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Growth Behaviour of Safflower under Different Potassium Levels

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Abstract: Safflower is an important multipurpose oilseed crop cultivated in a wide range of ecological habitats in many parts of the world. Nutritional requirements of this plant have not been fully analysed and success in its yield enhancement programmes has not been achieved yet. This paper reports the results of graded doses of potassium in presence of static dose of nitrogen and phosphorus on growth and yield of safflower. Higher potassium supplementation resulted in higher dry matter percentage, early onset of the reproductive stage and enhancement in yield. Lesser quantities of nitrogen and phosphorus fertilizers were required under optimum potassium application. From this study it can be concluded that the optimum potassium fertilization can be employed in place of heavy fertilizer use for sustainable and eco-friendly production of safflower with enhancing yield.

Key words: *Carthamus tinctorius* · Fertilizers · Leaf area · Sustainable agriculture · Yield

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is an important but underutilized multi-purpose oil seed crop belonging to family Asteraceae. A highly branched annual herb native to Mediterranean countries and Central Asia, safflower has globular flower heads (capitula) and a strong tap root system which enables it to utilize nutrients from below the root zone of other crops. It was primarily grown for the production of carthamine and safflower yellow, the dye used in cotton, wool and silk industries, but now it is mainly cultivated for its multipurpose oil and for producing medicines [1]. Presence of very high linoleic acid content in comparison to other commercial oilseed crops is a unique trait of safflower [2]. Safflower varieties rich in linoleic acid (70% and above) are used for edible oil products which is thought to decrease blood cholesterol and the related circulatory problems, while the varieties rich in oleic acid (70% and above) serve as drying or semidrying oil for various paints [2]. Regarding its production in 2010, India (171000 MT) occupied the top position followed by Kazakhistan (122240 MT) and USA (100400 MT) [3]. As regards the safflower statistics in the last decade (2001-10), lowest yield (370.7 kg ha^{-1}) in India was obtained in 2004 and highest (685.7 kg ha^{-1}) in 2007 (Table 1). A yield increase of 36.25% was observed in the second half (2006-10; average yield was 645.42 kg ha^{-1}) of the last decade as compared to its first half (2001-05; average yield was 473.70 kg ha^{-1}) [3]. Productivity of this crop in India (e.g., 631.9 kg ha^{-1} in 2010) and other Asian countries is much low in comparison to the world average (823.0 kg ha^{-1} as of 2010) and hence, a need was felt for the up-gradation of this commercial crop.

Macronutrient affect primary as well as secondary metabolism in plants [4-8] resulting into yield enhancement in crop plants. Among the macronutrients, the quality element potassium (K) makes up to 5% of a plant's dry weight and is essential for plant growth and development [9, 10]. Potassium is essential for many physiological processes like enzyme activation, protein synthesis, photosynthesis and translocation of photosynthates [10, 11]. It mediates osmoregulation, maintains the cation-anion balance in the cytosol as well as in the vacuole and regulates stomatal movements [12]. Application of K to plants affects their physiological and biochemical behaviour [13] and finally improves their productivity [14]. Under its deficiency, root and shoot elongation is hampered [15]. Consequently, an inadequate K supply from the soil is one of the factors limiting agricultural production due to a corresponding decrease in chlorophyll content and a depression in photosynthetic rate. K application increases nutrient use efficiency of

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Table 1: Area harvested, yield and production of safflower in India in the last decade (2001-2010)

Year	Area Harvested (ha)	Yield (kg ha^{-1})	Production (tonnes)
2001	424800	475.5	202000
2002	404300	568.9	230000
2003	369500	483.1	178500
2004	363900	370.7	134900
2005	369100	470.3	173600
2006	364600	627.0	228600
2007	350000	685.7	240000
2008	344842	652.5	225000
2009	300000	630.0	189000
2010	270600	631.9	171000
Average	356164	559.6	197260

Source: FAOSTAT, 2012

nitrogen (N) and phosphorus (P) of crops and therefore facilitates pollution alleviation [17, 18]. Safflower is able to meet its major nutrient requirements by drawing them (particularly, N) from deep in the subsoil and in this way also minimize nitrate leaching to groundwater [19]. Indian soils are moderately deficient in potassium and poor in terms of safflower yield. The objective of this study was to pave a way in reducing the negative environmental impacts of major inorganic fertilizers by reducing their application rate under an appropriate K application and the corresponding impact on the production of safflower.

