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Assessment of Potassium Element on Lentil (*Lens culinaris* Medic) Agronomy and Nutrient Use Efficiency in Calcareous Soils

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Abstract: Potassium (K) is considered as key element for plant growth and physiology and improvement of productivity and quality of crops. The potassium (K) reduction from agricultural soils of Indo-Gangetic plain had been observed due to rapidly increasing intensive cropping systems, in combination with imbalanced fertilization. Now, burning issue is needed to better understand the role and dynamic of K in plants and K-use efficiency of crops. Hence, this study was undertaken during two consecutive years of 2015-16 and 2016-17 to know the effects of different levels of potassium on lentil productivity, nodulation, nutrient uptake and K use efficiency. The experiment was laid out in randomized complete block design considering five treatments with thrice replicates. The treatments were T_1 (K Control), T_2 (15 kg K ha^{-1}), T_3 (30 kg K ha^{-1}), T_4 (45 kg K ha^{-1}) and T_5 (60 kg K ha^{-1}) along with the blanket dose of $N_{18}P_{20}S_{10}Zn_2B_{1.5}$ kg ha^{-1} and cowdung 3 t ha^{-1}. Yield and yield attributes of lentil responded significantly to K fertilizer. The highest mean seed yield (1684 kg ha^{-1}) and maximum seed yield increase over control (31.9%) got from T_5 treatment followed by T_4 treatment. The highest total nutrient (N, P, K, S, Zn and B) uptake, maximum nodulation and the highest protein content (29.4%) in seed was, however, recorded from the plot receiving of 60 kg K ha^{-1}. Apparent K recovery efficiency was recorded higher (17.8%) from T_4 treatment. Apparent K recovery efficiency followed the order: T_4>T_5>T_3>T_2. From the economic point of view, T_5 followed by T_4 treatment is viable and sound. The results of the experiment suggest that 60 kg K ha^{-1} might be applied along with $N_{18}P_{20}S_{10}Zn_2B_{1.5}$ kg ha^{-1} for lentil cultivation in calcareous soils of Bangladesh. The K rates for fertilizer recommendation in lentil need to be revised to take account for highest yield by higher increasing rate of K in soil.

Keywords: Potassium, Lentil Yield, Nodulation, Nutrient Uptake, Calcareous Soil

1. Introduction

Most of the crops during their growth stages experience one or more abiotic stresses such as drought, salinity, metal toxicity, high or chilling temperatures, etc [1]. Potassium plays a key role to mitigate the various abiotic stresses.

Potassium takes part in protein synthesis, carbohydrate metabolism, and enzyme activation. It assists in the cation-anion balance, osmoregulation, water movement, energy transfer, and many other processes [2]. A poor root system, lodging, and yield reductions are common phenomena related to K deficiency. Lacking of K fertilizer increases the plants susceptibility to various diseases and pest infestation and makes plants vulnerable to damage under various stress conditions [3]. Most of the soils in different agro-ecological zones of Bangladesh are more or less potassium deficient especially in calcareous soil [4].

Rapid growing population of Bangladesh is required nutritious (protein rich) food. Lentil (*Lens culinaris* Medic) is one of the protein rich nutritious crops which production needs to be increased by the application of judicious K level. It is well adapted and can produce reasonable yield on such soils of low mineral status. Lentil is an ancient edible pulse crop [5]. It is a small, light green, herbaceous plant with much branched stem which belongs to the family *Fabaceae* [6]. Lentil contains about 11% water, 25% protein and 60% carbohydrates. It is also rich in calcium, iron, zinc and niacin [7]. It improves the soil fertility status through biological nitrogen fixation [8]. The average yield of lentil in Bangladesh is low (752 kg ha^{-1}) due to non-judicious use of manures and fertilizers especially potassium [9]. Due to protein demand for rapid growing population, lentil production needs to be increased by the application of judicious K level.

Much practical experience in farmers' fields of Bangladesh, however, the K nutrition of this crop (lentil) is taken inadequate attention in research and management. On the other hand, several studies reported that high yielding variety and intensive cropping may cause heavy depletion of soil K [10-12]. Depletion of soil nutrients, particularly K, is a probable cause of yield decline of pulse (lentil) crop. Limited research work was done the assessment of K rate on lentil agronomy and nutrient use efficiency in calcareous soils of Bangladesh. Potassium nutrition is associated with the nodulation; grain quality and protein content [13]. It also helps to improve disease resistance, drought stress, tolerance to water stress, winter hardiness, tolerance to plant pests and uptake efficiency of other nutrients [14]. The observed decline in available K, however, highlights the need to revise current K fertilizer recommendation for sustaining lentil productivity and quality in calcareous soils. Hence, the present study was undertaken to evaluate the K dose for yield attributes, nodulation, quality, and yield maximization of lentil as well as to measure the nutrient use efficiency.

2. Method

2.1. Site Description

The study area is at the Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Jashore. The area was elevation 6.71m, 23.11°N and 89.14°E [15]. It belongs to the agroecological zone, High Ganges River Floodplain (AEZ-11). According to general soil classification, it falls under calcareous brown floodplain soils with Gopalpur soil series (Soil taxonomy: order-Inceptisols and sub-group-Aquic Eutrochrepts). The experimental site has subtropical humid climatic condition. It is characterized by comparatively high monsoon rainfall, high humidity, and high temperature. Long day with less clear sunshine, sometimes the sky remains cloudy for heavy rainfall during April to September. The scanty rainfall, low humidity and low temperature, short day and more clear sunshine during October to March. The average temperature ranges from 20 to 35°C and average annual rainfall varies from 1650 to 2000 mm across the year. The area got rainfall from 1.7 to 20 mm at 1st year (2015-16) and 7.9 to 12.2 mm at 2nd year (2016-17) during October to March. The mean minimum and maximum air temperatures during October to March of the experiment were 10.3 to 30.4°C at 1st year and 9.46 32.5°C at 2nd year, respectively. The average minimum and maximum humidity (%) were 71.6 to 88.6 at 1st year and 71.3 to 85.6 at 2nd year, respectively during October to March (Table 1).

