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Research Paper

Comparative assessment of organic, inorganic and integrated management practices in rice (*Oryza sativa*)-based cropping system in acid soil of Assam

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ABSTRACT

A field experiment was conducted from 2008-09 to 2014-15 under All India Coordinated Research Project on Integrated Farming System at Assam Agricultural University, Jorhat, Assam, to evaluate the effect of organic (alone), inorganic (alone) and integrated nutrient management on soil properties and productivity of rainfed winter rice (*Oryza sativa* L.)–*toria [Brassica rapa* subsp. *Dichotoma (Roxb.) Honalt]*–blackgram [*Vigna mungo* (L.) Hepper] system. The highest rice-equivalent yield (8.91 t/ha) was recorded with the application of 100% NPK through organic sources plus intercropping with wheat (*Triticum aestivum* L.) during the winter (*rabi*) season and okra [*Abelmoschus esculentus (*L.) Moench] during the summer. Application of 100% recommended dose of fertilizer (RDF) through FYM, vermicompost and mustard seed-cake in the rice during the rainy (*kharif*) season, followed by *toria* + wheat during *rabi* and blackgram + okra during the summer season resulted in the maximum average uptake of N, P and K (95.5, 20.1 and 84.9 kg/ha respectively). Bacteria, fungi and Actinomycetes counts as well as microbial biomass carbon in soil were the highest (253×10^4, 137×10^4, 195×10^4 and 163.95 μg/g respectively) in the organic management having 100% supply of nutrients through $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ mustard seed cake (MSC) along with 3.5 kg/ha each of *Azospirillum/Azotobacter* and phosphate-solubilizing bacteria. The highest dehydrogenase, phosphatase and urease activity in soil was also observed in the same treatment. Full dose of NPK through organic sources to rice–toria–blackgram sequence intercropping with wheat during the winter (*rabi*) and okra during the summer registered the highest earthworm count (25 numbers per m^3).

Key words : Enzymatic activity, Microbial and earthworm count, Nutrient availability, SMBC, Soil productivity, System-equivalent yield

Rice is a primary food source for more than one-third of world's population (Prasad *et al.,* 2010). India has the largest area under rice cultivation (44.3 million ha), accounting for 29.40% of the global rice area (Baishya *et al.,* 2015a). Rice cultivation depends to a large extent on improvements in soil properties, where mineral nutrition is by and large one of the most important factor. But, the application of all the needed nutrients through sole chemical fertilizers had deleterious effect on fertility and productivity status of soil (Jat *et al.,* 2006), and declining trend in productivity due to continuous use of chemical fertilizers alone have been observed in several long-term experiments all over India (Nambiar, 1994). However, conjunctive use of the organic and inorganic sources of nutrients helps in sustaining productivity and biological health of soil in one way and meet a part of chemical fertilizer requirements of crops in other (Gogoi, 2011).

On the other hand, organic farming is gaining importance in present day context. To the maximum extent feasible, organic farming system relies upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks and aspects of biological pest control to maintain soil productivity and to supply plants nutrients and to control insects, weed and pests (Ghosh *et al.,* 2007). Use of biofertilizers in cropping sequence not only fixes the biological nitrogen but also solubilizes the in-

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soluble phosphates in soil and improves fertilizer-use efficiency (Gogoi, 2011).

Assam has tremendous scope of organic farming because of meagre use of inorganic fertilizers and chemical pesticides. The chemical fertilizer consumption in the state is about 74.58 kg/ha against the national average of 129 kg/ha as of 2010–11. The pesticide consumption in the same period is 38 g *ai/*ha against national average of 381 g (Economic Survey of Assam, 2011–12). There is abundance of biowaste from the nature for recycling as organic and natural farming (Directorate of Agriculture, 2010). In Assam, manures obtained from livestock are not used as fuel rather most of the quantity available are applied in soil for farming thereby increasing potentiality of the state towards organic agriculture (Baishya *et al.,* 2007). With the advantage of considerable area under rice-fallow system and retreating monsoon, some oilseeds and pulse crops fits into the system and is preferred by the farming community of Assam (Gogoi *et al.,* 2010a). Thus, organic farming of winter rice–*toria*–pulse cropping system is expected to be promising for north-east region of India.

Hence, to develop an organic management package, an investigation was carried out to make a comparative assessment of organic, inorganic and integrated use of different sources of nutrients on winter rice–toria–blackgram system under acid Inceptisols in rainfed situation of Assam.

