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Potassium Supply Strategy for Enhancing Productivity and Nutrient Use Efficiency in FCV Tobacco grown in Northern Light Soils of Andhra Pradesh

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ABSTRACT

Flue Cured Virginia (FCV) tobacco, an important high value commercial crop in India, is preferentially grown on light textured soils for better quality and exports. However, light textured soils are characterized with low potassium (K) reserves, poor K retention and high vulnerability to K leaching. Of all the essential nutrients, K is taken up in the largest amount by tobacco grown in irrigated Northern Light Soils (NLS) region of Andhra Pradesh. The large requirement coupled with low efficiency of applied K calls for evolving a K supply strategy that ensures optimum K nutrition of the crop and enhances K use efficiency. A field investigation was carried out for two consecutive Rabi seasons to evaluate potassium supply strategies for their effects on productivity and nutrient use efficiency of irrigated FCV tobacco on a sandy loam soil (Alfisol). The experiment comprising eight K supply strategies varying in rate, number of splits and timing of K applications was laid out in a randomized block design with three replications. Results indicated that K application either at 120 or 80 kg K_2O ha^{-1} led to significant increase in green leaf yield, cured leaf and grade index of FCV tobacco over the no-fertilizer control and NP fertilizer use alone. K application in 4 equal splits (1:1:1:1) at 10, 25, 40 and 70 days after transplanting (DAT) resulted in higher yields as compared to its addition in 3 splits (1:2:1) at 10, 25 and 40 DAT or 25, 40 and 70 DAT. Nutrient uptake and use efficiency by tobacco was promoted by K application in 4 splits in contrast to its addition in 3 splits. All plots receiving K application maintained higher K availability as compared to the control and minus-K plots. The soil K availability was more or less similar for 120 kg K_2O $ha^{-1}$and 80 kg K_2O ha^{-1} with the identical K application strategies. Over all, the K application in 4 splits (1:1:1:1) timed at 10, 25, 40 and 70 DAT is the right K supply strategy for higher productivity and enhanced K use efficiency in irrigated FCV tobacco grown on light textured soils.

KEYWORDS

Potassium supply strategy, split application, FCV tobacco, light textured soil, nutrient use efficiency

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INTRODUCTION

Tobacco (Nicotiana tabaccum L.) is an important high value commercial crop in India (Prasad *et al*, 2021). It is grown in an area of 4.5 lakh ha with annual production of 804 million kg cured leaf. The Flue Cured Virginia (FCV) tobacco, used for manufacturing cigarettes, is preferentially grown on light textured soils for better quality and exports. Potassium (K) plays a critical role in growth, yield and quality of FCV tobacco. The K is absorbed by tobacco in largest amount as compared to all other essential nutrients (Krishnamurthy and Singh, 2002; Gurumurthy and Vageesh, 2007). The quantity of K absorbed by tobacco depends on several factors including, among others, soil type, K availability in soil, growing conditions (rain fed or irrigated), yield levels, variety and fertilizer management practices, A tobacco crop yielding about 2500 kg cured leaf under NLS conditions typically absorbs 100 -120 kg K ha^{-1} (Krishna *et al*, 2009). The concentration of K in tobacco leaf influences leaf quality in terms of colour, texture, body, and combustibility (Krishnamurthy and Singh, 2002). Leaf produced with adequate K is smooth and thin with better fire holding capacity.

The Alfisols supporting FCV tobacco in Northern Light Soils (NLS) region of Andhra Pradesh are characterized by sandy/sandy loam texture with high permeability, low clay and organic matter content, low CEC and poor buffering capacity (Krishnamurthy and Singh, 2002) and (Prasad *et al*, 2021). As the soils are light textured and crop is irrigated liberally (10-12 times) in this region, the fertilizer-K applied to FCV tobacco is subjected to leaching loss causing low K use efficiency. Several researchers reported the occurrence of K leaching in sandy soils due low CEC and buffer power (Jalali and Rowell, 2003; Kolahchi and Jalali, 2007).

