POLY4 Positively Improves the Growth, Fodder Yield and Quality of Oat (*Avena sativa* L.) in Semi-Arid Tropics of Central India

ABSTRACT

A study was carried out to examine the effects of different potassium fertilizer sources on growth, fodder yield, and quality at the Research Farm, Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh. The experiment was conducted under semi-arid climatic conditions in a simple Randomized Block Design (RBD) with ten treatments (control, 100% NP, 100% recommended dose of potassium (RDK) through MOP, 100% RDK through SOP, 100% RDK through POLY4, 75% RDK+ 1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through POLY4, 100% RDK through schoenite and 75% RDK+ 1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through schoenite, 75% RDK through MOP + KSB (potassium solubilizer bacteria, Seed treatment), KSB alone (Seed treatment) and three replications. Results showed that application of 75% RDK+ 1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through POLY4 recorded the significantly highest growth and yield contributing parameters, which is beneficially resulted in increased green fodder yield (159%) as compared to control. However, it was at par with the application 75% RDK+ 1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through schoenite. The fodder quality parameters viz. CP, ADF, and NDF were also remarkably improved with the application of 75% RDK+1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through POLY4 in oat crop. The results imply that farmers may apply 75% RDK+1% RDK foliar spray through POLY4 to achieve good quality higher green fodder in sandy clay loam soil for oat production.

Keywords: POLY4, crop growth, fodder yield, fodder quality; foliar spray.

1. Introduction

The green revolution has transformed India into a food grain surplus country from a deficit one due to intensive cultivation and enhanced use of agrochemicals [1]. On the other hand, the intensification of agricultural production systems has led to a decline in soil quality due to nutrient depletion [2], acidification, nutrient mining, and loss of soil organic carbon (SOC) [3]. This required increase in agricultural productivity is set against a backdrop of widespread and increasing land degradation, nutrient deficiencies, and growing challenges from a changing climate. Some estimates predict that agricultural productivity will need to triple by the year 2100 to meet global demand under a business-as-usual scenario [4].

One of the three important macronutrients for plants, together with nitrogen and phosphorus, is potassium (K), which crops ingest in relatively high quantities from the soil. The K increases crop yields and improves agricultural output quality [5, 6]. Additionally, it improves plants' resilience to a variety of harmful environmental factors, including disease, insect infestation, cold and drought stress [7]. It improves the efficiency of nutrient intake and usage while aiding in the formation of a robust and healthy root system. By increasing the content of protein and oil in fodder and seeds, respectively, starch in seeds, and sugar in fruits, it enhanced the nutritional value of grains, fodder, and fruits. When given enough K, cereals grow sturdy stalks and heft grains.

There is evidence that K deficiency is a worldwide problem [8]. A number of studies have reported that the K status of agricultural soils is decreasing in many particular regions of the world, such as Europe, North America, Africa, Australia, and Asia [9-11]. Fertility studies showed the declining trend of K status in Indian soils in most of the states, from high to medium or medium to low status. The K deficiency is more severe in areas where intensive cropping systems are being followed [12]. Widespread K deficiency was identified in the rice-wheat system of the Indo Gangetic Plain, in horticultural, plantation, ornamental, aromatic, and avenue plants [13]. Furthermore, India's dependency on imports at present is to the extent of 100% of K fertilizer [14] and it costs a huge amount of government exchequer.

In modern agriculture, K is necessary since it increases output and quality. Lack of sufficient potassium fertilization results in severe soil potassium reserve depletion and yield loss [15]. To overcome this constraint, research on the rational use of fertilizers is a critical factor for improving productivity and agricultural sustainability. Therefore, as mineral reserves have been depleted and prices of fertilizer raw materials are rising, it is important to identify an alternative source of K fertilizer is required urgently to sustain agricultural productivity. One alternative is the use of multi-nutrient sources like polyhalite, schoenite, sylvite, and glauconite [16]. Rathore et al. [17] reported that application of K through scheonite (60 kg/ha) significantly improved the growth and yield of groundnut as com-pared to potassium sulphate. Tiwari et al. [18] discovered an advantage in terms of oil production in mustard and sesame when using polyhalite compared with using equiva-lent amounts of soluble fertilizers. When polyhalite was used as a source of Mg and S in cabbage and cauliflower, it resulted in higher quality and yields when compared with fer-tilization with the equivalent soluble salts [19]. Tien et al. [20] reported that the combination of polyhalite and MOP as K source in the ratio of 1:1 improved most of the parameters of the maize crop as compared to farmer's practice. Similarly, Bhatt et al. [21] also reported that combining MOP and polyhalite equally to achieve an application rate of 80 kg K/ha is recommended to enhance sugarcane growth and yield.