MATERIALS AND METHODS

The experiment was laid out during 2008–09 under All India Coordinated Research Project on Integrated Farming System at Jorhat, (26°48'N, 95°50'E, altitude 86.6 m above mean sea-level) of the Assam Agricultural University (AAU), Asom. Up to 2003–04 only winter rice was grown with 40, 20, 20 N:P:K kg/ha fertilizer level in the field and during 2004–05, maize crop was cultivated without any fertilizer. Then up to conversion period (from 2005–06 to 2007–08) with the same 7 numbers of treatment combinations, i.e. organic (alone), inorganic (alone), and integrated sources of nutrients (Table 1), winter rice–potato–okra sequence were followed. During conversion period, long-duration (155 days), high-value winter rice variety (‘Keteki Joha’) followed by ‘Kufri Megha’ (potato variety) was used, but because of that, third crop okra performance was not satisfactory. Hence from 2008–09, medium-duration (130–135 days), high-value winter rice variety ‘Rajendra Suwasini’ was used and also changed the other 2 crops. The important characteristics of the soil were: sandy loam texture (coarse sand 6.68%, fine sand 61.43%, silt 15.23% and clay 15.50%), bulk density 1.24 Mg/m^3 maximum water-holding capacity 47.15%, field capacity 29.36%, permanent wilting point 7.60%, mean weight diameter 1.81 mm, water-stable aggregates 81.21%, *p*H 5.05, organic carbon 0.66%, available N 261.00 kg/ha, available P 6.20 kg/ha, available K 42.40 kg/ha, DTPA-extractable Fe 130.75 ppm, DTPA-extractable Mn 3.68 ppm, DTPA-extractable Zn 0.98 ppm, DTPA-extractable Cu 0.96 ppm and soil microbial biomass carbon 112.80 mg/kg. The 7 treatments, viz. T_1, 50% RDF (inorganic) + 50% RDN (organic) as FYM + inorganic sources of micro-nutrient as per soil test + pumello fruit, *Citrus grandis* Merr. (Bio-pesticide); T_2, 100% RDF (organic) as $^1/_3$ FYM/compost + $^1/_3$ vermicompost + $^1/_3$ mustard seed-cake (MSC) + pumello fruit (Bio-pesticide); T_3, T_2 + wheat and okra as intercrop during *rabi* and summer season respectively; T_4, T_2+ manual and mechanical weeding + pumello fruit (Bio-pesticide); T_5, 50% RDN (organic) as FYM/ compost + *Azospirillum*/*Azotobacter* in rice/*toria* and blackgram + 50% P as rockphosphate + phosphorus-solubilizing bacteria (PSB) + Pumello fruit (Bio-pesticide). (*Azospirillum* was used in rice and *Azotobacter* was used in *toria* and blackgram); T_6, T_2 + *Azospirillum/Azotobacter* + PSB + pumello fruit (Bio-pesticide); and T_7, 100% RDF (inorganic) + secondary and micronutrient based on soil test + pumello fruit (Bio-pesticide) system; (micronutrient and secondary nutrients are applied only in winter rice). The treatments were tested with an individual plot size of 30 m × 10 m. The recommended levels (100%) of N–P–K (kg/ha) were 80–40–40 for rice, 60–40–40 for *toria*, 80–64–42 for wheat, 50–50–50 for okra and 10–35–10 for blackgram. Seeds of blackgram were treated with *Rhizobium* for all the treatments. The cultivar used for different crops in the sequence were: ‘Suwasini’ for rice, ‘TS 38’ for *toria*, ‘PU 31’ for blackgram, ‘Parhbhani Kranti’ for okra and ‘HUW 234’ for wheat.

Nutrient content of different organic sources, viz. compost (50% moisture, 0.9% N, 0.3% P and 0.8% K), mustard seed-cake (9.6% moisture, 4.5% N, 1.5% P and 1% K) and vermicompost (20% moisture, 1.5% N, 1.2% P and 1.2% K) and their requirements were calculated as per different treatments. Biofertilizers i.e. *Azotobacter*, *Azospirillum* and phosphate-solubilizing bactria (PSB), were applied to the T_5 and T_6 treatments @ 3.50 kg/ha. Before sowing, blackgram seed was treated with *Rhizobium* @ 45 g/kg seed. The N, P and K nutrients applied through chemical fertilizers were in the form of urea, single superphosphate and muriate of potash. On the basis of soil-test value, sulphur @ 25 kg/ha, borax @ 5 kg/ha, copper sulphate @ 20 kg/ha and manganese sulphate @ 20 kg/ha were applied to the T_1 and T_7 treatments**.**

Pumello fruit (*Citrus grandis* Merr.) (after making pieces) was applied @ 30 kg/ha, as it prevents the crop from the insect-pests. Pest-controlling capacity of pumello fruit may be attributed to the presence of essential oil in particular and other secondary metabolites in abundance. Before using pumello fruit, a biopesticide '*Kamdhenu*' was used @ 1: 250 litre water, which is a mixture of cow urine and neem leaf extract developed by Gaushala, Guwahati, Assam [maintaining microbial *cfu* (10^5) *Trichoderma* 8, *Azotobacter* 204 and P solubulizer 267] applied to winter rice crop in all the treatments.

Soil samples were collected from effective root zone depth (0–30 cm) after the sequence from each plot, air dried and, processed. Soil and plant samples were analysed for physico-chemical and biological properties of soil using the standard procedures (Jackson, 1973; Baruah and Borthakur, 1997).

All data were subjected to the analysis of variance (ANOVA) appropriate to the design using the windows-based statistical package for the social science (SPSS, 2001).

