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Impact of biochar on nutrient uptake by tomato, residual soil properties and acidity indices in acid Inceptisol of Meghalaya

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Abstract

Aim: To investigate the impact of biochar as component of integrated nutrient management on nutrient uptake by tomato in acid soil of Meghalaya, North East India.

Methodology: A field experiment was conducted at research farm of SNRM, College of Post Graduate Studies in Agricultural Sciences (CPGS-AS), Central Agricultural University (CAU-I), Umiam during *rabi* 2017-18 taking tomato, cv. Megha Tomato-2 as test crop. Sixteen treatment combinations of recommended closes of fertilizers, biochar and vermicompost were tested in RBD with three replications.

Results: The experimental results revealed that combined application of biochar, fertilizers and vermicompost increased the uptake and available of N, P, K, Fe, Zn, Mn and Cu over graded doses of biochar + fertilizers, biochar alone and control. Electrical conductivity, bulk density, exchangeable acidity, exchangeable aluminium and acid saturation followed the same trend.

Interpretation: The 100% RDF + biochar 4 t ha⁻¹ + vermicompost @ 2.5 t ha⁻¹ is the most appropriate combination for increasing tomato productivity and improving soil health of acidic soil in Meghalaya.

Key words: Acid soil, Biochar, Integrated nutrient management, Tomato

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Introduction

Soil is the basic foundation of sustainable crop production and the soil quality impacts crop production. Out of 142 million ha of cultivable land in India, 49 million ha of land is acidic, of which 26 million ha of land having soil pH less than 5.5 and the rest 23 million ha of land having soil pH range 5.6 to 6.5. About 21 million ha of acid soils are found in North Eastern Hill (NEH) region, including Sikkim with the maximum area under Arunachal Pradesh. In Meghalaya, the soils under various acidic ranges are found like moderately acidic soil (1.19 million ha), and slightly acidic soils (1.05 million ha) (Maji *et al.*, 2012). The soils of Meghalaya are rich in organic carbon, which is a measure of nitrogen supplying potential of soil, deficient in available phosphorous, medium to low in available potassium, calcium, magnesium and toxic in Al and Fe. To overcome the problem of soil acidity, farmers adopt a variety of soil amendments like manures, lime, compost, and bio-sorbents to make soil nutrients available to crops as well as to protect them from toxic elements. Among soil amendments, liming is good practice to overcome the acidity problem. However, it may not be economical in the regions where it is expensive. The alternate cheap and good organic source to overcome the acidity problem is biochar (Chan *et al.*, 2008).

Biochar is a carbonaceous solid material obtained through thermally degrading process of biomass in presence of little oxygen. It is generally defined as charred organic matter, produced with the interest to apply into soils to improve soil properties and sequester carbon (Lehmann and Joseph, 2009). Biochar is produced through pyrolysis which is the direct thermal decomposition of biomass in the absence of oxygen that produces a mixture of solids (biochar), liquid (bio-oil), and gas (syngas). Quality and yield of biochar depend on maintaining a specific temperature (Demirbas, 2004). The temperature of 400–500°C produces more biochar, while temperatures above 700°C favour the yield of liquid and gas fuel components. The major resource required for the production of biochar is organic residue and/or weed biomass. North Eastern Hill (NEH) region of India produces a huge amount of weed biomass, crop residues and have large forest area making easy availability of different biomass for converting into biochar quantify (CRIDA, 2012).

The characteristics of biochar mainly depends on type of resource used for the preparation of biochar. These are governed by its chemical and physical constituents. The form and size of resources and pyrolysis product may affect the quality and potential uses of biochar (Sohi *et al.*, 2010). Biochar was found to be beneficial in various ways such as : moderating of soil acidity by one point increase in pH (Lehman and Rondon, 2006), reducing methane gas emission (Rondon *et al.*, 2005), decreasing emissions of nitrous oxide (Yanai *et al.*, 2007), increasing cation exchange capacity (Glaser *et al.*, 2002), soil moisture retention (Tryon, 1948), decreasing soil bulk density

(Laird, 2008), increasing number and activity of beneficial soil microbes (Warnock *et al.*, 2007), improving fertilizer use efficiency (Gaunt and Cowie, 2009). The usefulness of biochar increases when it is applied in combination with organic manures like FYM, vermicompost, poultry manure, pig manure (CRIDA, 2012). The state of Meghalaya is known for large array of vegetables both sub-tropical and temperate. Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops supporting the livelihood and improving the economic life of many vegetable growers in the NEH region of India. It is used as a vegetable, soup, salad, pickle, ketchup, sauce and many other ways. It is a good source of vitamin A, B, and C. Keeping these facts in view, the present investigation was carried out to study the impacts of biochar and vermicompost on nutrient uptake (N, P, K and micro-nutrients) by tomato in acid soil of Meghalaya and determine the residual soil properties, nutrient availability and soil acidity indices.

Materials and Methods

Study site: The field experiment was conducted at the Research Farm of School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences (CPGS-AS), Umiam, Ri-bhoi district, Meghalaya which is located at 91°18' to 92°18' E longitude and 25°40' to 26°20' N latitude at an altitude of 950 m above mean sea level. The experimental area falls under subtropical humid climate with high rainfall and cold winter.

