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Effect of Integrated Nutrient Management in Brinjal on Soil Properties

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ABSTRACT

An experiment was conducted at the Experimental farm of Department of Soil Science and Water Management, Neri, Hamirpur to study the combined effect of organic, inorganic and biofertilizer on soil properties. The experiment was laid out in a Randomized Block Design with three replications and consisted of 11 nutrient managements viz., control (T1), 100% RDF (T2), 75% RDN (IF) + 25% RDN (VC) (T3), 50% RDN (IF) + 50% RDN (VC) (T4), 25% RDN (IF) + 75% RDN (VC) (T5), 100% RDN (VC) (T6), 100% RDF + *Azotobacter* (T7), 75% RDN (IF) + 25% RDN (VC) + *Azotobacter* (T8), 50% RDN (IF) + 50% RDN (VC) + *Azotobacter* (T9), 25% RDN (IF) + 75% RDN (VC) + *Azotobacter* (T10) and 100% RDN (VC) + *Azotobacter* (T11). Surface soil samples (0-15 cm depth) were collected after the harvest of brinjal crop and analyzed for soil properties i.e., pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium, sulfur, exchangeable calcium, magnesium and DTPA extractable zinc, copper, iron and manganese using standard analytical methods. It was observed that the treatment comprising of 100% RDN through vermicompost + *Azotobacter* (T11) registered higher values of available nitrogen, phosphorus, potassium, sulfur, exchangeable calcium, magnesium and DTPA extractable micronutrient cations.

Keywords Biofertilizer, Brinjal, Nutrient management, Soil properties.

INTRODUCTION

Brinjal or egg plant (*Solanum melongena* L.) is an important and indigenous vegetable crop in India. It ranks as the fourth most produced and grown vegetable in the nation. Exceptional sources of carbs, proteins, minerals, vitamins, dietary fibers, and low-fat content can be found in brinjal fruits (Zenia and Halina 2008). It is a long duration crop that takes up land for close to 6–8 months. In addition, it yields heavily and uses up a lot of nutrients during one cycle of plant growth (Singh and Nath 2012), which causes quick depletion of nutrients and without proper replenishment it could severely affect soil fertility. In recent years, it has become apparent that

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the injudicious use of chemical fertilizers causes a number of serious issues, including fertility loss, soil structure, permanent nutrition losses from soil. With this constantly growing population, there is a need for increased agricultural productivity that is both sustainable and maintainable. Organic farming reduces the use of agrochemicals that degrade into the environment, like pesticides and synthetic fertilizers, by using inputs from natural sources. Renewable materials can be utilized in place of inorganic fertilizers to ensure environmental sustainability (Diacono *et al*. 2019). Addition of vermicompost to the soil reduce the C:N ratio which helps in stabilizing the soil. It also serves as a soil amendment that increases the soil's capacity to store water and facilitate cation exchange, hence reducing the need for mineral fertilizers in crop production. Additionally, vermicompost features microsites that are abundant in nitrogen and carbon and also increases the solubility of other nutrients (Haridha *et al*. 2020). Nitrogenous biofertilizers viz., *Rhizobium*, *Azotobacter* and *Azospirillum* are being widely used in vegetable crops for cutting down the requirement of inorganic fertilizers to be used for crop production. They are economically saving 25-50% of the recommended dose of nitrogenous fertilizers in vegetable crops (Singh and Nath 2012). Integrated nutrient management involves judicious use of organic and inorganic fertilizers along with biofertilizers, which not only takes cares of soil fertility but also significantly reduces the use of expensive chemical fertilizers thereby maintaining soil health over the long term. In light of the above information, a study was carried out to evaluate the effect of integrated nutrient management practices on the soil properties after the harvest of brinjal.

