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Effect of Long-Term Use of Inorganic Fertilizers, Organic Manures and their Combination on Soil Properties and Enzyme Activity in Rice-Rice Cropping System

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A field experiment entitled "Carbon sequestration and soil health under long term soil fertility management in rice-rice cropping system" was carried out under field conditions during *kharif* and *rabi* seasons of 2016-2017 and 2017- 2018 at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district in the ongoing All India Coordinated Research Project on Long Term Fertilizer Experiment Project. The results indicated that at initial, tillering, panicle initiation and at harvest stage, significantly the highest available nitrogen, phosphorus, potassium and micronutrients in soil were recorded with application of 100 % NPK + $ZnSO_4$ +FYM (T_7). The treatments T_9 (50 % NPK + 50 % N through green manures), T_{10} (50 % NPK + 50 % N through FYM) and T_{11} (50 % NPK + 25 % N through FYM + 25 % N through green manures) were on par with each other in all four seasons of study. The highest enzyme activity was observed with application of 100 % NPK + $ZnSO_4$ +FYM (T_7) (both *Kharif* and *Rabi*) which was significantly superior over remaining treatments in (*Kharif*, 2016 and *Rabi*, 2017). The application of zinc did not show any significant effect on enzyme activity.

Introduction

Rice-rice, the main cropping system in the eastern coast of India, requires heavy amount of plant nutrients that results in decline in net returns per unit area (Anonymous, 2001). Soil fertility and productivity in Godavari delta are likely to be affected due to intensive rice monoculture with imbalanced fertilization under excessive use of irrigation water. A declining trend in the productivity of rice even when grown under adequate application of N, P and K was reported by Nambiar and Abrol (1989). Continuous use of high level of chemical fertilizers had lead to soil degradation problems, which also proved detrimental to soil health.

This paper is a part of the first author's Ph.D. (Ag.) thesis entitled "Carbon sequestration and soil health under long term soil fertility management in rice-rice cropping system", submitted to Acharya N.G. Ranga Agricultural University, Lam, Guntur.

Many tropical soils are poor in nutrients and rely on the recycling of nutrients from soil organic matter to improve and maintain crop productivity. Intensive cultivation, growing of exhaustive crops, use of imbalanced and inadequate fertilizers, restricted use of organic manures has made the soils not only deficient in nutrients but also deteriorate soil health resulting decline in crop response to recommended dose of NPK fertilizers. To supply recommended dose of nutrients, large quantities of organic material is needed and also slow release of plant nutrients upon decomposition from organic material deprive crop growth. Under such conditions integrated plant nutrient management assumes greater significance and plays a vital role in maintenance of soil health and sustainable productivity.

Materials and Methods

The experiment was carried out under field conditions during *kharif* and *rabi* seasons of 2016-2017 and 2017- 2018 at Andhra Pradesh Rice Research Institute and Regional Agricultural Research Station, Maruteru, West Godavari district in the ongoing All India Coordinated Research Project on Long Term Fertilizer Experiment Project. The treatments consisted of control, 100 per cent recommended dose of NPK, 100 per cent recommended dose of NK, 100 per cent recommended dose of PK, 100 per cent recommended dose of NP, 100 per cent recommended dose of NPK+$ZnSO_4$ @ 40 kg/ ha, 100 per cent recommended dose of NPK+$ZnSO_4$ @ 40 kg/ ha + FYM @ 5 t ha^{-1}, 50 per cent recommended dose of NPK, 50 % NPK + 50 % N through green manures, 50 % NPK + 50 % N through FYM, 50 % NPK + 25 % N through green manures + 25 % N through FYM and FYM only @ 10 t/ha. All together there were twelve treatments laidout in RBD with three replications for both *kharif* and *rabi* seasons in two years of study. Nitrogen was applied through urea in three equal splits (1/3rd basal+1/3rd at tillering+1/3rd at panicle initiation stage). Phosphorus was applied through DAP was used duly taking its N content into account and potassium as muriate of potash (60 % K_2O) and zinc as zinc sulphate ($ZnSO_4.7H_2O$). The entire dose of phosphorus, potassium and zinc were applied as basal. Recommended dose of fertilizer for *kharif* season was 90: 60: 60 N: P_2O_5: K_2O kg ha^{-1} and for *rabi* season it was 180: 90: 60 N: P_2O_5: K_2O kg ha^{-1}. Well decomposed farmyard manure (FYM) manure and *Calotropis* (green leaf manure) were applied two weeks before transplanting. The experiment on rice – rice sequence as detailed above was repeated on a same site during *kharif* 2016-17 and *rabi* 2017-18, respectively. Popular cultivars of *kharif* rice and *rabi* rice, MTU-1061, MTU-1010 respectively, were used for the study. Data was collected on available nutrients and enzyme activities of both *kharif* and *rabi* rice.

