Effect of Soil Inversion and Potassium Management Strategies on Flue-Cured Virginia (FCV) Tobacco Productivity.

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.
Methodology: The experiment was laid out in split plot design with two soil inversion practices in main plots *viz*., M_1, soil inversion with MB plough to a depth of 25 cms and M_2, without soil inversion and seven sub plot treatments *viz.,* S_1, without potassium, S_2, 100% recommended dose of potassium (RDK) through sulphate of potash (SOP) treatments; S_3, 75% RDK through SOP; S_4, 100% RDK through SOP + Tobacco stalk biochar (TS Biochar) treatment [1:1] ; S_5, 75% RDK through SOP + TS Biochar [1:1]; S_6, 100% RDK through SOP + Barn wood Ashes (BWA) treatment [1:1]; S_7, 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 S_4, 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. It also provides livelihood security to millions engaged in its production, processing, and marketing. Globally, India ranks second in area and production after China and fifth in productivity. Currently, India grows tobacco in an area of 0.425 m. ha and produces 772 million kgs of cured leaf. 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 tonnes*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. 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 of the *Alfisols* accelerates the risk of K leaching, this resulted in raising potassium application rates. However, the Sulphate of potash, 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, potassium 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 and Turgeon 1977). Soil inversion with MB plough to a depth of 25 cms 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. IBI (2013), defines biochar as a solid material obtained from thermo-chemical 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 potassium 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 potassium, calcium and magnesium (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), potassium uptake (Coumaravel*et al.* 2015; Agegnehu*et al.* 2015; Bindu *et al.* 2020, 2023) and yield in several crops (Alburquerque *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. Amending soils with biomass ashes can be an effective strategy to substitute/supplement K supplies in tobacco production and reduce 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 and Deborah (2010); Arshad *et al.* (2012); Trunhe and 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 planned 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 potassium input management on productivity, nutrient uptake, nutrient use efficiency and quality of FCV tobacco.

2. MATERIAL AND METHODS

A field experiment was conducted during winter (*Rabi*) season of 2022 atICAR – Central Tobacco Research Institute, Research Farm, Jeelugumilli (17º 11' 30" N latitude, 81º 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 and Asija 1956), high in available P (105 kg P_2O_5 ha^{-1}) (Bray and Kurtz 1945) and medium in available K (230 kg K_2O 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.,* M_1: with soil inversion using Mold Board (MB) plough to a depth of 25 cm, M_2: without soil inversion and seven potassium management practices as subplots *viz.*, No K (S_1); 100% recommended doses (RD) of K through sulphate of potash (SOP) [S_2]; 75% RD of K through SOP (S_3); 100% RD of K through SOP and tobacco stalk biochar (TS Biochar) in 1:1 (S_4); 75% RD of K through SOP and TS Biochar in 1:1 (S_5); 100% RD of K through SOP and barn wood ash (BWA) in 1:1 (S_6); 75% RD of K through SOP and BWA in 1:1 (S_7). 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: P_2O_5: K_2O 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%.

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

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 leachingand 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 S_4 [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 S_6 [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 woodash is applied to the crop due to its efficiency in suppling 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 S_4 [100% K through SOP + Tobacco Stalk Biochar (1:1)] treatment which was on par with S_5 [75% K through SOP + Tobacco Stalk Biochar (1:1)] (Table 2). Cheema *et al*. (1999) observed an increased taller plantsproduction with increased K fertilization, in comparison to the control.The greater LAI were recorded in S_6 [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 S_4 [100% K through SOP + Tobacco Stalk Biochar (1:1)] at 60 DAP. However, at 75 DAP, the LAI recorded was on with S_4 [100% K through SOP + Tobacco Stalk Biochar (1:1)], S_2 [100% K through SOP], S_5 [75% K through SOP + Tobacco Stalk Biochar (1:1)] and S_3 [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 and Olojugba, 2010).The increase in yield attributes by the application of biochar and wood ash in our experimentmay 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 loses. 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 S_4 [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 S_6 [100% K through SOP + Barn Wood Ash (1:1)], S_2 [100% K through SOP]andS_5 [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. The co-application of biochar and NPK fertilizers boosts yield by combining the benefits of biochar's high pH, CEC, organic matter content and surface area with the nutrient richness of NPK fertilizers. This synergy enhances nutrient adsorption and ensures a steady release of N, P and K throughout the crop growth period, providing plants with sustained nutrient availability. Besides, biochar plays a prominent role in retaining soil nutrients by reducing the leaching loss of nutrients from the chemical fertilizer (Haider *et al.* 2017). The promotion effect of 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).