MATERIALS AND METHODS

Plant Material and Field Experiments: All experiments were carried out in the Experimental Farm of Jamia Hamdard, New Delhi. Seeds were procured from Herbal Garden, Jamia Hamdard, New Delhi. The soil of the experimental field was sandy loam. The soil N, P and K levels of the experimental site were 128 kg ha^{-1}, 14 kg ha^{-1}, 119 kg ha^{-1}, respectively. Soil pH was 7.1. The organic carbon content of the soil was 0.28% (w/w). The experiments were carried out during 2011-12 growth season. Four fertilizer treatments [$N_{60}P_{30}K_0$ (60 kg N ha^{-1}, 30 kg P h a^{-1} and 0 kg K ha^{-1}), $N_{60}P_{30}K_{30}$ (60 kg N ha^{-1}, 30 kg P ha^{-1} and 30 kg K ha^{-1}), $N_{60}P_{30}K_{60}$ (60 kg N ha^{-1}, 30 kg P ha^{-1} and 60 kg K ha^{-1}) and $N_{60}P_{30}K_{90}$ (60 kg N ha^{-1}, 30 kg P ha^{-1} and 90 kg K ha^{-1})] were applied. The treatment $N_{60}P_{30}K_0$ was taken as control. Fertilizers were broadcasted and mixed well in the top 15 cm of soil at the time of sowing. The sources of N, P and K were urea, single super phosphate and muriate of potash, respectively. Seeds were hand-planted in 3m × 3m plots using the factorial randomized block design with four replications. The seeds were sown in rows with row to row spacing of 30 cm. Plant to plant distance of 20 cm was maintained by thinning after germination. Irrigation was carried out at fortnight intervals. The crop was kept free of weeds by hoeing whenever necessary. Data obtained from the experiments were statistically analyzed by SPSS (Statistical Procedure for Social Sciences, ver. 11.0 Inc., Chicago, USA).

Plant Sampling: Samplings for growth characteristics were carried out at peak vegetative [i.e., 90 days after sowing (DAS)] and full bloom (i.e., 120 DAS) stages of plant development. Plant height was measured with the help of a meter scale. Plants were cut at ground level and leaves separated from the stem. Number of branches and number of leaves were counted on a per plant basis. After separating all the leaves at petiole and stem junction, total leaf area per plant was recorded at 90 DAS stage with the help of a portable and rotating belt leaf area meter (LI-3000A, LI-COR, USA) and expressed as cm^2 per plant. After cutting the plants at ground level, the plants were partitioned into constituent organs and their fresh weights (FW) were taken immediately. For the determination of dry weight (DW), the plant parts were dried in an oven set at 65 ºC until a constant weight was obtained. Weight of separated plant parts was recorded with the help of an electronic balance (Sartorius-GE 412). Dry matter (DM) percentage was expressed as [20]:

$$DM (\%) = (Sample\ DW/Sample\ FW) \times 100$$

Seed yield (g $plant^{-1}$ and kg ha^{-1}) for each treatment was recorded at harvest. Crop maturity data was taken on 120 DAS stage. Counting the mature (ripe) and immature (unripe, yellow and unopened) capitula, the percent maturity of the crop was obtained as:

$$Maturity (\%) = [Mature\ capitula/ (Mature\ capitula + Immature\ capitula)] \times 100$$