Results and Discussion

Nutrient status of soil

Available nutrient status of soil was significantly influenced by long-term use of different organics, inorganics and their combination during both the years of the study.

Nitrogen

At initial stage, the highest available nitrogen in soil was recorded in treatment T_7 (100 % RDF + $ZnSO_4$ +FYM) and it was significantly superior over all other treatments during *kharif* and *rabi* in two years of study and the lowest available nitrogen was observed in control (T_1). Similar trends were observed at initial stage of *rabi* rice with 279.6, 243.8 kg ha^{-1}, respectively. The available nitrogen values were higher during *rabi* due to residual effect of applied nutrients to *kharif* rice and also due to application of relatively higher doses of inorganic fertilizers to *rabi* rice. Among the inorganic treatments (T_2, T_3, T_4, $T_{5,}$ T_6 and T_8), the treatment T_6 was recorded highest available nitrogen and significantly superior over $T_{4,}$ T_5 and T_8 but however it was on par with T_2, $T_{3.}$ Similar results were obtained in both the years of study during *kharif* and *rabi* season at initial stage. These results were in close conformity with the findings of Kumar and Singh (2010).

The organic treatments, T_9, T_{10} and T_{11} were on par with each other. The results were in consonance with the findings of Malewer and Hasnabade (1995) who reported significant increase in available nitrogen with application of organics and inorganics and sustained the productivity. The minimum available nitrogen was observed in control (T_1). At initial, tillering, panicle initiation and at harvesting stage, significantly the highest (239.2, 274.3, 258.6, 241.5 and 243.1, 278.5, 257.8, 245.3 kg ha^{-1}, in *kharif*, 2016 and 17 available nitrogen in soil was recorded respectively with application of 100 % NPK + $ZnSO_4$ +FYM (T_7). Similar trend was observed in *rabi* season with 279.6, 240.9, 260.4, 244.3 and 243.8, 276.9, 259.8, 249.8 kg ha^{-1} in T_7 in *Rabi* 2017 and 18, respectively.

With respect to tillering stage the highest available nitrogen was observed in T_7 (100% NPK + ZnSO4+ FYM) and it was significantly superior over other treatments and the lowest soil available nitrogen was observed in control treatment (T_1). Similar set of results were observed in *kharif* and *rabi* during both the years of study. Among the inorganic treatments the treatment T_6 was recorded highest available nitrogen and significantly superior over T_3, T_4, T_5 and T_8 and however it was on par with treatment T_2. Similar results were obtained in both the years of study in *kharif* and *rabi*.

At panicle initiation stage, significantly higher value of the available nitrogen was observed in T_7 (100 % NPK+ $ZnSO_4$ +FYM) which was significantly superior over all other treatments and the lowest available nitrogen was observed in T_1 (absolute control). Similar results were obtained in both the years of study in *kharif* and *rabi*. Among the inorganic treatments (T_2, T_3, T_4, $T_{5,}$ T_6 and T_8), the treatment T_6 was recorded highest available nitrogen and significantly superior over T_4 and T_8 but however it was on par with T_2, T_3 and $T_{5.}$ Similar results were obtained in both the years of study in *kharif* and *rabi*.

At harvest stage, in *kharif*, *rabi* 2016-17 and 2017-18 the highest available nitrogen was observed in T_7 (50% RDP + FYM) which was significantly superior over all other treatments and lowest was observed in control treatment (T_1). Among inorganic treatments the treatment T_6 (100% RDF + $ZnSO_4$) was recorded highest available nitrogen and it was significantly superior over all other inorganic treatments. This increase in available nitrogen content can be attributed to the mineralisation of soil nitrogen leading to build up of available nitrogen (Swarup and Yaduvanshi, 2000).

Irrespective of treatments, the available nitrogen in soil was higher at initial stages of crop and declined to the later stages. This might be due to the uptake of N by the growing plants as reported by Prakash and Badrinath (1994) (Table 1 and 2).

Phosphorus

At initial stage, the higher available phosphorus (61.2 and 65.3 kg P_2O_5 ha^{-1} during 2016 and 2017, respectively) in *kharif*, whereas in *rabi* the higher available phosphorus (65.9 and 64.1 kg P_2O_5 ha^{-1} during 2017 and 2018, respectively) was recorded with the treatment of 100 % RDF + ZnSO4 +

FYM (T_7) it was significantly superior over other treatments but however it was on par with treatment (T_2) 100% RDF (59.4, 59.8; 60.8, 59.4 kg P_2O_5 ha^{-1}) during *kharif* and *rabi* in 2016-17 and 2017-18, respectively) and lowest phosphorus (35.8, 28.1; 31.9, 26.1 kg P_2O_5 ha^{-1}) was observed in control.

