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

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Abstract
A field experiment was directed at Regional Research Station, Anand Agricultural University, Anand during two consecutive *kharif* and *rabi* seasons of the year 2020-21 and 2022-23 to assess the direct and residual effects of different rates of applied potassium, sulphur and KSB on growth, yield and quality of direct seeded rice-chickpea cropping system. The experimental soil was loamy sand in texture having pH of 8.15. The experiment was set up as a randomized block design with a factorial approach, with three replications and eighteen treatment combinations, including two levels of KSB (0 and 1 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}). The *kharif* rice was fertilized as per different treatment combinations and its residual effect was studied on *rabi* chickpea. The results revealed that seed and haulm yield of succeeding chickpea increased significantly by 5.0, 6.3, 5.7 percent and 5.4, 5.8, 5.6 percent with KSB 1 L ha^{-1}, 11.6, 11.8, 11.7 percent and 7.7, 9.3, 8.5 percent with 60 kg K ha^{-1} as well as 15.2, 13.4, 14.3 percent and 9.5, 10.9, 10.2 percent with 40 kg S ha^{-1} applied to preceding rice crop over control. Application of potassium, sulphur and KSB had significant residual effect on plant height, No. of pods $plant^{-1}$ and crude protein content of chickpea. Interaction of potassium and sulphur having $K_{60}S_{40}$ treatment combination found their significant effects on seed yield and haulm yield.

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

Introduction
For optimum growth, productivity and quality, crops require a variety of essential nutrients. Each nutrient has a unique quality and takes part in a range of metabolic processes in plants. Due to the irregular application of fertilizers, it has been noted that the soil in India is becoming increasingly deficient in plant nutrients. Potassium (K) is the third macro-nutrient required by the crop plants and it is important for growth and development as well as providing resilience to biotic and abiotic stresses. Potassium is a significant macro element that is extensively absorbed from the soil and used in respiration, photosynthesis, chlorophyll synthesis, water management, and as a catalyst (Sahai, 2004) [13]. It also has a synergistic effect with nitrogen and phosphorus. Potassium mainly effects the nodulation of pulse crop thus increases ·the seed yield through improving nitrogen fixation. It is established that potassium is essential for N and carbohydrate metabolism, activation of several enzymes and the regulation of stomatal movement and water relations (Boyer & Stout, 1959) [3]. Potassium is the utmost importance for water status of plant meristematic tissues, helps the plant fight pests and diseases and controls enzymatic activities and the transfer of photosynthates (Mengel and Kirkby, 1987) [10]. Additionally, the use of K along with other elements had a beneficial effect on the crop production. The various levels of K with sulphur lead to maximum crop growth.

In countries such as India, extremely worried with increasing of food production, sulfur is one element that must not be overlooked". Sulphur deficiency is a common problem in Indian soils, and reports of more areas found deficient in sulfur are being proclaimed regularly. Widespread sulphur deficiency is being brought on by recent trends towards the use of high analysis fertilizers with little to no sulphur content, intense cropping, reduced use of pesticides and fungicides that contain sulphur, and decreased use of organic manures. Sulphur, the fourth most important nutrient for plants after N, P, and K, is a component of the 3 amino acids like methionine, cysteine, and cystine and is crucial for the growth and development of plants. Sulphur is also necessary for the synthesis of other metabolites such as co-enzyme A, biotin, thiamin (Vitamin B1) and glutathione, besides its role in the synthesis of chlorophyll and improves nodulation in legumes (Tisdale *et al.*, 2002) [15].

Pulses and oilseed crops have the highest sulphur needs and benefits from sulphur fertilization, while cereals have the lowest needs and benefits (Singh, 2001) [14]. Due to continuous use of high-grade S free fertilizers and intensive cropping, its deficiency has been found as hidden hunger in many crops, particularly pulses.