Oat (*Avena sativa* L.) is an important winter season cereal fodder crop. In the world, oat is the 6th most produced cereal after wheat, rice, maize, sorghum, and barley. In India, it is cultivated on one lakh ha in Punjab, Haryana, and UP and limited areas in MP, Orissa, Bihar, and West Bengal. It provides soft, palatable, and nutritive fodder to all categories of livestock in the form of green, dry fodder, silage, and hay. On an average, it contains 10–12.3% crude protein, 55–63% neutral detergent fibre, 30–32% acid detergent fibre, 22–23.5% cellulose, and 16–20% hemicellulose at 50% flowering stage. They also help with weight loss, controlling blood pressure, and building a strong immune system. Oat extracts an adequate quantity of nutrients from the soil and need promising strategies for replenishing removed nutrients in the soil to boost production and sustain the livestock production and profitability of the system [22]. Inadequate nutrition delivery is a significant barrier to accessing the genetic potential of oat in farmer's fields [23]. Considering oat as a qualitative fodder and feed for livestock and other purposes and limited studies on the effects of different potassium fertilizer sources on fodder crops in arid and semi-arid regions of India, the present study entitled "POLY4 positively improves the growth, fodder yield and quality of oat in semi-arid tropics of central India" was conducted to find out the comparative effect of different potassium fertilizer sources on the growth, fodder yield and quality of fodder oat cultivation.

2. Material and Methods

2.1. Description of the Experimental Site

The experiment was carried out during the *rabi* season 2021-2022 at the Central Farm, Rani Laxmi Bai Central Agricultural University, Jhansi, Uttar Pradesh, India. The experimental site is situated in the Bundelkhand region of Uttar Pradesh, India, covering about 7.16 million ha area, at 25°51' N latitude and 78°56' E longitude, at a height of 227 m above mean sea level. The mean summer and winter temperatures are 32.7ºC and 25.1 ºC, respectively [24]. The long-term average annual rainfall of the study site is 908 mm, received mostly by the South-West monsoon between June to August [25]. The soil type of the experimental site was a sandy clay-loam texture, with a pH 7.57, electrical conductivity 0.013 dS/m, available N, P, K, and S were 220, 11.25, 223, and 12.50 kg/ha, respectively, and having 28.50 % water holding capacity.

2.2. Experimental Design and Treatment Details

A field experiment was conducted using oat (*Avena sativa* L. cv. JHO-851) as a test crop in randomized block design (RBD) with ten treatments (i.e. control, 100% NP, 100% RDK through MOP, 100% RDK through SOP, 100% RDK through POLY4, 75% RDK+1%RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through POLY4, 100% RDK through schoenite and 75% RDK+1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through schoenite, 75% RDK through MOP + KSB (Seed treatment), KSB alone (Seed treatment) and three replications.

Field preparations were done using once with mouldboard plough followed by two passes of harrowing to get a finer tilth for oat crop sowing. Sowing of the seeds was done using the line sowing method (Seed rate: 100 kg/ha; row spacing: 20 cm).

A recommended fertilizer dose of 120:60 kg N: P_2O_5/ha using urea, diammonium phosphate were applied in all treatments except control with a seed drill. Half dose of nitrogen and a full dose of phosphorus were applied at the time of sowing as basal dose. The remaining half dose of nitrogen was applied after the first irrigation. A recommended fertilizer dose of 40 kg K_2O/ha was applied through various K fertilizer sources i.e. MOP, SOP, POLY4 and Schoenite (Table 1).

Table 1. Treatment details of the experiment

	Treatment	Abbreviation used
T_1	Control (no fertilizer application)	Control
T_2	100% NP (Only recommended dose of nitrogen and phosphorus)	100% NP
T_3	100% RDK through MOP (Muriate of potash)	100% RDK (MOP)
T_4	100% RDK through SOP (Sulphate of potash)	100% RDK (SOP)
T_5	100% RDK through POLY4	100% RDK (POLY4)
T_6	75% RDK through POLY4 + 1% RDK through POLY4 foliar spray (at 30 DAS & 30 days after fodder harvest)	75% RDK + 1% RDK FS* (POLY4)
T_7	100% RDK through Schoenite	100% RDK (Schoenite)
T_8	75% RDK through Schoenite + 1% RDK through Schoenite foliar spray (at 30 DAS & 30 days after fodder harvest)	75% RDK + 1% RDK FS* (Schoenite)
T_9	75% RDK through MOP + KSB (Seed treatment)	75% RDK (MOP) +KSB
T_{10}	KSB alone (Seed treatment)	KSB

*T_3 to T_{10} treatments, nitrogen and phosphorus were applied as per recommendation.