MATERIALS AND METHODS

The experiment was conducted at the Experimental farm of the Department of Soil Science and Water Management, College of Horticulture and Forestry, Hamirpur. In a Randomized Block Design, eleven treatments and three replications of each treatment were used. The recommended dose of fertilizer (RDF) was supplied in the form of urea, single super phosphate and muriate of potash as a source for nitrogen, phosphorus and potassium, respectively. The quantity of vermicompost was calculated based on its nitrogen content in treatments where recommended dose of nitrogen (RDN) was substituted by vermicompost to meet out the crop requirement. The control plots received no manure or fertilizer applications. The crop was planted at 60 cm x 45 cm spacing and standard cultural practices were followed consistently throughout all treatments (Tables 1-3).

Table 1. Treatment details of the experiment.

Treatments		Treatments combination
T1	:	Control
T2	:	100% RDF
T3	:	75% RDN (Inorganic fertilizer) + 25% RDN (Vermicompost)
T4	:	50% RDN (Inorganic fertilizer) + 50% RDN (Vermicompost)
T5	:	25% RDN (Inorganic fertilizer) + 75% RDN (Vermicompost)
T6	:	100% RDN (Vermicompost)
T7	:	100% RDF + *Azotobacter*
T8	:	75% RDN (Inorganic fertilizer) + 25% RDN (Vermicompost) + *Azotobacter*
T9	:	50% RDN (Inorganic fertilizer) + 50% RDN (Vermicompost) + *Azotobacter*
T10	:	25% RDN (Inorganic fertilizer) + 75% RDN (Vermicompost) + *Azotobacter*
T11	:	100% RDN (Vermicompost) + *Azotobacter*

Statistical analysis

The data gathered was subjected to statistical analysis using the technique of analysis of variance for Randomized Block Design as described by Gomez and Gomez (1984).

Table 2. Initial soil properties of the experimental farm.

Sl. No.	Soil property	Value
1	pH	6.76
2	Electrical conductivity (dS m^{-1})	0.195
3	Organic carbon (g kg^{-1})	4.40
4	Available nitrogen (kg ha^{-1})	188.16
5	Available phosphorus (kg ha^{-1})	16.15
6	Available potassium (kg ha^{-1})	169.50
7	Available sulfur (kg ha^{-1})	25.77
8	Exchangeable calcium [c mol (p^+) kg-^{1}]	8.64
9	Exchangeable magnesium [c mol (p^+) kg-^{1}]	2.47
10	Available zinc (mg kg^{-1})	0.91
11	Available copper (mg kg^{-1})	1.16
12	Available iron (mg kg^{-1})	13.51
13	Available manganese (mg kg^{-1})	14.74

RESULTS AND DISCUSSION

Soil pH and electrical conductivity

An inquisition of data presented in Table 4 indicates the effect of integrated nutrient management practices on soil pH. It was revealed that soil pH was not significantly influenced by the application of inorganic fertilizers, organic manure and biofertilizer. In general, pH of the soil varied from 6.77 to 6.86. Highest pH was recorded with the application of 100% RDN through vermicompost + *Azotobacter* (T11) and lowest under plots receiving no fertilizer, manure or biofertilizer (T1). On the whole, there was increase in soil pH over the control, however this increase was non significant. These results are in line with those of Lakra *et al*. (2017) and Dhiman *et al*. (2018). The electrical conductivity of the soil ranged from 0.194 to 0.208 dS m^{-1} (Table 4). The lowest electrical conductivity was obtained under control (T1) whereas highest was observed when plots were applied with 100% RDN through vermicompost + *Azotobacte*r (T11). Application of 100 RDF alone (T2) or in combination with *Azotobacter* (T7) increased the electrical conductivity of the soil. Similar trend was observed with the application of 100% RDN through vermicompost with and without the use of *Azotobacter* (T11 and T6, respectively). In general, there was slight increase in electrical conductivity of soil over control, however, this increase was not significant. Similar results were also reported by Salvi *et al*. (2015) and Lakra *et al.* (2017).

