



Optimizing Flue-cured Virginia (FCV) Tobacco Productivity Through Soil Inversion and Innovative Potassium Management Strategies

K. Meghana ^a, J. Poorna Bindu ^{b*}, D. Damodar Reddy ^c,
M. Sheshu Madhav ^b, I. Usha Rani ^a
and K. N. Sreenivasulu ^a

^a Agricultural College, Bapatla, ANGRAU, Andhra Pradesh- 522101, India.

^b ICAR- Central Tobacco Research Institute, Rajahmundry, Andhra Pradesh-533105, India.

^c ICAR- National Academy of Agriculture Research Management, Hyderabad, Telangana-500030, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the effect of soil inversion along with potassium management strategies on the growth, productivity and potassium use efficiency of FCV tobacco growing on light textured Alfisols
Study Design: Split Plot Design.

Place and Duration of Study: A field experiment was conducted at ICAR – Central Tobacco Research Institute, Research Farm, Jeelugumilli during *rabi* 2022-23.

*Corresponding author: E-mail: j.poornabindu@gmail.com;

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Methodology: The experiment was laid out in split plot design with two soil inversion practices in main plots viz., M₁, soil inversion with MB (Mould Board) plough to a depth of 25 cm and M₂, without soil inversion and seven sub plot treatments viz., S₁, without potassium, S₂, 100% recommended dose of potassium (RDK) through sulphate of potash (SOP) treatments; S₃, 75% RDK through SOP; S₄, 100% RDK through SOP + Tobacco stalk biochar (TS Biochar) treatment [1:1]; S₅, 75% RDK through SOP + TS Biochar [1:1]; S₆, 100% RDK through SOP + Barn wood Ashes (BWA) treatment [1:1]; S₇, 75% RDK through SOP + BWA treatment [1:1], with each treatment being replicated thrice.

Results: Results revealed that soil inversion has significantly influenced the yield attributes, yield, nutrient uptake and potassium use efficiency. Among the potassium supply strategies, the superior green leaf yield (10,625 kg ha⁻¹), cured leaf yield (1695 kg ha⁻¹); N, P, K uptake; potassium use efficiency and agronomic use efficiency were observed in the treatment S₄, 100% K through SOP + TS Biochar (1:1) treatment [S₄] than that of no K treatment. Moreover all, the quality parameters like nicotine (%), reducing sugars (%) and chloride (%) are in acceptable ranges in all the treatment plots.

Conclusion: Under scarce potassium sulphate situation, soil inversion with MB plough and TS Biochar/ BWA can act as potassium supplements.

Keywords: Potassium; tobacco stalk biochar; barn wood ash; MB plough.

1. INTRODUCTION

Tobacco (*Nicotiana tabacum* L.), also known as golden leaf, is one of the most important commercial crops which is vital to developing economies. In India, it is valued for its potential to fetch higher income to farmers, and to make significant contribution to national exchequer in terms of excise revenue and export earnings. Tobacco provides livelihood security to millions of people. Currently, India is the second-largest exporter of tobacco, accounts ~9% of global tobacco exports after Brazil. The exports of tobacco and tobacco products contributed Rs.9740 crore of foreign exchange during 2022-23 (Annual Report, 2023 ICAR-CTRI) India is a leading exporter of leaf tobacco and tobacco products contributing foreign exchange earnings to the tune of Rs. 6,880 Crores (Madhav, et al. 2022). In India, Andhra Pradesh ranks second in terms of tobacco production with 1.85 lakh tons i.e., 23.08 % of total India's production which is being produced in an area of 85,000 ha i.e., 40.13% of the total India's tobacco production area. Whereas, in Andhra Pradesh, FCV (Flue-Cured Virginia) tobacco is being cultivated in around 16,000 hectares area of northern light soils (NLS) during *rabi* under irrigated conditions (Agricultural statistics at a glance 2021).

Being a luxury consumer of potassium, tobacco needs relatively large quantity of K to attain optimum yield and quality. Among various tobacco types, the export quality FCV tobacco requires higher dose of potassium as it plays direct role in improving the burning quality and

optimizes the aroma and flavor of the tobacco. According to Krishna et al. (2015), FCV tobacco being produced under irrigated conditions in NLS region of Andhra Pradesh is considered semi-flavourful and quality tobacco. However, the low native K fertility of the *Alfisols* in NLS region increase the dependency on inorganic K fertilizers like Sulphate of Potash. Additionally, the low cation exchange capacity (CEC) of the *Alfisols* accelerates the risk of K leaching, this resulted in raising potassium application rates. However, the Sulphate of potash (MOP), which is usually imported to India is quite expensive and cannot be replaced by muriate of potash due to the chloride sensitivity of tobacco. Additionally, the outbreak of COVID-19 caused a drastic decline in SOP production which in turn effected its imports and supply chain. Thus, leading to a hike in its price. Under these circumstances, K management strategies are essential to maintain the optimum productivity and quality of tobacco.