At tillering stage, among different treatments, the treatment T_7 recorded highest available P_2O_5 71.3, 78.4; 75.8, 74.8 kg ha^{-1} in *kharif*, *rabi* 2016-17 and *kharif rabi* 2017-18 and it was significantly superior over other treatments but however it was on par with treatment T_2 (67.5, 73.9; 70.9, 74.8 kg ha^{-1} in *kharif*, *rabi* 2016-17 and *kharif rabi* 2017-18) and lowest available phosphorus was observed in control. The enhanced availability of soil P at tillering of rice might be due to the production of organic acids during microbial decomposition of the crop residues in soil.

The significant increase in P status of soil in these treatments could be due to the fact that organic acids released during decomposition of FYM might have converted the unavailable forms of phosphorus to available forms besides mineralization of organic form of phosphorus. These results confirm the findings of Lakshminarayana (2006).

At panicle initiation stage, the highest value of the available phosphorus was observed in T_7 (100 % NPK+ $ZnSO_4$ +FYM) it was significantly superior over all other treatments. The lowest available nitrogen was observed in T_1 (absolute control). The increase in available phosphorus status of soil from sowing to maximum tillering stage can be attributed to the flooding condition of the soil and it was in conformity with the results of Chakravarthi and Kar (1970).

The treatment T_7 (100% RDF + FYM + $ZnSO_4$) recorded significantly highest (64.4, 66.3; 66.8, 69.3 Kg P_2O_5 ha^{-1} in *kharif*, *rabi* 2016-17 and *kharif rabi* 2017-18) available phosphorus at harvest stage during both *kharif* and *rabi*. Lowest (32.4, 26.5 and 28.9, 25.1 kg ha^{-1} in *kharif*, *rabi* 2016-17 and *kharif rabi* 2017-18respectively) available phosphorus was recorded with T_1 (absolute control). The higher available phosphorus in farmyard manure amended treatments might be due to the release of P from the well decomposed FYM.

Among the inorganic treatments (T_2, T_3, T_4, T_5 T_6 and T_8), the treatment T_2 recorded the highest available phosphorus and it was significantly superior over T_3 and T_8. However it was on par with T_4, T_5 and T_6. The treatment T_2 (100 % NPK) was on par with T_6 (100% NPK + $ZnSO_4$) at all stages of crop growth during both the years of study in *kharif* and *rabi* season (Table 3 and 4).

Potassium (kg ha^{-1})

Available potassium in soils at initial stage ranged from 304.5 to 383.9; 299.1 to 384.1; and 302.1 to 385.9; 297.1 to 385.3 kg K_2O ha^{-1}, in *kharif* and *rabi* during 2016-17 and 2017-18, respectively during the two years of study. At initial stage the highest available K_2O content was observed in T_7 treatment that received 100% RD of NPK+FYM @ 5 t ha^{-1} which was significantly superior over other treatments but however it was on par with treatment T_6 (100 % NPK +$ZnSO_4$) in both *kharif* seasons and *rabi*, 2017 whereas in *rabi* 2018, the treatment T_7 was significantly superior over all other treatments and the lowest available potassium was observed in control (T_1) and this his was on par with T_5 (100% RD of NP) and T_8 (50 % NPK).

At tillering stage, available potassium in soils was ranged from 302.4 to 426.8; 298.3 to 429.3; and 301.4 to 435.9; 296.3 to 437.9 kg K_2O ha^{-1}, in *kharif*, *rabi* 2016-17 and 2017-18 respectively. The highest available potassium was observed in T_7 (100% RD of NPK+FYM @ 5 t ha^{-1} + $ZnSO_4$) and it was significantly superior over other treatments but however it was on par with T_6 and T_2 in *Rabi* season. Whereas in *kharif* season the treatment T_7 was significantly superior over other treatments but however it was on par with T_6. Obviously control (T_1) showed comparatively the lowest available potassium content.

Among the nutrient management treatments, application of NPK + FYM to rice recorded higher quantity of available soil NPK after crop harvest. This might be due to slow release of nutrients in FYM and also due to the chelating effect of FYM. Rathore *et al.,* (1995) also observed that residual soil fertility increased under FYM application, whereas, NPK alone made no impact on fertility buildup.

The beneficial effect of FYM on available potassium might be due to the reduction of potassium fixation, solubilisation and release due to the interaction of organic matter with clay besides the direct potassium addition to the potassium pool of soil. Similar results were observed by Tandon, 1987.