2.3. Biometric Observations

Biometric observations such as plant height, number of tillers/mrl, crop growth rate (CGR), and relative growth rate (RGR) were recorded at 30 days after sowing (DAS), fodder harvest, 30 days after fodder harvest (DAFH), and at maturity from the labelled plants and the average number was calculated.

2.4. Fodder Yield

The oat crop was harvested at 50% flowering to record green fodder yield (GFY) and weighing was done with the balance from each plot after removing border rows. The values are expressed as green fodder yield (GFY) in t/ha. For dry fodder yield (DFY), har-vested fresh plant samples were sun dried first and then kept in an oven at 72 °C for three days to get a constant weight. After weighing, the dry matter percentage was determined. The plot wise data on dry matter percentage was multiplied with corresponding GFY to obtain dry fodder yield in t/ha. After fodder harvest, the oat crop was allowed for seed production.

2.5. Plant Sampling and Fodder Quality Analysis

Plant samples were collected from each treatment after harvesting (at 50% flowering) and were kept in labelled paper bags and brought into the laboratory. These were oven-dried at 65°C for 70 hours. After that dry plant samples were ground in a Wiley mill having a 1 mm mesh screen. The crude protein (CP) was obtained by multiplying the nitrogen con-tent by a factor i.e. 6.25 [26]. The neutral detergent fibre (NDF) and acid detergent fibre (ADF) analysis were also done following the AOAC [26] procedure.

2.6. Statistical Analysis

Experimental data were analysed by adopting standard statistical methods of analysis of variance as given by [27]. The effect of different potassium fertilizer sources was analysed in RBD. Treatment effects were presented by making tables of means for different parameters with appropriate standard error [SEm+] and critical difference (CD) at p=0.05 using SAS v9.3 [28].

3. Results and Discussion

3.1. Growth Parameters of Oat Crop

Data of oat growth attributes viz. plant height, number of tillers/mrl, RGR, and CGR were influenced by the application of different potassium fertilizer sources. Data pertaining to plant height as influenced periodically by different treatments are present in Table 2. The height of the oat plant increased by all treatments in comparison to control at different days of the growth period. The data shows that at 30 days after fodder harvest (DAFH) and maturity, T_5, T_6, T_7, and T_8 recorded significantly higher plant heights than control.

Table 2. Effect of different potassium fertilizer sources on plant height of oat at different growth stages

Treatment	Plant height (cm)			
	30 DAS	At fodder harvest	30 DAFH	At maturity
T_1:Control	18.5	30.5	39.9	87.1
T_2:100% NP	20.6	30.9	41.7	111.2
T_3:100% RDK (MOP)	20.6	34.1	43.1	113.8
T_4:100% RDK (SOP)	21.5	33.4	45.3	112.5
T_5:100% RDK (POLY4)	21.8	36.9	50.9	116.5
T_6:75% RDK + 1% RDK FS* (POLY4)	22.9	39.2	56.4	130.7
T_7:100% RDK (Schoenite)	21.3	36.5	48.2	116.4
T_8: 75% RDK + 1% RDK FS* (Schoenite)	22.3	37.3	50.1	122.7
T_9:75% RDK (MOP) +KSB	21.6	35.6	47.0	115.0
T_{10}:KSB	19.1	31.0	42.5	111.8
SEm±	1.8	2.3	2.4	4.4
CD (P=0.05)	NS	NS	7.19	13.2

* Foliar spray at 30 days after sowing and 30 days after fodder harvest

Table 3. Effect of different potassium fertilizer sources on number of tillers/ mrl of oat at different growth stages

Treatment	Tillers (Number/mrl)			
	30 DAS	At fodder harvest	30 DAFH	At maturity
T_1:Control	33	65	47	62
T_2:100% NP	37	74	48	89
T_3:100% RDK (MOP)	38	81	53	100
T_4:100% RDK (SOP)	38	77	52	93
T_5:100% RDK (POLY4)	43	97	56	106
T_6:75% RDK + 1% RDK FS* (POLY4)	46	98	61	116
T_7:100% RDK (Schoenite)	42	96	56	102
T_8: 75% RDK + 1% RDK FS* (Schoenite)	45	98	59	106
T_9:75% RDK (MOP) +KSB	38	82	55	102
T_{10}:KSB	35	73	47	89
SEm±	3.0	5.1	2.9	5.3
CD (P=0.05)	NS	15.2	8.5	15.6

* Foliar spray at 30 days after sowing and 30 days after fodder harvest; mrl: meter row length

Table 4. Effect of different potassium fertilizer sources on crop growth rate and relative growth rate of oat at different growth stages