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

<u>Main Plots:</u> M_1: With Soil Inversion, M_2: Without Soil Inversion

	Leaf Number						**Plant Height (cm)**						**Leaf Area Index**					
PIM	**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**
S_1	14	14	**14**	20	18	**19**	49	40	**45**	106	87	**97**	1.48	1.19	**1.33**	2.07	1.54	**1.81**
S_2	17	15	**16**	29	21	**25**	54	42	**48**	116	95	**105**	1.81	1.18	**1.50**	2.72	1.85	**2.28**
S_3	16	13	**14**	28	20	**24**	53	41	**47**	114	89	**102**	1.80	1.13	**1.46**	2.69	1.82	**2.26**
S_4	18	18	**18**	31	24	**28**	61	45	**53**	120	99	**110**	1.88	1.37	**1.63**	2.73	1.87	**2.30**
S_5	17	15	**16**	27	22	**25**	58	42	**50**	118	92	**105**	1.87	1.24	**1.55**	2.68	1.80	**2.24**
S_6	17	18	**17**	29	22	**26**	55	42	**49**	120	93	**107**	1.95	1.50	**1.73**	2.88	1.80	**2.34**
S_7	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 (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**
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	

<u>Sub Plots:</u> S_1: No K, S_2: 100% K through SOP, S_3:75% K through SOP, S_4: 100% K through SOP + Tobacco Stalk Biochar (1:1), S_5: 75% K through SOP + Tobacco Stalk Biochar (1:1), S_6: 100% K through SOP + Barn Wood Ash (1:1), S_7: 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: M_1: With Soil Inversion, M_2: Without Soil Inversion

Sub Plots: S_1: No K, S_2: 100% K through SOP, S_3:75% K through SOP, S_4: 100% K through SOP + Tobacco Stalk Biochar (1:1), S_5: 75% K through SOP + Tobacco Stalk Biochar (1:1), S_6: 100% K through SOP + Barn Wood Ash (1:1), S_7: 75% K through SOP + Barn Wood Ash (1:1)

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 andPeignéet *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) [S_4] has recorded highest N uptake of 42.98 kg ha^{-1}, which was on par with S_2 [100% K through SOP] and S_6 [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). Similar results were observed by Bindu *et al.* (2023) maximum total nitrogen uptake by tobacco was observed in 100% NPK in combination with TS 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 S_4 [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) [S_4] (54.56 kg ha^{-1}) was applied to the soil which was on par with the S_2 [100% K through SOP] and S_6 [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).

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 AUE of tobacco by the application of 100 % NPK with biochar.This can be supported by the finding of Agbede and Oyewumi,(2022) who stated that the 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.

