www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(8): 846-851

www.thepharmajournal.com
Received: 18-05-2023
Accepted: 30-07-2023

PK Patel
Department of Soil Science & Agricultural Chemistry, Anand Agricultural University, Anand, Gujarat, India

NJ Jadav
Professor and Head, Department of Soil Science & Agricultural Chemistry, Anand Agricultural University, Anand, Gujarat, India

VH Kadivala
Department of Soil Science & Agricultural Chemistry, Anand Agricultural University, Anand, Gujarat, India

NB Gohil
Agriculture Experimental Station, Navsari Agricultural University, Paria, Gujarat, India

Corresponding Author:
PK Patel
Department of Soil Science & Agricultural Chemistry, Anand Agricultural University, Anand, Gujarat, India

Direct effects of potassium, sulphur and KSB on growth, yield and quality of direct seeded rice under direct seeded rice-chickpea cropping system

PK Patel, NJ Jadav, VH Kadivala and NB Gohil

Abstract
A field experiment was carried out during *kharif* season for two consecutive years (2020 and 2022) at Regional Research Station, Anand Agricultural University, Anand to assess the direct effects of different rates of applied potassium, sulphur and KSB on growth, yield and quality of direct seeded rice under direct seeded rice-chickpea cropping system. The experimental soil was loamy sand in texture having pH of 8.15. The experiment was arranged in a randomized block design with factorial concept, comprising eighteen treatment combinations *i.e.,* two levels of KSB (0 and1 L ha^{-1}), three levels each of potassium (0, 30 and 60 kg K ha^{-1}) and sulphur (0, 20 and 40 kg S ha^{-1}) with three replications. The results revealed that significantly increased in the grain and stover yield of direct seeded rice was 5.6, 5.7, 5.6 percent and 4.2, 4.3, 4.3 percent with KSB 1 L ha^{-1}, 11.8, 12.3, 12.4 percent and 11.0, 10.6, 10.8 percent with 60 kg K ha^{-1} as well as 13.6, 10.8, 12.2 percent and 10.7, 10.9, 10.8 percent with 40 kg S ha^{-1}over control in 2021, 2022 and in pooled result, respectively. Application of potassium @ 60 kg ha^{-1}, sulphur @ 40 kg ha^{-1} and KSB @ 1 L ha^{-1} recorded significantly higher plant height at 30, 60 DAS and at harvest and effective tillers m^{-1} row length of rice. The conjunctive use of potassium and sulphur significantly improved plant height at 30 and 60 DAS, grain and straw yield.

Keywords: Potassium, sulphur, potash solubilizing bacteria (KSB), yield, quality

Introduction
Crops need many essential nutrients for optimum growth, yield and quality. Every nutrient has a distinct characteristic and participates in a variety of plant metabolic activities. It has been noted that the inconsistent use of fertilizers to Indian soil is contributing to an increase in the lack of plant nutrients. Potassium (K) is the third major essential nutrient elements required by plants. It absorbed by plants in larger amounts than any other nutrients except nitrogen (N). As it is engaged in absorption, transport, storage tissue development, and by enhancing tolerance to various biotic and abiotic stresses, it plays a significant role in enhancing crop growth and production (Cakmak, 2005) [6]. It is a unique element in sense that plants can accumulate it in abundant amounts without exhibiting any toxicity symptoms. This behavior has been described as the luxury consumption (Khan *et al.,* 2007) [10]. Since, potassium is involved in many metabolic pathways that affect crop quality, it is often called as “the quality element” (Ali *et al.* 2019) [2]. It is referred to as a "master cation" because it is a univalent cation and found in the largest concentration in the plant cell sap”.
Sulphur (S) is one of the seventeen essential plant nutrients and ranks fourth major nutrient next to N, P and K because of its crucial role in protein synthesis, vitamins, enzymes, metabolism of carbohydrates, formation of flavor imparting compounds and marketing quality of the produce of several crops (Islam *et al.,* 2016) [8]. Sulphur is often needed by crops in the same quantities as phosphorus and one-tenth of nitrogen. It is one among the primary nutrients necessary for the production of chlorophyll, several amino acids including methionine, cystine, and cysteine, and some plant hormones like biotin and thiamine. (Rahman *et al.,* 2007) [16]. The presence or absence of sulphur affects the accumulation of inorganic nitrogen or organic non-protein nitrogen in the tissue, leaf area, seed number plant^{-1}, floral commencement, and anthesis in plants (Tiwari, 1994) [24]. Sulphur deficit in Indian soils was brought on by the use of sulphur-free fertilizers, highly intensive cropping, and the cultivation of sulphur-responsive plants.
The PGPRs such as Potash Solubilizing Bacteria (KSB) are root colonizing bacteria which can grow in, on/or around plant tissues and enhance plant growth (Meena *et al.,* 2017) [13].