Experiment set up: Tomato (cv. Megha tomato-2) was used as test crop for investigating the performance with 16 combinations of three doses of biochar (B) @ 2, 3 and 4 t/ha, two graded recommended doses of fertilizers (RDF) @ 75 and 100% and one dose of vermicompost (VC) @ 2.5 t ha⁻¹. The treatment combinations namely, T₁- Control, T₂- B @ 2 t ha⁻¹, T₃- B @ 3 t ha⁻¹, T₄- B @ 4 t ha⁻¹, T₅- 75% RDF + B @ 2 t ha⁻¹, T₆- 75% RDF + B @ 3 t ha⁻¹, T₇- 75% RDF + B @ 4 t ha⁻¹, T₈- 75% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T₉- 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T₁₀- 75% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T₁₁- 100% RDF + B @ 2 t ha⁻¹, T₁₂- 100% RDF + B @ 3 t ha⁻¹, T₁₃- 100% RDF + B @ 4 t ha⁻¹, T₁₄- 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T₁₅- 100% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T₁₆- 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. They were randomly allotted in a unit plot size of 2 m × 2 m. The experiment was replicated three times in Randomized Block Design (RBD). The nutrients N, P and K were applied through urea, single super phosphate and murate of potash, respectively, on the day of sowing whereas vermicompost and biochar was applied ten days prior to transplanting as per treatment wise. Seedlings of tomato were transplanted to the plots with 40 × 40 cm² spacing during *rabi* season of 2017-2018. The desired plant population was maintained uniformly by gap filling. Watering and hand weeding was carried out as and when required. The fruits were harvested in several pickings according to their physiological maturity.

Sampling and analysis: Bulk sample of biochar was collected from the Department of Agricultural Engineering, ICAR Research Complex for North Eastern Hill Region, Umiam (Barapani), Ribhoi district, Meghalaya. The feedstock used for preparation of biochar was waste from plywood industry and it was prepared at 450 to 600°C. The vermicompost used in this study was collected from Rural Resource and Training Centre, Umran, Meghalaya. The representative samples of biochar and vermicompost were brought to the laboratory for analysis. The physico-chemical properties of biochar and vermicompost were estimated by standard methods: pH (8.60 and 7.30) by potentiometry, nitrogen (0.61 and 2.11%) by Kjeldahl digestion and distillation method, phosphorus (0.22 and 1.23%) by Vanadomolybdate method, potassium (1.01 and 1.53%) by flame photometer method (Jackson, 1973), iron (0.06 and 250.20 ppm), zinc (1.72 and 1095.00 ppm), manganese (0.04 and 53.00 ppm), copper (0.12 and 248.60 ppm) by atomic absorption spectrophotometer (Lindsay and Norwell, 1978).

The composite soil sample from 0 to 15 cm depth was collected from the experimental area before land preparation using standard methods. Again the soil samples were collected after harvesting of crop and five plants were selected randomly in the net plot area and labeled for recording observations in each treatment. The soil samples were air dried ground and passed through 2 mm sieve for analysis of physico-chemical properties following standard protocol as pH, EC (dS m^{-1}), available K_2O (kg ha^{-1}), exchangeable acidity, exchangeable aluminium, exchangeable Ca and Mg, cation exchange capacity by Jackson (1973), bulk density (g cm^{-3}) by Campbell and Henshall (2001), available N (kg ha^{-1}) by Subbiah and Asija (1956), available P_2O_5 (kg ha^{-1}) by Bray and Kurtz (1945). Fe, Zn, Mn and Cu were estimated by the method of Lindsay and Norwell (1978). Nitrogen in plant samples was determined by Kjeldahl digestion distillation method as described by Jackson (1973). Digestion of fruit and plant samples was carried out with di-acid mixture containing HNO_3 and HClO_4 in the ratio of 3:1 and further used for determination of P, K, Fe, Zn, Mn and Cu by above stated standard protocol.

Nutrient uptake: N, P and K uptake in both fruit and haulm were calculated by the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Nutrient concentration (\%)} \times \text{yield (t ha}^{-1}\text{)} \times 10$$

Micronutrients uptake in both fruit and haulm were calculated by using the following formula:

$$\text{Nutrient uptake (g ha}^{-1}\text{)} = \text{Nutrient concentration (ppm)} \times \text{yield (t ha}^{-1}\text{)}$$

Soil acidity indices: Soil acidity indices as described by Fageria, (2008) were estimated by the standard methods and

calculated with the help of the following formulas:

$$\text{CEC (cmol}_c\text{ kg}^{-1}\text{)} = \Sigma(\text{Ca}^{2+}, \text{Mg}^{2+}, \text{K}^+, \text{H}^+, \text{Al}^{3+})$$

Where, Ca, Mg, K, H and Al are in centimoles of positive charge per kilogram.

$$\text{Base saturation (\%)} = \frac{\Sigma(\text{Ca}^{2+}, \text{Mg}^{2+}, \text{K}^+, \text{H}^+, \text{Al}^{3+})}{\text{CEC}} \times 100$$

$$\text{Acidity saturation (\%)} = \frac{(\text{H} + \text{Al})}{\text{CEC}} \times 100$$

Statistical analyses: The data obtained from the experiment were analyzed for analysis of variance (ANOVA) and the difference between treatment means was tested for their statistical significance with appropriate critical difference (CD) at 5% level of probability (Gomez and Gomez, 1984).

