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Effect of biochar on growth, yield and nutrient uptake by finger millet in acidic soil

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Abstract
A field experiment was conducted at farmer's field to study the effect of biochar on growth and yield of finger millet (GPU-28) during *Kharif* 2017. The experiment included seven treatments and three replications. The results revealed that application of 100 per cent RDF + 125 per cent of biochar equivalent of carbon in FYM recorded higher plant height and number of tillers hill^{-1}, yield parameters i.e, Number ear heads hill^{-1}, Number of fingers ear head^{-1}, 1000 grain weight, grain (4264 kg/ha) and straw yield (6416 kg/ha), uptake of nutrients by finger millet. The study clearly showed that application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of carbon in FYM is more beneficial in enhancing the crop yield, crop productivity as well as nutrient uptake.

Keywords: acidic soil, biochar, FYM, finger millet

Introduction
In the recent years, the environmentalists and agricultural scientists have realized that continued and unbalanced use of fertilizers will change the soil physical and chemical properties there by it cause environmental pollution and affect the soil biological activity. Thus, increasing awareness is being created on the use of biochar to sustain the soil fertility and productivity.

The biochar has emerged as an important amendment with fertilizer and hold a key role to improve the yield of crops. The biochar has been found to have a great impact on soil fertility and increase in crop yield without causing any detorious hazards to the soil. Biochar is a carbon-rich substance, produced by thermal decomposition of organic compounds at a relatively low temperature (<700°C) under limited supply of oxygen. It contains more than 60 per cent carbon, and is rich in various nutrients and trace elements essential for crop growth. Biochar is a fine-grained, highly porous charcoal substance that is differentiated from other charcoals in its use as a soil amendment. The particular heat treatment of organic biomass used to produce biochar contributes to its large surface area and its characteristic ability to persist in soils with very little biological decay (Lehmann *et al.*, 2006) [11, 12]. While raw organic materials provide nutrients to plants and soil microorganisms, biochar acts as a catalyst that enhances plant uptake of nutrients and water. Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and also provide food for microorganisms (Glaser *et al.*, 2002, Lehmann *et al.*, 2006, and Warnock *et al.*, 2007) [8, 11, 12, 18]. The objective was to study the effect of different levels of biochar on growth and yield of finger millet in acid soil.

Material and Methods
The study was conducted during *kharif* season 2017 at farmers field Byrasandra village of Chikkaballapura district located in Southern Dry Zone of Karnataka. During crop growth period, a total rainfall of 358.2 mm was received from September to December. Maximum temperature ranged from 27.2 ^{0}C to 34.5 ^{0}C and minimum temperature ranged from 19.0 ^{0}C to 20.5 ^{0}C. The test crop was finger millet with variety GPU-24. The experiment was laid out in a randomized complete block design (RCBD) with seven treatment combination replicated thrice. The treatments were T_1: NPK + $ZnSO_4$ alone, T_2: NPK + $ZnSO_4$ + FYM (POP), T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM, T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM, T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM, T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM, T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM

The representative biochar sample was obtained from locally available wood biochar (*Prosopis juliflora*). The wood biochar was ground to pass through 2 mm sieve and analyzed for different physical and chemical parameters and results are presented in Table 1.
The initial physical and chemical properties of experimental site were analyzed and are represented in Table 2. The soil of the experimental site was acidic in soil reaction (pH of 5.46) with organic carbon content of 5.30 g $kg^{-1}$and available nutrient status soil were low in available N (250.84 kg ha^{-1}), medium in available P_2O_5 (26.32 kg ha^{-1}) and medium in available K_2O (174.13 kg ha^{-1}) status.
Growth parameters i.e. plant height and number of tillers $hill^{-1}$ were recorded at 30, 60 days after transplanting and finally at harvest stage of finger millet. Yield parameters like grain and straw yield were recorded. Grains were separated by threshing the produce obtained from each plot and sun dried, winnowed and weighed. Grain yield per hectare was worked out from the grain yield per plot and expressed in quintal per hectare and Straw obtained from each plot was dried under the sun for ten days, weighed and expressed in quintal per hectare at harvest of the crop.
Nutrient uptake for all the major nutrients was calculated by the using formula nutrient concentration (%) x Biomass (kg ha^{-1}) / 100 Statistical analysis: Experimental data obtained were subjected to statistical analysis adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984) [9].