RESULTS AND DISCUSSION

Yield

Season-wise yield of crops at different phases of crop cycles (such as at initial level, mean yield up to conversion period and after conversion period) as affected by different organic, inorganic and integrated nutrient management practices in case of winter rice–toria–blackgram system under climatic condition of Asom (Table 1) indicated that during the initial year, yield of *kharif, rabi* and summer crops were higher with application of 100% recommended dose of nutrients through chemical fertilizers + secondary and micro-nutrient, followed by application of 50% RDF (inorganic) + 50% RDN (organic) as FYM/compost + inorganic sources of micro-nutrient as per soil test. On the other hand, mean yield up to conversion period (1st to 3rd crop cycle) was found to be the highest in treatment receiving both organic and inorganic sources of nutrients. After conversion period, the highest yield of rainy (*kharif*) crop was recorded in 100% NPK doses through organic sources plus intercropping with wheat during *rabi* and okra during the summer season, and the highest yield of winter (*rabi*) and summer were recorded in 100% RDF from organic sources as $^1/_3$ FYM/compost + $^1/_3$ vermicompost + $^1/_3$ MSC + pumello fruit as bio-pesticide.

System-equivalent yield (SEY) calculated at initial level, mean SEY up to conversion period and mean SEY after conversion period of winter rice–toria–blackgram system (Table 1) indicated that initially, the highest (11.19 t/ha) SEY was recorded in 100% RDF as inorganic source + secondary and micronutrient based on soil test, followed by 50% RDF as inorganic

Table 1. Effect of management practices on crop yield (t/ha) and economics of rice–*toria*–blackgram system on different phases

Treatment	Initial yield level of winter rice–potato–okra sequence				Mean yield of winter rice–potato–okra sequence up to conversion period (from 2005–06 to 2007–08)				Mean yield of winter rice–*toria*–blackgram after conversion period (from 2008–09 to 2014–15)				Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
	Rainy season	Winter season	Summer	REY	Rainy season	Winter season	Summer	REY	Rainy season	Winter season	Summer	REY			
T_1	3.28	9.50	1.02	10.96	3.10	6.18	1.52	8.92	3.10	0.51	0.50	6.36	109.5	63.0	1.58
T_2	2.60	7.76	0.87	6.19	2.65	5.91	1.19	7.22	3.27	0.52	0.55	7.51	96.4	27.0	1.80
T_3 (MC)*	2.76	4.00	0.58	7.26	2.66	4.18	0.93	7.80	3.48	0.44	0.41	8.91	159.9	80.6	2.09
T_3 (IC)**	-	3.00	0.30		-	4.00	0.28		-	1.20	2.58				
T_4	2.82	8.20	0.93	7.33	2.66	5.69	1.09	6.69	3.21	0.5	0.49	6.30	104.2	35.5	2.31
T_5	2.16	7.43	0.69	5.54	2.63	4.20	1.03	5.61	2.84	0.39	0.44	5.43	90.3	57.5	2.45
T_6	2.84	6.80	0.74	5.98	2.72	4.12	1.20	5.44	3.41	0.38	0.4	5.85	101.0	29.0	1.46
T_7	3.56	10.08	1.10	11.19	2.57	6.05	1.49	6.86	2.96	0.42	0.48	5.77	109.5	57.0	1.26
SEm±	–	–	–	–	0.23	0.30	0.11	0.45	0.20	0.03	0.02	0.42	–	–	–
CD (P=0.05)	–	–	–	–	0.72	0.87	0.33	1.03	0.70	0.07	0.06	1.00	–	–	–

*Main crop, **Intercrop, REY: rice-equivalent yield

T_1, 50% RDF (inorganic) + 50% RDN (organic) as FYM/compost + inorganic sources of micro-nutrient as per soil-test value; T_2, 100% RDF (organic) as $^1/_3$ FYM/compost + $^1/_3$ vermicompost + $^1/_3$ MSC; T_3, T_2 + wheat and okra as intercrop during winter and summer season respectively; T_4, T_2+ manual and mechanical weeding; T_5, 50% RDN (organic) as FYM/compost + *Azospirillum/Azotobacter* + 50% P as rock-phosphate + PSB; T_6, T_2+ *Azospirillum/Azotobacter* + PSB + pumello fruit (Bio-pesticide); and T_7, 100% RDF (inorganic) + secondary and micronutrient based on soil test value source + 50% RDN as organic + inorganic sources of micro-nutrient as per soil test value + pumello fruit. Mean SEY up to conversion period was the highest at 50% RDF as inorganic source + 50% RDN as organic + inorganic sources of micro-nutrient as per soil-test value + pumello fruit followed by 100% RDF (inorganic) + secondary and micronutrient based on soil test value + pumello fruit (bio-pesticide). However, mean SEY after conversion period was found to be the highest (8.91 t/ha) in treatment receiving 100% recommended doses of NPK through organic sources of nutrients. Rice was grown alone during the *kharif* season followed by intercropping with wheat + *toria* and okra + blackgram during the winter (*rabi*) and summer season respectively.