Additionally, the conventional tillage practices being followed by the tobacco farmers of NLS region of Andhra Pradesh resulting in an increased bulk density of soil due to decreased soil porosity. This leads to the formation of a perched water table at drainage level that restricts the root growth and water movement (Spomer & Turgeon 1977). Soil inversion with MB plough to a depth of 25 cm helps in breaking this perched water table usually seen at a depth of 22.5 cm in the plough layer. It also helps in replenishing the leached nutrients (especially K) from lower depths by bringing subsoil to top layers. Consequently, it promotes root growth

and nutrient uptake by plants. Hofbauer et al. (2022) conducted a field trial on a sandy loam soil in eastern Germany, where reduced tillage was carried out to 6 cm soil depth by means of a ring cutter and compared it to MB ploughing with 25 cm tillage depth. They reported that the total nitrogen uptake by winter rye in the ring cutter treatment was up to 44% smaller than in the MB plough treatment. Chaudhary et al. (1985) performed an experiment in maize crop and reported that sub-soiling, mould-board ploughing and deep digging increased plant height by 30-35 cm, stover yield by 80-100% and grain yield by 70-350% than the control.

Similarly, the burning of tobacco stalks in the fields, leads to huge environmental pollution. To overcome this issue, biochar can be made out of these tobacco stalks by combustion at controlled temperature in oxygen limited environment. The properties of biochar like pH, greater surface area, cation exchange capacity, and nutrient content positively influences the soil properties and ultimately improves the soil fertility (Premalatha, et al., 2023). IBI (2013), defines biochar as a solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment. Soil-applied biochar has been reported to increase soil fertility and decrease nutrient leaching in tropical soils. Specifically, tobacco stalk biochar (TS Biochar) is a source of nutrients, which contains negative carboxyl and carbonate functional groups capable of holding cationic nutrients like K which are otherwise prone to leaching (Bindu, et al. 2023). Thus, biochar obtained from the nutrient rich biomass feedstock can be used as a direct source of nutrients such as K, Ca and Mg (Atkinson, et al., 2010). Application of biochar is known to have reduced leaching of ammonium ions (Singh, et al. 2010; Bindu et al. 2017), improved soil available NPK (Bindu, et al., 2016, Pandian, et al., 2016, Zhang, et al., 2021, Yun, et al., 2017), K uptake (Coumaravel, et al., 2015, Agegnehu, et al., 2015, Bindu, et al., 2020, 2023) and yield in several crops (Albuquerque, et al., 2013, Partey, et al., 2014, Bindu, et al., 2020, 2023).

On the other hand, wood ash, a waste generated from fuel wood burning during the curing process of FCV tobacco can also act as a rich potassium source. Application of biomass ashes can be an effective strategy to substitute/supplement K requirement in tobacco production and helps in reducing the dependency on costly SOP fertilizer. Mahadevaswamy and Damodar (2019)

characterized various wood ashes and identified the following potassium levels: tobacco stem ash (16% K), cotton stem ash (20.5% K), pigeon pea stem ash (9.6 %), and eucalyptus wood ash (3.5 % K). Application of biomass ashes/wood ashes increase the soil pH (Ndubuisi & Deborah, 2010, Arshad, et al., (2012); Trunhe & Yli, (2016); Bonfimsilva et al. (2022). Several reports indicated that application of wood ashes has improved soil organic carbon content Adekayode and Olojugba (2010), soil available nutrients Agbede and Adekiya (2012); Bougnom et al. (2020); Trunhe and Yli (2016); Johansen et al. (2021), and potassium uptake Mahadevaswamy and Reddy (2019); Arseneau et al. (2021).

Interventions like soil inversion, along with the usage of organic sources of potassium like TS Biochar and BWA in combination with SOP fertilizer can sustain tobacco productivity, quality and improve nutrient use efficiency. Considering these factors, the present investigation was conducted to study the "Effect of Soil Inversion and potassium management strategies on improving crop productivity of FCV tobacco growing in NLS region of Andhra Pradesh". The objective of this study is to assess the effect of soil inversion and K input management on productivity, nutrient uptake, nutrient use efficiency and quality of FCV tobacco.