The FCV tobacco grown on the sandy/sandy loam Alfisols often experiences K deficiency owing to low native soil K reserves and poor K use efficiency and hence requires a large input of K in the form of sulfate of potash, an expensive K fer-

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tilizer. The large requirement coupled with low efficiency of applied K calls for evolving a K supply strategy that ensures optimum K nutrition of the crop and enhances K use efficiency.

The sulphate of potash (SOP), the most preferred K fertilizer for FCV tobacco, is very expensive (Rs. 90 per kg K_2O as in 2020) but critical input required for obtaining optimum leaf yield with desired quality. Presently, it is recommended at a rate of 120 kg K_2O ha^{-1} and accounts for 58% of cost of fertilizers used in tobacco production. But, the use efficiency of this costly input by tobacco remains low at less than 50% owing primarily to K leaching losses resulting from improper fertilizer management. Given the soil environment and number of irrigations conducive to K leaching and the fact that peak growth and nutrient accumulation in tobacco corresponds to period of 41 – 75 days after transplanting (Moustakas and Ntzanis, 2005), it makes more sense to apply K fertilizers in more splits and timing the application beyond 40 DAT. Against this backdrop, the present investigation was planned to evaluate K supply strategies varying in rate, number of splits and time of application in tobacco for enhanced productivity and nutrient use efficiency of FCV tobacco grown in NLS region of Andhra Pradesh.

MATERIALS AND METHODS

A field experiment was conducted for two consecutive years during the rabi season (2010–11 and 2011–12) at the ICAR-Central Tobacco Research Institute - Research Station, Jeelugumilli (17°11′30″ N and 81°07′50″ E at 150 m above mean sea-level) in the Northern Light Soils (NLS) region of Andhra Pradesh under semi- arid tropical climate. The soil of experimental field has sandy texture in surface and sandy loam in sub-surface layer, acidic pH (5.53), low organic carbon (0.24%), high available P (13.2 mg kg^{-1}) and low available K (39.6 mg kg^{-1}). The experiment was laid out in Randomized Block Design with eight treatments and three replications consisting of split application of potassium at different days after transplanting (DAT). Treatments included eight K supply strategies: (1) K_o - No K control with NP application; (2) K_{120} (120 kg K_2O ha^{-1}) in three splits at 10, 25, 40 DAT in the ratio of 1:2:1; (3) K_{120} (120 kg K_2O ha^{-1}) in three splits at 25, 40, 75 DAT in the ratio of 1:2:1; (4) K_{120} (120 kg K_2O ha^{-1}) in four splits at 10, 25, 40 & 75 DAT in the ratio of 1:1:1:1; (5) K_{80} (80 kg K_2O ha^{-1}) in three splits at 10, 25, 40 DAT in the ratio of 1:2:1; (6) K_{80} (80 kg K_2O ha^{-1}) in three splits at 25, 40, 75 DAT in the ratio of 1:2:1; (7) K_{80} (80 kg K_2O ha^{-1}) in four splits at 10, 25, 40 & 75 DAT in the ratio of 1:1:1:1; (8) Control -No NPK control. The fertilizer N and P_2O_5 at the rate of 120 and 60 kg ha^{-1}, respectively were supplied in all treatments except T_8. The data on tobacco green leaf and cured leaf yield were recorded and grade index was calculated. The cured leaf samples of tobacco collected from lugs and cutters (X) and leaf (L) positions were processed and analyzed for lamina chemical quality characters (reducing sugars, nicotine, and chlorides) as per the procedure given by Harvey et al.,1969 and reducing sugars to nicotine ratio was computed. The N, P and K contents in leaf and stem of all the treatments were determined. Nutrient uptake in terms of kg ha^{-1} (N, P and K) was estimated by multiplying the nutrient content with respective dry weights and total nutrient uptake was obtained by summing the individual uptakes of leaf and stem. Potassium harvest index (KHI) as ratio of K accumulated in economic part i.e. harvested leaf to total shoot nutrient was also estimated (Reddy *et al*, 2017).

