at 40 DAS was highest when 120 kg P₂O₅ was applied with 60 kg S ha⁻¹. Similar findings were reported by Irfan *et al.* (2015). At 30 DAS, S uptake was highest when 60 kg S was integrated with 90 kg P₂O₅ ha⁻¹, followed by the S uptake noted in case of applying 120 kg P₂O₅ with 60 kg S ha⁻¹. Similar results were noted by Khitabullah and Khan (2018) in wheat and Irfan *et al.* (2015) in maize. Sulphur nutrition has been reported to significantly affect nutrient uptake and biomass accumulation in maize, besides improving maize yield through improved gas exchange characteristics and antioxidant enzymes activity (Usmani *et al.*, 2020). Maximum fodder yield of maize was obtained when 120 and 90 kg P₂O₅ ha⁻¹ was applied with S @ 60 kg ha⁻¹ followed by the fodder yield noted in case of 120 kg P₂O₅ ha⁻¹ with 40 kg S ha⁻¹. This was in line with the findings of Khan *et al.* (2006). According to Irfan *et al.* (2015) P and S @ 120 and 45 kg ha⁻¹, respectively, were useful for increasing maize yield.

CONCLUSION

The study advocated integration of 120-60 kg P₂O₅-S ha⁻¹ for obtaining economically maximum fodder yield of maize.

CONFLICT OF INTEREST

The authors declares that they have no conflict of interest.

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