According to Nath *et al.* (2017) [15], the KSBs have the ability to liberate potassium from insoluble minerals and make it available to plants. It has been reported that inoculation with KSB formed positive impact on growth of many plants (Ahmad *et al.*, 2016) [1].

Rice (*Oryza sativa* L.) is the staple food for more than 65% of the people and it provides employment and livelihood security to 70% of Indian population. It continues to hold the key to sustain food production by contributing 20 to 25 percent and assures food security for more than half of the total population. 55% of the nation's entire cereal production is made up of rice. In India, per capita food intake is 2234 calories per day, of which 30% are from rice. India is the largest rice growing country covering an area of about 45.07 million hectares with 122.27 million tonnes in production and 2713 kg ha^{-1} productivity of rice during the year of 2020-21. In Gujarat, rice is cultivated on an area of 906.63 hectares with total production of 2145.7 tonnes per annum and productivity of 2367 kg ha^{-1} during 2020-21 (Anon., 2021) [3]. In several regions of south Gujarat as well as some districts of central Gujarat with access to permanent canal irrigation, this crop is mostly farmed during the *kharif* and summer seasons. It is grown an average about 6.5 to 7.25 lakh hectares of land comprising nearly 55 to 60% low land (Transplanted) and 40 to 45% of upland (Drilled) rice. Direct seeded rice (DSR) is one such technique for growing rice with limited water supply, labor requirement and optimum nutrients. When planted by direct seeding under aerobic conditions, rice develops more quickly and matures earlier (Rehman *et al.*, 2011) [20]. Direct seeded rice (DSR) has the potential to save up to 50% irrigation water requirement of rice (Kumar *et al.*, 2017) [11]. It has become a boon for farmers.

Materials and Methods

A field experiment was carried out for two years during 2021 and 2022 in *kharif* season at Regional Research Station, AAU, Anand (Gujarat) to study the direct effect of potassium, sulphur and KSB on growth, yield and quality of direct seeded rice under direct seeded rice -chickpea cropping system. The soil of experimental field was loamy sand in texture, alkaline (pH 8.15) in reaction, low in organic carbon (4.2 g kg^{-1}), available nitrogen (219.52 kg ha^{-1}) and sulphur (9.50 mg kg^{-1}) while, available phosphorus (57.33 kg ha^{-1}) was high and available potassium (217.7 kg ha^{-1}) was medium in status. The experiment was arranged in a factorial randomized block design with eighteen treatment combinations and replicated three times. It consists of two levels of KSB *viz.* 0 and 1 L ha^{-1}, three levels of potassium *viz.* 0, 30 and 60 kg K_2O ha^{-1} applied as Muriate of potash and three levels of sulphur *viz.* 0, 20 and 40 kg S ha^{-1} applied as Bentonite sulphur. The full dose of nitrogen (80 kg ha^{-1}) and P_2O_5 (40 kg ha^{-1}) were added through urea and DAP as basal application in each plot of rice. The treatment wise sulphur and potassium were applied through bentonite sulphur and muriate of potash, respectively as basal. The crop was drilled at 20 cm raw to raw spacing. The crop was grown using with standard package of practices. Crop was harvested at maturity and plot wise yield attributes, grain and straw yield were recorded. The crude protein content in the grain was determined by multiplying nitrogen content (%) of grain with the conversion factor of 6.25 as reported by Gupta *et al.* (1973) [7].