Table 1. *Weather data during the experimental period at Jashore.*

Months	Avg. Temperature (°C)				Avg. Humidity (%)				Rainfall (mm)	
	2015-16		2016-17		2015-16		2016-17		2015-16	2016-17
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	-	-
October	21.1	29.4	20.2	28.0	75.5	88.6	72.4	85.6	2.3	12.5
November	18.3	26.1	15.6	25.7	71.6	86.8	73.5	82.4	0	0
December	17.9	20.8	12.9	22.6	74.8	84.6	71.4	81.1	0	0
January	10.3	23.9	9.46	26.6	73.3	83.4	71.3	80.1	1.7	0
February	15.7	27.1	10.7	27.8	77.4	83.5	73.7	79.9	15	0
March	18.6	30.4	14.7	32.5	76.3	84.4	73.8	80.0	20	7.9

Source: Weather centre, RARS, Jashore, Bangladesh

The soil sample of the experimental area was collected (0-15 cm depth) with soil auger, before sowing the test crop. Percentage of sand, silt and clay was determined by hydrometer method [16]. The textural class was determined using Marshall's Triangular Coordinates of USDA system. The chemical properties and textural classes are shown in Table 2.

Table 2. *Fertility status of initial soil sample of the experimental field.*

Location	pH	Previous crop	OM (%)	Total N (%)	Ca	K	P	S	Zn	B	Soil particles (%)		
					meq. 100 g^{-1}		mg kg^{-1}				Sand	Silt	Clay
Jashore (result)	8.2	T. aman rice	1.63	0.071	16.4	0.14	14	14.6	0.86	0.15	19.25	62.80	17.95
Critical level	-		-	0.12	2.0	0.12	10	10	0.60	0.20	-	-	-
Interpretation*	slightly alkaline		low	very low	high	low	medium	medium	low	low	Silt loam		

*FRG [26]

2.2. Land Prepation, Treatments, Design and Layout

The land was first opened by a tractor operated chisel plough and then prepared thoroughly by ploughing with power tiller followed by laddering and leveling. The land was weed and stubbles free. The trial was arranged with 5 treatments including control. Five levels of K (0, 15, 30, 45 and 60 kg ha^{-1}) were considered for the treatments such as T_1 (K Control), T_2 (15 kg K ha^{-1}), T_3 (30 kg K ha^{-1}), T_4 (45 kg K ha^{-1}), T_5 (60 kg K ha^{-1}) along with the blanket dose of other fertilizers of $N_{18}P_{20}S_{10}Zn_2B_{1.5}$ kg ha^{-1} and cowdung 3 t ha^{-1}. The experiment was laid out in randomized complete block design (RCBD) with thrice replicates having 15 unit plots. The unit plot size was 12 m^2 (4 m × 3 m).

2.3. Agronomic Practices

Before plot preparation, cowdung was applied in the experimental field. The unit plot (4 m x 3 m) was prepared by manually with spade. Every plot received an equal amount of other fertilizers at $N_{18}P_{20}S_{10}Zn_2B_{1.5}$ kg ha^{-1} as urea, TSP, gypsum, zinc sulphate and boric acid. The potassium was applied treatment wise as muriat of potash (MoP). The unit plots were separated from each other by an alley of 50 cm width. Seeds of lentil (cv. BARI Masur-7) were treated using the fungicide Provex 200 (at 2.5 g kg^{-1} seeds) before sowing to control of root rot disease. Treated seeds were sown (@ 35 kg ha^{-1}) continuously in rows (10 rows/plot) maintaining row to row spacing of 30 cm on 13 November, 2015 and 12 November, 2016. Manually weeding as well as thining of seedlings was done at 25 days after sowing (DAS). Again, hand weeding was done at 50 DAS. Three sprays were done with fungicide of Rovral starting from 55 DAS to control *Stemphylium* blight disease and two times insecticide (Karate @ 2 ml L^{-1} of water) sprayed at 10 days interval starting from 60 DAS to overcome insect infestation. The crop was harvested at maturity. Data on seed yield (kg ha^{-1}) at around 10% moisture basis were recorded from the whole plot technique. For stover yield (kg ha^{-1}), mature plants were collected from two 1m^2 quadrates in each plot at harvest time. The yield contributing characters namely: number of branch per plant, plant height and number of pods plant^{-1} were recorded from ten plants selected randomly from each unit plot. Pods were detached from every plant and the number of pods per plant was counted and averaged. Thousand seed weight (g) was determined by the counting of 500 seeds randomly from each plot and weighing through electronic balance and converting it into 1000-seed weight. For nodule counting per plant, 5 plants from each plot were selected randomly at seedling, vegetative, flowering and podding stages. Plants were smoothly uprooted and the soil from roots was removed carefully using tap water. Separated nodules were sliced into two pieces to observe the inside color for nodules activity. The light-pink or red coloured nodules were considered as active. Percentage of harvest index (HI) was determined by the formula-

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \qquad (1)$$

2.4. Soil and Plant Analysis

Postharvest soil samples of the experimental plot were collected from 0-15 cm depth. The combined soil sample of each plot was brought to the laboratory and spread on a brown paper for air drying. The air-dried soil samples were ground and passed through a 2-mm sieve. After sieving, the prepared soil samples were kept into plastic containers with proper label for chemical analysis.

Soil pH was measured by glass electrode pH meter using soil: water ratio of 1:2.5 [17]. Organic carbon was determined following the wet oxidation method as described by Page et al. [17] and the organic matter content was calculated by multiplying the % organic carbon with the Van Bemmelen factor 1.73. Total N by Microkjeldahl method [18]; available P was determined following Olsen method as described by Page et al. [17]; exchangeable K by 1N NH_4OAc method [19]; exchangeable Ca by 1N NH_4OAc method [20]; available S by turbidity method using $BaCl_2$ [21]; available Zn by DTPA method [22]; available B by azomethine-H method [17].