RESULTS AND DISCUSSION

Growth Characteristics: Potassium application significantly ($p < 0.05$) increased plant height of safflower as observed at the two sampling stages corresponding to two developmental stages i.e., vegetative and flowering growth stages. The effect of K90 was more pronounced at both stages of growth and development as compared to other rates of K. Plant height in this experiment ranged between 68.25 cm at 90 DAS stage ($N_{60}P_{30}K_0$) to 97.25 cm at 120 DAS ($N_{60}P_{30}K_{90}$). Regarding the growth stages, plant height was higher at full bloom stage than at vegetative growth stage (Table 2). The plant height reported in this study was in range to that reported for safflower germplasm (50 - 211 cm) [21]. Numbers of branches per plant significantly increased at higher K application rate at both growth stages. The lowest number of branches (6.00 branches $plant^{-1}$) and highest number of branches (11 branches $plant^{-1}$) in this study was recorded in $N_{60}P_{30}K_0$ (90 DAS) and $N_{60}P_{30}K_{90}$ (120 DAS), respectively (Table 2). Number of leaves was higher at higher K application and regarding the stages it was higher at 120 DAS stage than at 90 DAS stage. At full bloom stage (120 DAS) number of leaves per plant was higher by 46.95% in the $N_{60}P_{30}K_{90}$ treatment as compared to $N_{60}P_{30}K_0$ treatment (Table 2). At 90 DAS stage, higher K application rate resulted in higher number of leaves but the leaves towards the top of the plant were small in size at this K rate (Figure 1).

Hafsi *et al*. [22] reported that a decrease in plant growth characteristics under potassium deprivation in *Hordeum maritimum* and Malik *et al*. [23] reported that K fertilized *Ruta graveolens* plants were more vigorous and taller. This might be due to the role of K in increasing the export of products of photosynthesis, resulting in better plant growth characteristics. This can also be ascertained to the availability of water in these plants as K application improves the water content of the plants by regulating stomatal movements as observed in *Houttuynia cordata* [11]. Hayashi and Hanada [24] pointed out that under water stress safflower internode elongation is inhibited, resulting in a short stem with few lateral branches, fewer inflorescences per plant and lower seed yields. A differential response was observed as regards the number of cauline and ramal leaves under K application. Number of cauline leaves was higher in absence of K ($N_{60}P_{30}K_0$) at 90 DAS stage. It can be explained that plants under higher K application rate branched early and quickly proceeded towards the flowering stage. As a result, translocation of photosynthates towards upper parts of the plants including branches and ramal leaves was quick.

Leaf Area: Leaf area per cauline leaf at 90 DAS stage was significantly ($p < 0.05$) lower in control and increased progressively with increase in K application rate. However, leaf area of all cauline leaves of a plant was lower at higher K rate although the values were statistically non-significant between all K application rates. Leaf area per ramal leaf was highest in control and decreased with increase in K application rate and had a reduction of 4.82% in $N_{60}P_{30}K_{90}$ treatment compared to that for $N_{60}P_{30}K_0$ treatment but leaf area of all ramal leaves per plant was higher at higher K rate and was statistically significant from all other K application rates. Total leaf area on a per plant basis was significantly increased by the application of all higher K fertilizer levels over control level (K_0). Among various fertilizer levels, $N_{60}P_{30}K_{90}$ produced the highest leaf area on a per plant basis (Table 3).

Leaf area is one of the most important growth parameter which is related to solar energy harvesting ability of the plant. It causes enhanced production of photosynthates; the subsequent translocation of photosynthates increases total dry matter production [25]. In the present study, higher K rates lead to bigger cauline leaves and greater leaf area at 90 DAS stage. Without external supply of K, leaf area was very small. It may be because K has been reported to augment cell division and cell expansion [26], which may lead to increase in leaf area. K also causes faster N absorption and accumulation. This is achieved by K activity as counter ion of nitrate in which form N is normally absorbed and translocated from root to shoot [27]. Highest leaf area was recorded with K_{90} at 90 DAS stage, which could have provided adequate amount of potassium and other nutrients. This shows that K has a marked effect in increasing the leaf area at this growth stage. Plants well supplied with K expand their leaves and hence the leaf area [28].