Table 1: Initial soil properties of experimental site

Sr. No.	Particular	Initial value
1.	Textural class	Loamy sand
2.	pH (1:2.5 soil: water)	8.15
3.	EC (dS m^{-1}) (1:2.5 soil: water)	0.17
4.	Organic carbon (g kg^{-1})	4.2
5.	CEC (meq/100 g)	10.35
6.	Available N (kg ha^{-1})	219.52
7.	Available P_2O_5 (kg ha^{-1})	57.33
8.	Available K_2O (kg ha^{-1})	217.7
9.	Available S (mg kg^{-1})	9.50

Results and Discussion

Effect of KSB on growth, yield and quality

The data presented in Table 2 suggested that plant population of rice at harvest was not significantly affected by KSB in both the individual years as well as in pooled result. KSB application had significant effect on plant height of rice at 30 and 60 DAS. Significantly higher plant height of rice at 30 DAS *i.e.*, 51.66, 52.65 and 52.16 cm and 60 DAS *i.e.*, 64.67, 65.26 and 64.96 cm were noed under the treatment with KSB 1 L ha^{-1} as compared to without KSB during 2021, 2022 and in pooled, respectively. Plant height at 30 and 60 DAS under KSB treatment was significantly maximum due to the fact that biofertilizers like KSB when applied to soil, colonize the rhizosphere and encourage growth by converting nutritionally important elements specifically potassium from unavailable to available forms and also increased enormous amount of microbial load which when applied to soil, multiply in the soil and plants under such management put forth better plant growth which in turn promoting the increased plant height. The conformity of finding also reported by Bakhshandeh *et al.* (2017) [4] in rice. Plant height at harvest was found non-significant during both the years and significant in pooled basis.

A perusal of data (Table 2) discovered that different levels of KSB application did not show any significant variation on panicle length and test weight of rice in both the years as well as in pooled analysis. An assessment of the results presented in Table 3 revealed that application of KSB was significantly influenced on the effective tillers m^{-1} row length and non-significant effect on non-effective tillers m^{-1} row length of rice at harvest in both the years and in pooled result. Significantly maximum number of effective tillers m^{-1} row length at harvest was recorded with the application of KSB 1 L ha^{-1} in 2021 (149), 2022 (147) as well as in pooled basis (148) results than without KSB application. This might be due to that response of KSB may be ascribed to solubilization of K from soil because of excretion of organic acids by the bacterial strains, thereby enhanced plant growth and tillers. Similar outcome was also reported by Savaliya *et al.* (2017) [21] in Wheat.

The data presented in Table 3 explicit that No. of seed panicle^{-1} and crude protein content of rice did not show any significant effect due to KSB application during both the years and pooled basis. Table 3 displays the yields of rice grains and straw as affected by various treatments. The results implicit that differences due to application of KSB with respect to grain yield and straw yield were found significant in both the years as well as in pooled analysis. The application of KSB 1 L ha^{-1} to rice crop recorded significantly higher grain yield (4060, 4008 and 4034 kg ha^{-1}) and straw yield

(6060, 6102 and 6181 kg ha^{-1}) during 2021, 2022 and in pooled results, respectively. The magnitude of increased in grain yield was 5.6, 5.7 and 5.6 percent and straw yield was 4.2, 4.3 and 4.3 percent as compared to control in 2021, 2022 and in pooled basis, respectively. This may be because of KSB are excellent in releasing K from inorganic and insoluble pools of total soil K through solubilization. It has been stated that inoculation with KSB produced positive effect on growth of different plants (Bakhshandeh *et al.,* 2017) [4], this might be due to the improvement in soil chemical properties and nutritional status, and increased microbial activity in the root zone because of the integrated effects of KSB strains with K fertilization. Certain growth-promoting chemicals released by the KSB may have contributed to improved root and shoot growth as well as improved water and nutrient absorption and deposition. The conformity of finding also reported by Kumar and Mehera (2022) [12] in maize.

Effect of potassium on growth, yield and quality

The result pertaining in Table 2 showed that different levels of potassium did not produce any significant differences on plant population at harvest of rice in 2021, 2022 and pooled analysis. Data given in Table 2 showed that application of potassium @ 60 kg ha^{-1} exerted a significant effect on plant height of rice at 30, 60 DAS and at harvest during both the years as well as in pooled result. Significantly the highest plant height at 30 DAS (53.91, 54.53 and 54.22 cm), 60 DAS (67.46, 67.16 and 67.31 cm) and at harvest (107.33, 108.70 and 108.02 cm) were observed with application of 60 kg K ha^{-1} during 2021, 2022 and in pooled, respectively. The beneficial effect of potassium on plant height at all growing stages may be due to in conjunction with specific enzymes and plant growth hormones, potassium is essential in transport of water and nutrients throughout the plant in the xylem, and transport of photosynthates to the phloem to other parts of plants for utilization and storage. Higher nutrient uptake led to enhanced cell division and elongation, which in turn led to increased meristematic cell activity and internode cell lengthening, which in turn contributed to a higher rate of stem development and encouraged the increased plant height of rice. Similar kinds of results were also reported by Vijayakumar *et al.* (2019) [26] in direct seeded basmati rice.