Ground stover and seed samples were digested with di-acid mixture (HNO_3-$HClO_4$) (5: 1) as described by Piper [23] for the determination- concentration of N (Micro-Kjeldahl method), P (spectrophotometer method), K (atomic absorption spectrophotometer method), S (turbidity method using $BaCl_2$ by spectrophotometer), Zn (atomic absorption spectrophotometer method, VARIAN SpectrAA 55B, Australia) and B (spectrophotometer following azomethine-H method).

2.5. Protein Content and Nutrient Uptake Determination

Protein content was measured by estimating the N content and then multiplying the N value by 6.25 [24]. Nutrient (N, P, K, S, Zn and B) uptake by the test crop was calculated from the results of crop yield and nutrient content in seed and straw [25].

2.6. Nutrient Use Efficiency

Agronomic efficiency (AE) was calculated according to equation

$$AE = \frac{Yield\ in\ kg\ with\ K\ fertilizer - Yield\ in\ kg\ with\ no\ K\ fertilizer}{Amount\ of\ K\ frtilizer\ applied\ in\ kg} \quad (2)$$

Physiological efficiency (PE) was calculated according to equation

$$PE = \frac{Y - Y_0}{U - U_0} \quad (3)$$

Where, Y is the economic yield of the potassium fertilized plot, Y_0 is the yield of the potassium unfertilized plot, U is the nutrient uptake by lentil with K fertilized plot and U_0 is the nutrient uptake by lentil with K unfertilized plot [26].

Apparent nutrient recovery efficiency (ANR) was calculated according to the equation below [27]

$$\text{ANR} = \frac{(Nutrient\ uptake\ F,kg - Nutrient\ uptake\ C,kg)}{(Quantity\ of\ nutrient\ applied,kg)} \times 100 \quad (4)$$

2.7. Statistical Analysis

Data of yield attributes, number of nodules per plant, protein content and N, P, K, S, Zn, B uptake were computed on average of two study years. Data of all parameters were statistically analysed by ANOVA procedure. Then, multiple comparisons were done by LSD at 5% level [28].

2.8. Partial Budget Analysis

Benefit cost ratio (BCR) refers the ratio of gross return to the total variable cost of production of any project in monetary terms. Higher BCR expresses higher return from the production and vice-versa. BCR was determined by the below formula [29]

$$BCR = \frac{GR}{VC} \quad (5)$$

BCR was counted for a hectare of land. Treatment wise management cost was calculated by adding the cost incurred for labours, ploughing and inputs for each treatment. The seed yield was converted kg ha^{-1}. This yield was utilized to calculate the gross return. The shadow prices (land rent, stover cost etc) were not considerd. The gross return was measured by multiplying the seed yield by the present unit price of lentil. Net return was calculated by subtracting management cost from gross return.

3. Results

3.1. Growth and Yield Attributes of Lentil

The number of branches per plant was showed significantly (P<0.05) difference due to application of potassium rates (Table 3). Results reveal that the highest number of primary branches per plant (2.93) was recorded from the treatment T_5 which was statistically similar with T_4, T_3 and T_2 treatments but significantly different with T_1 treatment. The lowest number of branches per plant (2.24) was achieved in K control (T_1) treatment (Table 3). Different rates of potassium contributed significantly (P<0.05) to improve the plant height of lentil (Table 3). This study results showed that the highest plant height (37.0 cm) was obtained in the plot receiving of 60 kg K ha^{-1} (T_5) which was significantly different over the other treatments but statistically identical to the plots receiving of 45 kg K ha^{-1} (T_4) and 30 kg K ha^{-1} (T_3). The lowest plant height (30.7 cm) was obtained from K control (T_1) treatment (Table 3).

Number of pods per plant is very important yield attribute which significantly correlated to achieve higher seed yield (Figure 1). However, the number of pods per plant affected significantly to different rates of potassium (Table 3). The maximum number of pods per plant (85.2) was found in the treatment T_5 followed by T_4 treatment and the minimum number of pods per plant (59.7) was observed in K control (T_1) treatment (Table 3). The seed weight also significantly correlated to reflect the higher yield of lentil (Figure 1). From the study, the thousand seed weight varied from 18.8 to 22.1 g across the different K rates. The highest 1000 seed weight (22.1 g) was obtained from the treatment T_5 which was significantly different with the others treatment but it was statistically identical to T_4 treatment and the lowest 1000 seed weight (18.8 g) was recorded in K control treatment (Table 3).

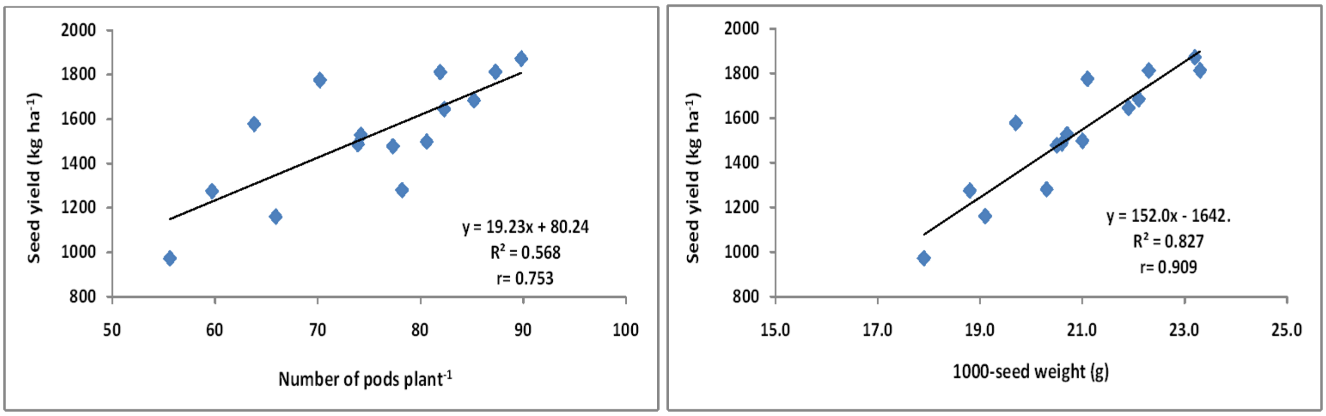

Figure 1. *Relationship between seed yield and number of pods per plant & 1000-seed weight of lentil.*