Table 1: Physical and chemical characteristics of Biochar

Parameters	Value
pH	10.12
EC (dS m^{-1})	2.92
Maximum water holding capacity (%)	62
Bulk density (Mg m^{-3})	0.48
Total carbon (%)	74.50
Nitrogen (%)	0.24
Phosphorus (%)	0.13
Potassium (%)	1.38
Calcium (%)	2.32
Magnesium (%)	0.46
Sulphur (%)	0.08
Iron (ppm)	432.60
Manganese (ppm)	514.27
Zinc (ppm)	22.80
Copper (ppm)	33.20

Table 2: Initial physico-chemical properties of the soil of the experimental site

Parameters	Value
Sand (%)	61.55
Silt (%)	21.5
Clay (%)	16.8
Textural class	Sandy loam
Bulk density (g cc^{-1})	1.41
Maximum water holding capacity (%)	34
Soil pH	5.46
Electrical conductivity (dS m^{-1})	0.098
Organic carbon (g kg^{-1})	5.30
Available N (kg ha^{-1})	250.84
Available P_2O_5 (kg ha^{-1})	26.32
Available K_2O (kg ha^{-1})	174.13
Available S (ppm)	15.82
Exchangeable Ca (c mol (p+) kg^{-1})	2.24
Exchangeable Mg (c mol (p+) kg^{-1})	1.78
DTPA Zn (ppm)	1.50
DTPA Fe (ppm)	12.18
DTPA Cu (ppm)	0.84
DTPA Mn (ppm)	30.94
Available B (ppm)	0.38
Exchangeable Al (c mol (p^+) kg^{-1})	1.19

Results and discussion

Effect of biochar application on plant height at different growth stages of finger millet

The perusal of data on plant height (cm) of finger millet as influenced by varied levels of biochar at different growth stages are presented in Table 3. Plant height significantly differed at all the growth stages with different treatments. Plant height increased progressively with increase in age of the crop up to 90 days after transplanting and there after increase was slightly lower.
Significantly higher plant height (45.27 cm) was recorded at 30 DAT in T_7 which received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar carbon equivalent of FYM. The data was found on par with T_2 (43.40 cm) which received 100 per cent NPK + $ZnSO_4$ + FYM (POP) followed by T_6 (42.67 cm) which received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar carbon equivalent of FYM over the other treatments. Lowest value was recorded in T_1 (32.23 cm) which received 100 per cent NPK + $ZnSO_4$ alone.
The plant height significantly varied with different treatment combinations of different levels of biochar at 60 DAS. Application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM (T_7) recorded significantly highest plant height (100.87 cm). However, it was on par with T_2 (99.40 cm) received 100 per cent NPK + $ZnSO_4$ + FYM (POP) followed by T_6 (91.47 cm) 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM over other treatments. Lowest value was recorded in T_1 (68.93 cm) received NPK + $ZnSO_4$ alone.
Plant height at harvest was significantly higher (112.87 cm) in T_7 received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar carbon equivalent of FYM and was on par with T_2 (112.60 cm) received 100 per cent NPK + $ZnSO_4$ + FYM (POP). The lower value was recorded in T_1 (88.27 cm) received NPK + $ZnSO_4$ alone. The increased in plant height was mainly due to application of biochar increases water holding capacity and nutrient retention capacity of soil and provide sufficient nutrients to plant there by it encourages the plant growth.

Table 3: Effect of biochar application on plant height at different growth stages of finger millet in acidic soil

Treatments	Plant height (cm)		
	30 DAT	60 DAT	At harvest
T_1: NPK + $ZnSO_4$ alone	32.23	68.93	88.27
T_2: NPK + $ZnSO_4$ + FYM (POP)	43.40	99.40	112.60
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	36.13	76.73	89.93
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	37.73	81.27	92.10
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	40.67	87.93	99.20
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	42.67	91.47	105.20
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	45.27	100.87	112.87
S.EM±	0.81	1.22	0.46
CD@ (5%)	2.49	3.75	1.42

Effect of biochar application on Number of tillers hill^{-1} at different growth stages of finger millet

The data on number of tillers hill^{-1} in finger millet at different growth stages as influenced by different levels of biochar is presented in Table 4.

