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RESEARCH ARTICLE

Potassium schoenite: A sustainable potassium source for Flue-Cured Virginia (FCV) tobacco production

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Abstract

India is meeting its potassium (K) fertilizer requirement mostly from other countries through imports. Price fluctuation and unavailability of sulphate of potassium during the crop season greatly impact the potassium (K) requirement for flue-cured Virginia (FCV) tobacco. We investigated potassium schoenite (PS/KMS), a sulphur-containing fertilizer as an alternate source of K for FCV tobacco. The field experiments were conducted on FCV tobacco (*Nicotiana tabaccum* L. var. Kanchan) under rainfed and irrigated conditions at ICAR-NIRCA Research Station, Hunsur, Karnataka and Research Station in Jeelugumilli, Andhra Pradesh, India, respectively. The study wasconducted to see the effectiveness of PS in comparison with a conventional sulphate of potash. Five treatments were tested using a randomized block design with four replications over two years and 2 locations. The results indicate that PS when utilized as a source of potash, produced cured leaf yield (CLY), K uptake and quality parameters of FCV tobacco at a par with sulphate of potash (SOP). Thus,indigenous PS is found to be highly effective in increasing the productivity of tobacco and its utilization in the tobacco crop compared to imported SOP. PS is a sustainable and effective alternative for the imported SOP for the cultivation of tobacco in the light soils of Karnataka (KLS) and Andhra Pradesh (NLS). PS application @ 652 kg/ha in 3 splits (1:2:1) at 10, 30 and 45 days after planting of FCV tobacco in Northern Light Soils (NLS) of Andhra Pradesh and PS @ 522 kg/ha in 2 equal splits (1:1) at 10 and 30 days' after planting of FCV tobacco in Karnataka Light Soils (KLS) of Karnataka was recommended for the FCV tobacco farming community.

Keywords: leaf quality; potassium schoenite; potassium sulphate; tobacco; uptake

Introduction

India is meeting its potassic fertilizers mostly from other countries through imports. Price fluctuation and unavailability of sulphate of potassium during the crop season, greatly impacts the potassium requirement for FCV tobacco. Tobacco is a quality conscious crop. The quality of the tobacco leaf is mainly influenced by the K content of the leaf. Tobacco majorly grown under light soils of Karnataka are known as Karnataka Light Soils (KLS) and light soils of Andhra Pradesh known as Northern Light Soils (NLS) of tobacco are characterized by their low clay content, organic carbon & cation exchange capacity and known for their poor K fertility and requires high external K requirement. The K deficiency is an important limiting factor for quality tobacco production on light textured soils. K is a key essential plant nutrient which plays a critical role in enhancing plant tolerance to abiotic and biotic stresses along with improving the quality of yields in crops like tobacco. Generally, K is absorbed by the FCV tobacco in larger quantity than any other nutrient. On an average, a tobacco crop yielding 2500 kg ha^{-1} takes up 100-120 kg K ha^{-1} (1). Magnesium (Mg) is a vital nutrient for tobacco crop that influencing photosynthesis, enzyme activation and protein synthesis. It also improves the plant's capacity of stress tolerance and enhances the quality of tobacco leaves. Additionally, magnesium is important in the synthesis of secondary metabolites like nicotine and other alkaloids, which are important for the commercial quality of tobacco. 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 K reserves, poor K retention and high vulnerability to K leaching (2). Of all the essential nutrients, K is taken up in largest amount by tobacco grown in irrigated NLS region of Andhra Pradesh. FCV tobacco grown in KLS are of typical sandy to sandy loam in nature with inherently low fertility (3). Among the major nutrients of importance to FCV tobacco, K plays an important role in improvement of yield and leaf quality. It improves the color, body, texture, leaf burn etc. (4). In FCV tobacco, high K content in cured leaves is a criterion of quality (5). Cured leaf from K deficient plants do not burn properly, which warrants optimum potassium levels throughout the crop growth (6).