The following measures/indices of K use efficiency were defined and estimated as per the standard calculations as outlined by Damodar Reddy (2009).

Let

Amount of K applied = A_K (kg ha^{-1})

Economic Yield without K application (No K) = Y_0(kg ha^{-1})

Economic Yield with K application = Y_K(kg ha^{-1})

Increase in yield due to K application = (Y_K- Y_0) = ΔY (kg ha^{-1})

Uptake by crop without K application (No K = KU0 (kg ha^{-1})

Uptake by crop with K application = KUK (kg ha^{-1})

Increase in K uptake due to K application = (KU_K - KU_0) = ΔKU (kg ha^{-1})

(i) Partial factor productivity for K (PFP_K) (kg kg^{-1}): The partial factor productivity from applied K is the ratio of cured leaf yield to amount K applied.

$PFP_K = Y_K{}_{\,/\,} A_K$

(ii) Agronomic Efficiency of K (AE_K): It is the increase in crop yield per unit of K applied (i.e ratio of the increase in yield to the amount of K applied) and expressed as kg kg^{-1}.

$AE_K = (Y_K - Y_0)/ A_K = \Delta Y/ A_K$

(iii) Recovery Efficiency of K (RE_K): It refers to the increase in K uptake by plant (above ground parts) per unit of K applied. The recovery efficiency is generally expressed in percentage terms (%).

$RE_{K\,=}$ ((KU_K- KU_0)/ A_K) x 100 = (ΔKU/ A_K) $_x$ 100

(iv) Physiological Efficiency of K (PE_K): It indicates the efficiency with which the plant utilizes the absorbed K to produce economic yield. It is the ratio of the increase in yield to the increase in K uptake, and expressed as kg kg^{-1}.

PE_P: (Y_K - Y_0) / (KU_K - KU_0) = ΔY/ ΔKU

Recovery Efficiency of N and P as affected by K supply strategies:

Nitrogen and Phosphorus recovery was also computed using the following equations:

Uptake by crop without N application (Control = NU_0 (kg ha^{-1})

Uptake by crop with N application = NUN (kg ha^{-1})

Increase in N uptake due to N application = (NU_N - NU_0) = ΔNU (kg ha^{-1})

Uptake by crop without P application (Control = PU_0 (kg ha^{-1})

Uptake by crop with P application = PUP (kg ha^{-1})

Increase in P uptake due to P application = (PU_P - PU_0) = ΔPU (kg ha^{-1})

(i) Recovery Efficiency of N(RE_N): It refers to the increase in N uptake by plant (above ground parts) per unit of N applied.

The recovery efficiency is generally expressed in percentage terms (%).

$RE_{N} = ((NU_{N} - NU_{0})/ A_{N}) x 100 = (\Delta NU/ A_{N})_{x} 100$

(ii) Recovery Efficiency of P(RE_{P}): It refers to the increase in P uptake by plant (above ground parts) per unit of P applied.

$RE_{P} = ((PU_{P} - PU_{0})/ A_{P}) x 100 = (\Delta PU/ A_{P})_{x} 100.$

The data on green leaf yield, cured leaf yield, grade index, nutrient uptake, nutrient use efficiency and leaf quality were recorded. Statistical analysis of data including analysis of variances was performed by using SAS program (SAS, 2002).

