Indian Journal of Agronomy **64** (3): 341–347 (September 2019)

Research Paper

Growth and productivity of wheat (*Triticum aestivum*) as influenced by potassium application

S. VIJAYAKUMAR[1], DINESH KUMAR[2], Y.S. SHIVAY[3], ANJALI ANAND[4], D.K. SHARMA[5], V.K. SHARMA[6] AND V. GOVINDASAMY[7]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received : June 2017; Revised accepted : March 2019

ABSTRACT

A field experiment was conducted during winter (*rabi*) seasons of 2015–16 and 2016–17 at New Delhi to assess the effects of rate, methods, time and sources of potassium (K) fertilization on wheat (*Triticum aestivum* L.) growth, growth indices, yield and returns from investment on K. Application of 60 kg K_2O/ha in 2 splits, half basal and remaining half at spike initiation stage or 75% basal and remaining 25% at spike initiation stage increased the grain yield (5.5 t/ha) by 8.8% over applying entire dose as basal. The split application of recommended dose of K (RDK) also increased the growth parameters (plant height, dry-matter, leaf area index) and growth indices [crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR)] significantly over control. All the growth parameters and growth indices were recorded the highest with 75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 (68.8 kg K_2O/ha), whereas control recorded the lowest. A strong positive and significant correlation was observed between dry matter production and grain yield during 90 days after sowing (DAS) (R^2=0.76) and 120 DAS (R^2=0.74). Similarly, positive and significant correlation was also observed between LAI and grain yield during 90 DAS (R^2=0.72) and 120 DAS (R^2=0.71). The highest returns from investment on K fertilizer was obtained with 2 foliar spray of 2.5% KNO_3, whereas 150% RDK as basal gave the lowest returns. Application of 60 kg K_2O/ha in 2 splits (50:50 or 75:25 ratio) increased returns from investment on K ₹4 by over application of entire dose as basal. Thus, for wheat, application of 60 kg K_2O/ha in 2 equal splits (50% as basal + 50% at spike initiation) is recommended to realize maximum benefit from K fertilization.

***Key words* :** Growth analysis, Growth parameters, Potassium, Wheat, Yields

India is the second largest producer and consumer of wheat in the world. It is the second most important food crop of India after rice. The production of wheat is mainly confined to the Indo-Gangetic Plains (IGP) Region, and 3 northern states, namely Uttar Pradesh, Punjab and Haryana, which together account 72% of India's total wheat production (Tripathi and Mishra, 2017). However, in recent years, the productivity of wheat is decreasing due to soil degradation (Bhandari *et al*., 2002), imbalance and inadequate fertilizer application, delayed sowing of wheat, increased irrigation demand (Humphreys *et al*., 2010), and terminal heat stress. The declining wheat productivity has threatened the country's food security.

Among the major plant nutrients, potassium (K) assumes greater significance since it is required in relatively larger quantities by plants and besides increasing the yield, it immensely improves the quality of the economic produce and tolerance to various stresses. In India, unlike nitrogen and phosphorus, recommendation of K is made as a maintenance dose. In general, 40–60 kg K_2O/ha is recommended, which is far less than the amount of K removed by rice and wheat, especially when the crop residues are not recycled back. As a result, rice–wheat cropping system (backbone of country's food security) is running in negative K balance (Vijayakumar *et al.,* 2019). The imbalanced fertilization was practiced in rice–wheat cropping system (RWCS) for more than 5 decades. In RWCS the application of nitrogen and phosphorus often exceed the recommended dose, whereas K application is omitted

Based on a part of the Ph.D. Thesis of the first author, submitted to the ICAR-Indian Agricultural Research Institute, New Delhi (Unpublished)

---

[1]**Corresponding author's Email:** vijitnau@gmail.com

[1]Scientist, Crop Production Division, ICAR-National Rice Research Institute, Cuttack, Odisha 453 006, [2,]Principal Scientist, [3]Ex-Professor and Principal Scientist, Division of Agronomy, [4]Principal Scientist, Division of Plant Physiology, [5]Principal Scientist, CESCRA, [6]Senior Scientist, Division of Soil Science and Agricultural Chemistry, [7]Scientist, Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Table 1. Detail of treatments