Panicle length and test weight of rice were not significantly influenced by various levels of potassium during both the years and pooled basis. Significantly the highest number of effective tillers m^{-1} row length *i.e.,* 151, 152 and 151 at harvest were observed in treatment K_{60} (60 kg K ha^{-1}) in 2021, 2022 and in pooled analysis, respectively. The beneficial effect of potassium application might be due to potassium fertilization ensures proper root growth and uptake of other nutrients like N, P and S, which ultimately increased the crop growth and development. Due to K-mediated carbohydrate metabolism, increased potassium rate aids in the production of large amounts of starch. Besides, it helps in efficient translocation of photo-assimilates to the developing tillers and enables the plants to utilize fully applied N and P fertilizers. It promotes the development of strong cell walls and therefore stiffer straw which might be resulted into excessive tillering. These results are in close harmony to Birla *et al.* (2020) [5] in rice.

The data presented in Table 3 indicated that various levels of potassium application had no any significant influence on non effective tillers m^{-1} row length, No. of seed $panicle^{-1}$ and crude protein content of rice at harvest during 2021, 2022 and in pooled result. The graded levels of potassium applied to rice significantly increased the grain and straw yield. The application of 60 kg K ha^{-1} noted 11.8, 12.3 and 12.4 percent higher grain yield as compared to control in both the years as well as in pooled basis, respectively. The increased in grain yield with K fertilization might be due to the fact that K nutrient is important for plant nutrition, in many physiological and metabolic processes, including photosynthesis, osmoregulation, transport of photosynthate and sucrose content within plant tissues, transport and storage of carbohydrates. Potassium increases root growth and facilitates photo-assimilates. Additionally, potassium is crucial for plant activities such nutrient uptake and translocation, enzyme activation, protein, cellulose, and starch synthesis, which improves crop growth, yield, and quality. The present result is in close promise with the result obtained by Kalita *et al.* (2002) [9] and Uddin *et al.* (2013) [25] in direct seeded rice. The results discovered that significantly the highest straw yield (6293, 6324 and 6309 kg ha^{-1}, respectively) was noticed under treatment K_{60} (60 kg K ha^{-1}) in 2021, 2022 and in pooled base results over control. The improvement in straw yield of rice was tune of 11.0, 10.6 and 10.8 percent observed under K_{60} over control in 2021, 2022 and in pooled analysis, respectively. The positive effect of potassium on straw yield may be attributed to its low availability in experimental soils. Potassium helps in the resistance to crops against pests and diseases, reduce lodging of crops and enhances their winter-hardiness which in turn, increased the yield. Additionally, it facilitates the efficient translocation of photo-assimilates to the developing sinks. In rice, increased K fertilizer application levels increased total biomass production, which can be attributed to K's role in transpiration, osmoregulation, stomatal regulation (Raza *et al.,* 2014) [19], cell elongation, and higher nutrient uptake. These factors led to higher plant height and a greater number of tillers per square meter, which in turn contributed to higher straw yield. Our results confirm the finding of Wakeel *et al.* (2017) [27] in aerobic rice.