India has imported 44454.37 metric tons of Potassium Sulphate worth of 56 crores, contributing to the 0.0038 % global share in imports during 2023-2024 (7). The COVID - 19 pandemics had a greater impact on the production, distribution and pricing of SOP. The pandemic had significantly disrupted the global supply chains due to lockdown; transportation restrictions and work force limitations also challenged the SOP production. Disruptions in supply chains lead to the reduced availability, high demand and prices for SOP increased. Tobacco farmers faced difficulties in accessing affordable fertilizers. Hence, all these circumstances led to increased interest and research on alternative K sources, such as indigenously produced PS, to cope the risks associated with imported SOP. PS, also known as potassium magnesium sulphate, is an important fertilizer. It contains three essential nutrients, K, Mg and S (sulphur) and is often used in agriculture to remediate deficiencies of these elements in the soil. PS as a source of K is not evaluated for FCV tobacco and it is a chloride-free, double sulphate fertilizer containing both K and Mg, has gained recognition as a specialized nutrient source for FCV tobacco. Its unique formulation addresses the crops high sensitivity to chloride which can adversely affect leaf quality while simultaneously providing Mg, another critical element for chlorophyll production and enzyme function. This dual-nutrient delivery system ensures balanced nutrition, contributing to better leaf yield, enhanced quality and sustainable soil health (8). PS has additional benefits like it is water soluble with neutral pH and ensures mainly balanced nutrient supply (9). It was found out that potassium schoenite as a source of potash significantly improved the growth, yield attributes and kernel yield of groundnut. The maximum dry pod yield, harvest index and oil yield were recorded with 60 kg/ha potash via schoenite (9). Thus, PS also helps in better nutrient uptake and their utilization in plants. PS application has resulted in the highest plant growth (height and dry matter accumulation), tuber number, potato yield and quality parameters (10). Mahalaabh ($K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$), a combination of K, S and Mg, offers a balanced solution to address these issues. The results demonstrated that Mahalaabh powder is effective in enhancing productivity across the cotton, groundnut and castor crops (11). Indigenously developed potassic fertilizer schoenite showed better effect on growth and yield of groundnut crop (12).

In India, PS ($K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$) is indigenously produced chemically using industrial by - products or through chemical reactions between soluble K, Mg and SO_4 salts; primarily to reduce import dependence and utilize industrial waste. The PS used in the present study is manufactured by Indian Borax Pvt. Ltd., Baroda, Gujarat. Field experiments were conducted with an objective to evaluate PS as a source of K for yield and quality of FCV tobacco grown under KLS and NLS.

Material and Methods

Field experiments were conducted during rainy season (*Kharif*) of 2022 and 2023 at the research farm of ICAR-National Institute for Research on Commercial Agriculture; NIRCA formerly Central Tobacco Research Institute; CTRI) Hunsur, Mysore district in Karnataka and winter season (*Rabi*) of 2022-2023 and 2023-2024 at research farm of ICAR-NIRCA Jeelugumilli, Eluru district in Andhra Pradesh. The five treatments in all were tested in a Randomized Block Design with 4 replications. T1: 100 % recommended K through SOP; T2: 100 % recommended K through PS; T3: 100 % recommended K through SOP+ $MgSO_4.7\ H_2O$ + Borax; T4: 50 % recommended K through SOP + 50 % recommended K through PS; T5: No K Control. It contains 23 % K, 6 % Mg and 16 % S. The tobacco seedlings of 60 days age were transplanted in the first week of June across two consecutive years in KLS. Nitrogen @60 kg ha^{-1}, potassium @120 kg K_2O ha^{-1} were applied in two splits at 10^{th} and 30^{th} day of post- planting while phosphorus @46 kg P_2O_5 ha^{-1} was given as a basal dose. The recommended packages of practices were followed to raise FCV tobacco in Karnataka. Whereas in the case of Andhra Pradesh, the tobacco seedlings of 60 days were transplanted in the second week of October in two seasons. Nitrogen @ 120 kg ha^{-1}, potassium @ 120 kg K_2O ha^{-1} each were applied in three splits at 10, 30 and 45 days after planting and phosphorus @ 46 kg P_2O_5 ha^{-1} applied as basal dose. The recommended package of practices was followed to raise FCV tobacco in *Rabi*. Sunn hemp a green manuring crop was raised and incorporated in both the locations before planting of the crop.

Yield parameters

Green leaf yield (GLY)

Tobacco leaves were harvested at maturity by priming, 2-3 matured leaves each time at 7-8 days' interval and cured in the flue-curing barn. Green leaves were harvested at regular intervals upon they attain maturity. Harvested leaves were stinged and subsequently kept in the barn for curing. Fresh weight of green leaves was recorded, computed GLY and expressed in kg ha^{-1}.