Application of 100% NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM (T_7) recorded highest number of tillers hill^{-1} (1.53) followed by T_2 (1.13) and T_6 which received 100 per cent NPK + $ZnSO_4$ + FYM (POP) at 30 DAT and 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM, respectively. The lower value was recorded in T_1 (0.33) which received NPK + $ZnSO_4$ alone.

At 60 days after transplanting of finger millet, the treatment which received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM (T_7) recorded significantly higher number of tillers hill^{-1} (3.33) followed by T_6 (3.00) and T_2 (2.87) which received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM and 100per cent NPK + $ZnSO_4$ + FYM (POP), respectively. The lower value was recorded in T_1 (1.60) which received NPK + $ZnSO_4$ alone.

At harvest stage maximum number of tillers hill^{-1} was noticed in T_7 (3.41) which received 100 per cent RDF + 125 per cent of biochar equivalent of FYM. However, it was on par with T_6 (3.23) received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM followed by T_2 (2.89) received 100per cent NPK + $ZnSO_4$ + FYM (POP). The lowest value was recorded in T_1 (1.60) which received NPK + $ZnSO_4$ alone.

Significant increase in growth parameters like plant height, number of tillers hill^{-1} of finger millet was recorded due to application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM (T_7). There were so many factors contributing for improvement of growth attributes of crop with biochar application. These factors can either work individually or simultaneously. Indeed, decrease in soluble Al and Fe, rise of pH, balanced and slow release of nutrients, increased plant available water and improved microbial activity would have contributed for improvement of growth parameters of biochar treated plots over control in different soils. All such improvements in physical and chemical properties of soil in biochar amended soils are in line with other studies (Liang *et al.*, 2006; Gundale and De Luca, 2007; Warnock *et al.*, 2007; Amonette and Joseph 2009a) [12, 10, 18, 1].

Table 4: Effect of biochar application on number of tillers at different growth stages of finger millet in acidic soil

Treatments	Number of tillers hill^{-1}		
	30 DAT	60DAT	At harvest
T_1: NPK + $ZnSO_4$ alone	0.33	1.60	1.60
T_2: NPK + $ZnSO_4$ + FYM (POP)	1.13	2.87	2.89
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	0.73	1.47	1.47
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	0.67	2.47	2.49
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	0.87	2.60	2.67
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	1.13	3.00	3.23
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	1.53	3.33	3.41
S.EM±	0.06	0.09	0.09
CD@ (5%)	0.19	0.27	0.29

Yield parameters

The data pertaining to yield parameters and yield of finger millet as influenced by the levels of biochar on soil are represented in Table 5 and Table 6.

Table 5: Effect of biochar application on yield and yield attributes of finger millet in acidic soil

Treatments	Number ear heads hill^{-1}	Number of fingers ear head^{-1}	1000 grain weight (g)
T_1: NPK + $ZnSO_4$ alone	3.67	4.27	2.98
T_2: NPK + $ZnSO_4$ + FYM (POP)	4.03	6.40	3.41
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	2.67	4.40	3.22
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	3.73	5.07	3.29
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	3.93	5.60	3.38
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	4.07	6.47	3.41
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	4.13	7.13	3.52
S.EM±	0.10	0.14	0.02
CD@ (5%)	0.30	0.42	0.06

Table 6: Effect of biochar application on grain and straw yield of finger millet in acidic soil

Treatments	Grain yield	Straw yield
T_1: NPK + $ZnSO_4$ alone	32.72	49.36
T_2: NPK + $ZnSO_4$ + FYM (POP)	40.49	61.18
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	33.58	50.06
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	35.83	52.99
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	38.34	56.43
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	40.17	59.72
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	42.64	64.16
S.EM±	0.59	0.61
CD@ (5%)	1.81	1.89

Number ear heads hill^{-1}

Number of ear heads hill^{-1} varied significantly due to varied levels of biochar application. Application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar carbon equivalent of FYM (T_7) recorded higher number of ear heads hill^{-1} (4.13) fallowed by T_6 (4.07), T_2 (4.03) and T_5 (3.93) which received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM, 100 per cent NPK + $ZnSO_4$ + FYM (POP) and 100 per cent NPK + $ZnSO_4$ + 75per cent of biochar equivalent of FYM, respectively. The lower value was recorded in T_1 (2.67) which received NPK + $ZnSO_4$ alone.