Treatment	Crop growth rate ($g/m^2/day$)				Relative growth rate (mg/g/day)	
	0-30 DAS	30 DAS-FH	FH-30 DAFH	30 DAFH-maturity	30 DAS-FH	30 DAFH-maturity
T_1:Control	0.43	3.22	2.01	4.52	79.5	24.0
T_2:100% NP	0.43	3.97	3.02	4.77	85.8	24.3
T_3:100% RDK (MOP)	0.46	4.67	3.17	5.28	89.7	25.0
T_4:100% RDK (SOP)	0.45	4.58	3.09	4.86	89.3	24.3
T_5:100% RDK (POLY4)	0.50	6.53	3.27	5.32	98.5	24.7
T_6:75% RDK + 1% RDK FS* (POLY4)	0.51	7.59	3.53	5.90	103.6	25.1
T_7:100% RDK (Schoenite)	0.49	6.40	3.25	4.31	99.2	22.0
T_8: 75% RDK + 1% RDK FS* (Schoenite)	0.45	7.68	3.38	5.22	108.5	29.3
T_9:75% RDK (MOP) +KSB	0.44	5.25	3.21	4.22	96.0	21.8
T_{10}:KSB	0.47	4.46	3.01	5.77	87.1	27.0
SEm±	0.02	0.48	0.18	0.43	3.8	1.6
CD (P=0.05)	NS	1.43	0.53	NS	11.2	NS

* Foliar spray at 30 days after sowing and 30 days after fodder harvest

In all growth periods, T_6 i.e. 75% RDK+ 1%RDK FS (30 DAS and 30 DAFH) through POLY4 gave best results followed by 100% RDK through POLY4 (T5) and 75% RDK+1% RDK FS (30DAS and 30 DAFH) through schoenite (T_8). The fact that POLY4 contains K, Ca, Mg, and S in complexes with organic moiety, assuring stronger K and S nutrition for increased enhancement of carbohydrates, proteins, enzymes, and energy synthesis, may be the cause of POLY4's strongest growth-encouraging effects [29]. The outward translocation of photo-synthesis from the leaf is accelerated by potassium foliar spray. Similar findings were made by

[30] and [31], who discovered that potassium applied at the maximum level as soil with foliar applications of K and S resulted in the highest vegetative parameters of onion and sweet pepper plants. Treatment T_6 followed by T_8 gave maximum numbers of tillers/mrl of oat crop. At fodder harvest, 30DAFH and maturity, T_5, T_6, T_7, and T_8 recorded significantly higher numbers of tillers/mrl than the control. Among them, T_6 i.e. 75% RDK+ 1%RDK FS (30 DAS and 30 DAFH) through POLY4 gave best results followed by 75% RDK+1% RDK FS (30DAS and 30 DAFH) through schoenite (T_8), which were statistically at par with T_5 and T_7 treatments (Table 3).

From Table 3, it can be observed that at 30 DAS, numbers of tillers/mrl of oat were more in all treatments over control, but none of the treatments reached to the level of significance compared to control. Treatment T_6 followed by T_8 gave maximum numbers of tillers/mrl of oat crop. At fodder harvest, 30DAFH and maturity, T_5, T_6, T_7, and T_8 recorded significantly higher numbers of tillers/mrl than the control. Among them, T_6 i.e. 75% RDK+ 1%RDK FS (30 DAS and 30 DAFH) through POLY4 gave best results followed by 75% RDK+1% RDK FS (30DAS and 30 DAFH) through schoenite (T_8), which were statistically at par with T_5 and T_7 treatments. These findings could be attributed to the role of potassium, an element important for numerous metabolic processes, including those that support and encourage vegetative growth and development in plants. By directly enhancing leaf growth and the leaf area index, as well as CO_2 assimilation, foliar application of K plays an important role in photosynthesis [32]. These findings concur with those of [33] and [34].

The significantly higher CGR at fodder harvest and 30DAFH was registered with the application of T_6 i.e. 75% RDK+ 1%RDK FS (30 DAS and 30 DAFH) through POLY4. However, it was at par with T_3 and T_5 to T_9 (Table 4). The RGR was at maximum during fodder harvest, and reduce drastically thereafter. The T_8 and T_6 treatments recorded higher RGR at both stages. Higher RGR (Table 4) under 75% RDK+1% RDK FS (30 DAS and 30 DAFH) through schoenite (T8) and 75% RDK+1%RDK FS (30 DAS and 30 DAFH) through POLY4 (T_6) is because the crop conditions were better than the control, including the availability of moisture, nutrients and the development of roots.