In the present study, higher K rates lead to a decrease in the size of the upper leaves but increase in total number of leaves. This finally caused an increase in total leaf area on a per plant basis. The plants were taller at higher K rate and exhibited greater number of branches particularly towards the top of the plant, giving a bushy shape to the plants. At higher levels of K, the leaves at the top of the plants were smaller, thicker and spinier but their number was very high. In this regard, a number of studies have reported an effect on leaf area of different plants by K application or its deficiency mainly because of its influence on leaf size and to a lesser extent on their number [16], but our results here establish an increase in leaf area mainly because of increase in number of leaves and not because of leaf expansion.

Table 2: Effect of fertilization on plant height, number of branches and number of leaves of safflower

	Plant height (cm)		Number of branches ($plant^{-1}$)		Number of leaves ($plant^{-1}$)	
Treatments	90 DAS	120 DAS	90 DAS	120 DAS	90 DAS	120 DAS
$N_{60}P_{30}K_0$	$68.25^{c}\pm4.30$	$73.50^{c}\pm5.80$	$6.00^{b}\pm0.82$	$7.25^{b}\pm0.96$	$96^{c}\pm11.90$	$227^{d}\pm13.35$
$N_{60}P_{30}K_{30}$	$78.50^{b}\pm4.43$ (15.02)	$83.75^{b}\pm6.24$ (13.95)	$7.25^{b}\pm1.26$ (20.83)	$9.00^{ab}\pm0.82$ (24.14)	$113^{bc}\pm9.00$ (18.06)	$256^{c}\pm18.04$ (12.55)
$N_{60}P_{30}K_{60}$	$88.00^{a}\pm3.92$ (28.94)	$94.75^{a}\pm6.70$ (28.91)	$9.25^{a}\pm1.26$ (54.17)	$10.00^{a}\pm1.41$ (37.93)	$123^{ab}\pm7.14$ (29.06)	$290^{b}\pm18.62$ (27.48)
$N_{60}P_{30}K_{90}$	$91.75^{a}\pm4.19$ (34.43)	$97.25^{a}\pm6.65$ (32.31)	$10.25^{a}\pm1.50$ (70.83)	$11.00^{a}\pm2.16$ (51.72)	$139^{a}\pm8.26$ (45.81)	$334^{a}\pm18.93$ (46.95)

Cell values are mean ± S.E.; mean values followed by different letters are significantly different within a column ($p<0.05$); values in parenthesis represent percent difference between treatment and control ($N_{60}P_{30}K_0$).

Table 3: Effect of fertilization on single leaf area as well as total leaf area at 90 DAS stage of safflower

	Leaf area (cm^2)				
Treatments	CL^{-1}	RL^{-1}	CL $plant^{-1}$	RL $plant^{-1}$	TL $plant^{-1}$
$N_{60}P_{30}K_0$	$44.16^{d}\pm0.77$	$11.31^{a}\pm0.06$	$1413^{a}\pm130$	$718^{c}\pm102$	$2131^{b}\pm231$
$N_{60}P_{30}K_{30}$	$48.01^{c}\pm0.78$ (8.72)	$11.22^{a}\pm0.05$ (-0.77)	$1428^{a}\pm106$ (1.07)	$931^{b}\pm76$ (29.67)	$2360^{ab}\pm182$ (10.71)
$N_{60}P_{30}K_{60}$	$50.36^{b}\pm0.74$ (14.04)	$10.94^{b}\pm0.04$ (-3.23)	$1385^{a}\pm96$ (-2.00)	$1048^{b}\pm60$ (45.85)	$2432^{ab}\pm150$ (14.13)
$N_{60}P_{30}K_{90}$	$52.84^{a}\pm0.72$ (19.65)	$10.76^{c}\pm0.04$ (-4.82)	$1361^{a}\pm109$ (-3.71)	$1221^{a}\pm75$ (70.05)	$2582^{a}\pm161$ (21.14)