Organic carbon

Data referred in connection with the effect of integrated nutrient management on soil organic carbon (Table 4) marked out that among all the treatments, highest soil organic carbon content (5.26 g kg^{-1}) was observed with the application of 100 % RDN through vermicompost + *Azotobacter* (T11) while lowest (4.14 g kg^{-1}) was under control (T1) where no application of fertilizer, manure or biofertilizer was done. Build-up of soil organic carbon was observed in all the treatments except control over the initial value. Application of recommended doses of fertilizers alone (T2) or in combination with *Azotobacter* (T7) showed increase in soil organic carbon over control. Substitution of RDN by vermicompost increased the soil organic carbon over 100% RDF but was found to be inferior when *Azotobacter* was applied additionally along with substituted RDN by vermicompost. Though, there was an increase in soil organic carbon content with the addition of *Azotobacter* to the treatments in comparison to the treatments where *Azotobacter* was not used but the respective treatments were at par with each other. Highest increase of 27.05 and 19.55% over control and initial status, respectively was observed under T11 where 100% RDN through vermicompost + *Azotobacter* was applied. Lower organic carbon content in control might be due to no addition of fertilizer, manure or biofertilizer. Higher organic carbon content in the plots where vermicompost, chemical fertilizer or *Azotobacter* was applied might be attributed to better crop growth along with more root biomass generation. Also, organic manures are effective in building up organic carbon in soil since increase in microbial population might have helped in sequestering the mineralized carbon from organic manures and loading in to the soil carbon pool. This effect is further enhanced by addition of fertilizer that improved the root and shoot growth. The results recorded are in testimony with the work done by Thingujam *et al*. (2016), Lakra *et al*. (2017) and Dhiman *et al*. (2018).

Table 3. Nutrient content of vermicompost.

Sl. No.	Nutrient	Vermicompost
1	Nitrogen (%)	1.12
2	Phosphorus (%)	0.41
3	Potassium (%)	0.57
4	Sulphur (%)	0.22
5	Calcium (%)	0.55
6	Magnesium (%)	0.17
7	Zinc (mg kg^{-1})	64.01
8	Copper (mg kg^{-1})	36.82
9	Iron (mg kg^{-1})	2026.59
10	Manganese (mg kg^{-1})	229.45

Available nitrogen

The data on the effect of integrated nutrient management on available nitrogen in soil (Table 4) indicates that available N in soil varied from 167.25 to 265.51 kg ha^{-1}. The maximum values were obtained with the application of 100% RDN through vermicompost + *Azotobacter* (T11), while minimum was observed under control (T1). Treatments where 100% RDF was applied alone (T2) or in combination with *Azotobacter* (T7) showed increase of 16.67 and 25.00% in nitrogen availability in the soil over initial value. The nitrogen availability in the soil was increased by the addition of *Azotobacter* along with RDF or substituted doses of RDN by vermicompost. Among the treatments where *Azotobacter* was applied (T7-T11), increase in available nitrogen to the tune of 20.95, 17.14, 14.29, 10.95 and 7.14% was observed with the application of 100% RDN through vermicompost + *Azotobacter* (T11), 25% RDN through inorganic fertilizer + 75% RDN through vermicompost + *Azotobacter* (T10), 50% RDN through inorganic fertilizer + 50% RDN through vermicompost + *Azotobacter* (T9) and 75% RDN through inorganic fertilizer + 25% RDN through vermicompost + *Azotobacter* (T8) and 100% RDF + *Azotobacter* (T7), respectively over 100% RDF.

Crop removal without application by fertilizer, manure or biofertilizer in control lead to lower N content in these plots. The increase in N content with the application of *Azotobacter* might be due to improved nitrogen availability in the rhizosphere. The increase with organic manure addition may also be attributed to higher microbial activity in the integrated nutrient management treatments which favored the conversion of the organically bound nitrogen into inorganic form. Organic sources when applied with inorganic sources increased N availability as when organic sources are added to soil, fertilizer use efficiency is increased. Moreover, nitrogenous compounds are slowly broken down and its availability in the form of nitrate N supply remains throughout crop growth. Therefore, organic manures increased the available nitrogen content in soil. The results are also in authentication with the conclusions of Thingujam *et al*. (2016), Manasa (2018) and Raut *et al*. (2019).