Among the treatments, higher (395.4, 394.5 and 399.5, 404.2 kg K_2O ha^{-1}) values of available K content were recorded at panicle initiation stage with application of 100% NPK+FYM+ $ZnSO_4$ which was significantly superior over remaining treatments in *kharif* season during both the years of study. Whereas in *rabi* the treatment T_7 was significantly superior over other treatments but however it was on par with treatment T_6 and lower available potassium content was recorded in control treatment (T_1).

At harvest, the highest available potassium (385.6, 386.9 and 386.7, 391.5 kg K_2O ha^{-1}) was observed in T_7 which was significantly superior over remaining treatments in both *kharif* and *rabi* seasons and the lowest (301.5, 297.3 and 299.8, 295.8 kg K_2O ha^{-1}) available potassium was observed in control, which was on par with T_5 (100 % NP).

Among the inorganic treatments (T_2, T_3, T_4, T_5, T_6 and T_8), the highest available potassium was observed in treatment T_6 it was significantly superior over T_5 (100 %NP) and T_8 (50 % NPK) and however it was statistically on par with T_2 (100% RDF), T_3 (100 % NK), T_4 (100 % PK). Similar results were obtained at all stages of crop growth during both the years of study in *kharif* and *rabi* season (Table 5 and 6).

Enzyme activities

Urease activity

The data relating the effect of different treatments on activity of soil urease (µg of $NH4^+$ released g^{-1} soil h^{-1}) at various growth stages of rice are presented in Table 7 and 8. A close perusal of data indicated significant differences between treatments at all the crop growth stages. In all the treatments, the urease activity showed an increasing trend with the age of the crop and exhibited highest activity at panicle initiation stage and thereafter the activity decreased towards harvest. From the tillering to filling stages, the rice roots excreted more organic acids and carbohydrates, which stimulated the correlative soil enzymatic activities. The results corroborate with the findings of Zeng *et al.,* (2005). During *kharif*, 2016 and 2017, significantly high urease activity of 42.34, 46.84, 52.19, 44.59 and 46.82, 51.29, 55.49, 48.38 mg NH_4^+ released g^{-1} soil h^{-1} was recorded by T_7 (100% NPK+FYM + $ZnSO_4$) followed by T_{10} (50% NPK+ 50 % N through FYM with 40.04, 43.61, 48.39, 41.64 and 43.21, 48.93, 52.81, 44.69 mg NH_4^+ released g^{-1} soil h^{-1} at initial, tillering, panicle initiation and at harvest was recorded, respectively.

Table.1 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil available nitrogen (kg ha^{-1})

Treatments	***Kharif* (2016)**				***Rabi* (2017)**			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	161.8	160.4	159.3	158.6	156.4	155.3	153.8	152.1
T_2 100 % RDF	222.9	256.3	240.8	226.5	224.9	265.9	239.1	225.9
T_3 100% NK	216.3	254.9	232.4	216.7	214.7	263.1	233.8	221.4
T_4 100% PK	176.4	212.7	186.7	178.3	175.3	225.8	193.3	177.3
T_5 100% NP	215.6	251.8	231.6	215.9	214.9	261.7	230.8	216.8
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	224.3	260.5	243.5	230.4	227.4	267.3	243.5	228.4
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	239.2	274.3	258.6	241.5	240.9	279.6	260.4	244.3
T_8 50% NPK	190.4	229.9	202.5	196.6	190.8	239.5	209.2	193.6
T_9 50% NPK + 50 % N Through Green Manures	212.3	252.3	235.1	218.8	215.3	257.8	235.1	218.7
T_{10} 50% NPK + 50 % N Through FYM	213.6	253.5	238.6	219.4	217.4	260.4	236.8	220.6
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	210.6	250.7	234.4	217.9	214.6	259.3	231.4	219.5
T_{12} FYM only @ 10 t/ha	195.4	238.5	212.5	199.4	196.8	245.5	213.8	198.8
SEm ±	4.603	4.364	4.944	4.194	5.080	3.853	5.387	5.592
CD @ 0.05	13.5	12.8	14.5	12.3	14.9	11.3	15.8	16.4
CV (%)	11.16	10.68	10.52	9.82	9.57	8.46	10.68	9.15

Table.2 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil available nitrogen (kg ha^{-1})