Treatment	Treatment details	K dose (kg K_2O/ha)
T_1	No K (control)	0
T_2	100% RDK as basal	60
T_3	50% RDK as basal	30
T_4	50% as basal + 50% at spike initiation	60
T_5	75% as basal + 25% at spike initiation	60
T_6	2 foliar spray of 2.5% KNO_3	8.8
T_7	100% RDK as basal + 2 foliar spray of 2.5% KNO_3	68.8
T_8	50% RDK as basal + 2 foliar spray of 2.5% KNO_3	38.8
T_9	75% RDK as basal + 2 foliar spray of 2.5% KNO_3	53.8
T_{10}	50% RDK as basal + 50% at spike initiation + 2 foliar spray of 2.5% KNO_3	68.8
T_{11}	75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3	68.8
T_{12}	150% RDK as basal	90

or applied at sub-optimal dose (Singh *et al*., 2005). The native soil potassium reserve are depleting at alarming rate each year due to K omission. The negative K balance was found in the range of 103–215 kg/ha and 63–157 kg/ha in Pantnagar and Ludhiana, respectively. The removal of K is more in intensively cultivated areas because of higher productivity and burning of rice straw (Bijay-Singh *et al*., 2003). Decline in crop yield due to lack of K supply was reported even in K rich soils like Vertisols (Srinivasarao *et al*., 2011; Singh and Wanjari, 2012). Furthermore, the inadequate supply of K also limits the responses to applied N and P fertilizer (Hegde and Babu, 2004; Prasad *et al*., 2004). Many long-term fertilizer experiments, claims that maintaining a balance between nutrient addition and removal in RWCS is essential for achieving the sustainability of the system (Singh *et al*., 2002). Judicious use of fertilizers depending upon the soil fertility status is the key to make RWCS sustainable (Bhatt, 2013).

Appropriate nutrient management will ensure optimum supply of nutrients to plants besides maintaining soil nutrient balance. Hence, fertilization based on 4R nutrient stewardship (right dose, right time, right method, right source and right proportion) is the key to sustain its productivity on long-term basis. Therefore, it is essential to find out optimum dose, time, method and source of K application in wheat to increase productivity, profitability and sustainability, for which a 2-year field experiment was conducted.

MATERIALS AND METHODS

A two-year field experiment was conducted during winter (*rabi*) seasons of 2015–16 and 2016–17 at research farm of ICAR-Indian Agricultural Research Institute (IARI), New Delhi, situated at a latitude of 28°40'N and longitude of 77°12'E and at an altitude of 228.6 m above the mean sea level. The climate of site is semi-arid type with hot and dry summer and cold winter with mean annual normal rainfall of 650 mm, of which 80% is received through south-west monsoon during July-September. The soil of experimental plot was sandy clay loam in texture with 7.5 *p*H, 0.32 dS/m EC, 0.55% OC available N-201 kg/ha (Subbiah and Asija, 1956), available P-12.8 kg/ha (Olsen *et al*., 1954) and available K-213.8 kg/ha (1 N NH_4OAc-extractable K) (Hanway and Heidel, 1952).

Field experiment was conducted in 3 times replicated randomized block design with 12 treatments (Table 1). First foliar spray was given at active tillering stage and second spray was given at spike initiation stage. For foliar spray, 2.5% potassium nitrate (KNO_3) solution was prepared by dissolving 10 kg KNO_3 (Krista K) -in 400 liters of water. So, for 2 sprays of 2.5% KNO_3 20 kg KNO_3 is used. 20 Kg KNO_3 supplies 2.6 Kg NO_3-nitrate nitrogen since it has 13% N. So to compensate this NO_3-N, we sprayed 16.8 kg $CaNO_3$ which is equal to 2.6 kg NO_3-N in those treatments, where KNO_3 was not sprayed. First foliar spray was given at active tillering (45-50 DAS) and second spray was given at spike initiation stage (75–80 DAS).