3.2. Green Fodder and Dry Fodder Yield

Both GFY and DFY of oat were influenced significantly due to the application of different potassium fertilizer sources (Table 5). The significantly highest GFY (13.53 t/ha) was recorded under 75% RDK+1% RDK FS (30 DAS and 30 DAFH) through POLY4 treatment (T_6). However, it was at par with 75% RDK+1% RDK FS (30 DAS and 30 DAFH) through schoenite (T_8).

The DFY was significantly highest in the T_8 treatment, which was at par with T_6, T_5 and T_7 treatments (Figure 1). The significantly lower GFY (5.23t/ha) and DFY (0.87 t/ha) were recorded in the control (T1). The GFY under T_6 showed a remarkable increase of increase being recorded 158% and 64% over the control (T_1) and T3 i.e. 100% RDK through MOP, respectively. More understanding is required for this yield reduction from the MOP treatment when compared with T_5 to T_8 treatments. This finding could be explained by chloride anions competing with accessible sulphate ions, resulting in lower tissue sulphur concentrations [35]. In DFY, a nearly identical pattern was noted. These outcomes could be due to the rivalry between chloride and sulphate anions as well as sulphur, calcium, and magnesium nutrition through POLY4 and scheonite [36, 37]. The greater fixing or adsorption of potassium from MOP to the clay particles may also be a contributing factor. Due to competitive rivalry between monovalent

(K^+) and divalent (Ca^{2+}, Mg^{2+}) cations, such adsorption or fixation may be less for POLY4 or scheonite.

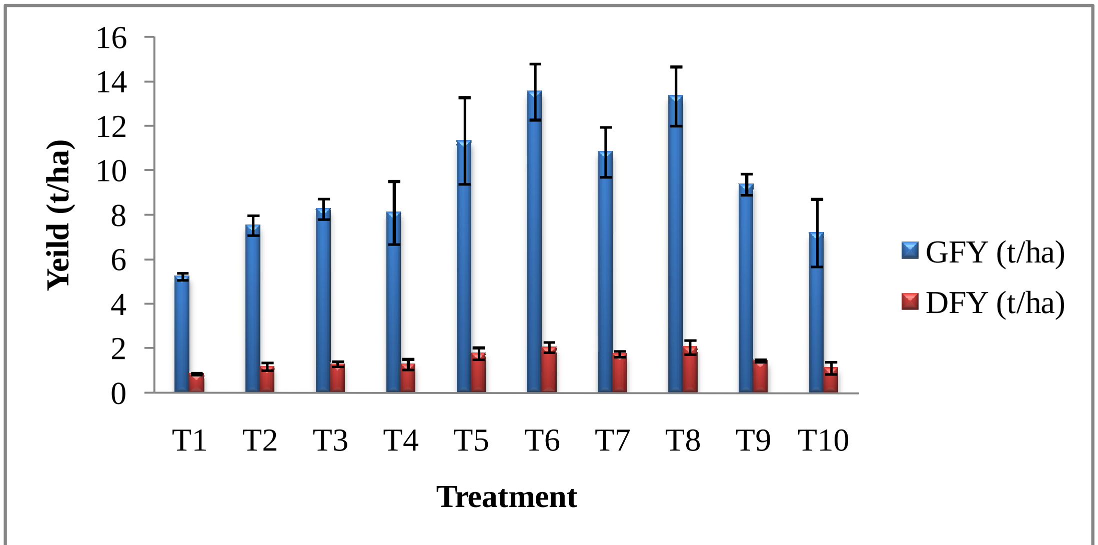

Figure 1. Effect of different potassium fertilizer sources on green fodder yield (GFY) and dry fodder yield (DFY) of oat

Furthermore, crop response to foliar K sulphate applications at various stages of development showed that soybean grain yield increased over 10 bu/acre when compared to a non-treated control [38]. According to [39], the enhanced grain production from polyhalite (POLY4) over MOP was due to the sulphur in the polyhalite (POLY4). The results were consistent with [33, 34, 40], who discovered that potassium thiosulfate was most effective when applied topically to crops.

3.3. Fodder Quality

Fodder quality (CP, ADF, and NDF) was significantly influenced due to the different potassium fertilizer sources (Table 5). The CP content was significantly higher in T_6 (10.4%), which was at par with T_5, T_7, T_8, and T_9 treatments. The CP content in the T_6 treatment was 8 %

and 14% higher than T_3 (100% RDK though MOP) and T_1 (control) treatments. Plant fibre refers to the cell-wall constituents of hemicelluloses, cellulose, and lignin. The NDF values represent the total fibre fraction that make up cell walls.

For forage quality, the lower the NDF value, the better is forage quality. The ADF values represent cellulose, lignin, and silica (if present). The ADF fraction of forages is moderately indigestible; therefore, lower values are better.