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 (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**
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: M_1: With Soil Inversion, M_2: Without Soil Inversion

Sub Plots: S_1: No K, S_2: 100% K through SOP, S_3:75% K through SOP, S_4: 100% K through SOP + Tobacco Stalk Biochar (1:1), S_5: 75% K through SOP + Tobacco Stalk Biochar (1:1), S_6: 100% K through SOP + Barn Wood Ash (1:1), S_7: 75% K through SOP + Barn Wood Ash (1:1)

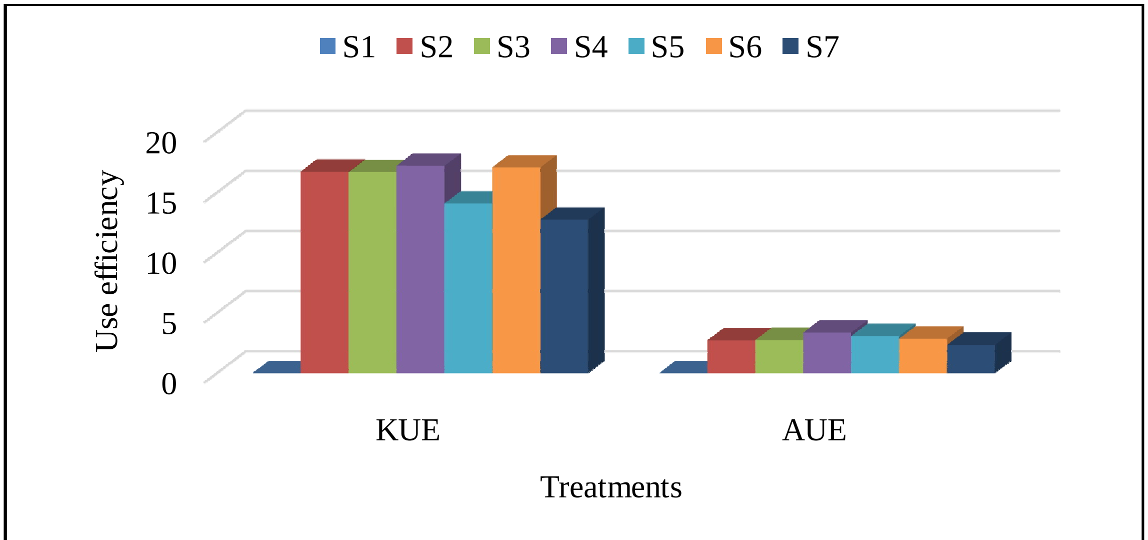

Fig. 1 Effect of soil inversion in conjunction with potassium interventions on potassium use efficiency (%) and agronomic use efficiency (kg kg^{-1}) of FCV tobacco grown under irrigated *Alfisols*

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.

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 (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**	**SEm±**	**CD (p=0.05)**	**CV %**
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: M_1: With Soil Inversion, M_2: Without Soil Inversion

Sub Plots: S_1: No K, S_2: 100% K through SOP, S_3:75% K through SOP, S_4: 100% K through SOP + Tobacco Stalk Biochar (1:1), S_5: 75% K through SOP + Tobacco Stalk Biochar (1:1), S_6: 100% K through SOP + Barn Wood Ash (1:1), S_7: 75% K through SOP + Barn Wood Ash (1:1)

[Type here]

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.

REFERENCES

Adekayode, F. O., &Olojugba, M. R. (2010). The utilization of wood ash as manure to reduce the use of mineral fertilizer for improved performance of maize (Zea mays L.) as measured in the chlorophyll content and grain yield. *Journal of Soil Science and Environmental Management, 1*(3), 40-45.

Agbede, T. M., &Adekiya, A. O. (2012). Effect of wood ash, poultry manure, and NPK fertilizer on soil and leaf nutrient composition, growth, and yield of okra (Abelmoschus esculentus). *Emirates Journal of Food and Agriculture*, 314-321.

Agbede, T. M., &Oyewumi, A. (2022). Soil properties, sweet potato growth, and yield under biochar, poultry manure, and their combination in two degraded Alfisols of humid tropics. *Scientia Horticulturae, 304*, 111331.

Agegnehu, G., Bass, A. M., Nelson, P. N., Muirhead, B., Wright, G., & Bird, M. I. (2015). Biochar and biochar-compost as soil amendments: Effects on peanut yield, soil properties, and greenhouse gas emissions in tropical north Queensland, Australia. *Agriculture, Ecosystems and Environment, 213*, 72-85.