Table 3. *Effect of different levels of potassium on growth and yield attributes of lentil (Pooled data of two years).*

Treatment	No. of branches plant^{-1}	Plant height (cm)	No. of pods plant^{-1}	1000 seeds wt (g)
T_1 (K Control)	2.24b	30.7c	59.7c	18.8c
T_2 (15 kg K ha^{-1})	2.45ab	34.0b	73.9b	20.6b
T_3 (30 kg K ha^{-1})	2.87a	35.1ab	74.2b	20.7b
T_4 (45 kg K ha^{-1})	2.88a	36.5ab	82.6ab	21.9a
T_5 (60 kg K ha^{-1})	2.93a	37.0a	85.2a	22.1a
CV (%)	10.3	4.16	5.97	2.24
LSD (0.05)	0.52	2.72	8.43	0.88

Values within the same column with a common letter do not differ significantly (P<0.05)

3.2. Yields of Lentil

The seed yield of lentil responded significantly to the application of different level of potassium (Table 4). The experimental results reveal that the highest seed yield (1701 kg ha^{-1}) in 1st year was recorded from T_5 treatment which was significantly different with the other treatments but it was statistically similar to T_4 treatment. Smilarly in 2nd year, the highest seed yield (1667 kg ha^{-1}) was found in T_5 treatment which was significantly different with the other treatments but it was statistically identical with T_4 and T_3 treatments. The lowest seed yield (1199 kg ha^{-1} in 1st year and 1352 kg ha^{-1} in 2nd year) was recorded from K control treatment (Table 4). Regarding straw yield of lentil, it was showed similar trend of seed yield. The percent seed yield increase over control varied from 16.5 to 31.9% (Table 4). The highest seed yield increase (31.9%) over control was calculated from T_5 followed by T_4 treatments and the lowest seed yield increase (16.5%) was found in T_2 treatment. In the present experiment, harvest index (HI) of lentil was ranged across K rates from 37.1% to 38.7 where the highest HI (38.7%) was recorded from T_3 treatment which was statistically similar to T_4 and T_5 treatment. The lowest HI (37.1%) was found in K control (T_1) treatment (Table 4).

Table 4. *Effect of different levels of potassium on seed and stover yields & harvest index of lentil.*

Treatment	Seeds yield (kg ha^{-1})			%yield increase	Straw yield (kg ha^{-1})			HI (%)
	1st Yr.	2nd Yr.	mean	over control	1st Yr.	2nd Yr.	mean	
T_1 (K Control)	1199c	1352c	1276	-	1999c	2314b	2157	37.1b
T_2 (15 kg K ha^{-1})	1493b	1480b	1487	16.5	2317b	2447b	2382	38.2ab
T_3 (30 kg K ha^{-1})	1494b	1562ab	1528	19.7	2335b	2484b	2410	38.7a
T_4 (45 kg K ha^{-1})	1642ab	1648a	1645	28.9	2629a	2668a	2649	38.3ab
T_5 (60 kg K ha^{-1})	1701a	1667a	1684	31.9	2737a	2718a	2728	38.2ab
CV (%)	5.35	3.85	-	-	2.59	3.68	-	2.08
LSD (0.05)	152	112	-	-	117	175	-	1.49

Values within the same column with a common letter do not differ significantly (P<0.05)

A linear positive relationship was observed in potassium application. The trend of seed yield increased significantly positive between the applications of 45 to 60 kg K ha^{-1}. Therefore, optimization doses of K fertilizer will be estimated after rearranging the K levels in future study (Figure 2).

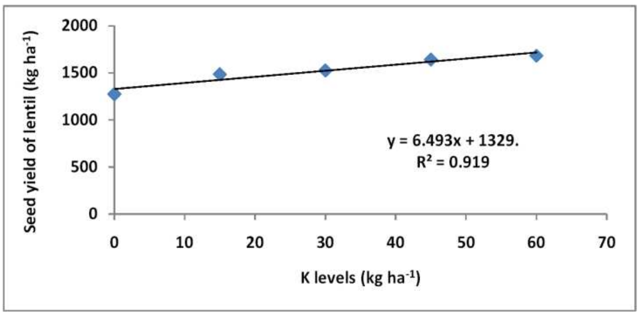

Figure 2. *Relationship between K application and seed yield of lentil.*

3.3. Number of Nodules Per Plant and Protein Content in Seed of Lentil

The results of the Table 5 has showed that the number of nodules per plant was gradually increased from 32 days after sowing (DAS) to 62 DAS, and then it was decreased. Number of nodules per plant was influenced significantly due to application of different levels of potassium. In 32 days after sowing, the numbers of nodules per plant varied from 7.37 to 10.0, in 47 DAS, it was ranged from 40.3 to 50.4, in 62 DAS, it was from 45.4 to 57.2 and in 77 DAS, this range varied from 20.6 to 28.8 (Table 5). The highest number of nodules per plant was recorded from the treatment T_5 in all the nodule collection dates followed by T_4 and T_3 treatments. The lowest nodule values were obtained from the K control treatment (Table 5). The experimental results demonstrate that the highest nodules formation were occured during early to mid flowering. After flowering, nodule efficiency was reduced and began to shut down. In the present study, the protein content in seed of lentil was affected significantly by the application of different levels of K (Table 5). The highest protein content (29.4%) was found in the treatment T_5 that was statistically similar to T_4 and T_3 treatment. The significantly lowest protein content (26.1%) was obtained without K fertilizer application (Table 5).