Cured leaf yield (CLY)

After harvesting, green leaves were loaded on to barn for curing. Leaves were cured as per the curing schedule. After attaining proper condition for handling, Bulking was done in view to efficient grading. Cured leaf weights were recorded from all the picks and CLY was expressed in kg ha^{-1}.

Grade Index (GI)

GI is one of the important production practices in FCV tobacco production. Grading is the sorting of cured leaf into lots which are homogeneous. In case of FCV tobacco, cured leaf quality is measured as GI in NLS and BLY (Bright Leaf Yield) in KLS. Cured leaves are initially graded based on their size, colour, body, maturity, texture, blemish percentage etc., accordingly, given the grade designation. While calculating GI, different grades of cued leaf are given different weights and expressed in kg ha^{-1}. GI is calculated based on the all-grade weights, which is usually followed in NLS grown tobacco. Whereas the first top two grades are being considered popularly for measuring the quality in KLS grown FCV tobacco and is referred to as bright leaf yield (13).

Nutrient Uptake

Plant samples were collected at final harvest. Dry weights of the plant parts were taken and K content was estimated in various plant parts, *viz.,* root, stem, cured leaves. K nutrient uptake in terms of kg ha^{-1} was estimated by multiplying the nutrient content in plant parts with respective dry weights of plant parts and total nutrient uptake was obtained by summing the individual uptakes of leaf, stem and root.

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient uptake (\%) x Dry matter production (kg ha}^{-1})}{100}$$

Estimation of nicotine, reducing sugars and chlorides

Mid rib is removed from the leaf samples and the stripped lamina portions are dried in an air oven at a temperature of 60 °C, subsequently powdered to pass through 60 mesh sieve (0.2 mm) for quality analysis. 0.25 g of tobacco leaf lamina powder was taken in 150 mL conical flask; to which 2 mL of carbon suspension and 48 mL extracting solution was added and shaked well for 15 min at 170 rpm. The solution is filtered and taken into cuvettes. Passed all reagents to the auto analyzer till it acquires a stable baseline, then switch on the sampler. Reagents when mixed with samples produces colour complexes. The intensity of the colour is measured at 460 nm, 420 nm and 480 nm respectively for nicone, reducing sugars and chlorides. Calorimetric technique is used to determine the quality parameters using Auto Analyzer (Bran: Luebbe; Auto Analyzer 3) (14) and the results were expressed in per cent.

Soil properties

Soil samples were processed and analyzed for the nutrient status as per the standard procedures

Soil reaction (pH)

Soil water suspension prepared in the ratio of 1: 2.5 (20 g of soil and 50 mL distilled water) was used. Soil pH was measured using the glass electrode of a digital pH meter as described by Jackson (15).

Electrical Conductivity (EC)

Electrical conductivity was measured in 1:2.5 soil extract with the help of a digital conductivity meter at room temperature (14) and the readings were expressed in dSm^{-1}.

Organic carbon

Soil organic carbon content was determined by wet digestion method (Walkley and Black, (16). This method involves oxidizing one gram of soil using a mixture of potassium dichromate and concentrated sulphuric acid; utilizing the heat of dilution of sulphuric acid. Unused potassium dichromate was back titrated with ferrous ammonium sulphate in the presence of diphenylamine as an indicator and organic carbon content was calculated using the blank and sample titre values. Results were expressed in percentage.

Available K

Five-gram soil was extracted with neutral normal ammonium acetate solution by shaking for 5 min. K concentration in the extract was determined flame photometrically as given by Jackson (15) and the results were expressed in K_2O ha^{-1}.

Statistical analysis

The data were statistically analysed following the analysis of variance (ANOVA) method as described by Panse and Sukhatme (17) Statistical significance was tested by applying F-test at 0.05 level of probability. Critical difference at 0.05 probability level was worked out for the effects that were significant.

Results and Discussion

Effect of PS on productivity of FCV tobacco grown under KLS and NLS.