Results and Discussion

The statistics have-to-do with nitrogen concentration (%) and uptake (kg ha^{-1}) in fruit and haulm dry matter as affected by biochar as a component of integrated nutrient management are presented in Table 1. The highest nitrogen concentration in fruit and haulm was noticed in the treatment receiving 100% RDF + biochar 4 t ha^{-1} + vermicompost 2.5 t ha^{-1} (T16) with 46 and 45% increase over control, respectively. Similar trend was also obtained in the case of nitrogen uptake (kg ha^{-1}) in fruit and haulm dry matter, and the highest nitrogen uptake (kg ha^{-1}) in fruit and haulm was recorded 51.26 and 37.80 kg ha^{-1} , whereas the lowest N uptake in fruit and haulm was recorded as 5.74 and 3.70 kg ha^{-1} in control treatments. The sole application of biochar has showed a slight increase in nitrogen concentration with increasing the doses of biochar in fruit and haulm. Addition of 75% RDF with biochar showed a significant increase over sole application of biochar at 4 t ha^{-1} in fruit, but in haulm. The application of 100% RDF in the combination of biochar slightly increased nitrogen concentration over 75% RDF in combination with biochar, whereas it showed a significant increase over the sole application of biochar. The application of vermicompost in combination with 75% RDF + biochar showed slight increase over combined application of 75% RDF + biochar and this increase was observed to be significant over sole application of biochar. The concentration of nitrogen in fruit and haulm was found less with 75% RDF + biochar + vermicompost in comparison to that observed under 100% RDF + biochar. Further, the addition of vermicompost with 100% RDF + biochar reflected a slight increase over combined application of 75% RDF + biochar + vermicompost, 75% RDF + biochar and 100% RDF + biochar but it had increased significantly over sole application of biochar (T_2 , T_3 , T_4).

The data relevant to nitrogen uptake revealed that the highest uptake in fruit and haulm (51.26 and 37.8 kg ha^{-1}) in the

treatment receiving 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ (T₁₆) whereas the lowest values of nitrogen uptake in fruit and haulm (5.74 and 3.70) was recorded under control plots. It was observed that nitrogen uptake was significantly increased by the addition of 75% RDF with biochar over sole application of biochar as well as over control. Similarly, it increased significantly with the inclusion of vermicompost with RDF + biochar @ 4 t ha⁻¹ over RDF + biochar @ 4 t ha⁻¹. The fruit and haulm dry matter recorded higher nitrogen concentration and uptake in the plots treated with biochar in the combination of inorganic fertilizers and organic manures might be due to decrease in nitrogen loss and slow release pattern of nitrogen synchrony with the demand of tomato crop. Lehmann *et al.* (2003a), Zhang *et al.* (2017) and McDonald *et al.* (2019) reported that insertion of biochar enhanced nitrogen uptake. The escalated in nitrogen concentration on supplying biochar was also suggested by Glaser *et al.* (2002) and Lehmann *et al.* (2003b). The improved in nitrogen uptake in plants on adding biochar was also observed by Agegnehu *et al.* (2015); Butnan *et al.* (2015) and Zwieter *et al.* (2010). Similar to these findings, Chan *et al.* (2008) also reported high nitrogen uptake by radish plants grown in soil amended by biochar.

The particulars on phosphorus concentration showed that the control plots had 0.22% phosphorus concentration which increased up to 0.40% (Table 1). This highest phosphorus concentration (0.40%) was observed under T₁₆ with 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹. In the same line, highest phosphorus uptake 20.78 kg ha⁻¹ in fruit was also recorded in T₁₆. The application of biochar showed a slight increase in phosphorus concentration on increasing the doses of biochar in fruit and haulm. Addition of 75% RDF with biochar also significantly increased phosphorus concentration in fruit and haulm over sole application of biochar at respective doses. The application of 100% RDF + biochar slightly increased phosphorus concentration than those observed with combined application of 75% RDF + biochar but showed a significant increase over sole application of biochar. The application of 75% RDF + biochar + vermicompost slightly increased phosphorus concentration over combined application of 75% RDF + biochar and it has increased significantly over the sole application of biochar. Further, the concentration of phosphorus was less in 75% RDF + biochar + vermicompost than that of 100% RDF + biochar. Application of vermicompost jointly with 100% RDF + biochar had increased phosphorus concentration slightly over combined application of 75% RDF + biochar + vermicompost and 100% RDF + biochar,

Table 1 : Impact of biochar as a component of integrated nutrient management on N, P and K concentration (%) and uptake (kg ha⁻¹) in tomato fruit and haulm dry matter