Table 5. *Effect of different rates of potassium on number of nodule per plant in different dates and protein content of lentil (Pooled data of two years).*

Treatment	No. of nodules in 32 DAS	No. of nodules in 47 DAS	No. of nodules in 62 DAS	No. of nodules in 77 DAS	Protein content (%)
T_1 (K Control)	7.37d	40.3b	45.4b	20.6b	26.1c
T_2 (15 kg K ha^{-1})	8.40c	45.4ab	48.8ab	24.2ab	27.7b
T_3 (30 kg K ha^{-1})	8.43c	46.6a	50.6ab	25.1ab	28.9ab
T_4 (45 kg K ha^{-1})	9.00ab	47.5a	52.4ab	26.0ab	28.8ab
T_5 (60 kg K ha^{-1})	10.0a	50.4a	57.2a	28.8a	29.4a
CV (%)	12.5	7.13	10.4	12.3	2.74
LSD (0.05)	2.04	6.18	10.0	5.81	1.45

Values within the same column with a common letter do not differ significantly (P<0.05)

3.4. Nutrient Uptake by Lentil

Different levels of potassium employed significantly to uptake the N, P, K, S, Zn, and B by lentil (seed and straw) (Tables 6). In the present study, the highest N uptake by lentil (78.6 kg ha^{-1} by seed and 44.6 kg ha^{-1} by straw) was found in T_5 treatment, which was significanly different over the other treatments but it was statistically similar to T_4 treatment. The lowest N uptake (53.2 kg ha^{-1} by seed and 33.4 kg ha^{-1} by straw) was noted from the K control (T_1) treatment (Table 6). The total N uptake by lentil was significantly increased due to increasing the rate of K application. The total N uptake by lentil varied from 86.6 to 123 kg ha^{-1} across the treatments (Figure 3). In this experiment, the highest P uptake by lentil seed (7.20 kg ha^{-1}) and straw (5.35 kg ha^{-1}) was observed in T_4 treatment followed by T_5 treatment and the lowest P uptake (4.22 kg ha^{-1} by seed and 3.02 kg ha^{-1} by straw) was found in K control treatment (Table 6). The total P uptake by lentil was ranged from 7.24 to 12.4 kg ha^{-1} across the different rates of K (Figure 3). Incase of K uptake, the maximum K uptake by lentil seed (11.1 kg ha^{-1}) was recorded from the T_5 treatment, which was significantly different with other treatments but statistically at par T_4 treatment. The highest K uptake by lentil straw (21.2 kg ha^{-1}) was obtained from the T_4 treatment, which was significantly different with other treatments but statistically similar to T_5 treatment. The lowest K uptake (7.78 kg ha^{-1} by seed and 15.1 kg ha^{-1} by straw) was observed in K control (T_1) treatment (Table 6). Across the treatment the total K uptake by lentil varied from 22.9 to 32.2 kg ha^{-1} where the highest total K uptake (32.2 kg ha^{-1}) was noted in T_5 treatment (Figure 3). Regarding S uptake, the highest S uptake by lentil (5.30 kg ha^{-1} by seed and 13.6 kg ha^{-1} by straw) was found in T_4 treatment which was shown significantly different over other treatments but statistically identical with T_5 treatment. The lowest S uptake (3.19 kg ha^{-1} by seed and 7.98 kg ha^{-1} by straw) was observed in K control (T_1) treatment (Table 6). The total S uptake by lentil across the treatments varied from 11.2 to 18.9 kg ha^{-1} however, the highest total S uptake (18.9 kg ha^{-1}) was obtained from T_4 treatment (Figure 3). In this trial, the highest Zn uptake by lentil seed (0.119 kg ha^{-1} by seed and 0.119 kg ha^{-1} by straw) was obtained from T_5 treatment which was showed statistically alike to T_4 and T_3 treatment for seed and alike to T_4 for stover. The lowest Zn uptake by the seed and straw of lentil was however, obtained from the K control (T_1) treatment (Table 6). The total Zn uptake by lentil ranged from 0.173 to 0.238 kg ha^{-1} across the treatments (Figure 3). The highest B uptake by lentil seed (0.066 kg ha^{-1}) was calculated from the T_5 treatment, which was statistically similar to T_4 treatment while the maximum B uptake by lentil straw (0.070 kg ha^{-1}) was noted from T_4 treatment, which was statistically similar to T_5 treatment. The lowest B uptake by lentil (both seed and straw) was assessed from K control (T_1) treatment (Table 6). The total B uptake by test crop varied from 0.097 to 0.135 kg ha^{-1} across the treatments (Figure 3).

Table 6. *Influence of of potassium on nutrient uptake by lentil seed and straw (pooled data of two years).*

Treatment	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	S (kg ha^{-1})	Zn (kg ha^{-1})	B (kg ha^{-1})
Lentil seed						
T_1 (K Control)	53.2d	4.22c	7.78d	3.19c	0.084c	0.046c
T_2 (15 kg K ha^{-1})	66.0c	5.35b	9.37c	4.02b	0.100b	0.056b
T_3 (30 kg K ha^{-1})	71.0b	5.81b	9.93bc	4.28b	0.110ab	0.058b
T_4 (45 kg K ha^{-1})	76.9a	6.95a	10.6ab	5.30a	0.117a	0.065a
T_5 (60 kg K ha^{-1})	78.6a	7.20a	11.1a	5.19a	0.119a	0.066a
CV (%)	2.49	7.16	3.77	7.81	6.31	6.26
LSD (0.05)	3.22	0.80	0.69	0.65	0.013	0.006
Lentil straw						
T_1 (K Control)	33.4c	3.02c	15.1c	7.98d	0.089d	0.051d
T_2 (15 kg K ha^{-1})	37.8b	4.05b	17.4b	10.0c	0.100c	0.057cd
T_3 (30 kg K ha^{-1})	39.3b	4.34b	18.0b	10.8b	0.110b	0.062bc
T_4 (45 kg K ha^{-1})	44.6a	5.35a	21.2a	13.6a	0.118a	0.070a
T_5 (60 kg K ha^{-1})	44.8a	5.14a	21.1a	13.5a	0.119a	0.069ab
CV (%)	2.11	8.78	5.65	2.04	2.02	6.16
LSD (0.05)	1.59	0.72	1.97	0.43	0.004	0.007

Values within the same column with a common letter do not differ significantly (P<0.05)