Productivity under KLS - Rainfed conditions

The results indicate that applying K through PS alone has recorded GLY as 8991 kg/ha (Table 1) at a par with SOP i.e., GLY: 8939 kg/ha. This indicates that PS, when applied at recommended doses, is equally effective as SOP in giving GLY. PS treatment alone recoded CLY at a par with SOP, indicating that PS is a good source of K and giving yields as effective as SOP in increasing the marketable cured leaf. Among the treatments numerically highest GLY, CLY and BLY were recorded when 50 % of the K was applied through PS and 50 % through SOP, demonstrating that the combined approach maximizes the effectiveness of both fertilizers. The possible reason could be that the ideal nutrient balance with enough K from SOP facilitates vigorous growth and sufficient Mg from KMS supports photosynthetic and metabolic functions. Although this treatment is numerically higher but not significant, which needs further studies to confirm the possible reasons for higher yields of combination.

Productivity under NLS- Irrigated conditions

PS has similar effects on GLY, CLY and GI like in KLS. The results indicated that applying K via PS alone has yielded a GLY of 19271 kg/ha, which is at a par with SOP, recorded a GLY of 19432 kg/ha. PS treatment alone recoded CLY (2702 kg/ha) at a par with SOP (2676 kg/ha) which is given in Table 2, indicating that PS is a good source of K and giving yields as effective as SOP in increasing the marketable cured leaf. GI is a good quality of leaf and is highly valued in the market; furthermore PS has recorded GI (1619 kg/ha) at a par with SOP (1630 kg/ha).

PS is a water-soluble potassium and magnesium sulfate, has been widely studied for its role in enhancing crop yields. The balanced nutrient composition of K and Mg makes it an efficient fertilizer for improving yield in various crops. KS enhances the yield of crops by improving photosynthetic efficiency, enzyme activation and carbohydrate translocation. In the present study, the FCV tobacco GLY, CLY and BLY were improved with application of PS and were found to be at a par with SOP. Results are in align with previous study which reported that application of 60 kg/ha of potash through schoenite resulted in the highest dry pod yield, harvest index and oil yield across the study period of two years (9). The effect of 60 kg/ha of schoenite was statistically comparable to that of 60 kg/ha of potassium sulfate on dry pod yield. Higher yield to the tune of 10 % with PS than with SOP was observed mainly due to the additional Mg, which improved chlorophyll content and photosynthesis (8). Similarly, in tomato, it was

Table 1. Effect of PS on productivity (kg ha^{-1}) of FCV tobacco grown in KLS (Pooled Analysis) under rainfed conditions

Treatment	GLY (kg ha^{-1})	CLY (kg ha^{-1})	BLY (kg ha^{-1})
T1	8939	1123	690
T2	8991	1125	712
T3	9300	1175	732
T4	9368	1179	744
T5	7206	906	515
SEm±	**306**	**36**	**27**
CD (5%)	**892**	**107**	**78**
Seasons			
Year1	8097	951	563
Year 2	7854	1043	662
SEm±	**193**	**23**	**17**
CD (5%)	**564**	**61**	**50**

T1: Recommended dose of K (RDK) through SOP in 2 equal splits (Basal and top dressing);

T2: RDK through PS in 2 equal splits (Basal and top dressing)

T3: RDK through SOP in 2 equal splits (Basal and top dressing) + MgSO4.7H20 @ 9gm /plant + Borax @ 0.5g/plant

T4: Recommended dose of 50% K through PS + 50% through SOP in 2 equal splits (Basal and top dressing)

T5: Control (Without K application)

Table 2. Effect of PS on productivity (kg ha^{-1}) of FCV tobacco grown in NLS under irrigated conditions (Pooled Analysis)

Treatment	GLY (kg ha^{-1})	CLY (kg ha^{-1})	GI (kg ha^{-1})
T1	19432	2676	1630
T2	19271	2702	1619
T3	20319	2762	1620
T4	19449	2644	1644
T5	17234	2202	1406
SEm±	**330**	**45**	**45**
CD (5%)	**963**	**133**	**132**
Seasons			
Year1	18024	2548	1487
Year 2	16881	2206	1401
SEm±	**209**	**29**	**29**
CD (5%)	**609**	**84**	**83**

T1: Recommended dose of K (RDK) through SOP in 3 splits (1:2:1) at 10 DAP, 30 DAP and 45 DAP

T2: RDK through PS in in 3 splits (1:2:1) at 10 DAP, 30 DAP and 45 DAP

T3: RDK through SOP in in 3 splits (1:2:1) at 10 DAP, 30 DAP and 45 DAP+ MgSO4.7H20 @ 9gm /plant + Borax @ 0.5g/plant