2. MATERIALS AND METHODS

A field experiment was conducted during winter (*Rabi*) season of 2022 at ICAR – Central Tobacco Research Institute, Research Farm, Jeelugumilli (17° 11' 30" N latitude, 81° 07' 50" E longitude, and an altitude of 150 m above Msl). The experimental site is situated in Godavari Agro-climatic Zone of Andhra Pradesh, India. The soil of the field belongs to *Alfisol* with sandy loam texture (sand 59.5 %, silt 10 % and clay 11.3%) and contains kaolinite as a dominant clay mineral. The experimental soil was highly acidic in nature with pH value 5.50, electrical conductivity (EC) 0.05 dS m⁻¹ in 1:2.5 (soil: water) suspension. The soil was rated to be in low category of organic carbon (2.0 g kg⁻¹) (Walkley and Black, 1934), low in available N (83.63 kg N ha⁻¹) (Subbiah & Asija, 1956), high in available P (105 kg P₂O₅ ha⁻¹) (Bray and Kurtz 1945) and medium in available K (230 kg K₂O ha⁻¹) (Jackson 1973). The experiment was laid in split plot design (SPD) replicated three times with two soil inversion treatments as main plots viz., M₁: with soil inversion using Mold Board (MB) plough to a depth of 25 cm, M₂: without soil

Table 1. Treatment details (amount of each K source to be applied)

Sl. No	Treatment (K source)	% K content	K rate (kg K ha ⁻¹)	Amount of SOP (or) [(TS Biochar / BWA) + SOP] applied (kg ha ⁻¹)	%K substitution by TS Biochar / BWA
1	No K	0	---	0	0
2	100% K through SOP	40	100	250 kg SOP	0
3	75% K through SOP	40	75	188 kg SOP	0
4	100% K through SOP + Tobacco Stalk Biochar (1:1)	22	100	455 (227.5 kg SOP + 227.5 kg TS Biochar)	9.3
5	75% K through SOP + Tobacco Stalk Biochar (1:1)	22	75	341 (170.5 kg SOP + 170.5 kg TS Biochar)	9.3
6	100% K through SOP + Barn Wood Ash (1:1)	22	100	455 (227.5 kg SOP + 227.5 kg BWA)	9.3
7	75% K through SOP + Barn Wood Ash (1:1)	22	75	341 (170.5 kg SOP + 170.5 kg BWA)	9.3

inversion and seven potassium management practices as subplots viz., No K (S₁); 100% recommended doses (RD) of K through sulphate of potash (SOP) [S₂]; 75% RD of K through SOP (S₃); 100% RD of K through SOP and tobacco stalk biochar (TS Biochar) in 1:1 (S₄); 75% RD of K through SOP and TS Biochar in 1:1 (S₅); 100% RD of K through SOP and barn wood ash (BWA) in 1:1 (S₆); 75% RD of K through SOP and BWA in 1:1 (S₇). Sixty days old seedlings of FCV tobacco variety (FCJ-11) were transplanted on the second week of October, 2022 with a spacing of 100 cm × 60 cm in a plot of size 10 × 3.6 m. The inorganic fertilizers with a rate of 120:46:120 (N: P₂O₅: K₂O kg ha⁻¹) were the recommended dose for FCV tobacco in the Northern Light Soil region of Andhra Pradesh, India. The Di-Ammonium Phosphate (DAP), Ammonium Sulphate and Sulphate of Potash (SOP) were used as sources of N, P and K, respectively. The fertilizers were applied as per recommended package of practices, means topdressing of fertilizers at 10 days after transplanting (DAT), 30 DAT and 45 DAT. For treatments 4 to 7, the respective TS Biochar/ BWA and SOP are mixed in equal proportion i.e., 1 part TS Biochar/BWA + 1 part SOP on material basis. TS Biochar/ BWA along with SOP were applied on K equivalent basis @ 100 kg K ha⁻¹ for FCV tobacco (Table 1). The TS biochar used in experiment having pH: 9.42, EC: 0.11, total organic carbon: 79%, total N: 1.23%, total P: 0.51%, total K: 4%. The BWA used in experiment having pH: 11.23, EC: 1.36, total organic carbon: 7.21%, total N: 0.39%, total P: 1.24% and total K: 4%.

2.1 Plant Sample Collection and Analysis

Three plants were selected at random from each plot and tagged. Growth and yield attributes viz., plant height, no. of leaves and leaf area index were recorded at 60 DAT, 75 DAT. 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 and on average 7 priming's were done to complete harvesting of tobacco. Fresh weight of green leaves was recorded and computed green leaf yield and expressed in kg ha⁻¹. 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 cured leaf yield was expressed in kg ha⁻¹. Stem and root samples were collected at final harvest. Dry weights of the plant parts were taken and N,

P, K contents were estimated in various plant parts, viz. root, stem, leaves using standard methods. 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. The following measures/indices of K use efficiency were defined and estimated as per the standard calculations.

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.

$$AE = (Y - Y_0) / A_K = \Delta Y / A_K$$

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

Statistical analyses: Data generated from the field experiment was analysed using Analysis of Variance (ANOVA) in a split plot design as suggested by Panse and Sukhatme, (1978). 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.