The gross returns, net returns and benefit: cost ratio of the winter rice–toria–blackgram system revealed the highest gross returns and net return in the winter rice–toria–black gram sequence (₹59,900/ha and ₹80,608/ha respectively) and benefit: cost ratio of 2.1 with the organic nutrient-management to substitute 100% NPK doses through $^1/_3$ FYM/compost + $^1/_3$ vermicompost + $^1/_3$ MSC plus intercropping with wheat during the winter (*rabi*) and okra during the summer season. However, benefit: cost ratio was found to be the highest (2.45) in 50% RDN (organic) as FYM/compost + *Azospirillum/Azotobacter* + 50% P as rock-phosphate + phosphate-solubilizing bacteria, as in this treatment costs of fertilizers were at minimum.

Soil properties

Significant changes were recorded in different properties of soil under organic, inorganic and integrated management practices (Table 2). Decreasing trends in bulk density of soil were recorded from the initial value in all the treatments. The lowest soil bulk density was recorded in treatment receiving 100% NPK through organic sources of nutrients. Soil aggregate sizes were varied between 0.68 and 0.81 mm. The highest increase (19.12%) in aggregate size of soil was recorded in treatment receiving 100% NPK through organics ($^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC) plus *Azospirillum/Azotobacter* + PSB application, whereas the lowest in case of 100% RDF as inorganic source + secondary and micronutrient application based on soil-test value. Infiltration rate of water was found to be highest in 100% NPK doses through organic sources plus intercropping with wheat during the winter (*rabi*) and okra during the summer season, followed by 100% NPK supplied as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC and T_2+ manual and mechanical weeding.

Water holding capacity of soil was increased over initial value (47.2%) in all the treatments under study except 50% RDN (organic) as FYM + *Azospirillum/Azotobacter* + 50% P as rock-phosphate + PSB treatment. The Highest increase (27.3%) in water holding capacity of soil over initial was observed when 100% recommended dose of NPK was supplied through organics as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC along with *Azospirillum/Azotobacter* + PSB application. This was followed by the treatment receiving 100% NPK as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC plus intercropping with wheat during the winter and okra during the summer season. Increase in water holding capacity might be owing to addition of organics that has favourable influence on better aggregation of soil

Table 2. Post harvest soil properties under various management packages in rice–*toria*–blackgram systems (data given are mean-value of 7 years from 2008–09 to 2014–15)

Treatment	Bulk density (Mg/m^3)	Aggregate size (mm)	Infiltration rate (mm/hr)	Water holding capacity (%)	*p*H	Electrical conductivity (dS/m)	Soil organic carbon(%)
T_1	1.22	0.74	5.5	53.01	5.15	0.173	0.71
T_2	1.19	0.78	6.2	57.28	5.30	0.180	0.76
T_3	1.19	0.80	6.3	58.98	5.29	0.194	0.88
T_4	1.21	0.79	6.2	57.20	5.26	0.146	0.76
T_5	1.23	0.72	5.6	46.00	5.29	0.079	0.76
T_6	1.21	0.81	5.8	60.00	5.24	0.140	0.79
T_7	1.23	0.68	4.9	49.98	5.03	0.292	0.70
Initial value	1.21	-	-	47.15	5.05	-	0.66
SEm±	0.01	0.003	0.02	0.65	0.01	0.003	0.08
CD (P=0.05)	0.027	0.009	0.05	1.36	0.03	0.008	0.18

T_1, 50% RDF (inorganic) + 50% RDN (organic) as FYM/compost + inorganic sources of micro-nutrient as per soil-test value; T_2, 100% RDF (organic) as $^1/_3$ FYM/compost + $^1/_3$ vermicompost + $^1/_3$ MSC; T_3, T_2 + wheat and okra as intercrop during winter and summer season respectively; T_4, T_2+ manual and mechanical weeding; T_5, 50% RDN (organic) as FYM/compost + *Azospirillum/Azotobacter* + 50% P as rock-phosphate + PSB; T_6, T_2+ *Azospirillum/Azotobacter* + PSB + pumello fruit (Bio-pesticide); and T_7, 100% RDF (inorganic) + secondary and micronutrient based on soil test value particles. Selvi *et al.* (2005) and Gogoi *et al.* (2015) also reported similar improvement in physical properties owing to increase in organic matter content of soil, improvement in overall soil structural condition and beneficial effect of certain polysaccharides formed during decomposition of organic residues by microbial activity in soil.

Soil chemical properties

Changes in soil *p*H and electrical conductivity (EC) during 2008–09 to 2014–15 as affected by different organic (alone), inorganic (alone) and integrated use of nutrient sources in case of winter rice-toria-blackgram system in acid soils of Asom (Table 2) indicates that soil *p*H was the highest (5.30) when 100% NPK were supplied as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC, whereas the lowest (5.03) was recorded in 100% recommended dose of nutrients through chemical fertilizers. Increase in *p*H with integrated treatments may be defined as the deactivation of Al^{3+} and concomitant release of basic cations due to addition of organic matter under long-term condition (Gogoi *et al.*, 2015). Data on EC in soil as affected by different treatments under study varied between 0.079 and 0.292 dS/m. Soil EC was highest when all the recommended doses of NPK were supplied solely through chemical fertilizers.