Agricultural Statistics at a Glance. (2021). Government of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture and Farmers Welfare, Directorate of Economics & Statistics.

Alburquerque, J. A., Salazar, P., Barrón, V., Torrent, J., Campillo, D. M. D. C., Gallardo, A., & Villar, R. (2013). Enhanced wheat yield by biochar addition under different mineral fertilization levels. *Agronomy for Sustainable Development, 33*, 475-484.

Arseneau, J., Bélanger, N., Ouimet, R., Royer, T. S., Bilodeau, G. S., Gendreau, B., & Rivest, D. (2021). Wood ash application in sugar maple stands rapidly improves nutritional status and growth at various developmental stages. *Forest Ecology and Management, 489*, 119062.

Arshad, M. A., Soon, Y. K., Azooz, R. H., Lupwayi, N. Z., & Chang, S. X. (2012). Soil and crop response to wood ash and lime application in acidic soils. *Agronomy Journal, 104*(3), 715-721.

Atkinson, C. J., Fitzgerald, J. D., &Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. *Plant and Soil, 337*, 1-18.

Bindu, J. P., Reddy, D., Rao, C., Manorama, K., Prasad, L. K., & Mathur, R. K. (2020). Effect of oil palm waste biochars on FCV tobacco productivity in light-textured Alfisols. *Tobacco Research, 46*(2), 47-52.

Bindu, J. P., Reddy, D., Santhy, P., Rao, C., & Prasad, L. K. (2016). Comparative study on tobacco stalks-based organic soil amendments and inorganic soil amendment (zeolite) on soil reaction and nutrient (N, K) availability of an Alfisol. *International Journal of Tropical Agriculture, 34*(6), 1783-1788.

Bindu, J. P., Reddy, D., Santhy, P., Rao, C., & Ghosh, R. K. (2023). Effect of chemical fertilizer and tobacco stalks-derived biochar on FCV tobacco yield, nutrient use efficiency, and carbon management index in a light-textured Alfisol. *International Journal of Plant & Soil Science, 35*(2), 88-107.

Bindu, J. P., Reddy, D., Santhy, P., Sellamuthu, K., Yassin, M. M., & Naik, R. (2017). Nutrient leaching behavior of an Alfisol as affected by tobacco stalk biochar and synthetic zeolite. *Tobacco Research, 43*(1), 10-14.

Bonfimsilva, E. M., Martinez, S. T., Silva, D. T. J., Alves, R. D. D. S., Pinheiro, E. A., & Duarte, T. F. (2022). Wood ash as a vegetative-growth promoter in soils with subsurface compaction. *Revista Brasileira de EngenhariaAgrícola e Ambiental, 26*(4), 258-265

Chan, K. Y., Zwieten, L. V., Meszaros, I., Downie, A., & Joseph, S. (2007). Agronomic values of green waste biochar as a soil amendment. *Australian Journal of Soil Research, 45*, 629-634.

Chaudhary, M. R., Gajri, P. R., Prihar, S. S., & Khera, R. (1985). Effect of deep tillage on soil physical properties and maize yields on coarse textured soils. *Soil and Tillage Research, 6*(1), 31-44.

Cheema, M. A., Iqbal, M., Cheema, Z. A., Basharatullah, & Rafique, M. (1999). Response of hybrid maize to potassium. *International Journal of Agricultural Biology, 1*(4), 267-269.

Coumaravel, K., Santhi, R., & Maragatham, S. (2015). Effect of biochar on yield and nutrient uptake by hybrid maize and on soil fertility. *Indian Journal of Agricultural Research, 49*(2), 185-188.

Danish, S., Ameer, A., Qureshi, T. I., Younis, U., Manzoor, H., Shakeel, A., & Ehsanullah, M. (2014). Influence of biochar on growth and photosynthetic attributes of wheat (*Triticum aestivum L.*) under half and full irrigation. *International Journal of Biosciences, 5*(7), 101-108.