Table 5. Effect of different potassium fertilizer sources on green fodder yield (GFY), dry fodder yield (DFY) and quality

Treatment	GFY (t/ha)	DFY (t/ha)	CP (%)	ADF (%)	NDF (%)
T_1:Control	5.23	0.87	9.3	35.61	57.34
T_2:100% NP	7.53	1.19	9.6	34.39	57.17
T_3:100% RDK (MOP)	8.24	1.31	9.8	33.95	55.34
T_4:100% RDK (SOP)	8.08	1.28	9.6	34.01	56.06
T_5:100% RDK (POLY4)	11.36	1.78	10.4	33.41	52.35
T_6:75% RDK + 1% RDK FS* (POLY4)	13.53	2.05	10.6	32.25	51.74
T_7:100% RDK (Schoenite)	10.80	1.75	10.4	33.78	53.63
T_8: 75% RDK + 1% RDK FS* (Schoenite)	13.33	2.06	10.1	32.57	51.94
T_9:75% RDK (MOP) +KSB	9.38	1.44	10.3	33.80	53.93
T_{10}:KSB	7.18	1.12	9.4	34.71	56.69

SEm±	0.68	0.12	0.20	0.62	0.57
CD (P=0.05)	2.03	0.36	0.71	1.85	1.70

* Foliar spray at 30 days after sowing and 30 days after fodder harvest

In this study, we also recorded lower NDF and ADF content in 75% RDK+ 1% RDK FS (30 DAS and 30 DAFH) through POLY4 (T_6) and 75% RDK+1% RDK FS (30 DAS and 30 DAFH) through schoenite (T_8) treatments. ADF decreased in the range of 5.27-10.41%, with the highest decreased being observed in T_6 (10.41%) as compared to T_1 (control) by the application of different potassium fertilizer sources. A similar trend was also recorded in NDF content. NDF content decreased in the range of 3.56- 10.82% as compared to the T_1 (control) treatment. The 1% RDK foliar application through POLY4 and schoenite recorded higher CP (T_6 and T_8) and lower ADF and NDF content than 100% soil application (T_5 and T_7). The increasing CP content in T_5 to T_9 treatments is due to the quick synthesis of carbohydrates and their conversion to protein and protoplasm, leaving just a smaller fraction for cell wall production since carbohydrates and N provide the backbone for protein synthesis, may be caused by increased N availability in soil [41]. The role of N in protein synthesis, the role of P in RNA synthesis, and the role of K in the activation of enzymes involved in protein synthesis could all be related to the greater CP content in T5 to T9 treatments. Additionally, in-creased sulphur triggers the creation of sulphur containing amino acids like cysteine and methionine as well as protein synthesis, all of which encourage an increase in the concentration of CP. These results are consistent with [42-45].

4. Conclusions

From this study, it may be summarized that the application of POLY4 showed a positive effect on crop growth, fodder yield, and quality of the oat crop. Crop growth parameters, viz.

plant height, number of tillers and green fodder yield (13.53 t/ha) of oat significantly increased due to the application of 75% RDK+ 1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through POLY4, which was at par with 75% RDK+ 1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through schoenite. In addition, the fodder quality parameters, viz. CP, ADF, and NDF were also significantly improved due to the application of 75% RDK+1% RDK foliar spray (30 days after sowing and 30 days after fodder harvest) through POLY4. Therefore, it can be recommended that application of 75% RDK+ 1% RDK foliar spray through POLY4 was more beneficial for achieving good quality higher green fodder in semi-arid tropics.

REFERNCES

1. Rahman, S. (2015). Green revolution in India: environmental degradation and impact on livestock. *Asian Journal of Water, Environment and Pollution*, *12*(1), 75-80.
2. Srivastava, P., Balhara, M., & Giri, B. (2020). Soil health in India: past history and future perspective. In *Soil Health* (pp. 1-19). Springer, Cham.
3. Singh, S., & Benbi, D. K. (2016). Punjab-soil health and green revolution: A quantitative analysis of major soil parameters. *Journal of Crop Improvement*, *30*(3), 323-340.
4. Cline, W. R. (2008). Global warming and agriculture. *Finance & Development*, *45*(001).
5. Hazra, B. S., & Tripathi, C. B. (1998). Effects of secondary and micronutrients in yield and quality of forages. Fertilizer News. 43(12), 77-89.
6. Pandey, D., Bhatnagar, A., Chandra, S., & Tewari, S. (2019). Soil nutrient balance under influence of differential placement of fertilizer doses and potassium splitting in maize (Zea mays L.). *Journal of Pharmacognosy and Phytochemistry*, *8*(4), 1568-1572.

7. Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. *International journal of molecular sciences*, *14*(4), 7370-7390.