Treatments	*Kharif* (2017)				*Rabi* (2018)			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	151.2	149.6	148.3	147.1	146.3	145.9	145.1	144.3
T_2 100 % RDF	224.3	262.9	245.6	224.6	223.6	264.7	242.3	230.4
T_3 100% NK	219.4	254.4	236.5	217.8	215.9	258.1	234.4	225.9
T_4 100% PK	173.8	220.1	208.4	176.4	174.5	226.8	196.7	180.3
T_5 100% NP	215.1	252.7	237.1	215.3	213.8	253.1	235.9	221.5
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	224.8	264.3	246.3	230.8	229.7	268.3	243.3	233.5
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	243.1	278.5	257.8	245.3	243.8	276.9	259.8	249.8
T_8 50% NPK	190.4	229.8	219.3	191.5	189.6	230.7	208.8	197.8
T_9 50% NPK + 50 % N Through Green Manures	216.5	251.5	238.6	220.6	218.3	253.8	231.6	222.5
T_{10} 50% NPK + 50 % N Through FYM	218.3	253.6	240.9	221.3	220.5	259.7	239.4	228.9
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	217.6	250.9	237.8	219.5	218.9	255.6	235.6	224.8
T_{12} FYM only @ 10 t/ha	196.3	234.6	225.2	198.4	197.9	239.6	216.5	203.6
SEm ±	5.148	4.739	3.512	4.057	3.716	5.043	4.732	4.362
CD @ 0.05	15.1	13.9	10.3	11.9	10.9	14.8	13.9	12.8
CV (%)	9.65	8.93	7.16	10.95	7.83	8.16	7.92	8.36

Table.3 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil available phosphorus (kg ha^{-1})

Treatments	*Kharif* (2016)				*Rabi* (2017)			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	35.8	34.9	33.3	32.4	31.9	30.8	29.5	28.9
T_2 100 % RDF	59.4	67.5	61.3	60.3	59.4	70.9	63.4	60.9
T_3 100% NK	36.1	44.4	42.8	37.3	41.2	49.4	43.5	42.1
T_4 100% PK	53.2	64.3	55.6	54.9	55.1	67.8	58.9	56.3
T_5 100% NP	53.8	63.8	54.7	54.1	54.3	68.1	58.1	55.8
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	56.0	65.2	59.6	57.3	56.2	69.3	62.9	57.8
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	61.2	71.3	65.7	64.4	64.1	75.8	69.7	66.8
T_8 50% NPK	48.6	52.4	50.1	49.3	48.2	55.4	49.4	48.9
T_9 50% NPK + 50 % N Through Green Manures	54.1	59.8	56.3	56.2	55.8	67.3	60.2	57.4
T_{10} 50% NPK + 50 % N Through FYM	55.5	62.8	58.3	57.3	56.1	66.8	61.8	58.9
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	54.3	61.4	55.6	55.4	53.4	65.1	59.3	55.3
T_{12} FYM only @ 10 t/ha	49.1	55.2	50.4	47.5	49.1	59.3	51.1	50.1
SEm ±	1.193	2.012	2.319	1.364	1.671	1.739	2.080	2.012
CD @ 0.05	3.5	5.9	6.8	4.0	4.9	5.1	6.1	5.9
CV (%)	10.6	8.1	8.3	9.5	9.5	9.0	8.9	11.2

Table.4 Effect of long-term use of inorganic fertilizers, organic manures and their combination on available phosphorus (kg ha^{-1})

Treatments	*Kharif* (2017)				*Rabi* (2018)			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	28.1	27.5	27.0	26.5	26.1	26.0	25.8	25.1
T_2 100 % RDF	59.8	73.9	65.8	61.9	60.8	74.8	66.4	62.5
T_3 100% NK	41.4	53.4	48.5	43.5	42.8	57.6	52.9	47.8
T_4 100% PK	55.9	68.1	58.6	56.3	55.3	70.5	63.4	58.1
T_5 100% NP	54.1	69.3	59.3	55.4	54.1	69.3	64.7	57.1
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	57.5	70.5	63.5	59.6	58.9	73.4	65.3	61.3
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	65.3	78.4	70.3	66.3	65.9	80.3	74.5	69.3
T_8 50% NPK	48.7	58.5	52.9	49.4	48.3	61.7	57.6	52.9
T_9 50% NPK + 50 % N Through Green Manures	56.5	67.1	61.5	58.3	57.6	70.3	65.1	58.9
T_{10} 50% NPK + 50 % N Through FYM	57.3	67.4	62.8	59.1	58.5	71.9	66.9	59.8
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	54.9	66.3	60.1	55.3	54.4	69.7	64.3	58.7
T_{12} FYM only @ 10 t/ha	49.5	61.0	54.5	50.9	50.1	63.1	58.2	54.2
SEm ±	1.807	1.637	1.330	1.432	1.534	1.296	1.398	1.603
CD @ 0.05	5.3	4.8	3.9	4.2	4.5	3.8	4.1	4.7
CV (%)	8.8	10.9	8.9	9.5	9.1	7.6	7.3	8.3