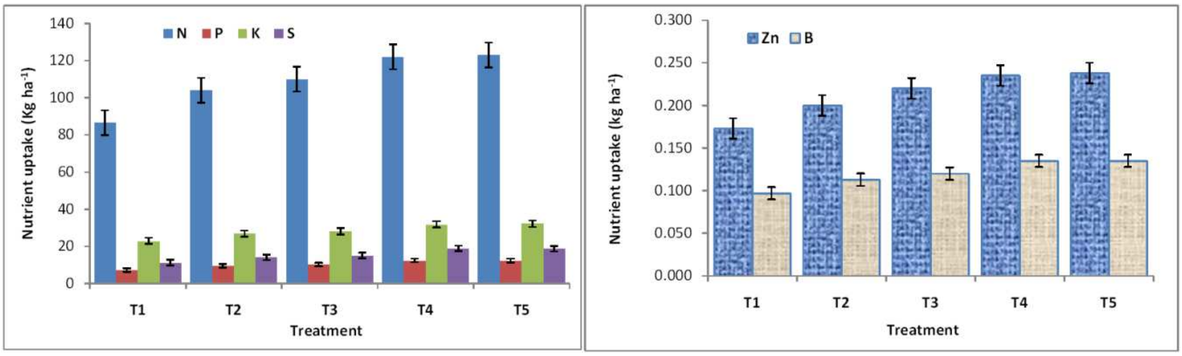

Figure 3. *Effect of different rates of potassium on nutrient uptake by lentil (seed+straw) (Mean data of two years).*

Error bars represent the SEM

Note: T_1 (K Control), T_2 (15 K kg ha^{-1}), T_3 (30 K kg ha^{-1}), T_4 (45 kg K ha^{-1}), T_5 (60 kg K ha^{-1})

3.5. Nutrient Use Efficiency

There was a significant influence of K application on agronomic efficiency (AE) of K in lentil. Among the treatments, AE of K varied over control from 6.30 to 7.58 kg kg^{-1}. The highest AE of K (7.58 kg kg^{-1}) was found in T_4 followed by T_2 treatment and the lowest AE of K in test crop (6.30 kg kg^{-1}) was obtained from T_3 and the 2nd lowest was in T_5 treatment (Figure 4). In this study, physiological efficiency of K in lentil was significantly influenced by different levels of K. The PE of K over control ranged from 42.5 to 54.1 kg kg^{-1} while the highest PE of K (54.1 kg kg^{-1}) was recorded from T_2 followed by T_3, T_5 and T_4 treatments and the lowest (42.5 kg kg^{-1}) was found in T_4 treatment (Figure 4). The PE of K in lentil decreased gradually with increase of K rates upto 45 kg ha^{-1}. Apparent K recovery efficiency in lentil was significantly affected by different levels of K application. Application of 45 kg K ha^{-1} (T_4) showed significantly highest apparent potassium recovery (17.8%) followed by application of 60 kg K ha^{-1} (T_5), 30 kg K ha^{-1} (T_3) and 15 kg K ha^{-1} (T_2), where the lowest apparent K recovery efficiency (13.0%) was found in the plot receiving of 15 kg K ha^{-1} (T_2) (Figure 5).

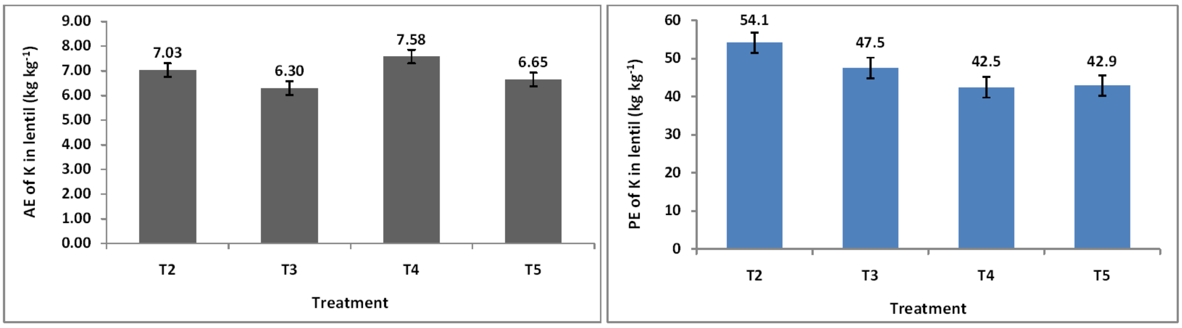

Figure 4. *Effect of different rates of potassium on agronomic efficiency (AE) and physiological efficiency (PE) of K in lentil.*

Error bars represent the SEM,

Note: T_1 (K Control), T_2 (15 K kg ha^{-1}), T_3 (30 K kg ha^{-1}), T_4 (45 kg K ha^{-1}), T_5 (60 kg K ha^{-1})

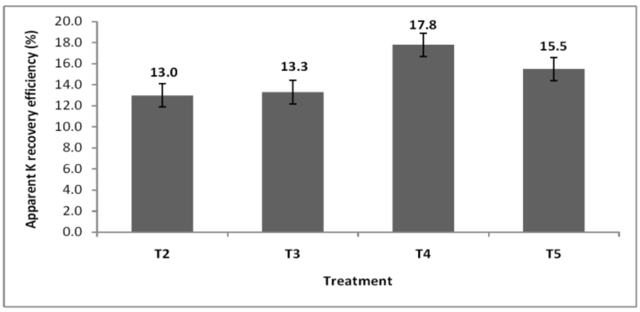

Figure 5. *Effect of different rates of potassium on apparent K recovery efficiency in lentil.*

Error bars represent the SEM,

Note: T_1 (K Control), T_2 (15 K kg ha^{-1}), T_3 (30 K kg ha^{-1}), T_4 (45 kg K ha^{-1}), T_5 (60 kg K ha^{-1})

3.6. Effect of K on Postharvest Soil Properties

Postharvest soil properties were affected positively by the application of different levels of potassium. In this trial, the pH of postharvest soils decreased slightly as compared with the initial value, however the changed showed significantly different across the K treatments (Table 7). Different rates of K tended to maintain the initial fertility or increased slightly of soil organic matter, N, P, K, S, Zn and B. The amount of organic matter (OM) depending on the K rates varied from 1.64 to 1.66%, while the highest amount of OM (1.66%) obtained from T_5 followed by T_3, T_4 and T_2 treatment and the lowest amount (1.64%) was found in K control (T_1) treatment (Table 7). In most of the cases, the highest N, P, S, Zn and B content in postharvest soil was recorded from the T_5 followed by T_4

treatment, but the S content was found maximum in T_4 followed by T_5 treatment and the lowest was from T_1 treatment (Table 7).