Available phosphorus

A glance of data presented in table 4 on the effect of integrated nutrient management on available phosphorus clearly revealed that highest available phosphorus (24.63 kg ha^{-1}) was obtained with the application of 100% RDN through vermicompost + *Azotobacter* (T11) whereas lower (15.31 kg ha^{-1}) was observed under control (T1). Sole use of inorganic fertilizers (T2) increased available phosphorus over control (T1) but was inferior when *Azotobacter* was applied along with RDF (T7). Similarly, substitution of 100% RDN through vermicompost + *Azotobacter* (T11) recorded higher available phosphorus over sole use of 100% RDN through vermicompost (T6). Hundred per cent substitution of recommended doses of nitrogen by vermicompost showed significant increase in phosphorus availability compared to sole application of chemical fertilizers. Among the treatments consisting of substitution of recommended doses of nitrogen with vermicompost (T3-T6), treatment T3, T4, T5 and T6 increased the available phosphorus in soil by 26.26, 35.99, 45.66 and 53.95%, respectively over control (15.31 kg ha^{-1}). In case of substitution of RDN

Table 4. Effect of integrated nutrient management on soil pH, EC, organic carbon, nitrogen, phosphorus and potassium after harvest of crop.

Treatment	Soil pH	Electrical conductivity (dS m^{-1})	Organic carbon (g kg^{-1})	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T1	6.77	0.194	4.14	167.25	15.31	162.76
T2	6.82	0.203	4.57	219.52	17.85	182.22
T3	6.83	0.204	4.74	223.70	19.33	196.81
T4	6.84	0.205	4.91	226.84	20.82	207.66
T5	6.85	0.206	5.00	229.97	22.30	220.38
T6	6.86	0.207	5.17	233.11	23.57	232.36
T7	6.82	0.204	4.65	235.20	18.70	186.71
T8	6.83	0.205	4.83	243.56	20.18	199.81
T9	6.84	0.206	5.00	250.88	21.67	210.28
T10	6.85	0.207	5.09	257.15	23.15	223.75
T11	6.86	0.208	5.26	265.51	24.63	235.35
CD at 5%	NS	NS	0.63	36.02	1.87	13.98

with vermicompost and biofertilizer treated plots (T8-T11), maximum available phosphorus (24.63 kg ha^{-1}) was observed when applied with 100% RDN through vermicompost + *Azotobacter* (T11) followed by 25% RDN through inorganic fertilizer + 75% RDN through vermicompost + *Azotobacter* (T10).

The build-up in available phosphorus with the application of 100% RDF might be attributed to direct availability of phosphorus through single super phosphate. In addition to this the increase in available phosphorus content in soil might be due to vermicompost addition which contained 0.41% phosphorus, therefore, its application contributed an appreciable additional amount of phosphorus to the soil. The release of organic acids during the decomposition process of vermicompost could be another reason for increase in phosphorus availability in the soil. Moreover, biofertilizers might have lead to better root development, better transportation of water uptake and deposition of nutrients resulting in increased availability of phosphorus. The results are in testimony with the finding of Lakra *et al*. (2017), Malavade (2019) and Raut *et al*. (2019).

Available potassium

An appraisal of data presented in Table 4 on the effect of integrated nutrient management on available potassium showed that application of 100% RDN through vermicompost + *Azotobacter* (T11) registered maximum values (235.35 kg ha^{-1}) of available potassium whereas least (162.76 kg ha^{-1}) were obtained under control (T1) where no application of chemical fertilizer, organic manure or biofertilizer was done. The data depicted that use of RDF (T2) recorded significantly higher available potassium over control (T1). Among the treatments where RDN was applied either through vermicompost or chemical fertilizer or both and *Azotobacter* was applied additionally (T7-T11), the potassium availability increased to the tune of 14.71, 22.76, 29.20, 37.37 and 44.60% under treatment T7, T8, T9, T10 and T11, respectively over control. However, treatment T10 and T11 were found to be at par with each other. Additional application of *Azotobacter* increased the available potassium over the respective treatments where *Azotobacter* was not applied, however differences were not significant among respective treatments. Further, it was noticed that all the treatment combinations were effective in increasing the potassium availability over initial value except control and highest increase of about 44.60 and 38.85% over control and initial status, respectively was observed under T11 where 100% RDN through vermicompost + *Azotobacter* was applied. The depletion in native potassium pool in control from initial value is due to no addition of fertilizer or manure or biofertilizer. Moreover, organic matter reduces potassium fixation releases potassium from non-exchangeable fraction to the available pool thereby increasing its availability. The reason attributed might be due to the organic and inorganic acids produced during decomposition of vermicompost which might have helped in the release of mineral bound insoluble potassium as well as reduce the potassium fixation. Inorganic fertilizer helps in direct deposition of nutrients to the soil thereby increasing their availability. These results are in line with those of Malavade (2019) and Raut *et al*. (2019) (Table 4).