Cell values are mean ± S.E.; mean values followed by different letters are significantly different within a column ($p<0.05$); values in parenthesis represent percent difference between treatment and control ($N_{60}P_{30}K_0$). CL-cauline leaf; RL-ramal leaf; TL-total leaves (cauline+ramal)

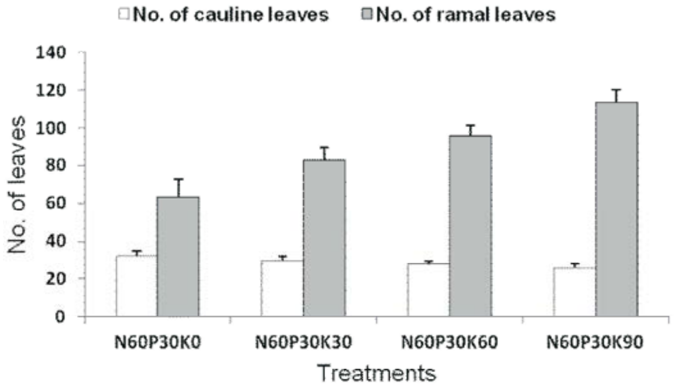

Fig. 1: Effect of nutritional treatments on number of cauline and ramal leaves of *C. tinctorius*. (Vertical error bars indicate standard error of average values from all replicates)

Reduced leaf elongation has been reported to reduce transpiration which may have resulted in an increase in leaf thickness and succulence and hence increase in its weight. Succulent safflower is considered good for livestock grazing.

Dry Matter Percentage: Fresh and dry weight of each plant organ (Fig. 2) as well as total above ground fresh and dry weight (Fig. 3) was highest at 120 DAS stage and was significantly ($p < 0.05$) affected by K fertilization. The increment percentage was many folds over control. Potassium application affected the DM percentage of each plant organ differentially at the two growth stages. It progressively increased the stem DM percentage at 90 DAS stage but resulted in a gradual decrease in it at 120 DAS stage. The same trend was followed as regards leaf DM percentage. However, K application strongly affected capitula DM percentage (calculated at 120 DAS stage only) (Table 4).

Applied K was found to increase fresh and dry weight of safflower. It was noted that safflower plants require high K concentration in the soil for high DM percentage. Higher K rates resulted in higher DM percentage. This can be associated to increase in leaf area by application of K which is in turn related to solar energy harvesting ability of the plant and hence, enhanced production of photosynthates; the subsequent translocation of photosynthates increases total DM production [25, 26]. Potassium reduces water loss by reducing transpiration [29] and its beneficial effects have

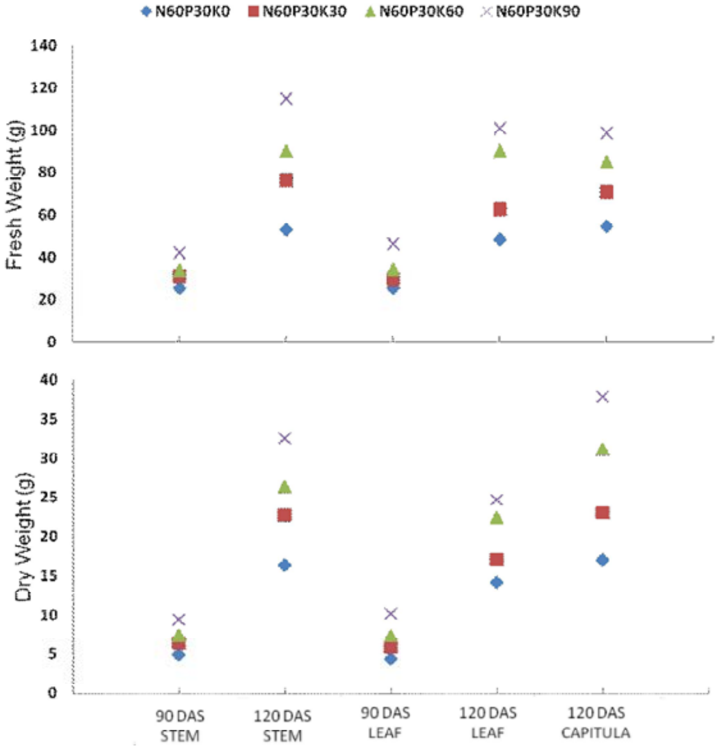

Fig. 2: Effect of nutritional treatments on fresh and dry weight of stem and leaf of *C. tinctorius* at two stages (90 DAS and 120 DAS) and fresh and dry weight of capitula at 120 DAS stage