Significant increase in soil organic carbon (SOC) over initial status of soil was observed and it varied from 0.70 to 0.88%. The highest increase (33.33%) in organic carbon over initial value was recorded when full amount of recommended NPK was supplied through organic sources (as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC) and intercropping was done with wheat and okra, respectively, during the winter and summer season. Increase in SOC might be owing to use of organic sources of nutrients for supplying the full doses of NPK requirement by the crops. The effect was further enhanced resulting in higher root and shoot growth and thus increased production of biomass might have raised the organic carbon content in soil (Banswasi and Bajpai, 2006; Gogoi *et al.*, 2015).

Nutrients status of soil

Post-harvest macro- and micro-nutrients in acid soil of Assam as affected by different management practices under rainfed condition with winter rice–*toria*–blackgram system (during 2008–09 and 2014–15) (Table 3) indicates there was an increase in primary nutrient status in soil in case of all the treatments compared to initial. Post-harvest N availability in soil was found to be highest in 100% recommended dose of NPK through FYM + vermicompost + MSC in winter rice (*kharif*)–*toria* + wheat (*rabi*)–blackgram + okra (summer) system. On the other hand, lowest available N was recorded in 50% RDN (organic) as FYM + *Azospirillum/Azotobacter* + 50% P as rock-phosphate + PSB. Due to effect of different sources of nutrients, phosphorus availability in soil varied from 8.15 to 9.48 kg/ha. Application of 50% RDN (as FYM) + 50% P as rock-phosphate + PSB + *Azospirillum/Azotobacter* (@ 3.5 kg/ha each) resulted in the highest availability of phosphorus in soil. This was followed by 100% NPK through organics ($^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC) plus *Azospirillum/Azotobacter* + PSB application. Application of entire recommended doses of NPK, using organic sources along with *Azospirillum/Azotobacter* + PSB (@ 3.5 kg/ha each) showed the highest K availability in soil after the end of the winter rice–*toria*–blackgram system. Sulphur (S) availability in soil due to sole and integrated use of organic and inorganic sources of nutrients varied significantly and ranged between 5.26 and 6.19 kg/ha. The maximum increase in soil-available S over other treatment combinations was recorded with application of FYM + vermicompost + MSK for supplying equally full recommended doses of NPK intercropping with wheat and okra, respectively during the winter and summer season.

Availability of DTPA-Fe, Mn, Zn, Cu and B varied from 8.30 to 10.80, 2.70 to 3.58, 1.00 to 1.24, 0.98 to 1.24 and 0.19 to 0.33 ppm respectively. Availability of Fe, Mn and Zn in soil after winter rice–*toria*–blackgram system were found to be maximum where intercropping was done with wheat and okra (respectively during *rabi* and summer season) and 100% of recommended dose of NPK were supplied only through organic sources of nutrients. However, Cu and B availability was the highest when application of full NPK doses was made through organic sources (as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC) plus manual and mechanical weeding. Such increase in DTPA micronutrients might be due to beneficial effects of organics, which helps in supplying micronutrients in readily available form (Gogoi *et al.*, 2010[b]). Kumar *et al.* (2008) also found increased available contents of Fe, Mn, Zn and Cu in soil with the application of organics as compared with 100% NPK in rice–wheat cropping system.

Increase in available N, P and K in soil after winter rice–toria–blackgram system as affected by organic (alone), inorganic (alone) and integrated use of organic and inorganic sources of nutrients; highest increases of 19.41% and 116.46% in soil-available N and K were recorded where entire recommended doses of NPK were applied through organic sources along with *Azospirillum/ Azotobacter* + PSB (@ 3.5 kg/ha each) (Fig.1). However, P availability was the highest (52.90%) in treatment receiving only half of recommended dose of N and P through organic (i.e. through FYM and rock-phosphate respectively) along with *Azospirillum/Azotobacter* + phosphate-solubilizing bacteria (@ 3.5 kg/ha each). Use of rock-phosphate along with PSB might be the possible rea-