RESULTS AND DISCUSSION

Potassium supply strategy effects on tobacco leaf productivity and grade index

The trends of FCV tobacco yield among treatments were more or less similar in both the years of experimentation, despite the fact that there existed a difference in tobacco leaf productivity between the years (Table 1). The potassium applied at the rate of either 120 or 80 kg K_2O ha^{-1} resulted in significant increases in green leaf yield, cured leaf and grade index of tobacco over the no-fertilizer control and NP fertilizer use alone in both years (Table 1). This indicated a clear crop response to K supply on Alfisols characterized by low native K reserves and low CEC coupled with high vulnerability to leaching losses. On average, the K supply rate of 120 and 80 kg K_2O ha^{-1} enhanced cured leaf yield by 59 and 44% in first year and 52.9 and 29.5% in second year, respectively over no-K treatment. These results corroborate findings of earlier researchers (Farrokh *et al*, 2011; Krishna *et al*, 2016) who reported that application of potassium fertilizer at different rates has improved the yield of tobacco. This is because of the fact that applied K fertilizer can increase K availability in soil and thus improves its uptake by plant. Potassium fertilizer is essential to the production of high yield and good quality FCV tobacco, with a healthy crop typically requiring roughly 100 kg K_2O ha^{-1} from the soil for optimum growth (Raper and Cants, 1967). Results are in agreement with the Krishna *et al* (2016). Zhengxiong *et al* (2010) who reported that yield and quality of flue-cured tobacco are greatly affected by fertilization and especially by nitrogen (N) and potassium (K) supplies.

Table 1: Effect of potassium supply strategies on FCV tobacco yield.

Treatments		**Tobacco yield (kg ha^{-1})**					
Rate	**K supply strategy**	**First Year**			**Second Year**		
		Green Leaf	Cured Leaf	Grade Index	Green Leaf	Cured Leaf	Grade Index
K0	No K control	3604	656	304	7914	1346	826
K120	1:2:1 - 10, 25 & 40 D	4938	939	478	11250	1914	1294
K120	1:2:1 - 25, 40 & 70 D	5110	1040	538	11739	1976	1326
K120	1:1:1:1 - 10, 25, 40 & 70 D	5602	1158	657	13034	2282	1493
K80	1:2:1 - 10, 25 & 40 D	4588	847	405	9298	1625	1116
K80	1:2:1 - 25, 40 & 70 D	4927	951	472	9564	1673	1155
K80	1:1:1:1 - 10, 25, 40 & 70 D	5484	1032	536	10840	1929	1282
Control	-	2482	407	202	4579	868	592
LSD (P = 0.05)		315	87	53	1606	266	189

The number of splits and timing of K application also had marked influence on tobacco yield (Table 1). Potassium application in 4 splits (1:1:1:1 at 10, 25, 40 and 70 DAT) resulted in higher yields as compared to its addition in 3 splits (1:2:1 at 10, 25 and 40 DAT or 25, 40 and 70 DAT). The cured leaf yield obtained with 80 kg K_2O ha^{-1} applied in 4 splits (1:1:1:1) at 10, 25, 40 and 70 DAT was more or less identical to the yield resulting from standard practice of applying 120 kg K_2O ha^{-1} in 3 splits (1:2:1) at 10, 25 & 40 DAT. Grade index was relatively greater with 4 splits than with 3 splits at both rates of K supply. Split application of K maintained the availability of K in root zone of growing tobacco plants and minimized the chances of applied K losses through leaching. As a result, crop attained better growth and higher leaf area that might have contributed to the improved cured leaf yield. It is widely reported in literature that split application of K has potential to enhance the yields of several important other crops. For example, Mathukia *et al* (2014) reported improved growth parameters of wheat with application of potassium in splits resulting in sustained K supply during crop growth period. Semma Sharma and Jagadeesh Singh, 2020 reported that the grain yield and biological yield agronomic efficiency were improved with the split application of potassium.

According to Rehman *et al* (2006) and Lu *et al* (2014), the split application of fertilizer-K improves K availability throughout the growth period and promotes plant metabolic activities and thereby contributing to increased nutrient uptake and higher productivity. Adequate and sustained K supply results in optimal growth, development, and superior quality of the whole plant due to improved efficiency of photosynthesis, energy transfer, photosynthates translocation, increased resistance to diseases, and greater water use efficiency (Wallace, 2001; Wang and Wu, 2013).