3. RESULTS AND DISCUSSION

3.1 Yield Attributes

Productivity of tobacco is directly influenced by the increase in number of curable leaves, leaf area index (LAI) and indirectly by height of the plant (Table 2). Soil inversion and potassium input management have significant effect on yield attributes at both 60 and 75 days after transplanting/ planting (DAT/P). While their interaction is not significant in both the cases. Soil inversion has significantly increased the plant height at 60 DAP to a mean value of 54.48 cm from 42.19 cm in plots with no soil inversion while the increase was from 91.92 cm to 114.85 cm at 75 DAP. The number of leaves per plant are more in soil inversion plots with a mean value of 16, 27 leaves per plant at 60, 75 DAP, respectively. Similarly, the highest mean leaf area indexes of 1.76 and 2.61 were recorded in soil inversion plots at 60 and 75 DAP respectively. Chaudhary et al. (1985) reported that the mould-board ploughing and deep digging increased plant height by 30-35 cm due to reduction in soil bulk density and penetration

resistance for roots. The increase in yield attributes owing to the use of MB Plough for soil inversion was due to improved soil physical and chemical properties, which in turn, promotes water retention, reduce nutrient leaching and increase nutrient availability in root zone. Similar results were observed by Parvin et al. (2014).

Whereas, among the potassium input management practices, a greater number of leaves were observed in S₄ [100% K through SOP + Tobacco Stalk Biochar (1:1)] treated plots, with mean values of 18, 28 leaves per plant at 60 DAP and 75 DAP, respectively. While, the results were on par with S₆ [100 % K through SOP + Barn Wood Ash (1:1)] treatment. Yang et al. (2021) has observed a similar trend of increase in the no. of leaves, yield of fresh tea leaves, 100-sprout weight, and sprout density of tea when biochar is applied in combination with inorganic fertilizers. Bonfimsilva et al. (2018) also reported a significant increase in stem diameter and number of leaves in cowpea when wood ash is applied to the crop due to its efficiency in supplying macro elements like P, K, Ca and some micronutrients nutrients to the plant. The plant height was recorded highest with mean values of 53 cm at 60 DAP and 109.77 cm at 75 DAP in S₄ [100% K through SOP + Tobacco Stalk Biochar (1:1)] treatment which was on par with S₅ [75% K through SOP + Tobacco Stalk Biochar (1:1)] (Table 2). Cheema et al. (1999) observed an increased taller plants production with increased K fertilization, in comparison to the control. The greater LAI were recorded in S₆ [100% K through SOP + Barn Wood Ash (1:1)] treated plots with a mean value of 1.73, 2.34 at 60 and 75 DAP which was on par with S₄ [100% K through SOP + Tobacco Stalk Biochar (1:1)] at 60 DAP. However, at 75 DAP, the LAI recorded was on with S₄ [100% K through SOP + Tobacco Stalk Biochar (1:1)], S₂ [100% K through SOP], S₅ [75% K through SOP + Tobacco Stalk Biochar (1:1)] and S₃ [75% K through SOP], respectively. The higher leaf area index was recorded in the maize and cassava crop upon co-application of wood ash and NPK fertilizers due to the availability of readily soluble nutrient for absorption by the plants (Adekayode & Olojugba, 2010). The increase in yield attributes by the application of biochar and wood ash in our experiment may be due to their conditioning effect which in turn enhanced nutrient supply. Biochar and wood ash improves soil pH and bulk density by increasing soil porosity and water retention, thereby, reducing the leaching losses, promoting the nutrient uptake by plants. Bindu et

al. (2023) also observed an increase in no. of curable leaves, leaf area index and plant height with the application of soil amendments like TS biochar, synthetic zeolites along with 100% NPK than that of the solo application of soil amendments. They proposed that the increase may be due to the presence of hydroxyl functional groups in biochar that promote adsorption of nutrients.

3.2 Crop Productivity

Crop Productivity is mainly a function of adequate nutrients supply from the soil and their utilization in metabolic process, resulting in building up of dry matter and quality of tobacco. Highest green leaf yields (GLY) and cured leaf yields (CLY) were obtained upon soil inversion with a mean value of 10449 kg ha⁻¹ and 1704 kg ha⁻¹ respectively (Table 3). Soil inversion with MB plough improved the tobacco yields, as it might have facilitated incorporation of organic residues into soil. This provides a favourable environment for microbial growth, thereby promoting rapid mineralization and release of nutrients. Also, improved soil porosity enhances the water holding capacity and minimizes nutrient leaching losses. Sub-soiling, mould-board ploughing and deep digging increased maize stover yield and grain yield by 80-100% and 70-350% respectively (Chaudhary, et al., 1985). Winter rye yield declined by 22–43% in the ring cutter treatment relative to the mould board plough treatment (Hofbauer, et al., 2022).