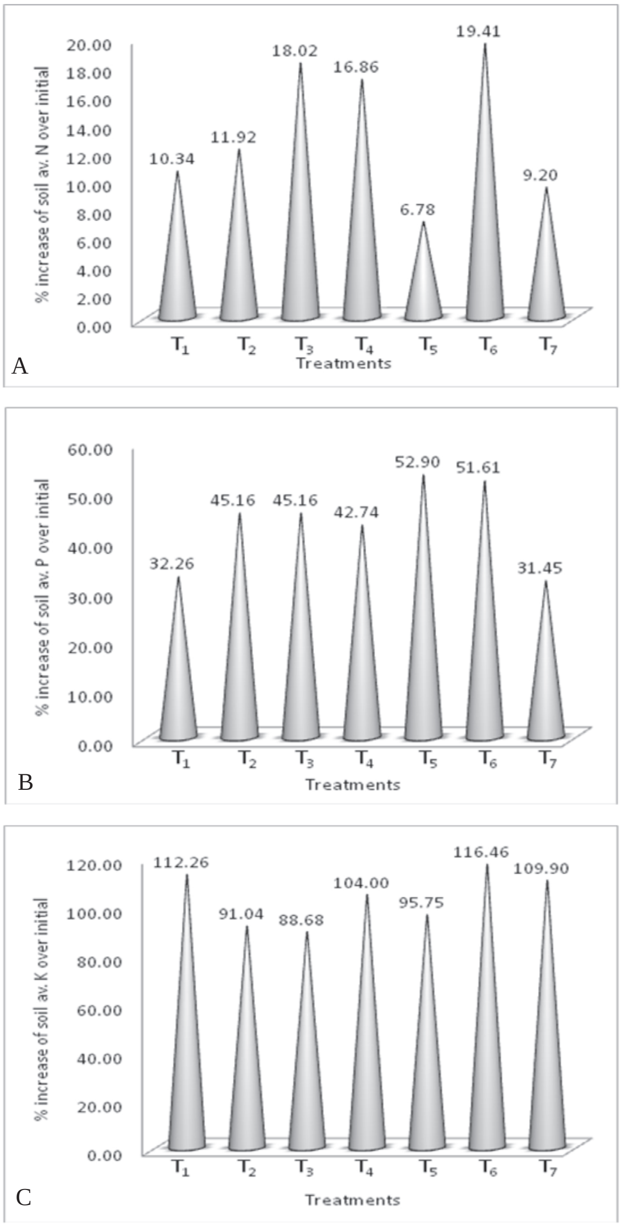

Fig. 1. Average (%) increase in available N, P and K (respectively in A, B and C) in acid soils under various nutrient management practices in rice–*toria*–blackgram system

son of increase in availability of P in soil.

Soil microbial count

Bacteria, fungi and *Actinomycetes* counts varied from 113×10^4 to 253×10^4, 58×10^4 to 137×10^4 and 88×10^4 to 195×10^4 respectively (Table 3). Application of 100% NPK nutrients in the form of organic sources ($^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC) along with *Azospirillum/Azotobacter* and phosphate-solubilizing bacteria (@ 3.5 kg/ha each) resulted in the highest bacteria and *Actinomycetes* counts in soil as compared to other treatments. However, fungi population in soil was found to be more in the treatments receiving 100% recommended dose of NPK through FYM + vermicompost + MSC under winter rice (*kharif*)–*toria* (*rabi*)– blackgram (summer) system as compared to integrated use of organic and inorganic sources of nutrients and sole inorganic sources of nutrient treatments. Application of full doses of nutrients solely through chemical fertilizers showed the lowest microbial count in soil. The microbial count was increased with the amount of applied organics. The most important factor which differentiated the microbial communities in different treatments is the amount of C inputs because C was often a limiting factor for soil microbial communities. As a consequence, organic inputs generally enhanced the development of microflora and increase the global activity of soil (Nath *et al.,* 2012).

Soil enzymatic activities

The activities of all the enzymes varied significantly in the different treatments of organic and inorganic alone and integrated application of both organic and inorganic sources of nutrients (Fig. 2). The pattern of variation of all the enzyme activities in the soil due to different treatment combinations was similar.

The dehydrogenase, phosphatase and urease activity in soil varied from 418.122 to 687.76 µg TTF/g soil/24 h, 149.36 to 243.12 ppm PNP/g soil/h and 2.21 to 4.38 ppm NH_4-N/g soil/2 h respectively. The activities of all enzymes were generally higher in the organic treatment receiving application of full doses of NPK nutrients as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC (mustard seed-cake) along with *Azospirillum/Azotobacter* and phosphate solubilizing bacteria (@ 3.5 kg/ha each). Application of 100% RDF through FYM, vermicompost and MSC in the sequence that includes rice alone during the rainy season followed by *toria* + wheat during the winter season and blackgram + okra during the summer season showed the second highest activities of all the soil enzymes under study. Use of inorganic chemical fertilizers solely showed the lowest dehydrogenase and phosphatase activities in acid soils of Assam as compared to integrated and sole organic treatments under study. However, urease activity was the lowest in only half of recommended dose of N and P through organic (i.e. through FYM and rock-phosphate respectively) along with *Azospirillum* + PSB (@ 3.5 kg/ha each).