Table.5 Effect of long-term use of inorganic fertilizers, organic manures and their combination on available potassium (kg ha^{-1})

Treatments	*Kharif* (2016)				*Rabi* (2017)			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	304.5	302.4	301.8	301.5	302.1	301.4	300.8	299.8
T_2 100 % RDF	363.5	405.5	372.6	364.3	364.9	417.8	380.5	365.4
T_3 100% NK	349.6	403.8	361.8	350.8	350.1	411.7	373.1	351.8
T_4 100% PK	347.1	401.6	365.4	349.7	348.6	409.3	370.2	350.2
T_5 100% NP	306.4	337.2	321.8	308.6	308.1	350.6	325.8	309.5
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	365.2	411.3	375.5	366.4	365.6	419.3	382.4	366.9
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	383.9	426.8	395.4	385.6	385.9	435.9	399.5	386.7
T_8 50% NPK	318.6	362.1	330.8	320.4	319.5	375.5	344.3	320.6
T_9 50% NPK + 50 % N Through Green Manures	356.4	397.6	367.7	358.6	357.8	403.1	375.7	359.1
T_{10} 50% NPK + 50 % N Through FYM	358.2	399.7	370.1	359.5	358.9	405.6	378.9	360.2
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	354.9	395.4	368.2	356.4	356.1	401.2	376.4	357.3
T_{12} FYM only @ 10 t/ha	326.2	374.8	342.9	328.1	327.2	382.7	352.6	329.1
SEm ±	6.444	6.751	6.581	5.967	7.228	6.205	5.830	6.478
CD @ 0.05	18.9	19.8	19.3	17.5	21.2	18.2	17.1	19.0
CV (%)	7.9	8.5	10.1	6.7	8.3	7.1	10.5	9.8

Table.6 Effect of long-term use of inorganic fertilizers, organic manures and their combination on available potassium (kg ha^{-1})

Treatments	*Kharif* (2017)				*Rabi* (2018)			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	299.1	298.3	298.1	297.3	297.1	296.3	296.1	295.8
T_2 100 % RDF	364.2	409.6	375.8	366.5	365.8	420.5	388.4	369.1
T_3 100% NK	350.6	408.2	368.4	353.4	352.7	403.1	373.9	354.5
T_4 100% PK	349.1	406.1	367.5	351.6	351.1	401.9	372.6	352.3
T_5 100% NP	310.7	349.8	320.4	313.7	312.2	363.8	333.2	309.5
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	365.2	410.1	377.5	367.4	366.2	421.9	390.9	372.4
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	384.1	429.3	394.5	386.9	385.3	437.9	404.2	391.5
T_8 50% NPK	317.9	368.6	343.9	319.8	319.1	370.2	339.7	323.2
T_9 50% NPK + 50 % N Through Green Manures	357.3	401.5	370.8	359.1	358.9	412.7	380.2	362.5
T_{10} 50% NPK + 50 % N Through FYM	360.1	403.8	373.6	363.8	362.7	417.9	384.3	364.9
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	356.8	398.6	369.7	359.6	357.3	413.7	382.7	361.7
T_{12} FYM only @ 10 t/ha	329.0	375.7	348.6	331.2	330.8	383.9	366.2	332.4
SEm ±	6.751	6.308	5.558	6.103	5.524	5.967	6.171	6.069
CD @ 0.05	19.8	18.5	16.3	17.9	16.2	17.5	18.1	17.8
CV (%)	9.1	7.5	8.9	10.6	9.5	8.2	7.7	8.5

Table.7 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil urease activity ($\mu g\ NH_4^+ - N\ g^{-1}$ soil h^{-1})

Treatments	***Kharif* (2016)**				***Rabi* (2017)**			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	21.34	26.39	28.43	24.16	22.14	27.94	31.27	25.38
T_2 100 % RDF	30.64	35.16	38.18	33.34	32.09	38.63	43.96	37.17
T_3 100% NK	28.39	34.39	33.81	31.98	30.18	35.68	41.08	34.31
T_4 100% PK	26.16	31.38	31.68	28.16	27.62	33.18	37.79	33.69
T_5 100% NP	27.19	32.49	34.79	31.14	29.94	36.19	40.29	35.72
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	31.96	36.24	39.38	34.18	33.41	39.19	45.24	38.84
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	42.34	46.84	52.19	44.59	43.69	50.34	58.94	48.13
T_8 50% NPK	25.39	29.14	30.18	26.93	26.32	32.79	36.18	31.19
T_9 50% NPK + 50 % N Through Green Manures	37.84	42.64	46.31	39.59	38.14	44.18	52.31	43.26
T_{10} 50% NPK + 50 % N Through FYM	40.04	43.61	48.39	41.64	40.16	47.28	55.01	44.19
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	36.39	40.38	44.56	39.32	39.15	45.39	51.38	45.63
T_{12} FYM only @ 10 t/ha	34.16	38.38	41.93	37.50	36.19	42.24	48.14	41.34
SEm ±	0.839	1.139	1.238	0.736	1.292	1.371	1.320	0.999
CD @ 0.05	2.46	3.34	3.63	2.16	3.79	4.02	3.87	2.93
CV (%)	8.19	7.68	8.23	9.16	7.04	7.47	8.39	7.89