Among the potassium input management practices, the plots treated with S₄ [100% K through SOP + Tobacco Stalk Biochar (1:1)] have recorded the highest green and cured leaf yields with mean values of 10625 kg ha⁻¹ and 1695 kg ha⁻¹ respectively. Also, the cured leaf yield was on par with S₆ [100% K through SOP + Barn Wood Ash (1:1)], S₂ [100% K through SOP] and S₅ [75% K through SOP + Tobacco Stalk Biochar (1:1)]. The results concur with (Bindu, et al., 2023) that the application of tobacco stalk biochar along with fertilizers has increased the FCV tobacco production by 13% over 100% RDF. Similarly, Jiang et al. (2022) observed an increase in FCV tobacco plant growth, yield and cured leaf quality with the application of tobacco straw. Combined application of biochar and nutrient fertilizers will enhance the yield and helps in slow release of nutrients during crop growth and continues the nutrient availability due to biochar high surface area and CEC. Besides, biochar plays a prominent role in retaining soil

Table 2. Effect of soil inversion in conjunction with potassium interventions on yield Attributes of FCV tobacco grown under irrigated Alfisols

PIM	Leaf Number			Plant Height (cm)						Leaf Area Index								
	60 DAP			75 DAP			60 DAP			75 DAP			60 DAP			75 DAP		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S₁	14	14	14	20	18	19	49	40	45	106	87	97	1.48	1.19	1.33	2.07	1.54	1.81
S₂	17	15	16	29	21	25	54	42	48	116	95	105	1.81	1.18	1.50	2.72	1.85	2.28
S₃	16	13	14	28	20	24	53	41	47	114	89	102	1.80	1.13	1.46	2.69	1.82	2.26
S₄	18	18	18	31	24	28	61	45	53	120	99	110	1.88	1.37	1.63	2.73	1.87	2.30
S₅	17	15	16	27	22	25	58	42	50	118	92	105	1.87	1.24	1.55	2.68	1.80	2.24
S₆	17	18	17	29	22	26	55	42	49	120	93	107	1.95	1.50	1.73	2.88	1.80	2.34
S₇	14	15	15	22	20	21	51	43	47	110	88	99	1.55	1.16	1.36	2.46	1.73	2.10
Mean	16	15		27	21		55	42		115	92		1.76	1.25		2.61	1.77	
	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %
		(p=0.05)			(p=0.05)			(p=0.05)			(p=0.05)			(p=0.05)			(p=0.05)	
M	0.27	NS	7.86	0.47	2.83	8.92	0.65	3.95	6.16	1.53	9.32	6.79	0.03	0.18	8.94	0.03	0.20	6.71
S	0.43	1.26	6.70	0.90	2.63	9.23	1.47	4.30	7.46	2.74	8.00	6.49	0.05	0.13	7.42	0.06	0.17	6.44
M x S	0.61	NS		1.27	NS		2.08	NS		3.88	NS		0.06	NS		0.08	NS	
S x M	0.63	NS		1.27	NS		2.03	NS		3.90	NS		0.07	NS		0.08	NS	

Main Plots: M₁: With Soil Inversion, M₂: Without Soil InversionSub Plots: S₁: No K, S₂: 100% K through SOP, S₃: 75% K through SOP, S₄: 100% K through SOP + Tobacco Stalk Biochar (1:1), S₅: 75% K through SOP + Tobacco Stalk Biochar (1:1), S₆: 100% K through SOP + Barn Wood Ash (1:1), S₇: 75% K through SOP + Barn Wood Ash (1:1)

Table 3. Effect of soil inversion in conjunction with potassium interventions on yield (kg ha⁻¹) of FCV tobacco grown under irrigated Alfisols

PIM	Green Leaf Yield (GLY)			Cured Leaf Yield (CLY)		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	8774	6590	7682	1429	1176	1302
S ₂	10850	8215	9533	1793	1450	1621
S ₃	10250	8118	9184	1747	1351	1549
S ₄	11885	9364	10625	1822	1568	1695
S ₅	10145	8698	9422	1703	1449	1576
S ₆	11215	8100	9658	1779	1496	1637
S ₇	10020	7097	8559	1654	1367	1510
Mean	10448	8026		1704	1408	
	SEm±	CD (p=0.05)	CV %	SEm±	CD (p=0.05)	CV %
M	166.04	1010.33	8.24	29.50	179.49	8.69
S	267.30	780.18	7.09	47.44	138.46	7.47
M x S	378.01	NS		67.09	NS	
S x M	387.36	NS		68.76	NS	