Available sulfur

A scrutiny of data presented in Table 5 on the effect of integrated nutrient management on availability of sulfur showed that available sulfur in soil ranged from 24.36 to 34.10 kg ha^{-1}. Application of 100% RDN through vermicompost + *Azotobacter* (T11) was found to be statistically superior over all the treatments except T10 (25% RDN through inorganic fertilizer + 75% RDN through vermicompost + *Azotobacter*) and lowest sulfur availability was observed under control (T1). Application of recommended doses of fertilizers alone (T2) enhanced the sulfur availability over control. However, this increase was found to be lesser over the conjoint application of RDF + Azotobacter (T7). On comparing the treatments where recommended doses of nitrogen was substituted with vermicompost but *Azotobacter* was not applied (T3-T6), maximum available sulfur (33.65 kg ha^{-1}) was obtained under treatment T6 followed by T5 and T4. Whereas application of 75% RDN through inorganic fertilizer + 25% RDN through vermicompost (T3) showed minimum (29.23 kg ha^{-1}) sulfur content. However, treatments T5 and T6 were found to be at par with each other. Addition of *Azotobacter* increased the available sulfur when RDN was applied through vermicompost or chemical fertilizer or both. Available sulfur was increased to the tune of 32.32, 27.36, 20.88 and 15.91% with the application of treatment T11 followed by T10, T9 and T8, respectively over initial value (25.77 kg ha^{-1}).

The increase in sulfur content with fertilizers applications may be attributed to addition of sulfur through single super phosphate which lead to direct deposition of sulfur in the soil. Substitution of RDN by vermicompost also increased the availability of sulfur in the soil due to slow release of nutrients through decomposition of vermicompost for longer period. Moreover, the increase in available sulfur with vermicompost incorporation could possibly be attributable to additional sulfur input to the soil. The results are in testimony with the findings of Mujawar (2012) and Chattoo *et al*. (2014).

Exchangeable calcium

Data referred in connection with the effect of integrated nutrient management on exchangeable calcium content in Table 5 marked out that among all the treatments, maximum exchangeable calcium [14.12 c mol (p+) kg^{-1}] in soil was reported with the application of 100% RDN through vermicompost + *Azotobacter* (T11) followed by 100% RDN through vermicompost (T6). Whereas, minimum values [8.18 c mol (p+) kg^{-1}] of exchangeable calcium were obtained under control (T1). Among the treatments where recommended dose of nitrogen was substituted with vermicompost without the addition of *Azotobacter* (T3-T6), lowest exchangeable calcium (10.66 c mol (p+) kg^{-1}) in soil was recorded with the application of 75% RDN through inorganic fertilizer + 25% RDN through vermicompost (T3) whereas maximum (13.93 c mol (p+) kg^{-1}) was observed with the incorporation of 100% RDN through vermicompost (T6). Additional application of *Azotobacter* to the treatments along with RDN applied through chemical fertilizer or vermicompost or both (T7-T11) acquired higher exchangeable calcium over 100% RDF (T2) and the highest increase of 45.12% was achieved under treatment T11 followed by 34.74, 24.67 and 12.54% increase under treatment T10, T9 and T8, respectively. Highest increase of about 72.62 and 63.43% over control and initial status, respectively was observed under T11 where 100% RDN through vermicompost + *Azotobacter* was applied.