Higher dehydrogenase activity in organic plot may be owing to higher organic matter content (Wlodarczyk *et al.,* 2002). The effect of organic sources of nutrients on enzyme activities is probably a combined effect of a higher degree of stabilization of enzymes to humic substances and an increase in microbial biomass with increased soil

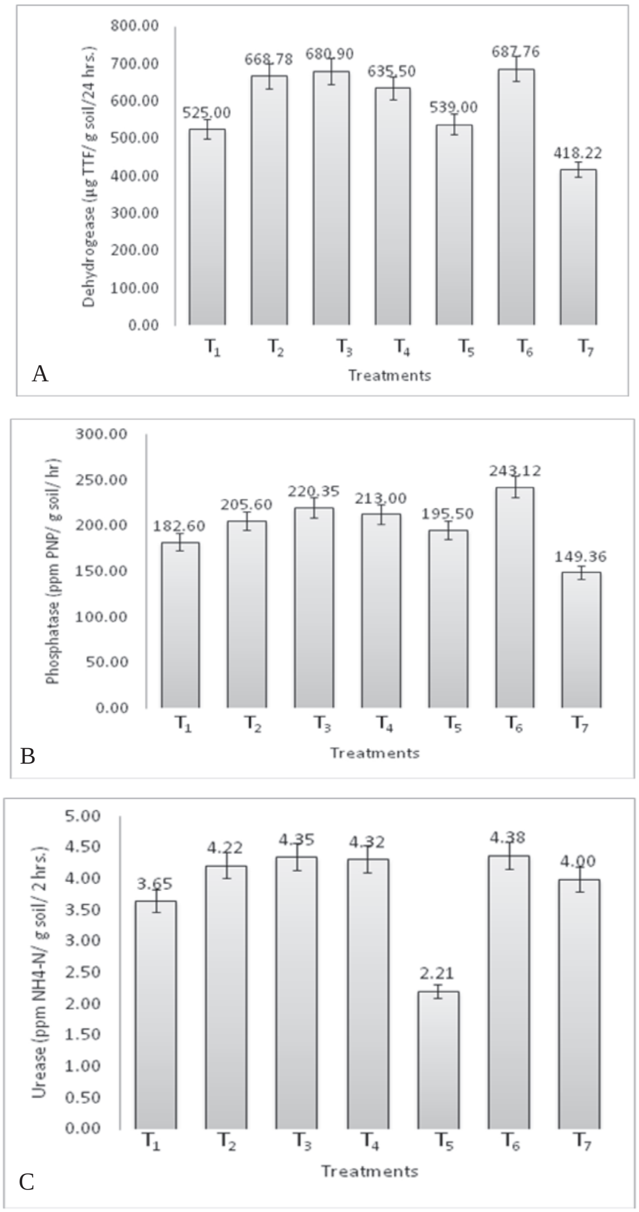

Fig. 2. Effect of organic (alone), inorganic (alone) and integrated use of organic and organic sources of nutrients on dehydrogenase (A), phosphatase (B) and urease (C) activities in acid soils

carbon concentration (Mohammadi *et al.,* 2012).

Earthworm count

The earthworm population was significantly varied due to the effect of organic (alone), inorganic (alone) and integrated use of organic and inorganic sources in acid soils. The data indicated that earthworm count ranged between 6 and 25 numbers/m^3 (Fig. 3) and it is explicit that the application of nutrients using organic sources increased the earthworm population in soil. The highest earthworm count was recorded with 100% NPK doses of nutrients through organic sources plus intercropping with wheat during the winter and okra during the summer. Supplying all the nutrients solely through chemical fertilizers showed the lowest earthworm count in this study. Increase in earthworm count might be owing to increase in organic matter which acts as a substrate for their activity.

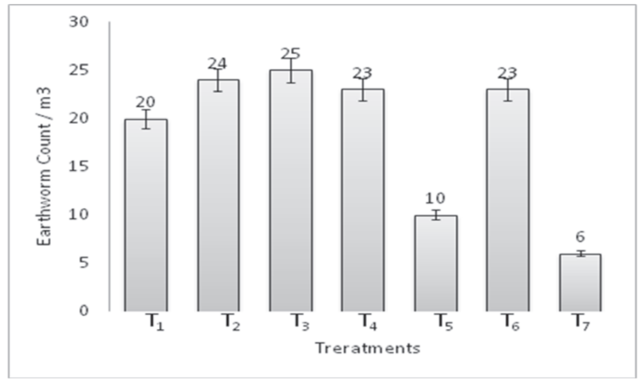

Fig. 3. Earthworm count under various nutrient management practices in rice–*toria*–blackgram system

Soil microbial biomass carbon

The soil microbial biomass carbon (SMBC), an agent of labile nutrients, is critically important for soil quality establishment and is thus one of the most sensitive indicators of the sustainability of a management system. The pattern of SMBC accumulation after 7th crop cycle of winter rice–*toria*–blackgram system illustrated significant differences among the treatments (Fig. 4). The data on SMBC varied from 82.76 to 163.95 µg/g dry soil. There were increases in SMBC over initial (112.80 µg/g dry soil) under all the treatments. Application of full doses of NPK nutrients through organics as $^1/_3$ FYM + $^1/_3$ vermicompost + $^1/_3$ MSC along with *Azospirillum* and phosphate-solubilizing bacteria (@ 3.5 kg/ha each) showed the highest SMBC. This was followed by application of full NPK