Treatments	N concentration		N uptake		P concentration		P uptake		K concentration		K uptake	
	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm
T ₁ -Control	0.67	0.81	5.74	3.70	0.22	0.28	1.90	1.29	0.48	0.54	4.14	2.49
T ₂ -B @ 2 t ha ⁻¹	0.70	0.84	7.08	4.60	0.25	0.31	2.56	1.69	0.52	0.57	5.28	3.11
T ₃ -B @ 3 t ha ⁻¹	0.72	0.87	8.15	5.42	0.27	0.33	3.03	2.03	0.54	0.59	6.08	3.64
T ₄ -B @ 4 t ha ⁻¹	0.73	0.88	9.53	6.41	0.28	0.34	3.66	2.47	0.55	0.61	7.18	4.35
T ₅ -75% RDF + B @ 2 t ha ⁻¹	0.81	0.97	13.01	8.80	0.31	0.38	4.95	3.44	0.58	0.64	9.25	5.78
T ₆ -75% RDF + B @ 3 t ha ⁻¹	0.84	1.01	14.87	10.06	0.33	0.41	5.87	4.09	0.60	0.67	10.65	6.67
T ₇ -75% RDF + B @ 4 t ha ⁻¹	0.86	1.03	17.65	12.18	0.34	0.43	6.99	5.02	0.61	0.68	12.58	8.04
T ₈ -75% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.83	1.00	16.77	11.58	0.33	0.41	6.63	4.71	0.59	0.66	11.89	7.61
T ₉ -75% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.86	1.04	32.57	23.15	0.35	0.43	13.19	9.61	0.61	0.69	22.77	15.28
T ₁₀ -75% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.88	1.06	38.15	27.44	0.36	0.44	15.59	11.35	0.62	0.70	26.63	17.97
T ₁₁ -100% RDF + B @ 2 t ha ⁻¹	0.86	1.03	16.16	10.96	0.34	0.43	6.36	4.59	0.61	0.68	11.36	7.23
T ₁₂ -100% RDF + B @ 3 t ha ⁻¹	0.90	1.08	26.60	18.82	0.36	0.46	10.71	8.04	0.64	0.72	18.89	12.56
T ₁₃ -100% RDF + B @ 4 t ha ⁻¹	0.93	1.12	30.98	21.97	0.37	0.48	12.38	9.54	0.66	0.74	21.92	14.49
T ₁₄ -100% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.89	1.07	20.14	13.83	0.35	0.49	7.92	6.32	0.63	0.71	14.22	9.14
T ₁₅ -100% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.94	1.13	40.35	29.02	0.38	0.51	16.27	13.03	0.67	0.75	28.77	19.21
T ₁₆ -100% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.98	1.18	51.26	37.8	0.40	0.52	20.78	16.52	0.70	0.78	36.35	24.82
SE(m)±	0.04	0.05	1.37	0.98	0.01	0.02	0.59	0.47	0.03	0.03	1.03	0.62
CD(p<0.05)	0.13	0.15	3.97	2.83	0.04	0.07	1.71	1.37	0.09	0.1	2.97	1.8

*RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost)

but it increased significantly over 75% RDF + biochar and sole application of biochar.

Phosphorus uptake in fruit and haulm of tomato is presented in Table 1. The examination of data reflected that phosphorus uptake in fruit varied from 1.90 to 20.78 kg ha⁻¹ whereas, in haulm, it ranged from 1.29 to 16.52 kg ha⁻¹. The highest phosphorus uptake in both fruit and haulm were recorded under T₁₆ with 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ whereas least uptake was recorded under control plots. The higher phosphorus concentration and uptake in fruit and haulm of tomato recorded under investigation is possible due to more phosphorus availability to crop through addition of biochar and vermicompost (McDonald *et al.*, 2019; Zhang *et al.*, 2017 and Agegnehu *et al.*, 2015). Chng *et al.* (2015) also reported an enhanced phosphorus concentration and uptake by the incorporation of biochar and vermicompost. Similarly, Uzoma *et al.* (2011) and Yamato *et al.* (2006) concluded an increase in plant available phosphorus in soil with the application of biochar. Moreover, the increased phosphorus availability may also be due to healthy root growth by decreased Al toxicity which causes damage to roots (Aziz *et al.*, 2006).

The least and highest potassium concentration in fruit and haulm was recorded 0.48 and 0.54 and 0.70 and 0.78, respectively, in control plot and treatment receiving 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ T₁₆ (Table 1). The same trend of potassium concentration was observed in haulm with the lowest value (0.54%) in control and the highest value (0.78%) in T₁₆. Addition of biochar slightly increased potassium concentration in fruit and haulm with the successive doses of biochar. Following similar pattern, 75% RDF + biochar non-significantly increased potassium concentration in fruit and haulm over sole application of biochar at respective doses. The application of 100% RDF + biochar slightly increased potassium concentration than 75% RDF + biochar whereas it showed a significant increase than biochar sole application. The combined application of 75% RDF + biochar + vermicompost had slightly increased potassium concentration over the application of 75% RDF + biochar, but it increased significantly over the sole application of biochar. It showed decreased values with respect to potassium concentration than 100% RDF + biochar. Application of vermicompost in combination with 100% RDF + biochar again increased potassium concentration slightly over combined application of 75% RDF + biochar + vermicompost, 75% RDF +

Table 2 : Impact of biochar as a component of integrated nutrient management on Fe, Zn, Mn, and Cu concentration (ppm) in tomato fruit and haulm dry matter

Treatments	Fe concentration		Zn concentration		Mn concentration		Cu concentration	
	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm
T ₁ – Control	11.29	13.70	3.07	4.21	5.93	7.91	1.71	2.83
T ₂ – B @ 2 t ha ⁻¹	12.42	15.61	3.70	4.62	7.51	9.12	2.13	3.25
T ₃ – B @ 3 t ha ⁻¹	12.46	15.72	3.71	4.80	7.62	9.33	2.17	3.31
T ₄ – B @ 4 t ha ⁻¹	12.75	16.62	4.04	4.81	7.68	9.62	2.23	3.42
T ₅ – 75% RDF + B @ 2 t ha ⁻¹	13.59	19.22	4.10	4.91	8.30	9.92	2.50	3.86
T ₆ – 75% RDF + B @ 3 t ha ⁻¹	13.64	20.73	4.12	4.83	8.46	10.70	2.69	3.99
T ₇ – 75% RDF + B @ 4 t ha ⁻¹	14.28	20.28	4.14	4.90	8.52	11.38	2.81	4.06
T ₈ – 75% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	27.71	36.04	7.25	8.42	14.11	15.72	5.69	6.9
T ₉ – 75% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	28.58	37.38	7.32	8.43	14.32	15.81	5.72	6.97
T ₁₀ – 75% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	29.24	37.16	7.41	8.61	15.43	16.01	5.81	7.01
T ₁₁ – 100% RDF + B @ 2 t ha ⁻¹	15.02	22.05	4.15	5.16	8.80	11.74	2.87	4.14
T ₁₂ – 100% RDF + B @ 3 t ha ⁻¹	15.09	22.23	4.18	5.27	9.01	11.98	2.92	4.21
T ₁₃ – 100% RDF + B @ 4 t ha ⁻¹	15.28	23.67	4.22	5.34	9.42	12.24	3.14	4.36
T ₁₄ – 100% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	29.65	39.25	7.51	8.50	16.41	17.62	5.87	7.14
T ₁₅ – 100% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	29.89	41.90	7.60	8.52	16.96	17.92	5.94	7.19
T ₁₆ – 100% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	30.15	42.62	7.70	8.61	17.39	18.35	6.12	7.24
SE(m)±	1.31	1.6	0.35	0.36	0.56	0.66	0.35	0.36
CD(p≤0.05)	3.8	4.63	1.03	1.04	1.64	1.92	1.03	1.04

*RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost)

Table 3: Impact of biochar as a component of integrated nutrient management on Fe, Zn, Mn and Cu uptake (g ha^{-1}) in tomato fruit and haulm dry matter

Treatments	Fe uptake		Zn uptake		Mn uptake		Cu uptake	
	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm	Fruit	Haulm
T ₁ – Control	9.73	6.31	2.64	1.93	5.10	3.63	1.47	1.30
T ₂ – B @ 2 t ha ⁻¹	12.78	8.35	3.66	2.46	7.53	4.94	2.06	1.72
T ₃ – B @ 3 t ha ⁻¹	14.06	10.01	4.24	3.01	8.65	5.80	2.51	2.08
T ₄ – B @ 4 t ha ⁻¹	16.63	12.07	5.24	3.50	10.06	7.01	2.92	2.49
T ₅ – 75% RDF + B @ 2 t ha ⁻¹	21.88	17.20	6.39	4.41	13.27	8.91	3.99	3.47
T ₆ – 75% RDF + B @ 3 t ha ⁻¹	24.31	20.89	7.33	4.83	15.73	11.20	4.79	3.99
T ₇ – 75% RDF + B @ 4 t ha ⁻¹	29.43	24.05	8.39	5.70	17.41	13.35	5.65	4.71
T ₈ – 75% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	56.03	41.24	14.60	9.67	41.75	27.35	11.46	7.95
T ₉ – 75% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	108.19	82.85	27.53	18.73	53.77	35.16	21.51	15.54
T ₁₀ – 75% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	126.76	95.69	32.02	22.17	66.25	41.06	25.14	18.05
T ₁₁ – 100% RDF + B @ 2 t ha ⁻¹	27.74	23.49	7.89	5.56	15.54	11.66	5.51	4.48
T ₁₂ – 100% RDF + B @ 3 t ha ⁻¹	44.78	38.79	12.29	9.14	17.97	13.76	8.57	7.30
T ₁₃ – 100% RDF + B @ 4 t ha ⁻¹	50.71	46.42	14.04	10.49	21.41	15.80	10.43	8.56
T ₁₄ – 100% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	66.80	50.74	16.97	10.96	54.67	32.73	13.26	9.21
T ₁₅ – 100% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	128.60	107.41	32.60	21.77	73.60	43.69	25.48	18.42
T ₁₆ – 100% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	155.79	136.42	40.21	27.46	90.42	55.07	31.96	23.12
SE(m)±	5.78	3.87	1.08	0.74	2.47	1.66	0.93	0.66
CD(p<0.05)	16.7	11.18	3.11	2.15	7.14	4.79	2.71	1.91

*RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost)

biochar and 100% RDF + biochar, but it increased significantly over sole application of biochar.

The increase in tissue potassium concentration also resulted due to biochar application could be attributed to the high K content in the biochar which was reflected by the higher exchangeable K in plots treated biochar (Syuhada *et al.*, 2016; Butnan *et al.*, 2015).

The highest potassium uptake in fruit and haulm of tomato was recorded 36.35 and 24.82 in the treatment receiving 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ (T₁₆) that was significantly higher over all the treatments (Table 1). In contrast to this, control plots exhibited at least potassium uptake in fruit and haulm *i.e.*, 4.14 and 2.49. Potassium uptake increased due to application of biochar over control non-significantly in fruit and haulm. Addition of 75% RDF with biochar showed a significant increase over biochar alone plots of respective doses. By increasing the dose of RDF to 100% in combination with biochar resulted in a significant increase in 3 and 4 t ha⁻¹ biochar but at 2 t ha⁻¹ it increased non-significantly over 75% RDF + biochar whereas it increased significantly over biochar alone plots. Supplying vermicompost in combination with 75% RDF + biochar had increased potassium uptake significantly over 100%

RDF + biochar @ 3 and 4 t ha⁻¹, 75% RDF + biochar and biochar alone. Addition of 100% RDF + biochar + vermicompost also showed significant increase over 100% RDF + biochar, 75% RDF + biochar @ at 3 and 4 t ha⁻¹ + vermicompost, 75% RDF + biochar, and biochar alone plots. Potassium uptake followed similar pattern as nitrogen and phosphorus. The soils amended by biochar increased potassium uptake which might be ascribed to the presence of potassium rich ash in the biochar (Zhang *et al.*, 2017) and Agegnehu *et al.* (2015). Moreover, biochar has the capacity to increase CEC of soil, thereby the ability of soil increased to hold potassium and make it available for plant uptake (McDonald *et al.*, 2019). Rondon *et al.* (2007) reported increased potassium uptake by plant biomass in common bean. Similarly, potassium concentration in maize grains also increased with the application of cow manure biochar as reported by Uzoma *et al.* (2011). Potassium availability increased as soil pH increased by the treating with biochar (Manolikaki and Diamadopoulos, 2016).