Effect of sulphur on growth, yield and quality

Glance of data offered in Table 2 explicit that application of different levels of sulphur found non-significant effect on plant population, panicle length and test weight at harvest of rice during both the years as well as in pooled analysis. The data given in Table 2 implicit that during both the years of experiment and in pooled analysis, application of sulphur @ 40 kg ha^{-1} significantly increased plant height of rice at 30 DAS, 60 DAS and at harvest compared to control. Application of 40 kg S ha^{-1} obtained significantly higher plant height at 30 DAS (52.95, 53.86 and 53.41 cm), 60 DAS (66.23, 66.93 and 66.58 cm) and at harvest (103.70, 104.56 and 104.13 cm) which was remained at par with treatment 20 kg S ha^{-1} in 2021, 2022 and pooled basis, respectively. The considerable increased in plant height at 30, 60 and at harvest might be due to the fact that sulphur application enhanced over all nutritional environment of the rhizosphere as well as plant system which could be more advantageous for abundant vegetative and root growth which activated higher absorption of nutrients from the soil and improved metabolic activities inside the plant by playing significant role in enzymatic process including photosynthesis and respiration activities. Similar results were also reported by Rahman *et al.* (2008) [17] in rice. The application of 40 kg S ha^{-1}produced significantly higher number of effective tillers m^{-1} row length *i.e.,* 147, 147 and 147 at harvest, but remained at par with treatment 20 kg S ha^{-1} in 2021, 2022 and pooled analysis, respectively. This may be due tillering is the result of developing auxiliary buds and is strongly related to the mother culm's nutritional status during its early growth phase, which gets improved by the application of sulphur. The results consistency was also linked to Ram *et al.* (2014) [18] in aerobic rice.

The data showed in Table 3 revealed that various levels of sulphur application had no any significant influence on non effective tillers m^{-1} row length, No. of seed panicle^{-1} and crude protein content of rice at harvest during 2021, 2022 and in pooled result. Application of 40 kg S ha^{-1} recorded significantly higher grain yield (4171, 4071 and 4121 kg ha^{-1}) in 2021, 2022 and pooled basis as compared to control, being on par with 20 kg S ha^{-1}. The increased in grain yield under 40 kg S ha^{-1} was to the tune of 13.6, 10.8 and 12.2 percent over control in 2021, 2022 and pooled basis. The increased in yield was mainly due to enhanced rate of photosynthesis, carbohydrate metabolism, energy transformation and activation of enzymes as influenced by sulphur application. Application of sulphur provides better condition for the development of crop due to improved physico-chemical properties of soil, better nutrients uptake and growth by crops. These results were enclosed conformity with the finding of Ram *et al.* (2014) [18] in aerobic rice. Significantly higher straw yield *i.e.*, 6199, 6245 and 6222 kg ha^{-1} was recorded under 40 kg S ha^{-1}application as compared to control, being at par with 20 kg S ha^{-1} during 2021, 2022 and pooled results, respectively. This might be due to that sulphur improved the nutritional environment, favorably influenced the carbohydrate metabolism, cell division, cell enlargement and elongation resulting in overall improvement in plant organs associated with faster and uniform vegetative growth of the crop resulting in higher straw yield. Our results confirm the finding of Singh *et al.* (2017) [23] in rice

Table 2: Direct effect of potassium, sulphur and KSB on growth parameters of direct seeded rice in direct seeded rice chickpea cropping system

Treatments	Plant population m^{-1} row length			Plant height (cm) at 30 DAS			Plant height (cm) at 60 DAS			Plant height (cm) at harvest			Panicle length (cm)			Test weight (g)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Levels of KSB (L ha^{-1})																		
KSB_0	15.11	15.15	15.13	49.77	50.43	50.10	62.23	61.79	62.01	97.79	98.86	98.33	21.73	21.68	21.71	16.39	16.46	16.43
KSB_1	15.25	15.36	15.30	51.66	52.65	52.16	64.67	65.26	64.96	101.56	102.60	102.08	21.90	22.19	22.04	16.54	16.64	16.59
S.Em. ±	0.13	0.12	0.09	0.55	0.42	0.41	0.77	0.70	0.51	1.69	1.46	1.09	0.38	0.39	0.27	0.26	0.31	0.19
C. D. at 5%	NS	NS	NS	1.59	1.22	1.15	2.22	2.03	1.45	NS	NS	3.09	NS	NS	NS	NS	NS	NS
Levels of Potassium (kg ha^{-1})																		
K_0	15.05	15.12	15.09	48.57	49.52	49.05	60.92	60.75	60.83	91.09	91.16	91.12	21.17	21.30	21.23	16.42	16.39	16.40
K_{30}	15.16	15.26	15.21	49.66	50.57	50.12	61.97	62.67	62.32	100.61	102.33	101.47	21.90	22.13	22.01	16.46	16.50	16.48
K_{60}	15.32	15.38	15.35	53.91	54.53	54.22	67.46	67.16	67.31	107.33	108.70	108.02	22.39	22.39	22.39	16.52	16.76	16.64
S.Em. ±	0.16	0.15	0.11	0.68	0.52	0.50	0.94	0.86	0.63	2.07	1.79	1.34	0.47	0.48	0.33	0.32	0.37	0.24
C. D. at 5%	NS	NS	NS	1.95	1.50	1.42	2.72	2.49	1.78	5.97	5.17	3.79	NS	NS	NS	NS	NS	NS
Levels of Sulphur (kg ha^{-1})																		
S_0	14.99	15.21	15.10	47.06	47.85	47.46	58.73	59.42	59.07	95.67	98.09	96.88	21.27	21.53	21.40	16.43	16.50	16.47
S_{20}	15.16	15.25	15.21	52.13	52.91	52.52	65.39	64.45	64.82	99.65	99.54	99.60	22.06	22.06	22.05	16.44	16.54	16.49
S_{40}	15.37	15.31	15.34	52.95	53.86	53.41	66.23	66.93	66.58	103.70	104.56	104.13	22.13	22.23	22.23	16.54	16.60	16.57
S.Em. ±	0.16	0.15	0.11	0.68	0.52	0.50	0.94	0.86	0.63	2.07	1.79	1.34	0.47	0.48	0.48	0.32	0.37	0.24
C. D. at 5%	NS	NS	NS	1.95	1.50	1.42	2.72	2.49	1.78	5.97	5.17	3.79	NS	NS	NS	NS	NS	NS
Significant interaction	-	-	-	K×S	K×S	K×S	K×S	K×S	K×S	-	-	-	-	-	-	-	-	-
CV%	4.51	4.34	4.36	5.69	4.30	5.91	6.33	5.79	5.99	8.84	7.57	8.05	9.25	9.44	9.14	8.40	9.73	8.84