Table 2: Nutrient uptake and Potassium harvest index (KHI) in tobacco as influenced by K supply strategies.

Treatments		**Nutrient uptake (kg ha^{-1})**			**KHI**
Rate	**K supply strategy**	N	P	K	
K$_0$	No K control	47.71	6.17	33.80	0.64
K$_{120}$	1:2:1 - 10, 25 & 40 D	61.08	7.72	56.70	0.69
K$_{120}$	1:2:1 - 25, 40 & 70 D	63.63	8.38	63.14	0.72
K$_{120}$	1:1:1:1 - 10, 25, 40 & 70 D	66.43	9.11	71.33	0.73
K$_{80}$	1:2:1 - 10, 25 & 40 D	56.44	7.16	52.66	0.68
K$_{80}$	1:2:1 - 25, 40 & 70 D	54.61	6.56	53.68	0.69
K$_{80}$	1:1:1:1 - 10, 25, 40 & 70 D	60.71	7.96	62.04	0.69
Control	-	21.97	3.53	23.64	0.73
LSD (P = 0.05)		7.59	1.14	7.55	-

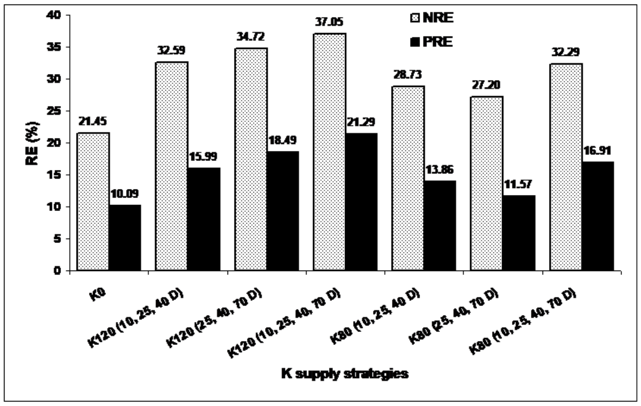

Fig. 1: Recovery efficiency (RE) of N and P in tobacco as affected by K supply strategies

Nutrient uptake and efficiency in tobacco as related to K supply strategies

Nutrient uptake (N, P and K) by FCV tobacco under different K supply strategies was computed as the product of tobacco bio-mass yield and respective nutrient concentration in plant. The K application at different rates resulted in enhanced N, P and K uptake by tobacco over the no-K treatment (Table 2). Application of K in 4 splits contributed to relatively higher nutrient uptake compared to its addition in 3 splits. The harvest index of K remained more or less same (0.64 to 0.73) across all K supply strategies. This implied that about 64 to 73 per cent of K uptake (leaf + shoot) was in the economic part (i.e. leaf) in all the treatments. Split application of K was instrumental in producing more leaf yield and maintaining higher K concentration and hence attaining relatively higher K accumulation.

K use efficiency under different K supply strategies was evaluated in-terms of partial factor productivity (PFP$_K$), agronomic efficiency (AE$_K$), physiological efficiency (PE$_K$) and recovery efficiency (RE$_K$) (Table 3). The PFP$_K$, AE$_K$, PE$_K$ and RE$_K$ values widely ranged from 19.14 to 28.79 kg kg^{-1}, 4.17 to 9.36 kg kg^{-1}, 14.79 to 24.95 kg kg^{-1}and 22.90 to 42.15 %, respectively among different K supply strategies. Expectedly, the Recovery K use efficiency decreased with increase in K rate from 80 kg K_2O ha^{-1} to 120 kg K_2O ha^{-1}. Earlier, Reddy *et al* (2017) reported that agronomic efficiency; physiological efficiency, internal efficiency, partial factor productivity and recovery efficiency were higher at lower levels of K and decreased with increase in its level. AE$_K$ was increased at higher dose with similar split application time and it indicated that the tobacco crop showed yield response at higher dose.