T4: Recommended dose of 50% K through PS + 50% through SOP in 3 splits (Basal and top dressing)

T5: Control (Without K application)

found that PS outperformed SOP in yield by 8 %, owing to better nutrient balance provided by the Mg content (18). It is reported no significant yield differences between the PS and potassium sulphate in sugarcane, attributing it to the high availability of Mg in the soil (19). It is reported that PS considerably increased potato growth along with yield characteristics, overall yield and the quality of tuber (20). PS has improved the GLY, CLY and GI in NLS and BLY in KLS. These results align with observations made in similar studies where PS increased growth and yield of maize, grapes, groundnut and potato (20-23,12,10).

Effect of PS on quality parameters of FCV tobacco grown under light soils of Karnataka and Andhra Pradesh

Quality parameters of FCV tobacco grown in KLS and NLS specifically nicotine content, reducing sugars and chlorides are presented in Table 3, 4. These are the key indicators of tobacco quality influencing both its flavour and marketability. There is no significant difference observed among the treatments indicating that PS does not negatively affect the nicotine levels in both KLS and NLS, which is an essential quality parameter in FCV tobacco. Reducing sugars are an indicator for better quality of tobacco indicating that PS can maintain the key quality parameter. Chloride content recorded was also within the acceptable limits indicating that there is no build-up of chlorides, which could otherwise affect the combustibility of tobacco. Leaf quality constituents *viz.*, nicotine, reducing sugar and chloride were found to be within the acceptable limits. It may be mainly because of no excessive accumulation of available nutrients in the soil with the PS, paving way for normal nutrient profile. K does not seem to have effect on the nicotine content of leaf (25). In FCV tobacco of KLS, the nicotine and reducing sugars were not affected by sources or levels of K (30). All the quality parameters are within the acceptable limits thus indicating that PS was as safe as SOP in maintaining the quality of FCV tobacco in both NLS and KLS.

Table 3. Effect of PS on Total K uptake (kg ha-1) of FCV tobacco grown in KLS

Treatment	K Uptake (kg ha-1)
Recommended dose of K (RDK) through SOP in 2 equal splits	55
RDK through PS in 2 equal splits	57
RDK through SOP in 2 equal splits + $MgSO_4.7H_20$ @ 9gm /plant + Borax @ 0.5g/plant	55
Recommended dose of 50% K through PS + 50% through SOP in 2 equal splits	61
Control (Without K application)	36
CD (5%)	8.1

Table 4. Effect of PS on Total K uptake (kg ha-1) of FCV tobacco grown in NLS

Treatment	K Uptake (kg ha-1)
Recommended dose of K (RDK) through SOP in 3 splits	123
RDK through PS in 3 splits	122
RDK through SOP in 3 splits + $MgSO_4.7H_20$ @ 9gm /plant + Borax @ 0.5g/plant	124
Recommended dose of 50% K through PS + 50% through SOP in 3 splits	130
Control (Without K application)	74
CD (5%)	6.1

Effect of PS on total K uptake of FCV tobacco grown under KLS and NLS

K Uptake under KLS- Rainfed conditions

K uptake is critical for tobacco burning and productivity. Results indicated that the total K uptake ranged from 55 to 61 kg/ha among the K applied plots. The control without K application has recorded the lowest uptake of 36 kg/ha (Table 5). Numerically the highest K uptake was seen where 50 % of K was applied via PS and 50 % through SOP, with a total uptake of 61 kg/ha.

K uptake under NLS- irrigated conditions

Results indicated that the K uptake ranged from 122-130 kg/ha among the K application plots under NLS irrigated conditions. The control without K recorded the lowest uptake at 74 kg/ha, highlighting the importance of providing external K, demonstrating that K fertilization plays a crucial role in enhancing the K uptake in FCV tobacco (Table 6). Among the K treatments, the numerically highest but not significant K uptake was seen in the treatment where 50 % of potassium was applied through PS and 50 % through SOP, with a total uptake of 134 kg/ha.