Table 3: Direct effect of potassium, sulphur and KSB on growth, yield and quality of direct seeded rice in direct seeded rice chickpea cropping system

Treatments	Effective tillers m^{-1} row length			Non effective tillers m^{-1} row length			No. of seed panicle^{-1}			Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Crude protein (%)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Levels of KSB (L ha^{-1})																		
KSB_0	139	142	141	23.83	23.21	23.52	252	254	253	3845	3793	3819	5815	5847	5831	8.21	8.39	8.30
KSB_1	149	147	148	24.00	23.95	23.97	257	260	259	4060	4008	4034	6060	6102	6081	8.38	8.49	8.44
S.Em. ±	1.21	1.20	0.87	0.32	0.26	0.22	3.95	5.11	3.26	57.85	58.10	40.01	85	83	59	0.08	0.07	0.05
C. D. at 5%	3.50	3.45	2.46	NS	NS	NS	NS	NS	NS	166	167	112	244	239	166	NS	NS	NS
Levels of Potassium (kg ha^{-1})																		
K_0	138	138	138	23.62	23.09	23.53	251	251	251	3753	3695	3715	5667	5718	5692	8.17	8.30	8.23
K_{30}	142	144	143	23.74	23.53	23.63	252	256	254	3923	3856	3889	5852	5881	5867	8.31	8.48	8.40
K_{60}	151	152	151	24.37	24.13	24.25	262	264	262	4199	4150	4175	6293	6324	6309	8.41	8.54	8.48
S.Em. ±	1.49	1.47	1.06	0.39	0.33	0.27	4.84	6.26	3.99	70.85	71.16	49.00	104	102	72	0.10	0.09	0.06
C. D. at 5%	4.29	4.22	3.01	NS	NS	NS	NS	NS	NS	203	204	138	299	293	203	NS	NS	NS
Levels of Sulphur (kg ha^{-1})																		
S_0	141	142	142	23.62	23.34	23.48	250	250	250	3671	3674	3673	5600	5630	5615	8.14	8.37	8.26
S_{20}	143	144	144	23.89	23.60	23.74	256	258	257	4015	3957	3986	6013	6048	6030	8.35	8.40	8.37
S_{40}	147	147	147	24.22	23.81	24.02	259	263	261	4171	4071	4121	6199	6245	6222	8.40	8.55	8.48
S.Em. ±	1.49	1.47	0.06	0.39	0.33	0.27	4.84	6.26	3.99	70.85	71.16	49.00	104	102	72	0.10	0.09	0.06
C. D. at 5%	4.29	4.22	3.01	NS	NS	NS	NS	NS	NS	203	204	138	299	293	203	NS	NS	NS
Significant interaction	-	-	-	-	-	-	-	-	-	K×S	K×S	K×S	K×S	K×S	K×S	-	-	-
CV%	4.40	4.31	4.44	6.97	5.94	6.82	8.07	10.33	9.36	7.60	7.74	7.48	7.45	7.24	7.27	5.25	4.79	5.00