Chickpea (*Cicer arietinum* L.) is a vital pulse crop grown and consumed all over the world. It is a good source of both protein and carbohydrates, and its protein is thought to be of higher quality than that of other pulses. Chickpea has significant amount of all the crucial amino acids excluding sulphur containing types, which can be supplemented by adding cereals to daily diet. Starch is the major storage carbohydrate followed by dietary fiber, oligosaccharides and simple sugars like glucose and sucrose. Important vitamins like riboflavin, niacin, thiamine, folate, and the vitamin A precursor, β-carotene, can all be found in chickpeas. In India, chickpea covering an area of about 9.85 million ha with the production and productivity of 11.99 million tonnes and 1217 kg ha^{-1}, respectively during the year of 2020-21 (Anon., 2021) [2]. In Gujarat, chickpea is grown in an area of 0.82 million hectare producing 1.28 million tonnes with the productivity of 1568 kg ha^{-1} (Anon., 2021) [2].

Materials and Methods

A field experiment entitled, "Residual effects of potassium, sulphur and KSB on growth, yield and quality of chickpea under direct seeded rice-chickpea cropping system" was carried out during 2021-22 and 2022-23 in *rabi* season at Regional Research Station, AAU, Anand (Gujarat). The texture of the soil of experimental field was loamy sand. It is suitable for variety of crops of tropical and sub-tropical regions. The soil of experimental site had 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 18 treatment combinations and replicated three times. There were 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 in rice crop only and residual effect was studied on chickpea crop var. GJG 3. The full dose of nitrogen (80 kg ha^{-1}) and P_2O_5 (40 kg ha^{-1}) were also added through urea and DAP as basal application in each plot of rice. After harvesting of rice, chickpea was sown in the same plots without disturbing the layout. Chickpea was sown in the second week of November using seed rate of 60 kg ha^{-1} at a row spacing of 30 cm. Only recommended dose of N (20 kg ha^{-1}) and P (40 kg P_2O_5 ha^{-1}) were applied through urea and diammonium phosphate, respectively to succeeding chickpea crop.

The crop was raised with recommended package of practices. Both the crops were harvested at maturity and plot wise yield attributes, seed and haulm yield were recorded. The crude protein content in the seed was calculated by multiplying nitrogen content (%) of seed with the conversion factor of 6.25 as reported by Gupta *et al.* (1973) [5]. The data of various parameters were statistically analyzed using analysis of variance (ANOVA) technique and the treatments were compared at 5% levels of significance (Panse and sukhatme, 1985) [11].

Results and Discussion

Residual effect of KSB on growth, yield and quality

The results presented in Table 1 revealed that plant population, plant height at 30, 60 DAS and at harvest, dry weight of root nodules and No. of branches $plant^{-1}$ of chickpea were no any significant influenced by residual effect of KSB application in the individual year as well as in pooled basis. KSB application had residual significant effect on the No. of pods $plant^{-1}$ in second year and in pooled basis results, but it was not differed significantly in first year. The treatment KSB @ 1 L ha^{-1} recorded significantly higher No. of pods $plant^{-1}$ (49.21, 48.70) in chickpea in 2022-23 and in pooled basis, respectively. An examination of results summarized in Table 2 revealed that application of KSB to rice crop was failed to give residual significant influence on seed index and crude protein content of chickpea in both the years as well as in pooled analysis.

Significantly higher seed yield (2382, 2407 and 2395 kg ha^{-1}) and haulm yield (3587, 3595 and 3591 kg ha^{-1}) of chickpea was recorded under KSB 1 L ha^{-1} application during 2021-22, 2022-23 and in pooled basis, respectively over control. The increased in yield might be due to potassium solubilizing bacteria can recover soil fertility and plant growth as biofertilizers by decomposing insoluble silicate minerals and releasing insoluble K into soluble forms. Efficient KSB have been stated to increase potassium uptake in plants leading to plant growth and yield. The results were resembled with findings of Patel *et al*. (2021) [12] in wheat.

Residual effect of potassium on growth, yield and quality

The data given in Table 1 and 2 expressed that residual effect of potassium application did not exert any imperial impact on plant population and seed index of succeeding chickpea crop at harvest during both the years and in pooled results. Residual effect of potassium did not produce significant influence on plant height at 30 DAS, dry weight of root nodules and No. branches $plant^{-1}$ of chickpea during both the years but, produced significant effect in pooled results. The treatment K_{60} (60 kg K ha^{-1}) was recorded significantly the highest plant height at 60 DAS (44.67, 46.30 and 45.49 cm) and at harvest (57.48, 57.42 and 57.45 cm) in 2021-22, 2022-23 and on the basis of pooled data, respectively. This might be due to that during the crop growth period it enhances plant vigour, strengthens stalk, affect the cell division and cell elongation which impact on the vegetative growth and resulted in increased plant height. Similar trend of result was also reported by Kumar and Hiremath (2015) [7] in maize-chickpea.