Number of fingers ear head^{-1}

Significantly higher number of fingers ear head^{-1} was observed in T_7 (7.13) imposed of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar carbon equivalent of FYM followed by T_6 (6.47) and T_2 (6.40) received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM and 100 per cent NPK + $ZnSO_4$ + FYM (POP). Lowest number of fingers ear head^{-1} was recorded in T_1 (4.27) received NPK + $ZnSO_4$ alone.

1000 grain weight

Application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar carbon equivalent of FYM (T_7) recorded significantly higher 1000 grain weight (3.52 g) followed by T_2 (3.41) which was found on par with T_6 (3.41) and T_5 (3.38) received 100 per cent NPK + $ZnSO_4$ + FYM (POP), 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM and 100 per cent NPK + $ZnSO_4$ + 75 per cent of biochar equivalent of FYM, respectively. Comparatively lower 1000 grain weight was recorded in T_1 (2.98 g) which received NPK + $ZnSO_4$ alone.

Significant increase in yield parameters like number of ear heads hill^{-1}, higher number of fingers ear head^{-1} and 1000 grain weight was recorded with the application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM (T_7). This may be due to the increased availability and supply of nutrients with application of increased rates of biochar. Biochar application has found to increase fertilizer use efficiency as reported by Dong *et al.* (2015) [6]; Chan *et al.* (2007) [4]; Chan *et al.* (2008) [3] and Taghizadeh- Toosi *et al.* (2012). The wood biochar contains high amount of total carbon, potassium, phosphorus, calcium and magnesium which improves the physical properties of soil thereby increase the yield parameters like number of ear heads hill^{-1}, higher number of fingers ear head^{-1} and 1000 grain weight. Similar results were noticed by Chan *et al.* (2007) [4].

Grain yield

The application of different levels of biochar significantly influenced the grain yield of finger millet. Significantly higher grain yield was recorded in T_7 (42.64 q ha^{-1}) where 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar carbon equivalent of FYM was applied followed by T_2 (40.49 q ha^{-1}) received 100per cent NPK + $ZnSO_4$ + FYM (POP) and was on par with T_6 (40.17 q ha^{-1}) received 100per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM. The lower value was observed in T_1 (32.72 q ha^{-1}) received 100 per cent NPK + $ZnSO_4$ alone.

Straw yield

The straw yield significantly differed due to application of biochar at varied doses. Application of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM (T_7) has recorded significantly highest straw yield (64.16 q ha^{-1}) followed by T_2 (61.18 q ha^{-1}) received 100 per cent NPK + $ZnSO_4$ + FYM (POP) and was on par with T_6 (59.72 q ha^{-1}) received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM. The lowest value was observed in T_1 (49.36 q ha^{-1}) received 100 per cent NPK + $ZnSO_4$ alone.

Significant increase in grain and straw yield was recorded with the application of 100 per cent NPK + $ZnSO_4$ + 125per cent of biochar equivalent of FYM (T_7). This might be due to increase in rate of biochar which increases the nutrient supply and moisture content in soil. Increase in crop productivity with application of biochar can be attributed to increased CEC of soil, pH and base saturation, available P, nutrient retention and increased plant-available water. Ultimately it might have increased the grain and straw yield of finger millet. Higher grain and straw yield in finger millet could also be attributed to better total uptake of essential nutrients and its translocation to economic parts as well as improvement in yield attributing characters like number of ear head hill^{-1}, number of fingers hill^{-1} and 1000 seeds grain weight. Such responses with application rates were reported by Chan *et al.* (2007) [4]; Chan *et al.* (2008) [3]; Major *et al.* (2010) [13] and Van Zwieten *et al.* (2010) [17].

Effect of biochar application on nutrient uptake by finger millet in acid soil

Nitrogen uptake

The perusal of the data in Table 7 showed that nitrogen uptake by finger millet grain and straw differed significantly due to application of different levels of biochar. Significantly higher nitrogen uptake (54.32 kg ha^{-1}) by grain was recorded in treatment imposed of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM and on par with T_2 (48.14 kg ha^{-1}) which received 100 per cent NPK + $ZnSO_4$ + FYM (POP) respectively and lower uptake in T_1 (32.15 kg ha^{-1}) which received 100 per cent NPK + $ZnSO_4$.