Interaction effect

The data showed in Table 2 revealed that interaction between potassium and sulphur on plant height of rice at 30 and 60 DAS was found significant in both the years as well as in pooled analysis. Significantly higher plant height was recorded with $K_{60}S_{40}$ (K @ 60 kg ha^{-1} + S @ 40 kg ha^{-1}) treatment combination in 2021, 2022 and in pooled basis. This may be due to the fact that potassium and sulphur application increased the concentration of nutrients in the rhizosphere, improved nutrient mobilization and nutrient uptake, which led to greater cell division and elongation. This increased activity of meristematic cells and cell elongation of internodes resulted in a higher growth rate of stem, which in turn encouraged the increased plant height. Similar trends of results were also reported by Singh *et al.* (2015) [22] in rice. The interaction effect of application of potassium and sulphur (K×S) was significantly influenced grain and straw yield of rice in both the years of investigation as well as in pooled analysis (Table 3). Combined application of potassium and sulphur increased grain and straw yield may be because of potassium has role is unloading sugars from chloroplasts to phloem cells, and from phloem cells into storage cells such as grains. The role of sulphur in energy conversion and enzyme activation also improved the nutritional environment and positively impacted carbohydrate metabolism. Potassium and sulphur has important role in carbon assimilation, starch formation, cell division, photosynthetic process and formation of chlorophyll in the leaf resulting in increasing in positive effect on growth parameter like plant height and tillers. This finding is supported by Muthukumararaja *et al.* (2010) [14] in rice.

Conclusion

On the basis of two years of experimentation, it can be concluded that for obtaining higher growth, yield, quality, *kharif* direct seeded rice crop should be fertilized with KSB 1 L ha^{-1}, 60 kg K ha^{-1} and 20 kg S ha^{-1} besides application of 80 kg N and 40 kg P_2O_5 ha^{-1}.