The magnitude of increased in No. of pods $plant^{-1}$ under K_{60} was to the tune of 27.7, 36.3 and 32.1 percent over control during both individual years and in pooled analysis, respectively. K application improved nitrogen and phosphorus availability, which resulted in better plant growth. Potassium said to be quality parameters and helps in balance nutrition of crops, enhanced the photosynthetic activity, translocation of photo-assimilates, carbohydrate assimilates, sugar and water to the developing pods hence its favorable effects on pod formation is supported by Kumar and Hiremath (2015) [7] in maize-chickpea.

The residual effect of varying levels of potassium significantly increased the chickpea seed yield in both the years and in pooled analysis. It was found significantly the highest (2470, 2487 and 2479 kg ha^{-1}) under application of 60 kg K ha^{-1} as compared to control in 2021-22, 2022-23 and in pooled basis, respectively. The increased in seed yield by residual effect of potassium might be due to that potassium has outmost importance for imparting drought and disease resistance and has synergistic effect with nitrogen and phosphorus (Das, 1999) [4]. It is not a constituent of organic structures, but regulates enzymatic activities, translocation of photosynthates and considerably improves seed yield of chickpea. The results of present investigation are in promise with Kumar and Hiremath (2015) [7] in maize-chickpea. Significantly the highest haulm yield (3666, 3681 and 3673 kg ha^{-1}) was recorded due to residual effect of application of potassium @ 60 kg ha^{-1} in 2021-22, 2022-23 and in pooled results, respectively over control. Residual potassium significantly increased haulm yield might be due to that potassium has utmost importance for imparting drought and disease resistance and has synergistic effect with nitrogen and phosphorus. Although it is not a component of organic structures, it controls enzymatic activities (more than 60 enzymes need K to be activated), the synthesis of carbohydrates, photosynthesis, cell elongation, and stomatal activity. Higher nutrient uptake at this level led to higher plant height and the number of branches per plant, which in turn contributed to the realization of a higher haulm yield. The similar results were obtained by Kumar *et al.* (2017) [16] in chickpea.

Table 1: Residual effect of potassium, sulphur and KSB on growth parameters of chickpea 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			Dry weight of root nodules (mg plant^{-1})			No. of branches plant^{-1}		
	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	10.11	10.15	10.13	23.96	24.79	24.73	40.59	40.71	40.65	52.98	53.75	53.36	39.44	39.42	39.43	3.96	4.01	3.99
KSB_1	10.25	10.36	10.30	24.94	24.86	24.90	41.30	42.19	41.75	54.85	54.23	54.54	40.86	39.97	40.42	4.10	4.12	4.11
S.Em. ±	0.13	0.12	0.09	0.38	0.43	0.28	0.62	0.71	0.46	0.68	0.48	0.42	0.58	0.47	0.37	0.06	0.05	0.04
C. D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Levels of Potassium (kg ha^{-1})																		
K_0	10.05	10.12	10.09	23.48	24.06	23.77	36.89	37.12	37.00	49.53	49.16	49.35	39.41	39.22	39.31	3.93	3.96	3.95
K_{30}	10.16	10.26	10.21	24.73	25.02	23.87	41.28	40.92	41.10	54.72	55.40	55.06	39.95	39.25	39.58	4.02	4.11	4.06
K_{60}	10.32	10.38	10.35	25.13	25.39	25.26	44.67	46.30	45.49	57.48	57.42	57.45	41.09	40.62	40.86	4.15	4.12	4.14
S.Em. ±	0.16	0.15	0.11	0.47	0.53	0.35	0.76	0.87	0.56	0.83	0.59	0.51	0.71	0.58	0.45	0.08	0.06	0.05
C. D. at 5%	NS	NS	NS	NS	NS	1.00	2.18	2.50	1.59	2.41	1.71	1.45	NS	NS	1.28	NS	NS	0.14
Levels of Sulphur (kg ha^{-1})																		
S_0	9.99	10.21	10.10	24.04	23.85	23.94	38.89	39.23	39.06	51.92	52.89	52.40	39.99	39.29	39.64	3.95	3.99	3.97
S_{20}	10.16	10.25	10.21	24.22	25.00	24.61	41.55	42.02	41.79	53.76	54.03	53.90	40.12	39.76	39.94	4.00	4.02	4.01
S_{40}	10.37	10.31	10.34	25.09	25.63	25.36	42.41	43.09	42.75	56.06	55.05	55.56	40.35	40.04	40.19	4.14	4.18	4.16
S.Em. ±	0.16	0.15	0.11	0.47	0.53	0.35	0.76	0.87	0.56	0.83	0.59	0.51	0.71	0.58	0.45	0.08	0.06	0.05
C. D. at 5%	NS	NS	NS	NS	NS	1.00	2.18	2.50	1.59	2.41	1.71	1.45	NS	NS	NS	NS	NS	0.14
Significant interaction	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CV%	6.73	6.46	6.50	8.24	9.09	8.64	7.88	8.91	8.22	6.59	4.67	5.74	7.54	6.25	6.82	8.60	6.91	7.64