Main Plots: M₁: With Soil Inversion, M₂: Without Soil Inversion

Sub Plots: S₁: No K, S₂: 100% K through SOP, S₃: 75% K through SOP, S₄: 100% K through SOP + Tobacco Stalk Biochar (1:1), S₅: 75% K through SOP + Tobacco Stalk Biochar (1:1), S₆: 100% K through SOP + Barn Wood Ash (1:1), S₇: 75% K through SOP + Barn Wood Ash (1:1)

nutrients by reducing the leaching loss of nutrients from the chemical fertilizer (Haider, et al., 2017). The combined application of biochar and biodegradable mulch increased the plant height, stem diameter, leaf area, total root area, root tip number, and root activity of tobacco, which led to increase in leaf and root biomass by 11.40–67.01% and 23.91–50.74%, respectively (Tang, et al., 2024). Biochar application on promoting crop growth was mainly due to the improvement in soil physical and chemical properties, soil nutrient availability, soil microbial abundance and community structure (Zwieten, et al., 2010). In addition, wood ash can also alter soil physical properties by swelling upon contact with water, which helps block soil pores. This improves the soil's water-holding capacity, thereby increasing the availability of water-soluble nutrients (Santalla, et al., 2011).

3.3 Nutrient Uptake

The nitrogen (N) and phosphorous (P) uptake was significantly influenced by both soil inversion and potassium management practices while their interaction was not significant. Soil inversion has increased the N, P uptake from 31.50 kg ha⁻¹, 3.46 kg ha⁻¹ without soil inversion to 42.15 kg ha⁻¹, 4.63 kg ha⁻¹ upon soil inversion (Table 4). The uptake of N, P, K in tobacco plant has increased significantly with soil inversion, as inverting soil using MB plough improves soil porosity and reduces penetration resistance, promoting luxurious root growth. Moreover, since our

experimental soils are prone to leaching losses, it also increases nutrient availability by homogenization as it brings the leached nutrients from bottom to top layers and helps in reduction of nutrient leaching as it increases water retention. This is in accordance with the findings of Hofbauer et al. 2022, Parvin et al. 2014 and Peigné et al. 2018.

Coming to the effect of potassium input management practices on N uptake by tobacco plant, the treatment 100% K through SOP + Tobacco Stalk Biochar (1:1) [S₄] has recorded highest N uptake of 42.98 kg ha⁻¹, which was on par with S₂ [100% K through SOP] and S₆ [100% K through SOP + Barn Wood Ash (1:1)]. The total N uptake in the tobacco plant was more when crop was provided with 100% K through SOP irrespective of the amendments. This may be because uptake of N increased with increased levels of N and K application (Krishna, et al., 2015). As same amount of N was given to all the plots, the plots receiving higher K showed high N uptake. While among the amendments, the biochar combination treatment showed high total N uptake than that of wood ash, owing to no or low N content in the wood ash (Vance, 1996). Results are in agreement with Bindu et al. (2023), where highest Total N uptake by tobacco was observed when 100% NPK was combined with tobacco stalk Biochar and synthetic zeolites. Also, Chan et al. 2007 observed high N uptake by radish plants grown in K rich biochar amended soils. Whereas, the highest P uptake

was also observed in S₄ [100% K through SOP + Tobacco Stalk Biochar (1:1)] treated plots. The reduced sorption and leaching of phosphorous with the addition of biochar, increases the P absorption by the groundnut plant tissues (Agegnehu, et al., 2015). Application of wood ash increased the soil pH which in turn increases the availability of P in soils because of the reduction in adsorption of P to Al and Fe oxides and increases the aluminium or Fe phosphate solubility resulting in more free orthophosphates available for plant uptake (Nweke, et al., 2017). However, the total potassium uptake by tobacco crop was significantly influenced by soil inversion, potassium input management and their interaction were also significant (Table 4). Inversion of soil has significantly increased total K uptake by plant from 39.57 kg ha⁻¹ without soil inversion to 57.21 kg ha⁻¹ upon soil inversion. In case of potassium input management practices, total K uptake by tobacco crop was observed more when 100% K through SOP + Tobacco Stalk Biochar (1:1) [S₄] (54.56 kg ha⁻¹) was applied to the soil which was on par with the S₂ [100% K through SOP] and S₆ [100% K through SOP + Barn Wood Ash (1:1)]. The higher cation exchange capacity of biochar reduced the losses of K through leaching, making it available for plant uptake. When added to the soil, biochar helps in the oxidation of the soil surface by biotic and abiotic agents, resulting in the development

of negative charges that increases the ability of biochar to sorb more cations like K which in turn increase the uptake of nutrients by plants (Danish, et al., 2014). As the ashes produced through combustion are rich in nutrients like K, Ca, Mg etc., when added to soil, they enhance the uptake of K⁺ which increases proportionally with ash application rates (Sharifi, et al., 2013, Nwite, 2015).