Total K uptake recorded was at a par with SOP in both rainfed and irrigated conditions. Uptake of K was highest with 60 kg/ha of potash through schoenite, comparable to 60 kg/ha of potassium sulphate in groundnut (9). K uptake in KLS is half of the NLS might be due to the moisture availability, dry spells, sandy to sandy loam texture, leaching losses, K fixation and other biotic stresses. It is reported that applied potash is subjected to leaching losses due to heavy rains or fixed in the soil through K fixation; because of which the entire quantity of applied potassium is not available to the crop in KLS condition (26). Dry spells during the crop growth period result in less uptake of K, thereby causing considerable loss in leaf yield especially the bright grade leaf production. It is reported that FCV tobacco growing soils of the KLS region are sandy to sandy loam in texture with poor moisture retention and cation exchange capacity; greatly affecting the nutrient uptake, productivity and quality of the crop considerably (27). 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 2000 kg cured leaf under NLS conditions typically absorbs 100 -120 kg K ha^{-1} (1). The uptake of K by FCV tobacco is hindered largely by the abiotic factors such as sandy nature and insufficient moisture availability; during the crop growth under red sandy loam soils of KLS. Apart from this, the K uptake by the plant is also known to be severely hampered due to biotic stresses like root knot infestation under field conditions. Incidentally the soils are also prone to biotic stresses like nematode infection and wilt disease (28). Cultivation of high yielding

Table 5. Effect of PS on quality parameters (%) of FCV tobacco grown in KLS

	Nicotine (%)		Reducing Sugars (%)		Chlorides (%)	
Treatments	X position	L position	X position	L position	X position	L position
T1	1.13	1.25	16.84	18.33	1.54	1.63
T2	1.18	1.30	15.02	17.07	1.24	1.38
T3	1.27	1.20	15.59	19.84	1.33	1.55
T4	1.23	1.08	16.11	20.82	1.41	1.46
T5	1.10	1.23	16.16	18.97	1.48	1.54
CD (5%)	0.21	0.24	1.9	3.5	0.28	0.23

T1: Recommended dose of K (RDK) through SOP in 2 equal splits (Basal and top dressing);

T2: RDK through PS in 2 equal splits (Basal and top dressing)

T3: RDK through SOP in 2 equal splits (Basal and top dressing) + MgSO4.7H20 @ 9gm /plant + Borax @ 0.5g/plant

T4: Recommended dose of 50% K through PS + 50% through SOP in 2 equal splits (Basal and top dressing)

T5: Control (Without K application)

Table 6. Effect of PS on quality parameters (%) of FCV tobacco grown in NLS

	Nicotine (%)		Reducing Sugars (%)		Chlorides (%)	
Treatment	X Position	L Position	X Position	L Position	X Position	L Position
T1	1.98	1.12	13.39	14.30	2.08	1.14
T2	1.86	1.18	13.88	14.20	1.88	1.13
T3	1.66	1.02	14.84	14.42	2.13	0.94
T4	1.43	1.02	14.76	14.13	1.80	1.04
T5	1.58	1.24	15.25	15.29	1.73	1.09
CD (5%)	0.03	0.13	0.66	0.50	0.12	0.03

T1: Recommended dose of K (RDK) through SOP in 3 splits (1:2:1) at 10 DAP, 30 DAP and 45 DAP

T2: RDK through PS in 3 splits (1:2:1) at 10 DAP, 30 DAP and 45 DAP

T3: RDK through SOP in in 3 splits (1:2:1) at 10 DAP, 30 DAP and 45 DAP+ MgSO4.7H20 @ 9gm /plant + Borax @ 0.5g/plant

T4: Recommended dose of 50% K through PS + 50% through SOP 3 splits (Basal and top dressing)

T5: Control (Without K application)

varieties like Kanchan coupled with potential K losses in KLS do affect the optimum uptake and desired K concentration levels in leaf for optimum burn. Maintenance of sufficient K levels in soil for tobacco cultivation plays an important role for sustaining the productivity and quality of FCV tobacco (24).

Effect of PS on soil properties of FCV tobacco grown under KLS of Karnataka

Results of post-harvest soil analysis in KLS revealed that the soil pH value ranges from 5.39 to 6.38, indicating slight acidity. The soluble salts are low, ranging from 0.32 and 0.39 dS.m^{-1}. Soil organic carbon ranges from 0.52 % to 0.57 %. The highest K concentration was recorded in the plots where SOP was applied with 464 kg ha^{-1}. The lowest K concentration (363 kg ha^{-1}) was recorded in the control (Table 7).