Table 2: Residual effect of potassium, sulphur and KSB on growth, yield and quality of chickpea in direct seeded rice-chickpea cropping system

Treatments	No. of pods plant^{-1}			Seed index (g)			Seed yield (kg ha^{-1})			Haulm yield (kg ha^{-1})			Crude protein (%)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Levels of KSB (L ha^{-1})															
KSB_0	46.33	47.19	46.76	22.69	22.73	22.71	2268	2265	2266	3404	3398	3402	21.73	22.13	21.93
KSB_1	48.19	49.21	48.70	22.87	22.76	22.82	2382	2407	2395	3587	3595	3591	21.90	22.41	22.16
S.Em. ±	0.74	0.69	0.51	0.24	0.22	0.15	23.95	33.8	20.2	36.8	42.5	28.9	0.23	0.17	0.14
C. D. at 5%	NS	2.00	1.45	NS	NS	NS	69	97	57	108	122	82	NS	NS	NS
Levels of Potassium (kg ha^{-1})															
K_0	41.32	42.18	41.75	22.65	22.60	22.63	2213	2224	2219	3402	3367	3384	20.81	21.86	21.34
K_{30}	47.69	44.93	46.31	22.73	22.81	22.77	2292	2297	2294	3419	3442	3430	21.70	22.16	21.93
K_{60}	52.78	57.50	55.14	22.96	22.83	22.89	2470	2487	2479	3666	3681	3673	22.93	22.79	22.86
S.Em. ±	0.90	0.85	0.63	0.29	0.27	0.19	29.34	41.4	24.7	45.0	52.1	35.4	0.28	0.21	0.17
C. D. at 5%	2.61	2.45	1.78	NS	NS	NS	84	119	70	129	149	100	0.83	0.62	0.50
Levels of Sulphur (kg ha^{-1})															
S_0	44.23	43.39	43.81	22.69	22.65	22.67	2133	2161	2147	3325	3302	3313	20.74	21.31	21.03
S_{20}	47.55	50.06	48.80	22.77	22.70	22.74	2385	2396	2390	3521	3526	3523	22.11	22.49	22.30
S_{40}	50.00	51.16	50.58	22.88	22.89	22.89	2457	2451	2454	3641	3662	3651	22.60	23.01	22.80
S.Em. ±	0.90	0.85	0.63	0.29	0.27	0.19	29.34	41.4	24.7	45.0	52.1	35.4	0.28	0.21	0.17
C. D. at 5%	2.61	2.45	1.78	NS	NS	NS	84	119	70	129	149	100	0.83	0.62	0.50
Significant interaction	-	-	-	-	-	-	K×S	K×S	K×S	K×S	K×S	K×S	-	-	-
CV%	8.16	7.52	7.96	5.53	5.04	5.16	5.35	7.52	6.37	5.47	6.32	6.08	5.61	4.13	4.83

The treatment of 60 kg K ha^{-1} registered significantly the highest crude protein content of 22.93, 22.79 and 22.86 percent during 2021-22, 2022-23 and in pooled basis, respectively over rest of the treatment. Potassium application increased crude protein content in chickpea might be due to that potassium is responsible for the activation and synthesis of protein forming nitrate reductase enzyme. As potash has synergistic effect on nitrogen uptake, accelerates protein synthesis and activate different enzymes therefore, protein contents increased significantly with each increase in potassium level. Our results confirm the finding of Ali *et al.* (2007) [1] in chickpea.