During both the years of experiment, the wheat cultivar 'HD2967' was sown using seed drill and harvested in the mid of November and April respectively with the row spacing of 22.0 cm and seed rate of 100 kg/ha. The recommended dose of N (120 kg/ha) was applied in 3 splits by applying one-third at 10 DAS, one-third at tillering (45–50 DAS) and remaining one-third at spike initiation stage (75–80 DAS). The entire dose of phosphorus (60 kg P_2O_5/ha) was incorporated into the soil as basal just before sowing of the crop. The nitrogen and phosphorus was applied by broadcast method through urea and single super phosphate (SSP). Potassium was applied based on treatments. In total, 6 irrigations were given every year. Crop was harvested manually and after threshing, cleaning and drying, the grain yield of wheat was measured at 14% moisture content and expressed in t/ha. Remaining all other cultural practices were carried out according to standard recommendations.

Data of plant height was collected at 30 days interval from sowing to harvest from 5 randomly selected plants in the net plot area of each treatment. The plant height (cm) was measured using wooden scale from the ground surface to the tip of the tallest leaf and the mean value was considered for analysis. For computing LAI, leaves from 5 plants were collected and cleaned with water and then wiped with tissue paper. Using a leaf area meter (Model LICOR 3000, USA), the area of fresh green leaves was measured and expressed in cm^2/plant. While placing the leaf on the roller utmost care was taken to avoid overlapping of the leaf. LAI was calculated using the following formula (Evans, 1972).

$$\text{LAI} = \frac{\text{Total leaf area (cm}^2\text{)/plant}}{\text{Ground area (spacing cm}^2\text{)/plant}}$$

Plants from one-meter row length were cut near the ground surface for dry-matter estimation from each treatment, at 30 days interval from sowing to harvest. The whole plants along with leaf in 1 m^2 area were collected and shade dried for 7 days and then oven dried at $65\pm5^{\circ}C$ for one week. The dry weight was recorded with the help of electronic balance and expressed in g/m^2. The recorded dry weight data at 30 days interval was used to calculate the mean crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR). The mean CGR, RGR and NAR was worked out with the following formulas (Watson *et al*., 1952) and expressed as g/m^2 land area/day, mg/g dry matter/day and g/m^2 leaf area/day respectively.

$$\text{Mean CGR} = \left(\frac{W_2 - W_1}{T_2 - T_1}\right)\left(\frac{1}{S}\right)$$

$$\text{Mean RGR} = \frac{\text{Ln}W_2 - \text{Ln}W_1}{T_2 - T_1}$$

$$\text{Mean NAR} = \left(\frac{W_2 - W_1}{LA_2 - LA_1}\right)\left(\frac{\text{Ln}LA_2 - \text{Ln}LA_1}{T_2 - T_1}\right)$$

Where, W_1 and W_2 are the dry weight of plants in g at the time of T_1 and T_2 respectively; LA_1 and LA_2 are the leaf area in m^2 at the time of T_1 and T_2 respectively; T_1 and T_2 are the time interval in days; S is the land area occupied by plants in m^2. Ln is the natural logarithm.

Return on investment (ROI) on K was calculated using standard formula.

$$\text{ROI on K fertilizer} = \frac{\text{Yield increase due to K fertilizer (kg/ha)} \times \text{MSP of crop (₹/kg)}}{\text{Applied } K_2O \text{ (kg/ha)} \times \text{Cost of } K_2O \text{ (₹/kg)}}$$

All the data were subjected to one-way analysis of variance (ANOVA) using the general linear model procedures of the Statistical Analysis System (SAS Institute, Cary, NC). The F-test was used to determine significant effects of the K fertilization and least significant difference (LSD) was used to compare means.