It is also found that higher total nitrogen uptake was noticed in significantly T_7 (132.41 kg ha^{-1}) which received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM compared to T_2 (117.06 kg ha^{-1}) imposed of 100 per cent NPK + $ZnSO_4$ + FYM (POP). The lowest uptake was recorded in T_1 (73.26 kg ha^{-1}) which received 100 per cent NPK + $ZnSO_4$.

The reason for higher uptake of nitrogen under high doses of biochar might be due to the synergetic effect of biochar on crop growth, along with positive effects on nutrient (P, K, Ca and Mg) uptake by crop plants and the availability of soil P, K, Ca and Mg. Increase in pH of acidic soil may decrease Al activity, hence better root growth and nutrient uptake can be expected. Nutrient uptake is a function of nutrient content and biomass production. Increased rate of application of biochar increased biomass production which obviously increased nutrient uptake. Chan *et al.* (2007) [4] observed an increase in the uptake of N at higher levels of biochar. Similar findings were reported by Zhao *et al.* (2014) [21]. Angst and Sohi (2013) [2] and Yao *et al.* (2013) [20] reported that the bioavailability and plant uptake of primary nutrients increased in response to biochar application, particularly by added fertilizer. DeLuca *et al.* (2009) stated that biochar added to soil with an organic N source yielded an increase in net nitrification and improves the nitrogen availability to the plants. Similar findings were reported by Eazhilkrishna *et al.* (2017) [7], Rajkovich *et al.* (2012) [15] and Xu *et al.* (2014) [19].

Table 7: Uptake of nitrogen by grain and straw of finger millet as influenced by different levels of biochar application

Treatment details	Nitrogen (kg ha^{-1})		
	Straw	Grain	Total uptake
T_1: NPK + $ZnSO_4$ alone	41.11	32.15	73.26
T_2: NPK + $ZnSO_4$ + FYM (POP)	68.92	48.14	117.06
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	50.41	36.57	86.98
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	56.17	40.27	96.45
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	61.85	43.29	105.14
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	67.67	47.50	115.18
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	78.10	54.32	132.41
S.EM±	3.77	2.12	4.58
CD@ (5%)	11.63	6.52	14.11

Phosphorous uptake

The data in Table 8 indicated that the phosphorus uptake by finger millet grain did not show any significant difference among the treatments due to different levels of biochar application. Higher phosphorus uptake (9.38 kg ha^{-1}) was noticed in treatment imposed of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM as compared to T_2 (7.87 kg ha^{-1}) received 100 per cent NPK + $ZnSO_4$ + FYM (POP). The lower uptake was recorded in T_1 (4.89 kg ha^{-1}) received 100 per cent NPK + $ZnSO_4$ without application of biochar. There was a significant difference in total phosphorus uptake by finger millet due to different levels of biochar application. The significantly higher total uptake of phosphorus (27.78 kg ha^{-1}) found in treatment (T_7) which received 100 per cent NPK + $ZnSO_4$ + 125per cent of biochar equivalent of FYM compared to all treatments. However, lower uptake was noticed in T_1 (10.98 kg ha^{-1}) which received 100 per cent NPK + $ZnSO_4$ without application of biochar.

The significantly higher uptake of phosphorus (27.78 kg ha^{-1}) was recorded in T_7 received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM. The addition of nutrient enriched biochar increased the soil pH, thereby increasing available phosphorus. This is in line with the findings of Milla *et al.* (2013) [14]. Increase in pH of acidic soil may decrease Al activity, hence better root growth and nutrient uptake can be expected. Nutrient uptake is a function of nutrient content and biomass production. Increased rate of application of biochar increased biomass production which obviously increased nutrient uptake. Angst and Sohi (2013) [2] and Yao *et al.* (2013) [20] reported that the bioavailability and plant uptake of primary nutrients increased in response to biochar application, particularly in the presence of added fertilizer. Similar results were also reported by Eazhilkrishna *et al.* (2017) [7] and Xu *et al.* (2014) [19].