Haider, G., Steffens, D., Moser, G., Müller, C., & Kammann, C. I. (2017). Biochar reduced nitrate leaching and improved soil moisture content without yield improvements in a four-year field study. *Agriculture, Ecosystems & Environment, 237*, 80-94.

Hofbauer, M., Bloch, R., Bachinger, J., & Gerke, H. H. (2022). Effects of shallow non-inversion tillage on sandy loam soil properties and winter rye yield in organic farming. *Soil and Tillage Research, 222*, 105435.

IBI. (2013). Standardized product definition and product testing guidelines for biochar that is used in soil. *IBI-STD-01.1*, International Biochar Initiative. Retrieved from www.biochar-international.org/characterization_standard.

Jackson, M. L. (1973). *Soil Chemical Analysis.* Prentice Hall of Inco, New York, USA.

Jiang, C., Zu, C., Wang, H., Yan, Y., Liu, Y., & Shen, J. (2022). Straw return with biochar increased soil macro-aggregates and improved flue-cured tobacco (*Nicotiana tabacum L.*) yield and quality. *Applied Ecology and Environmental Research, 20*(1), 207-219.

Johansen, J. L., Nielsen, M. L., Vestergård, M., Mortensen, L. H., Cruz, P. C., Rønn, R., ... & Ekelund, F. (2021). The complexity of wood ash fertilization disentangled: Effects on soil pH, nutrient status, plant growth and cadmium accumulation. *Environmental and Experimental Botany, 185*, 104424.

Krishna, S. K., Reddy, S. K., Krishnamurthy, V., Rao, C. C., & Anuradha, M. (2015). Effect of N and K levels on growth, yield and nutrient uptake of FCV tobacco cv. Kanchan. *Indian Journal of Agricultural Sciences, 86*(5), 691–695.

Mahadevaswamy, M., & Reddy, D. D. (2019). Biomass residue/wood ash as potential supplements for potassium nutrition, yield and quality of FCV tobacco in KLS. *Tobacco Research, 45*(2), 81-84.

Ndubuisi, M. C., & Deborah, N. (2010). Response of maize (*Zea mays L.*) to different rates of wood-ash application in acid Ultisol in Southeast Nigeria. *African Journal of Agricultural Research, 6*(1), 53-57.

Nweke, I. A., Mbah, C. N., Oweremadu, E. O., Dambaba, N., Orji, E. C., Ekesiobi, A. I., ... &Nnabuife, E. L. C. (2017). Soil pH, available P of an Ultisol and castor performance as influenced by contrasting tillage methods and wood ash. *African Journal of Agricultural Research, 12*(8), 606-616.

Nwite, J. N. (2015). Effect of biochar on selected soil physical properties and maize yield in an Ultisol in Abakaliki Southeastern Nigeria. *International Journal of Advances in Agriculture Research, 3*(12), 31-36.

Pandian, K., Subramaniayan, P., Gnasekaran, P., &Chitraputhirapillai, S. (2016). Effect of biochar amendment on soil physical, chemical and biological properties and groundnut yield in rainfed Alfisol of semi-arid tropics. *Archives of Agronomy and Soil Science, 62*(9), 1293-1310.

Panse, V. G., &Sukhatme, P. V. (1978). *Statistical methods for agricultural workers* (3rd ed.). Indian Council of Agricultural Research Publication, New Delhi.

Partey, S. T., Preziosi, R. F., & Robson, G. D. (2014). Short-term interactive effects of biochar, green manure, and inorganic fertilizer on soil properties and agronomic characteristics of maize. *Agricultural Research, 3*, 128-136.

Parvin, N., Parvage, M. M., & Etana, A. (2014). Effect of mouldboard ploughing and shallow tillage on sub-soil physical properties and crop performance. *Soil Science and Plant Nutrition, 60*(1), 38-44.