RESULTS AND DISCUSSION

Growth parameters

Study of growth parameters reflects the growth behavior of wheat plant in response to K fertilization. The plant height and dry-matter production was found non-significant up to 60 days after sowing (DAS), whereas leaf area index (LAI) was found non-significant up to 30 DAS (Table 2). The progressive increase in plant height and dry-matter production was observed up to harvest of wheat crop, whereas LAI increased up to 90 DAS, beyond that it started declining. On pooled average basis, treatment T_7 (100% RDK as basal + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha), recorded the highest plant height, however, it remained at par with most of the treatments except T_6 (2 foliar spray of 2.5% KNO_3), T_3 (50% basal), T_1 (control). The dry-matter production of wheat increased greatly with the advancement of crop age and it showed quadratic pattern of growth. The maximum dry-matter production was recorded at harvesting stage. Various rate, sources, time and method of K application showed non-significant difference on dry-matter production up to 60 DAS. Whereas, at 90 DAS, it showed significant difference and the maximum dry-matter production was recorded in T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha) which remained at par with T_4, T_7, T_9, T_{10}, and T_{12}. During 120 DAS and harvest the dry matter production was found in the order of $T_{11} > T_4 = T_7 = T_9 = T_{10} = T_{12} > T_2 = T_5 = T_8 > T_6 > T_1$. It clearly shows that the dry-matter production of wheat significantly increased by split application of 60 kg K_2O and 2 foliar spray of 2.5% KNO_3. In general, the LAI remained same in most of the treatments except T_1 (control), T_3 (50% basal), and T_6 (2 foliar spray). The LAI was found in the order of $T_2 = T_4 = T_5 = T_7 = T_8 = T_9 = T_{10} = T_{11} = T_{12} > T_3 = T_6 > T_1$. LAI indicates the size of the assimilatory system of the crop. A strong positive and significant correlation (Fig. 1, 2) was observed between dry-matter production and grain yield during 90 DAS (R^2=0.76) and 120 DAS (R^2=0.74). Similarly, strong positive and significant correlation (Fig. 3, 4) was observed between LAI and grain yield during 90 DAS (R^2=0.72) and 120 DAS (R^2=0.71). Bednarz *et al*. (1998) reported that, the LAI and sunlight interception both were reduced dramatically when the supply of K fell below the required level. Thus, increased photosynthesis might have increased dry-matter of wheat plant. Zelelew *et al*. (2016)