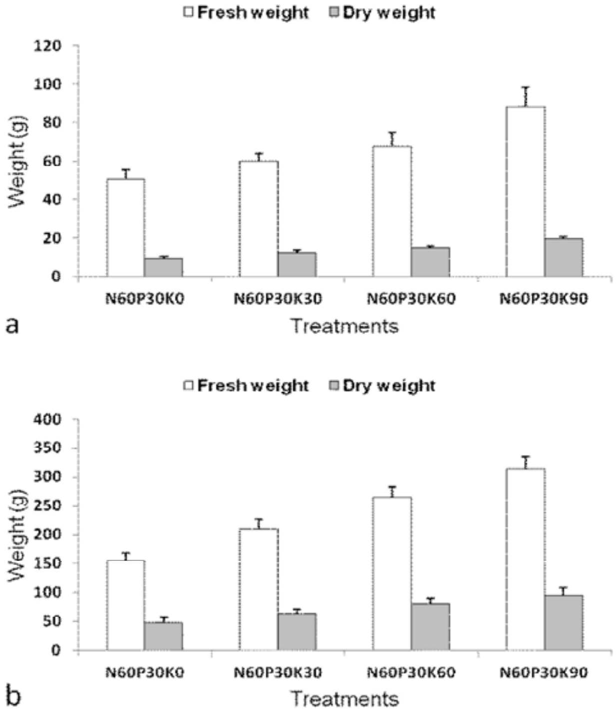

Fig. 3: Effect of nutritional treatments on above ground herb fresh and dry weight of *C. tinctorius*: stem + leaf at 90 DAS stage (a) and stem + leaf + capitula at 120 DAS stage (b). (Vertical error bars indicate standard error of average values from all replicates)

Table 4: Effect of fertilization on dry matter percentage of stem, leaf and capitula of safflower.

	Stem DM (%)		Leaf DM (%)		Capitula DM (%)
Treatments	90 DAS	120 DAS	90 DAS	120 DAS	120 DAS
$N_{60}P_{30}K_0$	19.71^b±0.86	30.76a±6.25	17.59b±1.44	29.24a±4.37	31.21^b±1.33
$N_{60}P_{30}K_{30}$	20.77^{ab}±1.25 (5.37)	29.83a±2.68 (-3.04)	20.05ab±1.62 (14.01)	27.22a±2.63 (-6.93)	32.37^b±1.42 (3.72)
$N_{60}P_{30}K_{60}$	22.27^a±1.15 (12.95)	29.33a±2.46 (-4.66)	21.71a±1.40 (23.44)	24.87a±0.72 (-14.95)	36.65^a±3.26 (17.44)
$N_{60}P_{30}K_{90}$	22.60^a±0.64 (14.65)	28.15a±3.60 (-8.51)	22.20a±2.05 (26.22)	24.47a±2.18 (-16.32)	38.46^a±1.41 (23.26)

Cell values are mean ± S.E.; mean values followed by different letters are significantly different within a column (*$p<0.05$*); values in parenthesis represent percent difference between treatment and control ($N_{60}P_{30}K_0$).

Table 5: Effect of fertilization on crop maturity percentage at120 DAS stage and seed yield at harvest of safflower.