Table 7. *Effect of different levels of potassium on postharvest soil pH and the status of different nutrients at Jashore (mean of two years) with reference to initial soil.*

Treatment	pH	OM (%)	Total N (%)	Ca	K	P	S	Zn	B
				meq. 100 g^{-1}		mg kg^{-1}			
Jessore									
Initial	8.2	1.63	0.071	16.4	0.14	14.0	14.6	0.86	0.15
T_1 (K Control)	8.1a	1.64b	0.072c	15.5b	0.13e	13.8b	14.6e	0.80c	0.15c
T_2 (15 kg K ha^{-1})	8.0ab	1.65ab	0.074b	15.8a	0.15d	14.0b	15.0d	0.92b	0.16bc
T_3 (30 kg K ha^{-1})	7.9bc	1.66a	0.075ab	15.6b	0.16c	14.6a	15.4c	0.93ab	0.17ab
T_4 (45 kg K ha^{-1})	7.9bc	1.65ab	0.075ab	15.2c	0.17b	14.5a	15.9a	0.94a	0.17ab
T_5 (60 kg K ha^{-1})	7.8c	1.66a	0.076a	15.6b	0.18a	14.6a	15.6b	0.94a	0.18a

Values within the same column with a common letter do not differ significantly ($P<0.05$)

3.7. Economic Analysis

Regarding the cost and return analysis, the maximum gross return TK. 117880 ha^{-1} was calculated from T_5 followed by T_4. The minimum gross return TK. 89110 ha^{-1} was found in K control treatment. Similarly, the highest net return TK. 80657 ha^{-1} also recorded from T_5 treatment. The highest benefit cost ratio (BCR) 3.17 was counted from T_5 followed by T_4 treatment and the lowest BCR (2.51) was from K control treatment (Table 8).

Table 8. *Effect different levels of potassium on partial economic of lentil (Pooled data of two years).*

Treatment	Seed yield (kg ha^{-1})	Gross return (Tk. ha^{-1})	Cultivation cost (Tk. ha^{-1})	Net return (Tk. ha^{-1})	BCR
T_1 (K Control)	1276	89110	35543	53567	2.51
T_2 (15 kg K ha^{-1})	1487	104090	36313	67777	2.87
T_3 (30 kg K ha^{-1})	1528	106960	36593	70367	2.92
T_4 (45 kg K ha^{-1})	1645	115150	36893	78257	3.12
T_5 (60 kg K ha^{-1})	1684	117880	37223	80657	3.17

Input prices: Urea= Tk. 20 kg^{-1}, T.S.P= Tk. 22 kg^{-1}, MoP= Tk. 16 kg^{-1}, Gypsum= Tk. 8 kg^{-1}, Zinc sulphate= Tk. 140 kg^{-1}, Boric acid= Tk. 145 kg^{-1}, Rovral= Tk. 600 100^{-g}, Karate= Tk. 450 500^{-ml}, Lentil seed= Tk. 80 kg^{-1}, Plowing= Tk. 1400 ha^{-1} (one pass), Wage rate= Tk. 260 day^{-1}
Output price: Lentil grain @ TK. 70 kg^{-1}.

4. Discussion

Among the macro nutrients, K is a vital inorganic constituent, inherently involved in plant growth and development processes. However, management of K fertilizer is beneficial for improving the plant growth and yield contributing characters of crop [30]. Thus, Ali *et al.* [31] reported that application of K_2O @ 150 kg ha^{-1} produced significantly higher number of branches per plant of chickpea and second highest was produced by 125 kg K_2O ha^{-1} which was statistically at par 100 kg K_2O ha^{-1}. In the present study, the number of primary branches per plant was increased about 9.4%, 28.1%, 28.6% and 30.8% by the application of 15, 30, 45 and 60 kg K ha^{-1}, respectively over K control. Potassium might be influenced on this increment of the branches. Potassium influences the physiological processes which are responsible for plant growth and development. Similar observation corroborated by Wang *et al.* [2]. Different rates of potassium contributed significantly ($P<0.05$) to improve the plant height of lentil. This study results showed that the highest plant height (37.0 cm) was obtained in the plot receiving of 60 kg K ha^{-1} and the lowest (30.7 cm) was obtained from K control treatment. Hussain *et al*. [32] reported that application of different levels of K (0, 30, 60, 90, and 120 kg sulfate of potash (SOP) ha^{-1}) in mungbean trial and found the highest plant height at 90 kg SOP ha^{-1} and the lowest at 0 kg K ha^{-1}. Sahay *et al*. [33] found highest plant height (43.49 cm) of lentil in the plot receiving of 90 kg K_2O ha^{-1}. Plant height is the significant part of vegetative phase that responsible to get higher biomass yield. However, K deficiency in soil is reduced the plant growth. Gerardeaux *et al.* [34] observed that the K deficiency in the vegetative phase of crops reduced the plant dry matter production, leaf area, and internode size, which leads to a reduction in plant growth. In the experiment, the maximum number of pods per plant (85.2) was found in the treatment receiving of 60 kg K ha^{-1}. This result is in agreement with the findings of Zahan *et al.* (9). Ali *et al.* [31] reported on chickpea that application of 150 kg K_2O ha^{-1} produced significantly maximum number of pods plant^{-1} (61.9). Seed weight might be genetically controlled, the growing condition and nutrient (especially K) management showed significant influence on its expression [3]. Highest seed weight in the study was obtained at 60 kg K ha^{-1}. Higher potash levels resulted appreciably in higher seed weight probably due to role of potash in translocation of photosynthates and its ability to develop bold seeds [31]. Sahay *et al.* [33] corroborated the similar result. Islam and Muttaleb [35] reported that the higher amount of K helps to transfer food material to develop grains.