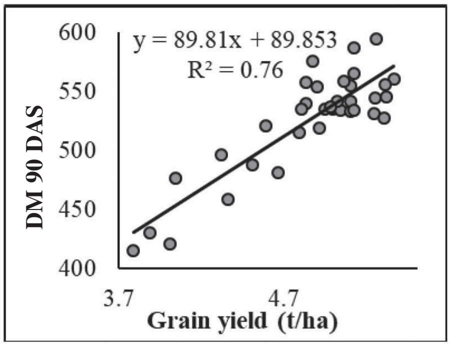

Fig. 1. Dry-matter 90 DAS vs grain yield

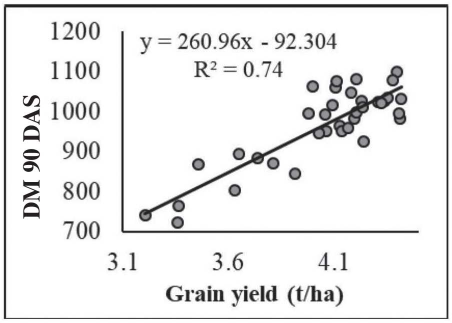

Fig. 2. Dry matter 120 DAS vs grain yield

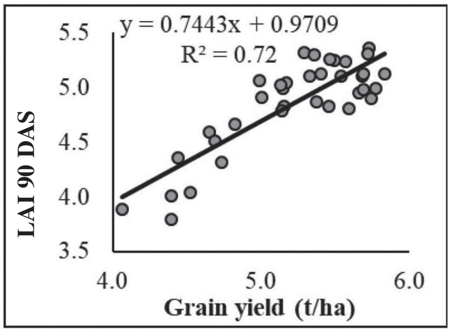

Fig. 3. LAI 90 DAS and vs grain yield

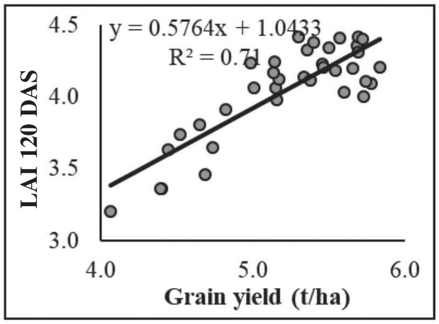

Fig. 4. LAI 120 DAS vs grain yield

reported that the plant height, aerial stem number, and leaf number/plant increased with the increasing K levels from 0 kg to 150 kg/ha. Similarly, Gerardeaux *et al*., (2010) reported that the deficiency of K during vegetative stage of cotton reduced the plant dry matter production, leaf area, and internode size, which leads to a reduction in plant growth. The deficiency of potassium in T_1 (control), T_3 (50% basal) and T_6 (2 foliar spray) reduces the fixation of CO_2 and production of photosynthates, which eventually reduces crop yield. Pettigrew (2008); Zorb *et al*. (2014); Lu *et al*. (2016) and Waraich *et al*. (2011) reported that in potassium deficit plant, photosynthesis is reduced due to reduced CO_2 fixation.

Table 2. Effect of K application on growth parameters of wheat (pooled data of 2 years)

Treatment	Plant height (cm)			Dry-matter (g/m^2)			Leaf-area index		
	90 DAS	120 DAS	Harvest	90 DAS	120 DAS	Harvest	60 DAS	90 DAS	120 DAS
T_1	79	86	88	422	742	949	1.92	3.90	3.31
T_2	90	100	104	544	973	1,285	2.22	4.96	4.09
T_3	86	94	97	499	870	1,122	2.11	4.52	3.79
T_4	90	100	103	544	1028	1,323	2.22	5.14	4.21
T_5	89	101	104	538	976	1,251	2.20	5.08	4.22
T_6	85	93	95	474	852	1,085	2.01	4.30	3.61
T_7	93	103	106	561	1033	1,322	2.33	5.10	4.25
T_8	88	99	102	522	942	1,273	2.04	4.93	4.15
T_9	89	101	103	541	1034	1,333	2.23	5.11	4.28
T_{10}	89	100	102	542	1024	1,328	2.21	5.14	4.28
T_{11}	90	102	105	565	1080	1,389	2.26	5.11	4.30
T_{12}	93	104	105	557	1026	1,304	2.27	4.97	4.14
SEm±	2.90	3.86	3.64	12.88	22.12	23.95	0.10	0.15	0.11
CD (P=0.05)	6.00	8.00	7.55	26.71	45.87	49.68	0.20	0.31	0.23

T_1, No K (control); T_2, 100% RDK as basal; T_3, 50% RDK as basal; T_4, 50% as basal + 50% at spike initiation; T_5, 75% as basal + 25% at spike initiation; T_6, 2 foliar spray of 2.5% KNO_3; T_7, 100% RDK as basal + 2 foliar spray of 2.5% KNO_3; T_8, 50% RDK as basal + 2 foliar spray of 2.5% KNO_3; T_9, 75% RDK as basal + 2 foliar spray of 2.5% KNO_3; T_{10}, 50% RDK as basal + 50% at spike initiation + 2 foliar spray of 2.5% KNO_3; T_{11}, 75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3; T_{12}, 150% RDK as basal