Increased calcium availability with the application of chemical fertilizer is attributed to the addition of single super phosphate to the soil as a source of phosphorus which also contains a certain amount of calcium thereby increasing its content in the soil. Also, incorporation of vermicompost lead to release of nutrients gradually during the decomposition and mineralization process which maintains optimal levels over prolonged period of time and increase in calcium availability. Lower calcium content in control might be due to removal of calcium by crop without its addition. The findings are in conformity with those of Salvi *et al*. (2015) and Batabyal *et al*. (2017).

Exchangeable magnesium

Similar to exchangeable calcium different treatments also had significant effect on exchangeable magnesium as it increased with the application of fertilizer or vermicompost or both with or without the *Azotobacter* (Table 5). An inquisition of data indicated that maximum content of exchangeable magnesium [2.87 c mol (p+) kg^{-1}] was observed with the application of 100% RDN through vermicompost + *Azotobacter* (T11) and lowest [2.35 c mol (p+) kg^{-1}] under control (T1) where no inorganic fertilizer, organic manure or biofertilizer application was done. Incorporation of 100% RDN through vermicompost alone (T6) or in combination with *Azotobacter* (T11) showed increase of 9.65 and 10.81%, respectively in exchangeable magnesium content of soil over 100% RDF (T2). While comparing the effect of combined application of recommended doses of nitrogen through inorganic fertilizer and vermicompost along with addition of *Azotobacter* (T8-T11) on exchangeable magnesium, it was found that treatment T8, T9, T10 and T11 increased the magnesium content to the tune of 14.04, 16.60, 19.15 and 22.13%, respectively over the control value (2.35 c mol (p^+) kg^{-1}). *Azotobacter* was found to be beneficial for increasing exchangeable magnesium in all the treatments (T7-T11) as compared to the same treatments where it was not used (T2-T6). However, the exchangeable magnesium content in soil in the treatments where *Azotobacter* was used was at par with the respective treatments where it was not used.

Table 5. Effect of integrated nutrient management on soil sulfur, exchangeable calcium and magnesium and DTPA extractable micronutrients (zinc, copper, iron and manganese) after harvest of crop.

Treatment	Available sulfur (kg ha^{-1})	Exchangeable calcium (c mol (p+) kg^{-1})	Exchangeable magnesium (c mol (p^{+}) kg^{-1})	Zinc (mg kg^{-1})	Copper (mg kg^{-1})	Iron (mg kg^{-1})	Manganese (mg kg^{-1})
T1	24.36	8.18	2.35	0.85	1.04	12.87	13.34
T2	27.82	9.73	2.59	0.92	1.19	14.22	15.05
T3	29.23	10.66	2.65	0.94	1.22	14.43	15.16
T4	30.64	11.77	2.70	0.96	1.25	14.86	15.33
T5	32.24	12.85	2.76	0.98	1.29	15.07	15.52
T6	33.65	13.93	2.84	1.00	1.32	15.35	15.85
T7	28.40	10.02	2.63	0.93	1.21	14.48	15.19
T8	29.87	10.95	2.68	0.95	1.24	14.72	15.46
T9	31.15	12.13	2.74	0.97	1.27	15.14	15.51
T10	32.82	13.11	2.80	0.99	1.30	15.35	15.70
T11	34.10	14.12	2.87	1.01	1.35	15.78	16.02
CD at 5%	2.19	0.67	0.12	0.07	0.15	1.41	1.00

Substitution of RDN by organic manure in combination with reduced rate of RDN by chemical fertilizers showed positive influence on magnesium availability. The increase in exchangeable magnesium with the addition of vermicompost could also be attributed to additional supply of magnesium by vermicompost to the soil. Higher availability in treatments with the application of biofertilizers might attributed to the synergistic effect of biofertilizer with organic manure and chemical fertilizer. These results are in line with those of Batabyal *et al*. (2017) and Dhiman *et al*. (2018).