Peigné, J., Vian, J. F., Payet, V., & Saby, N. P. (2018). Soil fertility after 10 years of conservation tillage in organic farming. *Soil and Tillage Research, 175*, 194-204.

Santalla, M., Omil, B., Rodríguez, S. R., & Merino, A. (2011). Effectiveness of wood ash containing charcoal as a fertilizer for a forest plantation in a temperate region. *Plant and Soil, 346*, 63-78.

Sharifi, M., Cheema, M., Vicar, M. K., Blanc, L. L., & Fillmore, S. (2013). Evaluation of liming properties and potassium bioavailability of three Atlantic Canada wood ash sources. *Canadian Journal of Plant Science, 93*(6), 1209-1216.

Sheshu Madhav, M., Sarala, K., Ravisankar, H., Bindu, J. P., Hema, B., & Sailaja Jayasekharan, B. (Eds.). (2022). *CTRI Annual Report – 2022*. ICAR-Central Tobacco Research Institute, Rajahmundry.

Singh, B. P., Hatton, B. J., Balwant, S., & Cowie, L. A. (2010). The role of biochar in reducing nitrous oxide emissions and nitrogen leaching from soil. *Soil Solutions for a Changing World, 19th World Congress of Soil Sciences,* 1-6 August, Brisbane, Australia.

Spomer, L. A., & Turgeon, A. J. (1977). Vertical soil water retention in newly□sodded, drained turfgrass sites. *Communications in Soil Science and Plant Analysis, 8*(5), 417-423.

Subbiah, B. V., & Asija, G. J. (1956). A rapid procedure of estimation of available nitrogen in soils. *Current Science, 65*(7), 477-480.

Trunhe, A. M., &Yli, H. M. J. (2016). Effects of applications of lime, wood ash, manure and mineral P fertilizer on the inorganic P fractions and other selected soil chemical properties on acid soil of Farta District, Northwestern highland of Ethiopia. *African Journal of Agricultural Research, 22*(1), 184-192.

Vance, E. D. (1996). Land application of wood□fired and combination boiler ashes: An overview. *Journal of Environmental Quality, 25*(5), 937-944.

Walkley, A., & Black, C. A. (1934). Estimation of organic carbon by chromic acid titration method. *Soil Science, 37*, 29-38.

Widowati, W., Asnah, A., & Utomo, W. H. (2014). The use of biochar to reduce nitrogen and potassium leaching from soil cultivated with maize. *Journal of Degraded and Mining Lands Management, 2*(1), 211.

Wu, X., Wang, D., Riaz, M., Zhang, L., & Jiang, C. (2019). Investigating the effect of biochar on the potential of increasing cotton yield, potassium efficiency and soil environment. *Ecotoxicology and Environmental Safety, 182,* 109451.

Yang, W., Li, C. S., Wang, B., Zhou, Y., Mao, C., Rensing, C., & Xing, S. (2021). Influence of biochar and biochar-based fertilizer on yield, quality of tea and microbial community in an acid tea orchard soil. *Applied Soil Ecology, 166,* 104005.

Yun, C., Ma, Y., Guo, D., Wang, Q., & Wang, G. (2017). Chemical properties and microbial responses to biochar and compost amendments in the soil under continuous watermelon cropping. *Plant Soil and Environment, 63*(1), 1-7.

Zhang, Y., Yan, J., Rong, X., Han, Y., Yang, Z., Hou, K., ... & Hu, W. (2021). Responses of maize yield, nitrogen and phosphorus runoff losses and soil properties to biochar and organic fertilizer application in a light-loamy Fluvo-aquic soil. *Agriculture, Ecosystems & Environment, 314*, 107433.

Zwieten, L. V., Kimber, S., Morris, S., Chan, K. Y., Downie, A., Rust, J., ... & Cowie, A. (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil, 327*, 235-244.