Effect of PS on soil properties of FCV tobacco grown under NLS of Andhra Pradesh

Results of post-harvest soil analysis in NLS showed that the soil pH value ranges from 5.22 to 5.42, signifying that the soil is slightly acidic. The soluble salts are low, ranging from 0.3 and 0.4 dS.m^{-1}. Soil organic carbon ranges from 0.43 % to 0.57 %. The highest K concentration was recorded in the plots where 50 % PS and 50 % SOP was applied with 444 kg ha^{-1}, indicating that this treatment was effective in maintaining residual soil K. The lowest K concentration (173 kg ha^{-1}) was recorded in the control. Post-harvest soil analysis indicated that PS did not negatively affect the soil properties. The soil pH, electrical conductivity (EC), organic carbon (OC) and K content remained within acceptable ranges (Table 8).

The post-harvest soil analysis also revealed that PS has a positive impact on maintaining soil fertility. The nutrient content of the soil remained sufficient after the application of PS and there were no harmful effects on soil pH, EC, or organic carbon in both NLS and KLS. The K fertility status of soils growing FCV tobacco in KLS and NLS showed medium to high levels of potassium (29, 30). According to our results, the high available K status which is in align with the earlier studies indicating that the application of PS does not negatively alter the K availability.

Table 7. Effect of PS on Post - harvest soil properties of FCV tobacco grown in KLS

Treatment	Soil pH	EC dSm^{-1}	OC (%)	K kg.ha^{-1}
Recommended dose of K (RDK) through SOP in 2 equal splits (Basal and top dressing);	6.38	0.35	0.57	464
RDK through PS in 2 equal splits (Basal and top dressing)	5.87	0.39	0.56	447
RDK through SOP in 2 equal splits (Basal and top dressing) + MgSO4.7H20 @ 9gm /plant + Borax @ 0.5g/plant	5.82	0.37	0.53	414
Recommended dose of 50% K through PS + 50% through SOP in 2 equal splits (Basal and top dressing)	5.65	0.36	0.54	400
Control (Without potassium application)	5.39	0.32	0.52	363
CD (5%)	1.08	0.07	0.06	110

Table 8. Effect of PS on Post - harvest soil properties of FCV tobacco grown in NLS

Treatment	Soil pH	EC dSm^{-1}	OC (%)	K kg.ha^{-1}
Recommended dose of K (RDK) through SOP in 3 splits	5.42	0.4	0.57	399
RDK through PS in 3 splits	5.38	0.3	0.51	293
RDK through SOP in 3 splits + $MgSO_4.7H_20$ @ 9gm /plant + Borax @ 0.5g/plant	5.22	0.4	0.50	375
Recommended dose of 50% K through PS + 50% through SOP in 3 splits	5.23	0.4	0.43	444
Control (Without K application)	5.28	0.4	0.50	173
CD (5%)	0.37	0.2	0.09	52

Conclusion

Under both irrigated and rainfed conditions of NLS and KLS grown tobacco, PS application has improved FCV tobacco yield and potassium uptake, which is at a par with SOP, furthermore, maintained the quality parameters within the acceptable limits without affecting the post-harvest soil properties. As the PS is indigenously produced, it is a highly accessible option for tobacco farmers, especially in the event of the non-availability of SOP. Hence, tobacco farmers can be greatly benefitted with this K source, especially when compared to SOP, whose availability is often uncertain, imported and dependent on market conditions. Besides being a good source of K, the PS can potentially supply other nutrients namely Mg and S, which are also playing an important role in tobacco nutrition contributing to balanced fertilization.

Keeping in view of these beneficial roles, recommendation of PS application @ 652 kg/ha in 3 splits (1:2:1) at 10, 30 and 45 days after planting of FCV tobacco in NLS of Andhra Pradesh and PS @ 522 kg/ha in 2 equal splits (1:1) at 10 and 30 days' after planting of FCV tobacco in KLS of Karnataka was given to the FCV tobacco farming community.

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Authors' contributions

The study was conceptualised by JPB, DDR and CCSR. Methodology was designed by JPB, SKK, MM. Results were validated by JPB and BH. Investigation was done by JPB and MM. Required resources were collected by MSM, RR and K. Manuscript was written by JPB. Visualization was done by JPB and RDVV. The research was supervised by MSM and RRK. Funding acquisition was done by DDR. All authors have read and agreed to the published version of the manuscript."

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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