The concentration and uptake of micronutrients in fruit and haulm increased as the doses of biochar increased has shown in Table 2 and 3, respectively. Higher nutrient concentration of tomato in biochar and vermicompost treatments might be ascribed to favourable soil chemical and physical

conditions that might have increased the availability of micronutrients with the application of biochar and vermicompost which has the high organic load. The uptake of micronutrients in fruit and haulm increased as the doses of biochar increased. Jatav *et al.* (2018) concluded an enhanced micronutrient uptake by the insertion of biochar in the combination of sewage sludge in rice. The higher micronutrient uptake was due to improved fruit and haulm dry matter production by incorporating of biochar in soil as it improves nutrient retention capacity coupled with the beneficial effect of vermicompost. Therefore, increasing doses of biochar application in soil enhanced the sorption of micronutrients and released slowly fulfilling the requirement for tomato plant. Zhang *et al.* (2017) and Chintala *et al.* (2013) also delineated that the uptake of micronutrients (Fe, Zn, Mn, and Cu) increased in corn plants with the application of biochar.

pH varied from 5.1 in control to 5.30 (Fig. 6) in the treatment receiving 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ (T₁₆). It was non-significant with all the treatments. Raison (1979) and Khanna *et al.* (1994) reported the capacity of ashes to neutralize the acidic soil. Soil pH enhanced on supplying biochar which could be due to alkaline, porous nature and more surface area of biochar which increases the soil cation exchange capacity (Jatav *et al.*, 2018; Warnock *et al.*, 2007). Another cause

for increase in soil pH may be high content of calcium carbonate and release of basic cations of biochar (Chintala *et al.*, 2014; McDonald *et al.*, 2019). However, decrease in pH in some treatments, may be due to the acidifying nature of ammonium nitrate fertilizer, as a result product of proton-generating reaction of ammonium ions (McDonald *et al.*, 2019) and also it may cause due to N nitrification after urea and NPK were added (Chathurika, *et al.*, 2016; Syuhada *et al.*, 2016; Zhu *et al.* 2014).

The data pertaining to electrical conductivity of post-harvest soil as influenced by biochar as a component of integrated nutrient management is given in Table 4. The lowest EC recorded was 0.39 dS m⁻¹ with 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ application which increased by 0.07 units in the treatment receiving 100% RDF + biochar 2 t ha⁻¹ + vermicompost 2.5 t ha⁻¹, 100% RDF + biochar 2 t ha⁻¹ and 75% RDF + biochar 2 t ha⁻¹ giving highest value of 0.46 dS m⁻¹. This was also observed to be at par over all other treatments corroborating the previous findings (Obour *et al.*, 2020; Usman *et al.*, 2016; Agegnehu *et al.*, 2015; Cely *et al.*, 2015).

The bulk density varied non-significantly from 1.33 to 1.44 g cc⁻¹ (Table 4). The highest bulk density 1.44 was recorded in control plots and it decreased on applying biochar and

Table 4 : Impact of biochar as a component of integrated nutrient management on soil EC (dS m⁻¹), bulk density (g cc⁻¹), available N, P and K (kg ha⁻¹) and available Fe, Zn, Mn and Cu (mg kg⁻¹) after harvest of tomato crop.

Treatments	EC	Bulk density	Available N	Available P	Available K	Available Fe	Available Zn	Available Mn	Available Cu
T ₁ – Control	0.45	1.44	221.13	12.35	215.16	5.70	32.16	43.67	14.62
T ₂ – B @ 2 t ha ⁻¹	0.44	1.38	227.65	13.67	219.19	6.01	32.21	43.73	14.64
T ₃ – B @ 3 t ha ⁻¹	0.42	1.34	231.71	14.83	221.22	6.12	32.25	43.79	14.66
T ₄ – B @ 4 t ha ⁻¹	0.41	1.32	234.13	15.76	222.98	6.18	32.27	43.81	14.67
T ₅ – 75% RDF + B @ 2 t ha ⁻¹	0.46	1.41	242.45	17.44	227.65	6.21	33.46	45.43	15.21
T ₆ – 75% RDF + B @ 3 t ha ⁻¹	0.45	1.36	249.12	19.14	230.06	6.33	33.47	45.44	15.21
T ₇ – 75% RDF + B @ 4 t ha ⁻¹	0.43	1.33	254.60	20.64	232.81	6.45	33.49	45.47	15.22
T ₈ – 75% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.44	1.39	247.13	25.27	230.84	6.81	36.28	49.26	16.49
T ₉ – 75% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.43	1.34	258.33	27.39	234.54	6.90	36.34	49.34	16.18
T ₁₀ – 75% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.42	1.30	266.67	27.86	237.51	7.02	36.53	49.60	16.60
T ₁₁ – 100% RDF + B @ 2 t ha ⁻¹	0.46	1.43	245.75	20.85	229.15	6.28	33.49	45.47	15.22
T ₁₂ – 100% RDF + B @ 3 t ha ⁻¹	0.44	1.37	254.13	22.07	232.78	6.39	33.50	45.48	15.22
T ₁₃ – 100% RDF + B @ 4 t ha ⁻¹	0.42	1.34	261.13	23.41	234.93	6.48	33.51	45.50	15.23
T ₁₄ – 100% RDF + B @ 2 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.46	1.40	251.21	28.15	236.29	6.85	36.55	49.63	16.61
T ₁₅ – 100% RDF + B @ 3 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.42	1.35	266.62	30.34	240.62	6.94	36.58	49.67	16.62
T ₁₆ – 100% RDF + B @ 4 t ha ⁻¹ + VC @ 2.5 t ha ⁻¹	0.39	1.33	277.13	31.35	243.08	7.05	36.61	49.71	16.64
SE(m)±	0.02	0.07	5.63	1.24	4.94	0.27	0.84	0.95	0.89
CD(p<0.05)	NS	NS	16.27	3.59	14.28	0.79	2.43	2.74	NS

*RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost)

vermicompost. The application of 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ recorded lowest bulk density (1.33 g cc⁻¹). The minimum bulk density on adding biochar as well as vermicompost. It might be decreased because biochar possess low bulk density.