8. Dobermann, A., Cassman, K. G., Mamaril, C. P., & Sheehy, J. E. (1998). Management of phosphorus, potassium, and sulfur in intensive, irrigated lowland rice. *Field Crops Research*, *56*(1-2), 113-138.

9. Hedlund, A., Witter, E., & An, B. X. (2003). Assessment of N, P and K management by nutrient balances and flows on peri-urban smallholder farms in southern Vietnam. *European Journal of Agronomy*, *20*(1-2), 71-87.

10. Malo, D. D., Schumacher, T. E., & Doolittle, J. J. (2005). Long-term cultivation impacts on selected soil properties in the northern Great Plains. *Soil and tillage research*, *81*(2), 277-291.

11. Brennan, R. F., & Bell, M. J. (2013). Soil potassium—crop response calibration relationships and criteria for field crops grown in Australia. *Crop and Pasture Science*, *64*(5), 514-522.

12. Naidu, L. G. K., Sidhu, G. S., Sarkar, D., & Ramamurthy, V. (2011). Emerging deficiency of potassium in soils and crops of India. *Karnataka Journal of Agricultural Sciences*, *24*(1).

13. Ramamurthy, V., Naidu, L. G. K., Chary, G. R., Mamatha, D., & Singh, S. K. (2017). Potassium status of Indian soils: need for rethinking in research, recommendation and policy. *International Journal of Current Microbiology and Applied Sciences*, *6*(12), 1529-1540.

14. Press Information Bureau (2015). Ministry of Chemicals and Fertilizers, Government of India. *Self–sufficiency in fertilizer production*.

15. Pasricha, N. S. (2002). Potassium dynamics in soils in relation to crop nutrition. *Journal of the Indian Society of Soil Science*, *50*(4), 333-344.

16. Indian Minerals Year book (2017). Potash, 56th Edition, Part- III: mineral reviews. *Government of India, Ministry of Mines, Indian Bureau of Mines Nagpur* 23, 1–5.

17. Rathore, S. S., Chaudhary, D. R., Vaisya, L. K., Shekhawat, K., & Bhatt, B. P. (2014). Schoenite and potassium sulphate: Indigenous potassic fertilizer for rainfed groundnut (Arachis hypogaea L.). *Indian Journal of Traditional Knowledge*, 13(1): 222-226.

18. Tiwari, D.D., Panday, S.B., & Katiyar, N.K. (2015). Effects of polyhalite as a fertilizer on yield and quality of the oilseed crops mustard and sesamum. International Potash Institute e-ifc. 42, 9-15.

19. Satisha, G. C., & Ganeshamurthy, A. N. (2016). Bioefficacy of polyhalite application on yield and quality of cabbage and cauliflower. *Electronic International Fertilizer Correspondent (e-ifc)*, (44), 21-31.

20. Tien, T. M., Trang, T. T. T., Ha, P. T. N., Chien, D. T., Thai, T. T., Thang, D. T., & Thu, T. T. M. (2020). Polyhalite effects on winter maize crop performance on degraded soil in Northern Vietnam. e-ifc Int. *Potash Inst*, *62*, 3-12.

21. Bhatt, R., Singh, P., Ali, O. M., Abdel Latef, A. A. H., Laing, A. M., & Hossain, A. (2021). Polyhalite positively influences the growth, yield and quality of sugarcane (*Saccharum officinarum* L.) in potassium and calcium-deficient soils in the semi-arid tropics. *Sustainability*, *13*(19), 10689.

22. Palsaniya, D. R., & Ahlawat, I. P. S. (2009). Sulphur management in pigeonpea (Cajanus cajan)--Wheat (Triticum aestivum) cropping system. *Indian Journal of Agronomy*, *54*(3), 272.

23. Rawat, A. & Agrawal, S.B. (2010). Effect of soil enrichment in conjugation with bio-organics and chemical fertilizers on yield and quality of fodder oat (*Avena sativa* L.). *Forage Research* 35: 190-192.

24. Prasad, M., Mahawer, S.K., Govindasamy, P. & Kumar, S. (2020). Assessment of soil fertility attributes in selected districts of Bundelkhand region of central India. *Current Journal of Applied Science and Technology* 39:326-334. https://doi.org/10.9734/cjast/2020/v39i4831238.

25. Prasad, M., Chaudhary, M., Ramakrishnan, S., Singh, H.V., Kumar, S. & Ghosh P.K., (2021). Impact of long term land use changes on carbon dynamics and soil quality in the semi arid bundelkhand region of India. *Fresenius Environmental Bulletin* 30: 2536–2544.

26. AOAC (Association of Official Analytical Chemists) 1995. Official Methods of Analysis. 15th ed. AOAC, Washington, DC.