Table.8 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil urease activity ($\mu g\ NH_4^+ - N\ g^{-1}$ soil h^{-1})

Treatments	***Kharif* (2017)**				***Rabi* (2018)**			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	23.19	28.08	32.79	25.73	22.15	27.83	32.15	26.89
T_2 100 % RDF	35.24	39.13	42.81	36.89	34.89	39.14	44.81	38.24
T_3 100% NK	32.18	35.19	39.18	33.16	30.29	35.84	41.83	33.14
T_4 100% PK	31.16	34.96	37.49	32.17	29.14	32.16	35.92	31.84
T_5 100% NP	34.14	36.19	38.32	35.86	31.63	33.89	37.84	32.94
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	36.29	40.94	44.02	37.62	35.24	39.18	44.89	37.84
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	46.82	51.29	55.49	48.38	45.84	53.89	60.18	51.98
T_8 50% NPK	29.28	32.68	36.84	30.42	27.32	33.14	35.82	30.15
T_9 50% NPK + 50 % N Through Green Manures	42.19	45.62	49.55	42.35	39.19	49.18	55.97	46.89
T_{10} 50% NPK + 50 % N Through FYM	42.36	48.93	52.81	44.69	41.52	51.62	59.73	49.18
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	43.21	46.37	51.13	43.28	40.13	48.34	52.63	45.92
T_{12} FYM only @ 10 t/ha	39.36	42.73	45.86	39.07	35.24	45.85	51.13	43.81
SEm ±	1.333	1.190	1.418	1.197	1.146	1.377	1.016	1.279
CD @ 0.05	3.91	3.49	4.16	3.49	3.36	4.04	2.98	3.75
CV (%)	7.26	7.91	7.73	8.48	7.16	8.28	7.97	7.34

Table.9 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil dehydrogenase activity (µg of TPF g^{-1} soil Day^{-1})

Treatments	***Kharif* (2016)**				***Rabi* (2017)**			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	259.62	263.14	269.19	261.83	260.14	265.19	269.96	263.16
T_2 100 % RDF	325.63	338.82	350.26	334.92	331.39	341.29	355.92	339.62
T_3 100% NK	295.28	326.93	339.17	319.62	317.82	329.62	343.19	323.32
T_4 100% PK	281.39	300.62	312.15	292.81	291.49	305.81	318.82	301.83
T_5 100% NP	300.86	312.39	321.29	309.65	307.89	317.89	327.76	312.96
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	331.92	347.21	354.01	340.38	338.12	350.13	361.32	345.82
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	416.31	424.29	439.36	421.38	420.16	429.19	446.89	426.23
T_8 50% NPK	262.93	274.89	281.59	269.89	267.83	281.18	286.17	279.14
T_9 50% NPK + 50 % N Through Green Manures	344.32	359.84	379.70	351.42	349.34	365.13	382.19	360.39
T_{10} 50% NPK + 50 % N Through FYM	375.66	388.01	399.13	383.29	380.62	388.96	409.13	383.42
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	360.84	371.32	381.29	367.89	365.81	379.13	391.32	370.34
T_{12} FYM only @ 10 t/ha	385.62	394.42	413.29	391.82	389.34	396.81	419.19	391.35
SEm ±	12.21	13.61	11.87	13.77	13.06	14.62	12.22	12.66
CD @ 0.05	35.81	39.92	34.84	40.39	38.32	42.89	35.86	37.13
CV (%)	7.89	8.13	8.64	9.13	7.32	8.16	7.52	8.35

Table.10 Effect of long-term use of inorganic fertilizers, organic manures and their combination on soil dehydrogenase activity (µg of TPF g^{-1} soil Day^{-1})