The highest nitrogen, phosphorus and potassium content was recorded in the treatment receiving 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹. It increased from initial soil N status by 6% and 25% over control, from initial soil P status by 67 and 153% over control and from initial soil K status by 3 and 12% over control. Agegnehu *et al.* (2015) reported increase in N, P and K content in soil after harvest of maize. This may be owing to N immobilization and decreased loss of N by leaching in the presence of recalcitrant biochar materials (Rondon *et al.*, 2007). Biochar has the ability to act as a slow release N fertilizer, so availability of nitrogen increased (Chan and Xu, 2009; Steiner *et al.*, 2008). An increase in soil pH and CEC, which reduces the activity of Fe and Al, can also contribute to higher values of available nutrients in soils treated with biochar (McDonald *et al.*, 2019). The available P content enhanced due to high porous nature of biochar which provides favourable environment for mycorrhizal fungi. It make unavailable phosphorus available to plants by secreting P-solubilizing organic acid (Chaturika, *et al.*, 2016; Gul and Whalen, 2016; Warnock *et al.*, 2007). An experiment was also conducted by Uzoma *et al.*, (2011) on maize

by application of cow manure biochar and reported increase in P availability as a result of enhanced in soil pH. Similarly, the application of biochar increase the CEC of soil thereby increasing the capability of soil to hold K. The availability of K in soil might be increased by enhancing pH of soil by application of biochar as increase in pH of soil may force the strongly attached K on clay particles and pulled into the soil solution (McDonald *et al.*, 2019; Manolikaki and Diamadopoulos, 2016; Smider and Singh, 2014).

There was improvement in the content of Fe, Zn, Mn and Cu (Table 4) with the application of biochar. The content of Fe, Zn, Mn and Cu varied from 5.7 to 7.05, 32.16 to 36.61, 43.67 to 49.71 and 14.62 to 16.64 g ha⁻¹, respectively. The maximum content of Fe, Zn, Mn and Cu was filed with the application of 100% RDF + biochar 4 t/ha + vermicompost 2.5 t/ha whereas the lowest contents were recorded in control, however, the Cu content showed non-significant increase. The increase in micronutrients availability may be due to supply of sufficient amount Fe, Zn, Mn and Cu through vermicompost resulting in enhanced availability of Fe, Zn, Mn and Cu by mineralization of organic matter and release during decomposition of vermicompost (Jatav *et al.*, 2018; Prasanna, 2012).

The data pertaining to exchangeable acidity, exchangeable aluminium and acid saturation is shown in Fig. 1, 2

Fig. 1 : Impact of biochar as a component of integrated nutrient management on exchangeable acidity (cmol(p+) kg⁻¹) after harvest of tomato crop. T1 - Control, T2 - B @ 2 t ha⁻¹, T3 - B @ 3 t ha⁻¹, T4 - B @ 4 t ha⁻¹, T5 - 75%RDF + B @ 2 t ha⁻¹, T6 - 75% RDF + B @ 3 t ha⁻¹, T7 - 75% RDF + B @ 4 t ha⁻¹, T8 - 75%RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T9 - 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T10 - 75%RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T11 - 100% RDF + B @ 2 t ha⁻¹, T12 - 100% RDF + B @ 3 t ha⁻¹, T13 - 100% RDF + B @ 4 t ha⁻¹, T14 - 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T15 - 100%RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T16 - 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. *RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost). CD (p ≤ 0.05); NS (Non-significant).

Fig. 2 : Impact of biochar as a component of integrated nutrient management on exchangeable aluminium (cmol(p+) kg⁻¹) after harvest of tomato crop. T1 - Control, T2 - B @ 2 t ha⁻¹, T3 - B @ 3 t ha⁻¹, T4 - B @ 4 t ha⁻¹, T5 - 75% RDF + B @ 2 t ha⁻¹, T6 - 75% RDF + B @ 3 t ha⁻¹, T7 - 75% RDF + B @ 4 t ha⁻¹, T8 - 75% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T9 - 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T10 - 75% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T11 - 100% RDF + B @ 2 t ha⁻¹, T12 - 100% RDF + B @ 3 t ha⁻¹, T13 - 100% RDF + B @ 4 t ha⁻¹, T14 - 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T15 - 100% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T16 - 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. *RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost). CD (p ≤ 0.05): NS (Non-significant).

Fig. 3 : Impact of biochar as a component of integrated nutrient management on acid saturation (%) after harvest of tomato crop. T1 - Control, T2 - B @ 2 t ha⁻¹, T3 - B @ 3 t ha⁻¹, T4 - B @ 4 t ha⁻¹, T5 - 75% RDF + B @ 2 t ha⁻¹, T6 - 75% RDF + B @ 3 t ha⁻¹, T7 - 75% RDF + B @ 4 t ha⁻¹, T8 - 75% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T9 - 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T10 - 75% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T11 - 100% RDF + B @ 2 t ha⁻¹, T12 - 100% RDF + B @ 3 t ha⁻¹, T13 - 100% RDF + B @ 4 t ha⁻¹, T14 - 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T15 - 100% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T16 - 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. *RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost). CD (p ≤ 0.05): NS (Non-significant).