DTPA extractable zinc

The data with respect to effect of integrated nutrient management on DTPA extractable zinc have been presented in Table 5. DTPA extractable zinc varied from a minimum of 0.85 mg kg^{-1} in control (T1) to a maximum of 1.01 mg kg^{-1} in plots receiving 100% RDN through vermicompost along with *Azotobacter* (T11). Increase in zinc content over initial was observed under all the treatments except control. Application of recommended doses of fertilizers alone (T2) or in combination with *Azotobacter* (T7) increased the DTPA extractable zinc over control however, the increase in T2 was at par with T1. Substitution of recommended doses of nitrogen with vermicompost positively influenced the DTPA extractable zinc. It is apparent from the data that with the increase in the substitution there was increase in the zinc content. Among the treatments where RDN was substituted by vermicompost (T3-T6), treatment T6, T5, T4 and T3 increased the zinc content by 17.65, 15.29, 12.94 and 10.59% , respectively over control. Application of *Azotobacter* showed significant influence on zinc content over control and similar trend was observed among the treatments where RDN was substituted by vermicompost and *Azotobacter* was applied additionally (T8-T11) as compared to the treatments where RDN was substituted by vermicompost but *Azotobacter* was not applied (T3-T6).

Lower content of zinc in control over the initial value is the result of no fertilizer or manure or biofertilizer application in these plots. The application of organic manures has solubilizing effect on plant nutrients and chelating effect on metal ions resulting in their increased availability. The increase in zinc with biofertilizers might be due to its synergistic effect with organic manures in making availability of plant nutrients more readily and by solubilizing the nutrients in the soil in addition to supplying essential plant nutrients present in them. The findings are in conformity with those of Batabyal *et al*. (2017), Malavade (2019) and Raut *et al*. (2019).

DTPA extractable copper

An appraisal of data presented in Table 5 on effect of integrated nutrient management on DTPA extractable copper showed that copper content in soil ranged from 1.04 to 1.35 mg kg^{-1} where maximum value was observed under treatment T11 (100 % RDN through vermicompost + *Azotobacter*), while minimum under T1 (control). Use of 100% RDF in conjunction with *Azotobacter* (T7) increased the copper content in soil over sole application of 100% RDF (T2). Similarly, substitution of 100% RDN through vermicompost in conjunction with *Azotobacter* (T11) had a profound effect on copper content than substitution of 100 % RDN with vermicompost only (T6). Increase in copper content by 16.38, 12.07, 9.48 and 6.90% was observed in treatments T11, T10, T9 and T8, respectively over the initial value. On comparing treatments comprising of substitution of nitrogen by vermicompost without the use of *Azotobacter* (T3-T6), it was observed that the highest copper (1.32 mg kg^{-1}) was recorded under treatment T6 (100% RDN through vermicompost) followed by treatment T5 (25% RDN through inorganic fertilizer + 75% RDN through vermicompost) and T4 (50% RDN through inorganic fertilizer + 50% RDN through vermicompost). Whereas, treatment T3 (75% RDN through inorganic fertilizer + 25% RDN through vermicompost) resulted in lowest copper content (1.22 mg kg^{-1}).

Low copper availability in control as compared to initial soil status might be due to the lower nutrient availability in these plots as no chemical fertilizer, organic manure or biofertilizer application. Synergistic effect of treatment combinations of inorganic, organic and biofertilizers might be attributed due to increase in availability of nutrients to the plant. Organic compounds in the soil solutions are capable of chelating solution Cu^{2+} thereby increasing the concentration of Cu^{2+} in soil solution (Raut 2017). Moreover, slow and steady release of nutrients into the soil system for a longer period of time by organic manure decomposition results in increased availability of macro and micro nutrients in the soil. These results are in accordance with those obtained by Batabyal *et al*. (2017), Raut (2017), Malavade (2019) and Raut *et al.* (2019).