Growth indices

On pooled average basis, the CGR was found non-significant up to 60 DAS (Table 3). Whereas at 61–90 DAS, 91–120 DAS and 121-harvest, the CGR was highest in T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha) and it remained at par with T_4, T_7, T_9 and T_{10}. It shows the rate of dry-matter production/unit land area was increased by split application of K or supplementation of K through foliar spray in addition to basal application. The RGR was found non-significant up to 30 DAS, after that it showed significant difference up to harvest of the crop. At 61-90 DAS, the highest RGR was found in T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha), however, it remained at par with all other treatments except T_1 (control) and T_6 (2 foliar spray). Whereas during 91–120 DAS and 121 DAS-harvest, treatment T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha) recorded the highest RGR which remained at par with T_4, T_7, T_9 and T_{10}. The NAR was found non-significant up to 60 DAS (Table 3). Whereas during 61–90 DAS, T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha) recorded the highest NAR and it remained at par with T_2, T_4, T_5, T_7, T_9, T_{10} and T_{12}. Similarly, at 121 DAS–harvest the maximum NAR was recorded in T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3 = 68.8 Kg K_2O/ha), however it remained at par with T_4, T_7, T_9 and T_{10}. It shows that the RGR and NAR of wheat increased by supplying K in later stage either by foliar spray or top dressing. This may be due better translocation of stored photosynthates of stem and leaf to grain. K has role in translocation of photosynthates from source to sink (Hartt, 1969). These results were in close conformity with the findings of Zheng *et al*. (2010); Uddin *et al*. (2013) and Kumar *et al*. (2016). K application at the time of sowing may have increased the N availability by reducing the NH_4 fixation in the soil. Thus, the basal application of higher dose of K in T_2 (100% basal), T_7 (100% basal + 2 foliar spray), T_{11} (75% basal + 25% spike initiation + 2 foliar spray), T_{12} (150% basal + 2 foliar spray) allows K ions to occupy the non-exchangeable sites and thereby decrease the interspace available for NH_4 fixation (Raju and Mukhopadhyay, 1975; Badhe *et al*., 1976) and increase N concentration in the soil solution. The increased N availability might have increased plant height and dry-matter production, which subsequently increased CGR, RGR and NAR.

Yield and economics

The grain and straw yields of wheat were found in the range of 4.28 to 5.62 t/ha and 5.67 to 6.47 t/ha respectively (Table 3). On pooled average basis, the highest grain yield was recorded in T_{11} (75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3), which remained at par with T_4, T_5, T_7, T_9 and T_{10}. Treatments viz. T_4, T_5, T_7, T_9, T_{10} and T_{11} increased the grain yield by 9% and 18% over T_2 (100% basal) and T_3 (50% basal) respectively. The

Table 3. Effect of K application on crop growth rate and relative growth rate of wheat (pooled data of 2 years)

Treatment	Crop growth rate (g/m² land area/day)			Relative growth rate (mg/g dry-matter/day)			Net assimilation rate (g/m² leaf area/day)		Grain yield (t/ha)	ROI in K fertilizer
	61–90 DAS	91–120 DAS	121–Harvesting	61–90 DAS	91–120 DAS	121–Harvesting	91–120 DAS	121–Harvesting		
T_1	6.7	10.7	6.9	21.8	18.9	8.2	1.7	3.3	4.28	–
T_2	10.2	14.3	9.2	27.5	19.4	8.3	2.1	3.5	5.15	7.7
T_3	9.0	12.4	8.4	25.8	18.5	8.5	2.0	3.3	4.73	7.9
T_4	10.4	16.2	10.4	28.3	21.3	9.3	2.0	3.9	5.59	11.5
T_5	10.2	14.6	9.8	28.0	19.9	8.4	2.0	3.6	5.57	11.4
T_6	8.3	12.6	7.8	24.7	19.5	8.0	1.9	3.5	4.55	15.4
T_7	10.8	15.7	10.3	28.6	20.4	8.4	2.1	3.9	5.60	10.2
T_8	9.6	14.0	9.6	26.7	19.8	8.2	2.0	3.4	5.16	12.0
T_9	10.3	16.4	10.0	28.1	21.7	8.5	2.0	3.7	5.58	12.7
T_{10}	10.4	16.1	10.1	28.5	21.3	8.7	2.0	3.8	5.61	10.2
T_{11}	11.1	17.1	11.0	29.8	21.6	10.1	2.2	4.0	5.62	10.3
T_{12}	10.6	15.7	9.2	28.3	20.4	8.0	2.1	3.8	5.17	5.2
SEm±	0.41	0.57	0.52	1.54	0.69	0.51	0.09	0.17	0.137	0.74
CD (P=0.05)	0.85	1.17	1.08	3.20	1.43	1.06	0.18	0.35	0.284	1.55