Seed yield of lentil responded significantly to the application of potassium. Seed yield is the key reflection for any study involving to the seed production and commercial cultivation of a crop. The experimental results reveal that the highest seed yield was observed in the treatment receiving of 60 kg K ha^{-1}. The study of Chanda *et al.* [36] concluded that the application of higher level of 120 kg K ha^{-1} increased mungbean grain yield. Potassium might be regulated the biosynthesis, conversion, and allocation of metabolites that ultimately increases the yield. Many research works strongly supported the idea that K is directly or indirectly responsible for higher yield of crops [3]. Potassium involves increasing the utilization of carbohydrates, enhances the dry matter accumulation and ultimately increases the yields of crop [37]. The highest percent seed yield increase (31.9%) over control was found by the application of 60 kg K ha^{-1}. Zahan *et al.* [9] reported that 34.2% lentil grain yield increase over control by the application of 42 kg K_2O ha^{-1}. In the present experiment, potassium influences the physiological processes which are responsible for plant growth, biomass production and development and eventually improved harvest index (38.7%). Kirthisinghe [38] reported that the HI of lentil shown variability due to management practices and environmental condition. The variation of HI of lentil ranged from 1% to 60%.

Nodulation results of the study showed that the number of nodules per plant was gradually increased from 32 days after sowing to 62 days after sowing, and then it was decreased. Number of nodules per plant in different dates was influenced significantly due to application of potassium. Maximum nodulation was happened in the improved dose of K. Ali and Srinivasarao [39] noted that improved K supply enhances biological nitrogen (N) fixation. These findings were supported by Kurdali *et al.* [40]. Protein content in seed of lentil was observed highest (29.4%) by the application of 60 kg K ha^{-1}. Potassium might be involved to get improved protein. However, similar result was corroborated by Ali *et al.* [31] in chickpea who noted that the maximum protein content (23.87%) in seed was recorded for 150 kg K_2O ha^{-1}. Wang *et al.* [2] studied on the correlation between phytohormones and K; phytohormones interact with one another and other signaling molecules, which regulate biochemical processes and metabolism. Auxin-regulated genes regulate proteins that affect the transcriptional repressors of stress responses in plants [41].

Potassium is an essential macronutrient that plays significant role to uptake the N, P, K, S, Zn, and B by lentil (seed and straw). In the present study, most of the nutrient showed highest uptake by lentil in application of 60 kg K ha^{-1}. Our observation indicated that nutrient uptakes were significantly governed by the crops yield, performance of the yield attributes and nutrient concentration of crop. Potassium might be involed to enhance the crop growth with increase in utilization and translocation of other nutrient especially N to plant and synergy between N and K in soil system resulting in improvement of yield [42, 43]. Hence, nutrient especially K uptake by lentil in K-control plots can be a reliable measure of K-supplying capacity of soil [44, 45]. Different previous studies also reported that K applications have been influenced the uptake of N, P, K, S, Zn, and B by crops [46, 47].

There was a significant influence of K application on agronomic efficiency (AE) of K in lentil. Result of AE of K in some cases showed decreasing trend with increasing the K rate. Similar phenomenon noted by Islam *et al.* [6] in maize that lowest AE of K (12.9 kg kg^{-1}) was recorded for K dose (160 kg ha^{-1}). The physiological efficiency (PE) of the nutrient refers utilization capacity of nutrient by plant. The higher efficiency indicates more capacity of plant to increase yield with per unit nutrient uptake [25]. In this study, physiological efficiency of K in lentil was significantly influenced by different levels of K. The PE of K in lentil decreased gradually with increase of K rates upto 45 kg ha^{-1}. The recovery efficiency of any nutrient refers to the increase in nutrient uptake by plants per unit of an applied nutrient. It depends on the growing environment and method of nutrient application. Apparent K recovery efficiency in lentil was significantly affected by different levels of K application. Other studies have also shown that crop K use efficiency depends on the rooting pattern of different crops and varieties, and their productivity, which depends also on the K status and K dynamics in soils [48, 49]. Potassium application in soil contributed positively to biomass production and increases the number of nodules per plant and both were influenced to the postharvest soil properties. In this trial, the pH of postharvest soils decreased slightly as compared with the initial value. Kumar and Yadev [50] and Mian and Eaqub [51] reported that continuous application of inorganic (NPK) fertilizer and incorporation of stover in soil resulted lower pH by 0.1 to 0.3 units. Different rates of K tended to maintain the initial fertility or increased slightly of soil organic matter, N, P, K, S, Zn and B. Organic matter might be increased the cation exchange capacity, which contributes to a high base saturation of the soil. Hence, the base saturation increases the relative amount of cations. The result of the experiment is supported by the researchers-Ogbodo [52]; Hinsinger, [53]. Our observation seemed that agronomic biofortification with K had a significant effect on the availability of nutrients in the soil. It has been reported that legume crops might be saved of about 23 to 30 kg N ha^{-1} for the succeeding crop [54]. The study has been denoted that rate of 60 kg K ha^{-1} economically viable due to obtain highest net return and benefit cost ratio. Similar results observed by Ali *et al.* [31] in chickpea.

5. Conclusion

From two years study it is clear that different rates of K significantly increased the seed yield of lentil. The application of potassium 60 kg ha^{-1} contributed significantly to have had more pod setting and seed weight, which ultimately enhanced the seed yield. The use of 60 kg K ha^{-1} followed by 45 kg K ha^{-1} had a significant effect to obtain the maximum number of nodules per plant and the highest protein content in seed. The total uptake of N, P, K, S, Zn and B was also highest in the plot receiving of 60 kg K ha^{-1}. The same dose was observed economically sound. Use of 60 kg K ha^{-1} followed by 45 kg K ha^{-1} showed encouraging effects on soil organic matter, total N, available P, K, Zn and B. Results of the current study suggested that 60 kg K ha^{-1} along with $N_{18}P_{20}S_{10}Zn_{2}B_{1.5}$ kg ha^{-1} is better for yield maximization of lentil and sustained the fertility of calcareous soils in Bangladesh. The present experiment also highlighted for the readjustment of K fertilizer dose by further study and to better understand the dynamics of K in lentil production.

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