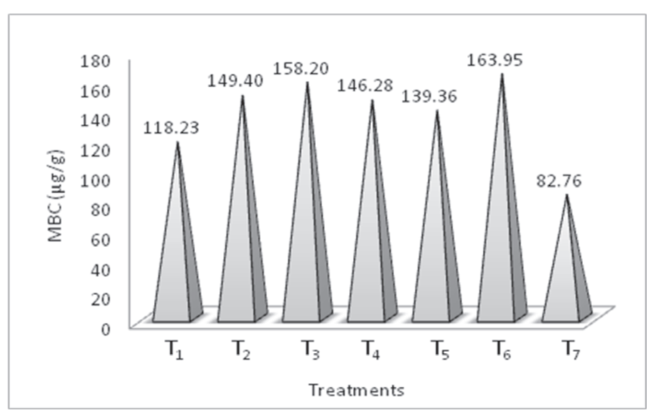

Fig. 4. Effect of organic (alone), inorganic (alone) and integrated use of organic and organic sources of nutrients on microbial biomass carbon (MBC) in acid soils of Assam

Table 3. Nutrient availability and microbial count in soil under various management treatments in rice–*toria*–blackgram systems (data given are mean-value of 7 years from 2008–09 to 2014–15)

Treatment	Available macro-nutrients (kg/ha)				Available micronutrients (ppm)					Microbial count (c.f.u./g soil)		
	N	P	K	S	Fe	Mn	Zn	Cu	B	Bacteria	Fungi	Actinomycetes
T_1	288.0	8.2	90.0	5.80	10.0	3.24	1.23	1.19	0.31	185×10^4	90×10^4	122×10^4
T_2	292.1	9.0	81.0	6.00	10.3	3.44	1.22	1.20	0.22	239×10^4	137×10^4	180×10^4
T_3	308.1	9.0	80.0	6.19	10.8	3.58	1.24	1.22	0.31	244×10^4	137×10^4	185×10^4
T_4	305.0	8.9	86.5	5.90	10.0	3.00	1.24	1.24	0.33	240×10^4	120×10^4	172×10^4
T_5	278.7	9.5	83.0	5.26	7.9	2.70	1.00	0.98	0.19	201×10^4	113×10^4	130×10^4
T_6	311.7	9.4	91.8	6.00	10.0	3.10	1.23	1.19	0.31	253×10^4	122×10^4	195×10^4
T_7	285.0	8.2	89.0	5.98	8.3	3.09	1.24	1.20	0.33	113×10^4	58×10^4	88×10^4
Initial value	261.0	6.2	42.4	-	13.1	3.68	0.98	0.96	-	-	-	-
SEm±	2.30	0.20	2.00	1.60	1.02	0.25	0.04	0.06	0.1	-	-	-
CD (P=0.05)	6.37	0.51	5.40	3.61	2.26	0.78	0.11	0.19	0.3	-	-	-

T_1, 50% RDF (inorganic) + 50% RDN (organic) as FYM/compost + inorganic sources of micro-nutrient as per soil-test value; T_2, 100% RDF (organic) as $^1/_3$ FYM/compost + $^1/_3$ vermicompost + $^1/_3$ MSC; T_3, T_2 + wheat and okra as intercrop during winter and summer season respectively; T_4, T_2+ manual and mechanical weeding; T_5, 50% RDN (organic) as FYM/compost + *Azospirillum/Azotobacter* + 50% P as rock-phosphate + PSB; T_6, T_2+ *Azospirillum/Azotobacter* + PSB + pumello fruit (Bio-pesticide); and T_7, 100% RDF (inorganic) + secondary and micronutrient based on soil test value

doses through organic sources in the sequence that includes rice alone during the rainy *kharif* season followed by *toria* + wheat during the season and black gram + okra during the summer season. Application of biofertilizers, besides showing primary effect is also known to produce diverse growth-promoting substances that might contribute to intense proliferation of the microbial growth. Moreover the rhizode positions (Jones *et al*., 2009) from the 7th crop cycles could also contribute towards the increased MBC in soil. As a consequence, organic inputs generally enhanced the development of microflora and increased the global activity of soil. The lowest SMBC was found in 100% recommended dose of nutrients through chemical fertilizers, which might be due to non-use of organic sources of nutrients leading to lower microbial activities in soil as compared to other treatments under study. The more SMBC under organic treatments might be due to the direct application of carbon input (Ros *et al*., 2003), which were further enhanced through root exudates, root residue of rice–toria–blackgram system and biofertilizers application (Singh and Pathak, 2003).

Overall, from the study, it can be concluded that application of full recommended doses of nutrients through organic sources ($^1/_3$ FYM/ compost + $^1/_3$ vermicompost + $^1/_3$ MSC) and plant protection with biopesticides (pumello fruit) (applied to winter rice) to winter rice (*kharif*)–*toria*+ wheat (winter)–blackgram + okra (summer) sequence increases the soil productivity by improving the physico-chemical and biological properties of acid Inceptisols under rainfed situation of Assam.

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