T_1, No K (control); T_2, 100% RDK as basal; T_3, 50% RDK as basal; T_4, 50% as basal + 50% at spike initiation; T_5, 75% as basal + 25% at spike initiation; T_6, 2 foliar spray of 2.5% KNO_3; T_7, 100% RDK as basal + 2 foliar spray of 2.5% KNO_3; T_8, 50% RDK as basal + 2 foliar spray of 2.5% KNO_3; T_9, 75% RDK as basal + 2 foliar spray of 2.5% KNO_3; T_{10}, 50% RDK as basal + 50% at spike initiation + 2 foliar spray of 2.5% KNO_3; T_{11}, 75% RDK as basal + 25% at spike initiation + 2 foliar spray of 2.5% KNO_3; T_{12}, 150% RDK as basal highest returns on investment (RIO) in K fertilizer were obtained in T_6 (2 foliar spray) whereas T_{12} (150% basal) gave the lowest returns. The ROI in K was found in the order of $T_6 > T_4=T_5 > T_8=T_9 > T_7 > T_{10}=T_{11} > T_2=T_3 > T_{12}$. The ROI in K was in the range between of 5.2 to 15.4/₹ investment in K. The highest ROI in K on T_6 (2 foliar spray) was due to very low amount of K fertilizer application and higher yield improvement. The lowest ROI in K in T_{12} (150% basal) is due to higher dose of K application and lower grain yield improvement. Thus, the time and method of K application is very important than K application itself.

Based on two years of study, it is found that application of K influences plant growth, growth indices and yield positively. The basal application of entire RDK at the time of sowing is not beneficial as compared to split application. In order to realize maximum benefit from K application the RDK (60 kg K_2O/ha) should be applied in 2-split at the ratio of 50 : 50 or 75 : 25 as basal and spike initiation, respectively.

REFERENCES

Badhe, M.N., Begum, M. and Varade, S.B. 1976. Effect of potassic fertilizers on ammonium fixation in soils of Marathwada. (In) *Bulletin 10. Indian Soil Science Society, New Delhi, India*. pp. 103–106.

Bednarz, C.W., Oosterhuis, D.M., Evans, R.D. 1998. Leaf photosynthesis and carbon isotope discrimination of cotton in response to potassium deficiency. *Environmental and Experimental Botany* **39**: 131–139.

Bhandari, A.L., Ladha, J.K., Pathak, H., Padre, A.T., Dawe, D. and Gupta, R.K. 2002. Yield and soil nutrient changes in a long term rice–wheat rotation in India. *Soil Science Society of America Journal* **66**: 162–170.

Bhatt, R. 2013. Soil test based fertilization to improve production of oilseed crops in Kapurthala district of Punjab. *International Journal of Science and Environment Technology* **2**(3): 521–526.

Bijay-Singh., Yadvinder-Singh., Imas, P. and Xie. J.C. 2003. Potassium nutrition of the rice–wheat cropping system. *Advances in Agronomy* **81**: 203–259.

Evans, G.C. 1972. Quantitative analysis of growth. Blackwell Scientific Publication Oxford, London.

Gerardeaux, E., Jordan-Meille, L., Constantin, J., Pellerin, S. and Dingkuhn, M. 2010. Changes in plant morphology and dry matter partitioning caused by potassium deficiency in *Gossypium hirsutum* L. *Environment and Experimental Botany* **67**: 451–459.

Hartt, C.E. 1969. Effect of potassium deficiency upon translocation of 14C in attached blades and entire plants of sugarcane. *Plant Physiology* **44**: 1,461–1,469.

Hegde, D.M. and Babu, S.N.S. 2004. Balanced fertilization for nutritional quality in oilseeds. *Fertilizer News* **49**(4): 52–93.

Humphreys, E., Kukal, S.S., Christen, E.W., Hira, G.S., Singh, B., Yadav, S. and Sharma, R.K. 2010. Halting the groundwater decline in north-west India-which crop technologies will be winners? *Advances in Agronomy* **109**: 156–199.

Kumar, M., Sarangi, A., Singh, D.K., Rao, A.R. and Sudhishri, S. 2016. Response of wheat cultivars to foliar potassium fertilization under irrigated saline environment. *Journal of Applied and Natural Science* **8**(1): 429 – 436.