PE$_K$ was increased at higher K dose (120 kg K_2O ha^{-1}) over 80 kg K_2O ha^{-1}and it indicated good internal efficiency of present tobacco variety for K utilization toward economic yield. RE$_K$ is lower in higher K dose with similar split application time and it may be explained by leaching process. Low

Table 3: Potassium use efficiency of tobacco under different K supply strategies.

Treatments		Potassium use efficiency			
Rate	**K supply strategy**	**PFP_K (kg/kg)**	**AE_K (kg/kg)**	**PE_K (kg/kg)**	**RE_K (%)**
K_{120}	1:2:1 - 10, 25 & 40 D	19.14	5.68	24.81	22.90
K_{120}	1:2:1 - 25, 40 & 70 D	19.76	6.30	21.48	29.34
K_{120}	1:1:1:1 - 10, 25, 40 & 70 D	22.82	9.36	24.95	37.53
K_{80}	1:2:1 - 10, 25 & 40 D	24.25	4.17	14.79	28.15
K_{80}	1:2:1 - 25, 40 & 70 D	24.98	4.89	16.47	29.67
K_{80}	1:1:1:1 - 10, 25, 40 & 70 D	28.79	8.71	20.65	42.15

K efficiency at higher K rate is attributable to the fact that leaf yield does not increase quantitatively in proportion with the increase in rate of nutrient application following the law of diminishing return and due to K leaching losses. Leaching of K^+had been found to be a problem on sandy soils and magnitude of leaching varied directly with rate of K application (Sparks, 1980).

Application of K in 4 splits generally resulted in greater K use efficiency indices as compared to K addition in 3 splits only. The recovery efficiencies of N and P by tobacco were also markedly enhanced by K application at either rate in 4 splits as against 3 splits (Figure 1). Application of K in more splits benefits the crop as K remained available during the entire growing season and chances of K leaching losses also diminished, with the net result being increased K recovery. These findings draw credence from the results of Kolar and Grewal (1994) who reported that split application of K in soybean was more beneficial in terms of higher leaf area index, crop growth rate, chlorophyll content of fresh leaves, K accumulation in soybean and better agronomic and physiological efficiency of applied K. Therefore, split application enabled synchronization of K supply with the plant demand for K can be considered as a potential strategy to improve crop productivity and K use efficiency.

Leaf quality in relation to K supply strategies

Quality of tobacco in relation to K supply strategies was assessed in terms of nicotine, reducing sugars (RS), potassium and chloride concentration in lamina of X and L positions (Table 4 and Table 5). The concentrations of nicotine and chloride for X and L position leaves, and RS for X position leaf were affected by K supply strategies, while K concentration of leaf at both positions did not vary significantly between K supply treatments.The chloride content of leaf was significantly low in all fertilized plots over the unfertilized control, apparently due to 'dilution effect' caused by yield response to applied nutrients. Contents of nicotine, reducing sugars, and sugars to nicotine ratio in lamina in different plant positions of tobacco were in the normal and acceptable ranges (Gopalachari, 1984).