DTPA extractable iron

An examination of data presented in Table 5 on the effect of integrated nutrient management on DTPA extractable iron depicted that the iron content in the soil varied from 12.87 to 15.78 mg kg^{-1} and the highest iron content was registered with the application of 100% RDN through vermicompost + *Azotobacter* (T11) and lowest from control (T1). The treatments receiving 100% RDF (T2) showed increased iron content over control, however it was found to be inferior over the application of 100% RDF along with *Azotobacter* (T7). Substitution of RDN by vermicompost had a positive influence on the DTPA extractable iron content and increase to the tune of 13.62, 11.55, 9.99 and 6.81% was obtained with the application of treatment T6, T5, T4 and T3, respectively over the initial value (13.51 mg kg^{-1}). *Azotobacter* showed positive influence on DTPA extractable iron content. Among the treatments with the application of *Azotobacter* (T7- T11), the highest iron content (15.78 mg kg^{-1}) was obtained from treatment T11 followed by treatment T10. Further examination of the data revealed that iron content was higher in plots where *Azotobacter* was applied (T7-T11) in comparison to respective treatments where *Azotobacter* was not applied (T2-T6). In comparison to the initial iron status of soil, all the treatments showed an increment in iron content except control which marked a decline.

Addition of vermicompost resulted in higher iron availability may be due to the fact that nutrients are released gradually during the decomposition and mineralization process which maintains optimal soil levels over prolonged periods of time. Some of the organic substances released during the mineralization may act as chelates that help in the absorption of iron and other micro-nutrients. Lower availability in control treatment is attributed to poor nutritional status of these plots. The results are also in authentication with the conclusion of Batabyal *et al.* (2017), Raut (2017), Malavade (2019) and Raut *et al*. (2019).

DTPA extractable manganese

The perusal of data presented in Table 5 on the effect of integrated nutrient management on DTPA extractable manganese in soil revealed the significant effect of different treatments on manganese content in soil over control. The highest manganese content (16.02 mg kg^{-1}) was obtained in treatment T11 (100 % RDN through vermicompost + *Azotobacter*) while lowest

(13.34 mg kg^{-1}) was observed under treatment T1 (control). Application of 100% RDF (T2) showed higher manganese content over control, however it was found to be inferior over the use of 100% RDF with *Azotobacter* (T7). On comparing treatments comprising use of *Azotobacter* along with recommended doses of nitrogen applied through vermicompost and chemical fertilizers (T7 to T11), treatment T11, T10, T9 and T8 increased the manganese content by 20.09, 17.69, 16.27 and 15.89% , respectively over control. Among the treatments where addition of RDN by vermicompost was done without the application of biofertilizer (T3-T6), application of 100% of RDN through vermicompost (T6) showed higher manganese content whereas lowest was obtained with the application of 75% RDN through inorganic fertilizer + 25% RDN through vermicompost (T3). Increase in manganese content over initial status was observed under all the treatment except control.

The increased manganese content due to applications of inorganic, organic and biofertilizers over control might be attributed to the synergistic effect of these combinations which improved the physical conditions of the soil and sustained availability of nutrients. Organic manure also supplied macro and micro nutrients along with organic acids that improved the nutrient availability in the soil. This might be the reason for the increase in manganese content with the increase in rate of substituted dose of RDN by vermicompost. Low manganese content in control might be attributed to no fertilizer or manure or biofertilizer application in these plots. The results are in testimony with the findings of Batabyal *et al.* (2017), Raut (2017), Malavade (2019) and Raut *et al*. (2019) (Table 5).

CONCLUSION

The use of chemical fertilizer or organic manure or both with or without the inclusion of *Azotobacter* improved the soil properties after the harvest of brinjal crop. Soil pH ranged from 6.77 to 6.86 and electrical conductivity varied from 0.194 dS m^{-1} to 0.208 dS m^{-1}. However, they were not significantly influenced by the application of chemical fertilizer or organic manure or biofertilizer. Substitution of RDN with vermicompost with or without the addition of *Azotobacter* improved the soil properties *viz*., organic carbon, available nitrogen, phosphorus, potassium, sulfur, exchangeable calcium and magnesium, DTPA extractable zinc, copper, iron and manganese over the initial value. Therefore, application of 100% RDN through vermicompost + *Azotobacter* could be an appropriate integrated nutrient supply package for brinjal for improving the soil health.

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