27. Gomez, K.A., & Gomez, A.A. (1984). *Statistical procedures for agricultural research.* 2nd ed. John Wiley and Sons, New York.

28. SAS Institute (2011). SAS/STAT. Version 9.3 for windows. SAS Institute, Inc., Cary (NC, USA).

29. Marschner, H. (1995). Function of mineral nutrients: micronutrients. *Mineral nutrition of higher plants*. 2nd Ed., Academic Press, London, (pp.313-404).

30. EL Bassiony, A. M. (2006). Effect of potassium fertilization on growth, yield and quality of onion plant. *Journal of Applied Sciences Research*, 2 (10), 780-785.

31. El-Bassiony, A. M., Fawzy, Z. F., Abd El-Samad, E. H., & Riad, G. S. (2010). Growth, yield and fruit quality of sweet pepper plants (Capsicum annuum L.) as affected by potassium fertilization. *Journal of American Science*, *6*(12), 722-729.

32. Wolf, D. D., Kimbrough, E. L., & Blaser, R. E. (1976). Photosynthetic Efficiency of Alfalfa with Increasing Potassium Nutrition 1. *Crop Science*, *16*(2), 292-294.

33. El-Tohamy, W. A., El-Abagy, H. M., Badr, M. A., Abou-Hussein, S. D., & Helmy, Y. I. (2011). The influence of foliar application of potassium on yield and quality of carrot (Daucus carota L.) plants grown under sandy soil conditions. *Aust. J. Basic & Appl. Sci*, *5*(3), 171-174.

34. Subrahmanyam, S. V. S., & Raju, D. V. R. (2000). Influence of foliar feeding with water soluble speciality fertilizers on three vegetable crops. *Advances in Plant Sciences*, *13*(2), 589-594.

35. Pavuluri, K., Malley, Z., Mzimbiri, M. K., Lewis, T. D., & Meakin, R. (2017). Evaluation of polyhalite in comparison to muriate of potash for corn grain yield in the Southern Highlands of Tanzania. *African Journal of Agronomy*, *5*(3), 325-332.

36. Rathore, S. S., Chaudhary, D. R., Vaisya, L. K., Shekhawat, K., & Bhatt, B. P. (2014). Schoenite and potassium sulphate: Indigenous potassic fertilizer for rainfed groundnut (Arachis hypogaea L.). *Indian Journal of Traditional Knowledge*, 13(1): 222-226.

37. Ghosh, D., Sarkar, S., Brahmachari, K., Garai, S., Pal, M., & Sharma, A. (2017). Potassium schoenite: an emerging source of potassium for improving growth, yield and quality of potato. *Journal of Experimental Biology and Agricultural Sciences*, *5*, 173-182.

38. Nelson, K. A., Motavalli, P. P., & Nathan, M. (2005). Response of no-till soybean [Glycine max (L.) Merr.] to timing of preplant and foliar potassium applications in a claypan soil. *Agronomy Journal*, *97*(3), 832-838.

39. Sutradhar, A., Kaiser, D. E., & Rosen, C. J. (2016). Evaluation of polyhalite as a source of potassium and sulfur for a corn-soybean rotation in Minnesota. In *Proceedings of the 46th North Central Extension-Industry Soil Fertility Conference* (Vol. 32, pp. 125-135).

40. Milev, G. (2014). Effect of foliar fertilization on nodulation and grain yield of pea (Pisum sativum L.). *Türk Tarım ve Doğa Bilimleri Dergisi*, *1*(Özel Sayı-1), 668-672.

41. Russell, E.W. (1973). Soil conditions and plant growth .The English language book Society and Longman, London, Tenth edition, 31-36.

42. Bhalerao, P.D., & Gaikwad, G.S. (2010).Effect of nutrient sources on productivity and sustainability of seed cotton yield under rainfed condition. *Dr. Punjabrao Deshmukh Krishi Vidyapeeth Research Journal.* 35(1), 66-70.

43. Bhalerao, P.D., & Gaikwad, G.S. (2011). Response of deshi and american cotton to potassium under rainfed conditions. *Dr. Punjabrao Deshmukh Krishi Vidyapeeth Research Journal*. *35*(1), 59-62.

44. Sarkar, R. K., & Mahasin, M. D. (2007). Productivity, quality and profitability of oat (Avena sativa)-based intercropping system under graded fertility levels. *Indian journal of agricultural science*, *77*(12), 862-865.

45. Parlawar, N. D., Giri, M. D., Raut, R. S., & Katkar, R. N. (2018). Response of Bt Cotton (Gossypium hirsutum L.) to Sulphur application under rainfed conditions. *Journal of Pharmacognosy and Phytochemistry*, *7*(1), 1694-1698.