Fig. 4: Impact of biochar as a component of integrated nutrient management on exchangeable Ca²⁺ and Mg²⁺ (cmol(p+) kg⁻¹) after harvest of tomato crop. T1 - Control, T2 - B @ 2 t ha⁻¹, T3 - B @ 3 t ha⁻¹, T4 - B @ 4 t ha⁻¹, T5 - 75% RDF + B @ 2 t ha⁻¹, T6 - 75% RDF + B @ 3 t ha⁻¹, T7 - 75% RDF + B @ 4 t ha⁻¹, T8 - 75% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T9 - 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T10 - 75% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T11 - 100% RDF + B @ 2 t ha⁻¹, T12 - 100% RDF + B @ 3 t ha⁻¹, T13 - 100% RDF + B @ 4 t ha⁻¹, T14 - 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T15 - 100% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T16 - 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. *RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost). CD (p < 0.05): NS (Non-significant).

Fig. 6: Impact of biochar as a component of integrated nutrient management on pH after harvest of tomato crop. T1 - Control, T2 - B @ 2 t ha⁻¹, T3 - B @ 3 t ha⁻¹, T4 - B @ 4 t ha⁻¹, T5 - 75% RDF + B @ 2 t ha⁻¹, T6 - 75% RDF + B @ 3 t ha⁻¹, T7 - 75% RDF + B @ 4 t ha⁻¹, T8 - 75% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T9 - 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T10 - 75% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T11 - 100% RDF + B @ 2 t ha⁻¹, T12 - 100% RDF + B @ 3 t ha⁻¹, T13 - 100% RDF + B @ 4 t ha⁻¹, T14 - 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T15 - 100% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T16 - 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. *RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost). CD (p < 0.05): NS (Non-significant).

Fig. 5: Impact of biochar as a component of integrated nutrient management on base saturation (%) after harvest of tomato crop. T1 - Control, T2 - B @ 2 t ha⁻¹, T3 - B @ 3 t ha⁻¹, T4 - B @ 4 t ha⁻¹, T5 - 75% RDF + B @ 2 t ha⁻¹, T6 - 75% RDF + B @ 3 t ha⁻¹, T7 - 75% RDF + B @ 4 t ha⁻¹, T8 - 75% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T9 - 75% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T10 - 75% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T11 - 100% RDF + B @ 2 t ha⁻¹, T12 - 100% RDF + B @ 3 t ha⁻¹, T13 - 100% RDF + B @ 4 t ha⁻¹, T14 - 100% RDF + B @ 2 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T15 - 100% RDF + B @ 3 t ha⁻¹ + VC @ 2.5 t ha⁻¹, T16 - 100% RDF + B @ 4 t ha⁻¹ + VC @ 2.5 t ha⁻¹. *RDF (Recommended doses of fertilizers), B (Biochar), VC (Vermicompost). CD ($p \leq 0.05$): NS (Non-significant).

and 3 The influence of biochar on exchangeable acidity of post-harvest soil as a constituent of integrated nutrient management showed statistically non-significant results between treatments, but exchangeable aluminium recorded significant statistically among the treatments. However, the lowest exchangeable acidity and aluminium was documented with the application of 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹. This may be due to the fact that organic manure and biochar have ability to consume protons which reduce the acidity. Soil application of biochar can reduce Al concentration either due to decrease in exchangeable Al through adsorption on the surfaces of negatively charged biochar or reduction of Al activity in soil solution through chelation with soluble organic compounds from the biochar (Syuhada *et al.*, 2016; Butnan *et al.*, 2015; Hati *et al.*, 2008). The exchangeable aluminium decreased due to increase in soil pH (Syuhada *et al.*, 2016; Opala *et al.*, 2012; Narambuye and Haynes, 2006). Similar trend was observed in exchangeable acidity and exchangeable aluminium for acid saturation.

The highest exchangeable Ca²⁺ + Mg²⁺ was recorded (2.07 cmol(p+) kg⁻¹) in the treatment receiving 100% RDF + biochar 4 t ha⁻¹ + vermicompost 2.5 t ha⁻¹ (Fig. 4). However, Ca²⁺ + Mg²⁺ showed increase with application of biochar and vermicompost, which may be due to increase in soil pH that leads to enhance formation of organic anions during decomposition of organic matter (McDonald *et al.*, 2019; Butnan *et al.*, 2015; Narambuye and Haynes, 2006) which consumed acidity causing protons (Haynes and Mokolobate, 2001) and solubilise inherent Ca and Mg ions content present in the organic matter. Application

of biochar and vermicompost improved the soil physical condition which provided suitable environment for microbiological activity which improved mineralization and increased the content of exchangeable Ca²⁺ + Mg²⁺ (Syuhada *et al.*, 2016; Agegnehu *et al.*, (2015) and Uzoma *et al.*, 2011). Similar trends were observed for base saturation as observed in exchangeable Ca²⁺ + Mg²⁺ (Fig. 5).

Based on the findings of above investigation it may be concluded that biochar is an effective component of integrated nutrient management under acidic soil condition. The application of biochar @ 4 t ha⁻¹ in combination with 100% RDF + vermicompost @ 2.5 t ha⁻¹ may be recommended as most appropriate combination for increase in tomato productivity and improving health of acidic soil in Meghalaya.

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