Lu, Z., Lu, J., Pan, Y., Lu, P., Li, X., Cong, R. and Ren, T. 2016. Anatomical variation of mesophyll conductance under potassium deficiency has a vital role in determining leaf photosynthesis. *Plant Cell and Environment* **39**: 2,428–2,439.

Pettigrew, W.T. 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Plant Physiology* **133**: 670–681.

Prasad, R., Kumar, D., Sharma, S.N., Gautam, R.C. and Dwivedi, M.K. 2004. Current status and strategies for balanced fertilization. *Fertilizer News* **49**(12): 73–80.

Raju, G.S.N. and Mukhopadhyay, A.K. 1975. Each of the sequence of addition of K and NH_4 and pre-absorbed cations on fixation of applied NH_4 ions in soils. *Journal of Indian Society of Soil Science* **23**(2): 172–176.

Singh, A.K., Choudhury, B.U. and Bouman, B.A.M. 2002. Effects of rice establishment methods on crop performance, water use, and mineral nitrogen. (In) Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, B., Tuong, T.P., Ladha, J.K. (Eds.). *Proceedings of the International Workshop on Water-wise Production*. International Rice Research Institute, Los Baños, Philippines, pp. 237–246.

Singh, M. and Wanjari, R.H. 2012. All India Coordinated Research Project on Long-Term Fertilizer Experiments to study changes in soil quality, crop productivity and sustainability. AICRP-LTFE. Indian Institute of Soil Science, Bhopal. *Annual Report*-2010-11, pp.1–114.

Singh, V.K., Dwivedi, B.S., Shukla, A.K., Chauhan, Y.S. and Yadav, R.L. 2005. Diversification of rice with pigeon pea in a rice-wheat cropping system on a Typic Ustochrept: Effect on soil fertility, yield and nutrient use efficiency. *Field Crops Research* **92**: 85–105.

Srinivasarao, Ch., Satyanarayana, T. and Venkateswarlu, B. 2011. Potassium mining in Indian Agriculture: Input and output balance. *Karnataka Journal of Agriculture Sciences* **24**: 20–28.

Tripathi, A. and Mishra, A.K. 2017. The Wheat Sector in India: Production, Policies and Food Security. (In) Gomez y Paloma S., Mary S., Langrell S., Ciaian P. (Eds). *The Eurasian Wheat Belt and Food Security*. Springer, Cham.

Uddin, S., Sarkar, M.A.R. and Rahman, M.M. 2013. Effect of nitrogen and potassium on yield of dry direct seeded rice cv. NERICA 1 in aus season. *International journal of Agronomy and Plant Production* **4**: 69–75.

Vijayakumar, S., Kumar, D., Shivay, Y.S., Anand. A., Saravanane, P., Poornima, S., Jinger, D. and Singh, N. 2019. Effect of potassium fertilization on growth indices, yield attributes and economics of dry direct seeded basmati rice (*Oryza sativa* L.). *Oryza* **56**(2): 214–220.

Waraich, E.A., Ahmad, R., Hur, R.G.M., Ahmad, A. and Mahmood, N. 2011. Response of foliar application of KNO_3 on yield, yield components and lint quality of cotton (*Gossypium hirsutum* L.). *African Journal of Agricultural Research* **6**: 5,457–5,463.

Zelelew, D.Z., Lal, S., Kidane, T.T. and Ghebreslassie, B.M. 2016. Effect of potassium levels on growth and productivity of potato varieties. *American Journal of Plant Science* **7**: 1,629–1,638.

Zheng, Y., Xu, X., Simmons, M., Zhang, C., Gao, F. and Li, Z. 2010. Responses of physiological parameters, grain yield, and grain quality to foliar application of potassium nitrate in two contrasting winter wheat cultivars under salinity stress. *Journal of Plant Nutrition and Soil Science* **173**: 444–452.

Zorb, C., Senbayram, M. and Peiter, E. 2014. Potassium in agriculture-Status and perspectives. *Journal of Plant Physiology* **171**: 656–669.