3.4 Recovery Efficiency of Potassium (RE_K) and Agronomic Use Efficiency (AE_K)

The recovery use efficiency of potassium in the present study ranged from 12.74 % to 17.20 % and the highest potassium use efficiency was observed in plots treated with 100% K through SOP + Tobacco Stalk Biochar (1:1). Whereas, the agronomic use efficiency (AUE) ranged from 2.33 to 3.34 although no much variation was observed among the treatments. The highest AUE of 3.34 was seen in plots treated with 100% K through SOP + Tobacco Stalk Biochar (1:1) (Fig. 1). Our finding is in accordance with Wu et al. (2019) who demonstrated that biochar could increase cotton yield by improving potassium use efficiency (KUE), thereby decreasing the dependency on chemical K fertilizer. Bindu et al. 2023 also reported an increase in Agronomic Use efficiency of tobacco by the application

Table 4. Effect of soil inversion in conjunction with potassium interventions on Total Nutrient Uptake (kg ha⁻¹) of FCV tobacco grown under irrigated Alfisols

PIM	N uptake			P uptake			K uptake		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	33.56	27.72	30.64	3.46	2.78	3.12	38.12	29.34	33.73
S ₂	46.73	34.19	40.46	5.18	3.72	4.45	63.01	45.02	54.02
S ₃	41.84	28.52	35.18	5.03	3.32	4.17	60.24	38.55	49.39
S ₄	48.89	37.07	42.98	5.44	4.18	4.81	64.34	44.79	54.56
S ₅	37.71	30.25	33.98	4.19	3.41	3.80	53.18	40.68	46.93
S ₆	48.06	33.11	40.59	4.95	3.68	4.32	65.08	43.70	54.39
S ₇	38.24	29.61	33.92	4.13	3.10	3.62	56.52	34.94	45.73
Mean	42.15	31.50		4.63	3.46		57.21	39.57	
	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %
		(p=0.05)			(p=0.05)			(p=0.05)	
M	0.52	3.18	6.50	0.13	0.78	14.56	0.70	4.28	6.66
S	1.40	4.08	9.30	0.12	0.35	7.31	1.31	3.83	6.64
M x S	1.98	NS		0.17	NS		1.86	5.42	
S x M	1.90	NS		0.20	NS		1.86	5.42	

Main Plots: M₁: With Soil Inversion, M₂: Without Soil Inversion

Sub Plots: S₁: No K, S₂: 100% K through SOP, S₃: 75% K through SOP, S₄: 100% K through SOP + Tobacco Stalk Biochar (1:1), S₅: 75% K through SOP + Tobacco Stalk Biochar (1:1), S₆: 100% K through SOP + Barn Wood Ash (1:1), S₇: 75% K through SOP + Barn Wood Ash (1:1)

Table 5. Effect of soil inversion in conjunction with potassium interventions on nicotine (%), reducing sugars (%) and chlorides (%) of FCV tobacco grown under irrigated Alfisols

PIM	Nicotine			Reducing Sugars						Chlorides								
	X position			L Position			X position			L Position			X position			L Position		
	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean	M ₁	M ₂	Mean
S ₁	1.02	1.03	1.02	0.95	1.00	0.97	17.96	18.17	18.06	17.89	16.70	17.30	0.34	0.27	0.30	0.28	0.38	0.33
S ₂	0.91	0.97	0.94	0.94	1.24	1.09	18.19	18.49	18.34	17.75	15.72	16.73	0.24	0.28	0.26	0.27	0.34	0.30
S ₃	0.83	1.02	0.92	0.96	1.08	1.02	18.90	19.47	19.19	17.13	16.74	16.93	0.25	0.24	0.24	0.29	0.30	0.29
S ₄	0.86	0.98	0.92	1.03	0.97	1.00	19.60	18.42	19.01	17.71	16.23	16.97	0.29	0.23	0.26	0.27	0.28	0.28
S ₅	0.90	0.89	0.90	1.09	1.02	1.06	19.97	18.16	19.06	17.59	15.67	16.63	0.28	0.26	0.27	0.27	0.31	0.29
S ₆	0.82	0.95	0.89	1.05	1.06	1.06	17.49	17.65	17.57	17.91	15.76	16.84	0.27	0.27	0.27	0.31	0.33	0.32
S ₇	0.85	1.01	0.93	0.98	1.18	1.08	20.24	19.14	19.69	18.15	16.64	17.39	0.29	0.23	0.26	0.26	0.32	0.29
Mean	0.88	0.98		1.00	1.08		18.91	18.50		17.73	16.21		0.28	0.25		0.28	0.32	
	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %	SEm±	CD	CV %
		(p=0.05)			(p=0.05)			(p=0.05)			(p=0.05)			(p=0.05)			(p=0.05)	
M	0.03	NS	13.68	0.03	NS	11.33	0.25	1.51	6.10	0.07	NS	6.99	0.01	NS	15.45	0.01	NS	12.59
S	0.05	NS	12.77	0.05	NS	11.29	0.71	2.05	9.25	0.28	NS	6.01	0.02	NS	16.00	0.02	NS	13.09
M x S	0.07	NS		0.07	NS		1.00	NS		0.39	NS		0.02	NS		0.02	NS	
S x M	0.07	NS		0.07	NS		0.96	NS		0.37	NS		0.02	NS		0.02	NS	