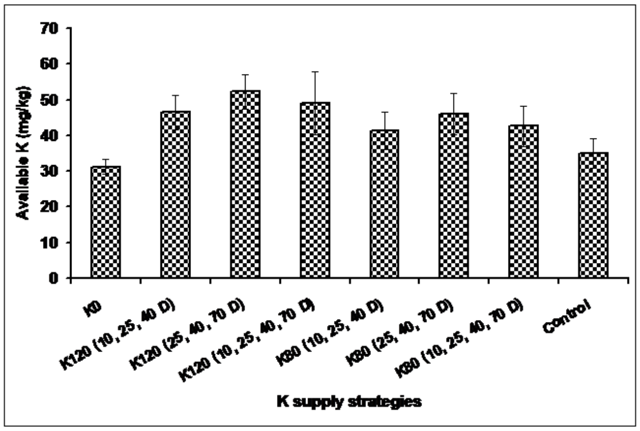

Fig. 2: Soil K availability in relation to K supply strategies

Soil K availability in relation to K supply strategies

Soil samples from the plots treated with different K supply strategies were drawn at 90 DAT and analyzed for K availability (Neutral normal ammonium acetate extractable K). The changes in K availability of soil in relation to K supply strategies are depicted in Figure 2 . All plots receiving K application maintained higher K availability as compared to the control and minus-K plots. The soil K availability was more or less similar for 120 kg K_2O ha^{-1} and 80 kg K_2O ha^{-1}in the identical K application strategies. Further at a particular application rate, the K availability in soil was relatively high with the supply strategies having last split dose timed at 70 DAT. This signifies that split applications and delayed timing of applications would ensure increased soil K availability for extended

Table 4: Potassium supply strategy effects on tobacco leaf quality - X position.

Treatments		X position				
Rate	**K supply strategy**	**Nicotine (%)**	**RS (%)**	**RS/ Nicotine**	**K (%)**	**Chlorides (%)**
K_0	No K control	1.97	16.45	8.35	2.20	0.43
K_{120}	1:2:1 - 10, 25 & 40 D	1.75	15.78	9.02	2.57	0.44
K_{120}	1:2:1 - 25, 40 & 70 D	1.95	15.99	8.20	2.52	0.45
K_{120}	1:1:1:1 - 10, 25, 40 & 70 D	1.73	16.90	9.77	2.53	0.47
K_{80}	1:2:1 - 10, 25 & 40 D	1.93	16.40	8.50	2.33	0.44
K_{80}	1:2:1 - 25, 40 & 70 D	1.99	17.25	8.67	2.30	0.44
K_{80}	1:1:1:1 - 10, 25, 40 & 70 D	1.74	18.24	10.48	2.37	0.50
Control	-	1.16	17.72	8.35	2.21	0.75
LSD (P = 0.05)		0.13	1.04	—	NS	0.059

Table 5: Potassium supply strategy effects on tobacco leaf quality - L position.

Treatments		L position				
Rate	**K supply strategy**	**Nicotine (%)**	**RS (%)**	**RS/ Nicotine**	**K (%)**	**Chlorides (%)**
K_0	No K control	1.88	17.38	9.25	1.61	0.53
K_{120}	1:2:1 - 10, 25 & 40 D	1.87	20.21	10.81	1.85	0.45
K_{120}	1:2:1 - 25, 40 & 70 D	1.64	19.66	11.99	1.95	0.37
K_{120}	1:1:1:1 - 10, 25, 40 & 70	1.58	21.13	13.37	1.97	0.41
K_{80}	1:2:1 - 10, 25 & 40 D	1.58	18.81	11.91	1.84	0.37
K_{80}	1:2:1 - 25, 40 & 70 D	1.78	19.74	11.09	1.84	0.40
K_{80}	1:1:1:1 - 10, 25, 40 & 70	1.48	19.42	13.12	1.78	0.39
Control	-	1.11	21.28	19.17	1.60	0.55
LSD (P = 0.05)		0.143	NS	–	–	0.063

period during crop season. Akhter *et al* (2017) reported that the available K decreased steadily with recommended application but maintained its status quo when applied in split dose. Wani et al. 2014 reported that split application of potassium helps in retention of soil available potassium.

CONCLUSION

The results of the present study clearly demonstrate that appropriate K management strategy is critical for achieving optimum productivity and quality of FCV tobacco on light textured soils under irrigated conditions. The K supply strategy comprising fertilizer-K rate of 120 or 80 kg K_2O ha^{-1} applied in 4 equal splits (1:1:1:1) timed at 10, 25, 40 and 70 DAT proved superior for getting higher yields, acceptable leaf quality, nutrient uptake and use efficiency in irrigated FCV tobacco grown on light textured Alfisols. Besides being effective in achieving higher productivity with acceptable quality, the K supply strategy identified in this study represents a way to enhance K use efficiency in FCV tobacco by minimizing K leaching losses in light textured soils.

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