References

1. Ahmad M, Nadeem SM, Naveed M, Zahir ZA. Potassium-solubilizing bacteria and their application in agriculture. Springer India, New Delhi; c2016. p. 293-313.
2. Ali I, Khan AA, Munsif F, He L, Khan A, Ullah S, *et al*. Optimizing rates and application time of potassium fertilizer for improving growth, grain nutrients content and yield of wheat crop. Open Agriculture. 2019;4(1):500-508.
3. Anonymus. Government of India, Ministry of Agriculture, Department of Agriculture and cooperation, Directorate of Economics and Statistics, 2021.
4. Bakhshandeh E, Pirdashti H, Lendeh KS. Phosphate and potassium-solubilizing bacteria effect on the growth of rice. Ecological Engineering. 2017;103:164-169.
5. Birla V, Vyas MD, Dubey M, Waskle U, Mandre BK. Effect of different doses of potassium on growth, yield attributing characters of rice in vertisol soil of Madhya Pradesh, India. International Journal of Current Microbiology and Applied Sciences. 2020;9(3):2629-2642.
6. Cakmak. Effect of N, P and K levels on yield, nutrient content, uptake and quality of summer groundnut grown on typic haplustepts. Journal of the Indian Society of Soil Science. 2005;53(1):125-128.
7. Gupta BR, Pathak RK, Bhan S, Singh A. Effect of NPK on yield, nutrient and quality of toria (*Brassica camperstris* vartoria.). Indian Journal of Agronomy. 1973;17:88-91.
8. Islam AS, Rana MS, Rahman MM, Mian MJA, Rahman MM, Rahman MA, *et al*. Growth, yield and nutrient uptake capacity of rice under different sulphur levels. Turkish Journal of Agriculture-Food Science and Technology. 2016;4(7):557-565.
9. Kalita U, Suhrawardy J, Das JR. Effect of seed priming with potassium salt and potassium levels on growth and yield of direct seeded summer rice under rainfed upland condition. Indian Journal of Hill Farming. 2002;15(1):50-53.
10. Khan R, Gurmani AR, Gurmani AH, Zia MS. Effect of potassium application on crop yields under wheat-rice system. Sarhad Journal of Agriculture. 2007;23(2):277-280.
11. Kumar A, Nayak AK, Pani DR, Das BS. Physiological and morphological responses of four different rice cultivars to soil water potential-based deficit irrigation management strategies. Field Crops Research. 2017;205:78-94.
12. Kumar KV, Mehera B. Effect of bio-fertilizers and potassium on growth and yield of maize (*Zea mays* L.). The Pharma Innovation Journal. 2022;11(3):2348-2351.
13. Meena VS, Meena SK, Verma JP, Kumar A, Aeron A, Mishra PK, *et al*. Plant beneficial rhizospheric microorganism (PBRM) strategies to improve nutrients use efficiency: A review. Ecological Engineering. 2017;10(7):8-32.
14. Muthukumararaja T, Sriramchandrasekharan MV, Ravichandran M. Studies on the effect of sulphur and potassium on the growth and yield of rice. Advances in Plant Sciences. 2010;23(2):633-635.
15. Nath D, Maurya BR, Meena VS. Documentation of five potassium and phosphorus solubilizing bacteria for their K and P-solubilization ability from various minerals. International Society of Biocatalysis and Agricultural Biotechnology. 2017;10:174-181.
16. Rahman MN, Islam MB, Sayem SM, Rahman MA, Masud MM. Effect of different rates of sulphur on the yield and yield attributes of rice in old Brahmaputra floodplain soil. Journal of Soil and Nature. 2007;1(1):22-26.
17. Rahman MT, Jahiruddin M, Humauan MR, Alam MJ, Khan AA. Effect of sulphur and zinc on growth, yield and nutrient uptake of boro rice (cv. BRRI DHAN 29). Journal of Soil and Nature. 2008;2(3):10-15.
18. Ram A, Kumar D, Singh N, Anand A. Effect of sulphur on growth, productivity and economics of aerobic rice (*Oryza sativa* L.). Indian Journal of Agronomy. 2014;59(3):404-409.
19. Raza MAS, Saleem MF, Shah GM, Khan IH, Raza A. Exogenous application of glycine betaine and potassium for improving water relations and grain yield of wheat under drought. Journal of Soil Science and Plant Nutrition. 2014;14:348-364.
20. Rehman H, Basra, SMA, Farooq A, Ahmed N, Afzal I. Seed priming with $CaCl_2$ improves the stand establishment, yield and quality attributes in direct seeded rice (*Oryza sativa* L.). International Journal of Agriculture Biology. 2011;13:786-790.

21. Savaliya NV, Mathukia RK, Solanki JN, Barasiya RA. Response of wheat (*Triticum aestivum* L.) to phosphate and potash solubilizing bacteria on calcareous clayey soil. International Journal of Pure and Applied Bioscience. 2017;5(6):247-251.
22. Singh D, Singh R, Kumar A. Response of transplanted rice (*Oryza sativa* L.) to potassium and sulphur application with and without green manuring. Environment & Ecology. 2015;30(2):276-280.
23. Singh V, Raghuvansi N, Singh AK, Kumar V, Yadav RA. Response of zinc and sulphur on growth and yield of rice (*Oryza sativa* L.) undersodic soil. International Journal of Current Microbiology and Applied Sciences. 2017;6(8):1870-1879.
24. Tiwari RJ. Response of gypsum on morpho physiochemical properties of cotton cultivars under salt affected vertisols of Madhya Pradesh. Crop Research. 1994;7:197-200.
25. Uddin S, Sarkar MAR, Rahman MM. Effect of nitrogen and potassium on yield of dry direct seeded rice cv. NERICA 1 in aus season. International Journal of Agronomy and Plant Production. 2013;4(1):69-75.
26. Vijayakumar S, Kumar D, Sharma VK, Shivay YS, Anand A, Saravanane P, *et al*. Potassium fertilization to augment growth, yield attributes and yield of dry direct seeded basmati rice (*Oryza sativa* L.). Indian Journal of Agricultural Sciences. 2019;89(11):164-168.
27. Wakeel A, Rehman HU, Mubarak MU, Dar AI, Farooq M. Potash use in aerobic production system for basmati rice may expand its adaptability as an alternative to flooded rice production system. Journal of Soil Science and Plant Nutrition. 2017;17(2):398-409.