Main Plots: M₁: With Soil Inversion, M₂: Without Soil InversionSub Plots: S₁: No K, S₂: 100% K through SOP, S₃: 75% K through SOP, S₄: 100% K through SOP + Tobacco Stalk Biochar (1:1), S₅: 75% K through SOP + Tobacco Stalk Biochar (1:1), S₆: 100% K through SOP + Barn Wood Ash (1:1), S₇: 75% K through SOP + Barn Wood Ash (1:1)

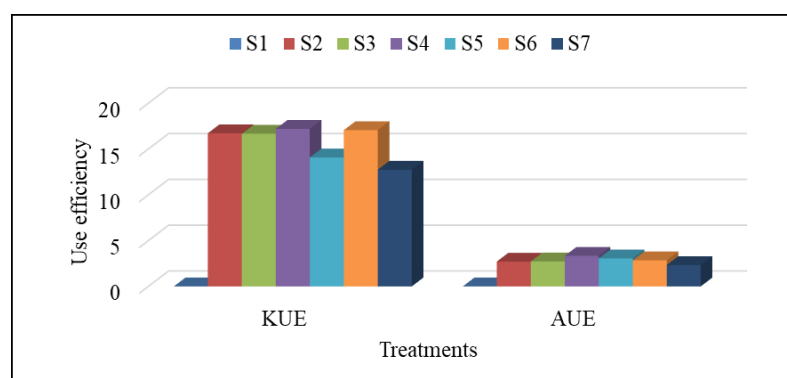


Fig. 1. Effect of soil inversion in conjunction with potassium interventions on potassium use efficiency (%) and agronomic use efficiency (kg kg⁻¹) of FCV tobacco grown under irrigated Alfisols

of 100% NPK with tobacco stalk biochar and results are in agreement with Agbede and Oyewumi, (2022) reported that interaction of the biochar and the NPK may lead to high fertilizer use efficiency due to adsorption of nutrients in the fertilizer on the surface of biochar. Thus, facilitating the reduction of the plant nutrient loss, promoting cell division and physiological performance. This was further supported by Partey et al. (2014) that the conditioning effect of biochar application augments the interactive ability of soil resulting in adsorption of available minerals and cations, improving nutrient synchrony with crop nutrient demands thereby, improving the nutrient use efficiency of maize.

3.5 Quality Parameters: Nicotine, Reducing Sugars, and Chlorides

Quality parameters such as nicotine (%), reducing sugars (%) and chlorides (%) are presented in the Table 5 respectively. Even though slight changes in quality parameters were observed in our study, neither soil inversion nor potassium input management practices have shown a significant effect on tobacco quality parameters and their interaction was also not significant. Quality and chemical composition of cured leaf is predetermined fairly by the interplay of nitrogen and carbohydrate metabolism, thus with the increase in N fertilization and concentration, nicotine content of cured leaf increases while the reducing sugars will be reduced. However, these factors were positively increased with increase in potassium levels (Krishna, et al., 2015). In accordance with it, an increase in the nicotine content from X to L and decrease in reducing sugars percentage from X to L positions is observed in our experiment and there is no much change in quality parameters in

the present experiment. This may be due to the application of equal amount of N fertilizer in all the treatment plots. No trend was observed in the case of chlorides % in both the positions but all the quality parameters were in acceptable ranges in the experiment (Widowati, et al., 2014).

4. CONCLUSION

The soil inversion with MB plough to a depth of 25 cm has played an important role in improving the soil and plant characteristics, thus contributing to better yields in tobacco. The improvement in soil properties through potassium input management practices like 100% K through SOP + TS biochar (1:1) and 100% K through SOP + Barn Wood Ash (1:1) irrespective of soil inversion have contributed a lot in increasing the yield, nutrient uptake by tobacco plant and nutrient use efficiency significantly. Thus, soil inversion with MB plough and potassium input strategies viz., TS biochar and barn wood ash offer sustainable K-management under scarce potassium sulphate situation i.e., around 25 kg SOP application can be reduced per hectare by combining SOP with either TS biochar or BWA, based on K content in the biochar and barn wood ashes.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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