Treatments	Maturity (%)	Yield (g bed^{-1})	Yield (kg ha^{-1})
$N_{60}P_{30}K_0$	40.46^b±8.89	482^c±24.62	534^c±25.81
$N_{60}P_{30}K_{30}$	53.17^b±5.37 (31.41)	517^c±23.20 (7.32)	576^c±23.55 (7.80)
$N_{60}P_{30}K_{60}$	71.65^a±6.43 (77.10)	630^b±22.17 (30.84)	701^b±23.82 (31.37)
$N_{60}P_{30}K_{90}$	77.60^a±4.64 (91.81)	819^a±23.06 (69.99)	911^a±23.84 (70.54)

Cell values are mean ± S.E.; mean values followed by different letters are significantly different within a column (*$p<0.05$*); values in parenthesis represent percent difference between treatment and control ($N_{60}P_{30}K_0$)

been studied by various authors. It was reported to have a positive influence on DM production of various crops [16, 30]. Cakmak *et al.* [31] stated that K nutrition had pronounced effects on carbohydrate portioning by affecting either phloem export of photosynthates (sucrose) or growth rate of sink and/or source organs. As K is mobile within the plant, it is retranslocated to places of new growth (buds, flowers) and under severe deficiency, the source organs become chlorotic and necrotic [9]. In addition to its significance for water homeostasis, impairment in lignifications of vascular bundles has also been reported under K deficiency [32], making the plant more susceptible to lodging. Water content of different organs followed opposite trend to dry matter percentage.

Crop Maturity and Seed Yield: Potassium application significantly affected crop maturity data obtained exactly on second sampling i.e., 120 DAS stage. Highest K application rate resulted in highest maturity percentage of 77.60%. Regarding grain yield, lower fertilizer application rate ($N_{60}P_{30}K_{30}$) did not influence the yield significantly, but higher rates ($N_{60}P_{30}K_{60}$ and $N_{60}P_{30}K_{90}$) increased the yield significantly over the control treatment ($N_{60}P_{30}K_0$). The highest seed weight (819 g bed^{-1}) was produced in plots which received higher fertilizer rate ($N_{60}P_{30}K_{90}$). Seed yield on per hectare basis was lower (534 kg ha^{-1}) in $N_{60}P_{30}K_0$ treatment and highest (911 kg ha^{-1}) in $N_{60}P_{30}K_{90}$ treatment (Table 5).

Yield is the final manifestation of several complex agro-physiological parameters. Growth characteristics, leaf area, fresh and dry herb yield as well as DM percentage of each organ were all influenced in positive direction by the graded application of K, resulting in early maturity of the crop and enhancement in its yield. Leaf area in safflower plants has been shown to have a positive relationship with seed yield under normal conditions. Seed yield (g $plant^{-1}$ and kg ha^{-1}) corresponded well with the maturity data obtained on 120 DAS stage. This suggests that early onset of the reproductive period of the crop finally results in yield enhancement and *vice versa* mainly because reproductive as well as the grain filling periods are extended in such case and the plant gets sustained supply of photosynthates for grain filling for a greater period of time. The lower seed yield obtained in case of control treatment could also be attributed to higher temperatures at the time of its full flowering which in turn affected its pollination as well as fertilization events, as has been reported earlier [33]. For attaining high seed yield in safflower, translocation of pre-anthesis assimilates to seed has a big role to play as photosynthesis generally diminished during grain filling stage [34]. Potassium fertilization resulted in greater accumulation of pre-anthesis assimilated in terms of higher DM accumulation which may have finally increased seed weight and hence, yield. Another aspect of yield increase by K application may be the role of K in overcoming the drought stress of the plants as water stress has been related to its reduced height and diminished yields [35]. Seed yield did not seem to saturate or decline at higher K levels. Progressive increment in yield was obtained at higher K application rates, suggesting that higher yields of the crop can be obtained at a still higher K application rate.

From the present study, we conclude that K application positively influences growth and favours yield in upward direction and reduces heavy requirement of other leachable fertilizers. Hence, optimum K fertilization is a way to achieve sustainable, environment friendly and enhanced agricultural production with special reference to safflower cultivation.

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