Residual effect of sulphur on growth, yield and quality

The appraisal of data pertaining in Tables 1 and 2 indicated that different levels of sulphur did not show any exert significant residual influence on plant population, plant height at 30 DAS, dry weight of root nodules, No. of branches plant^{-1} and seed index during both the years and in pooled results. Significantly higher plant height at 60 DAS (42.41, 43.09 and 42.75 cm) and at harvest (56.06, 55.05 and 55.56 cm) was logged under application of 40 kg S ha^{-1} in 2021-22, 2022-23 and in pooled analysis over control and statistically at par with 20 kg S ha^{-1}. This might be due to sulphur helps to increased chlorophyll formation and meristematic tissue activity resulting in increased vegetative growth at higher sulphur levels. Sulphur also resembles nitrogen to enhance cell division, cell elongation and tissue differentiation which overall improved plant height. Significantly higher No. of pods plant^{-1} (50.00, 51.16 and 50.58, respectively) was recorded under the treatment S_{40} (40 kg S ha^{-1}) in 2021-22, 2022-23 and pooled results over control and being at par with 20 kg S ha^{-1}. This may because of sulphur plays crucial and significant role in energy storage and transformation, carbohydrate metabolism and activation of enzymes also increase the photosynthetic activity of plant. Probably greater number of pods may be due to balanced nutrition and healthy vegetative growth which later converted into reproductive phase and resulted might in more number of pods per plant.

Application of 40 kg S ha^{-1} recorded significantly higher chickpea seed yield (2457, 2451 and 2454 kg ha^{-1}) and haulm yield (3641, 3662 and 3651 kg ha^{-1}) in both the years as well as in pooled basis, respectively while it was being at par with application of 20 kg S ha^{-1}. The beneficial residual effect of sulphur might be because of enhanced chlorophyll system that permits photosynthesis through which plants produce starch, sugars, oils, fats, vitamins and other compounds, improved nutritional availability in the soil, which positively influenced the carbohydrate metabolism due to the role of S in energy conversion and initiation of carbon fixing enzymes. Effect of sulphur application on cell division, enlargement and elongation resulting in overall improvement in plant organ related with quicker and more consistent vegetative growth of the crop. These promising effects lead to increase transformation of photosynthates towards sink and resulted in the formation of relatively bold grain and increased the yield. The present results are agreed with Makol *et al.* (2020) [8] in rice-chickpea. Significantly higher crude protein content (22.60, 23.01 and 22.80 percent) was recorded due to residual effect of sulphur application at 40 kg ha^{-1} than control (S_0), but it was on par with S_{20} during 2021-22, 2022-23 and on pooled results, respectively. A significant increase in protein content of chickpea with the application of sulphur might be due to sulphur plays an vital role in synthesis of essential amino acids like cysteine, cystine and methionine and certain vitamins like biotin, thiamine, Vit B1 as well as formation of ferredoxin and iron containing plant protein that act as an electron carrier in the photosynthetic process and chlorophyll formation which required for the production of protein.

Interaction effect

The data presented in table 2 revealed that interaction effect of residual potassium and sulphur levels, which was found significant for seed and haulm yield of chickpea. Combined application of 60 kg K and 40 kg S ha^{-1} gave significantly higher seed and haulm yield during 2021-22, 2022-23 and in pooled basis. The combined effect of potassium and sulphur do the overall development of root and shoot of plant which might have absorbed more nutrient and enhanced photosynthesis and production of assimilates. This was reflected in higher yield of chickpea. The results obtained in present investigation were resembled with findings of Manjunatha *et al.* (2013) [9] in rice-cowpea crop sequence.

Conclusion

On the basis of two years of experimental results, it can be concluded that residual effect of application of 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} gave higher growth, yield and quality of residual *rabi* chickpea in direct seeded rice-chickpea cropping system.

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