Table 8: Uptake of phosphorous by grain and straw of finger millet as influenced by different levels of biochar application

Treatment details	Phosphorus (kg ha^{-1})		
	Straw	Grain	Total uptake
T_1: NPK + $ZnSO_4$ alone	6.09	4.89	10.98
T_2: NPK + $ZnSO_4$ + FYM (POP)	11.03	7.87	18.90
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	6.50	4.63	11.13
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	8.31	6.35	14.66
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	9.59	7.19	16.77
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	12.74	8.63	21.36
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	18.40	9.38	27.78
S.EM±	1.57	1.45	1.94
CD@ (5%)	4.84	NS	5.97

Potassium uptake

Perusal of the data on potassium uptake data (Table 9) indicated the significant difference among treatments in K uptake by grain due to different levels of biochar application. Significantly higher K uptake (16.06 kg ha^{-1}) was noticed in T_7 imposed of 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM as compared to T_2 (12.47 kg ha^{-1}) where 100 per cent NPK + $ZnSO_4$ + FYM (POP) was applied. The lower uptake was recorded in T_1 (6.99 kg ha^{-1}) which received 100 per cent NPK + $ZnSO_4$ without application of biochar.

The significant difference was noticed among the treatments in total K uptake by finger millet crop due to different levels of biochar application. Significantly higher total potassium uptake (65.55 kg ha^{-1}) was found in T_7 received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM compared to all other treatments. However, it was found on par with T_6 (55.79 kg ha^{-1}) received 100 per cent NPK + $ZnSO_4$ + 100 per cent of biochar equivalent of FYM and T_2 (52.87 kg ha^{-1}) received 100 per cent NPK + $ZnSO_4$ + FYM (POP). The lower uptake was recorded in T_1 (22.62 kg ha^{-1}) received 100 per cent NPK + $ZnSO_4$ alone.

Significantly higher potassium uptake was noticed in T_7 (65.55 kg ha^{-1}) received 100 per cent NPK + $ZnSO_4$ + 125 per cent of biochar equivalent of FYM. The reason for higher uptake of potassium under high doses of biochar may be due to the positive effects of biochar on crop growth, along with positive effects on nutrient (N, P, Ca and Mg) uptake by crop plants and the availability of soil N, P, Ca and Mg. Similar findings were reported by Zhao *et al.* (2014) [21]. Increase in pH of acidic soil may decrease Al activity, hence better root growth and nutrient uptake can be expected. Nutrient uptake is a function of nutrient content and biomass production. Increased rate of application of biochar increased biomass production which obviously increased nutrient uptake. Angst and Sohi (2013) [2] Yao *et al.* (2013) [20] reported that the bioavailability and plant uptake of primary nutrients increased in response to biochar application, particularly by added fertilizers. Similar findings were also reported by Eazhilkrishna *et al.* (2017) [7] and Xu *et al.* (2014) [19].

Table 9: Uptake of potassium by grain and straw of finger millet as influenced by different levels of biochar application

Treatment details	Potassium (kg ha^{-1})		
	Straw	Grain	Total uptake
T_1: NPK + $ZnSO_4$ alone	15.63	6.99	22.62
T_2: NPK + $ZnSO_4$ + FYM (POP)	40.40	12.47	52.87
T_3: NPK + $ZnSO_4$ + 25% of biochar equivalent of FYM	19.51	8.16	27.67
T_4: NPK + $ZnSO_4$ + 50% of biochar equivalent of FYM	22.42	9.41	31.83
T_5: NPK + $ZnSO_4$ + 75% of biochar equivalent of FYM	26.91	11.80	38.71
T_6: NPK + $ZnSO_4$ + 100% of biochar equivalent of FYM	42.98	12.81	55.79
T_7: NPK + $ZnSO_4$ + 125% of biochar equivalent of FYM	49.49	16.06	65.55
S.EM±	4.41	1.01	4.47
CD@ (5%)	13.60	3.12	13.78

Conclusion

The treatment imposed of 125 per cent of biochar equivalent of FYM + 100 percent NPK + $ZnSO_4$ significantly improved growth, yield and nutrient uptake by finger millet as compared to 100 per cent NPK + $ZnSO_4$ + FYM (POP). Thus, with application of 125 per cent of biochar equivalent of carbon in FYM with recommended dose of nutrients is more beneficial in enhancing the crop productivity as well as nutrient uptake in acidic soil.

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