Treatments	*Kharif* (2017)				*Rabi* (2018)			
	Initial	Tillering	Panicle Initiation	Harvest	Initial	Tillering	Panicle Initiation	Harvest
T_1 Control	262.27	265.19	267.82	263.29	262.91	270.12	273.12	267.14
T_2 100 % RDF	338.89	348.34	350.13	343.13	339.14	345.84	349.16	340.16
T_3 100% NK	321.16	330.19	339.72	327.21	323.81	330.28	335.82	306.28
T_4 100% PK	300.82	309.62	315.84	305.32	292.87	299.84	304.12	293.62
T_5 100% NP	311.16	319.34	326.82	315.82	313.86	318.69	324.89	315.81
T_6 100 % RDF + $ZnSO_4$ @ 40 kg/ha	342.19	352.16	359.74	349.39	343.81	346.82	353.28	345.72
T_7 100 % RDF + $ZnSO_4$ @ 40 kg/ha + FYM @ 5t/ha	425.21	434.91	449.82	430.32	427.69	435.62	446.81	431.84
T_8 50% NPK	278.29	283.19	296.81	281.26	274.83	279.89	283.29	276.15
T_9 50% NPK + 50 % N Through Green Manures	359.13	369.82	379.95	364.19	359.19	365.39	370.82	361.06
T_{10} 50% NPK + 50 % N Through FYM	381.42	393.65	404.13	389.27	385.24	391.41	396.79	389.96
T_{11} 50% NPK + 25 % N Through GM + 25 % N Through FYM	368.19	379.24	386.24	375.81	370.89	379.32	386.28	375.28
T_{12} FYM only @ 10 t/ha	389.26	399.16	413.72	393.97	395.24	401.18	410.12	398.12
SEm ±	13.04	13.69	14.97	12.21	13.57	14.31	10.85	12.58
CD @ 0.05	38.26	40.17	43.92	35.82	39.34	41.97	31.84	36.92
CV (%)	8.65	8.13	7.93	7.81	7.13	8.69	7.74	8.24

Lowest urease activity 21.34, 26.39, 28.43, 24.16 and 23.19, 28.08, 32.79, 25.73 mg NH_4^+ released g^{-1} soil h^{-1} at initial, tillering, panicle initiation and at harvest was recorded by T_1 (control).

At initial stage the highest urease activity (42.34, 43.69, 46.82 and 45.84 µg of NH4+ released g^{-1} soil h^{-1}, *kharif, rabi* 2016-17 and *kharif, rabi* 2017-18, respectively) was recorded in the treatment which received 100 % NPK + FYM @5t ha^{-1} (T_7) and it was significantly superior over other treatments but however it was on par with T_9 and T_{10}.

At tillering stage, in both *Kharif* and *Rabi* seasons, among the all treatments the highest urease activity was observed in treatment (T_7) which was significantly superior over other treatments but however it was on par with treatment T_{10}. The lowest urease activity observed in treatment T_1 (control) in 2016-17 and 2017-18 in both the seasons.

At panicle initiation satge, the urease activity was ranged from 28.43 to 52.19 in *kharif*, 2016; 32.79 to 55.49 in *kharif* 2017; 31.27 to 58.94 in *rabi*, 2017 and 32.79 to 55.49 in *rabi*, 2018. During the first year *kharif* and *rabi* the highest urease activity was observed with treatment T_7 it was significantly superior over other treatments. In second year the treatment T_7 was on par with T_{10} and significantly superior over remaining treatments and lowest urease activity was observed in control (T_1).

At harvesting stage, during *kharif* 2016 & 17 the highest urease activity was observed with treatment T_7 (100 % NPK + FYM @5t ha^{-1} + $ZnSO_4$) it was significantly superior over all other treatments. During *rabi* (2017 &2018) the highest urease activity was observed in the treatment T_7 over other treatments but it was on par with T_{10}. Lowest urease activity was observed in control (T_1).

Among the inorganic treatments, the highest urease activity was observed in treatment T_6 (100% RDF %+ $ZnSO_4$) and it was significantly superior over other treatments but however it was on par with treatment T_2 (100% NPK). Similar results were observed at initial, tillering, panicle initiation and harvest during both the years of study in *kharif* and *rabi* seasons.

The higher enzyme activity with 100% NPK+FYM and FYM treatments might be ascribed to the fact that the organic matter added to low land rice soil (with water more than saturation capacity) enhances microbial fermentation of the organic compounds producing compounds which are subjected to reduction and oxidation. A number of fermentation products like ethanol, acetate, lactate act as rich energy sources for proliferating microorganisms and the microorganisms release these enzymes into the soil for the reactions necessary to release energy.

The treatment with 100% recommended dose of NPK through chemical fertilizers recorded lower enzyme activities than the INM treatments which was attributed to lack of sufficient substrate *i.e.* organic carbon which acts as an energy source and food for proliferating the microbial population (Nagendra, 2015).

Dehydrogenase activity

The dehydrogenase activity gradually increased with the age of the crop, attained highest activity at panicle initiation stage and gradually decreased to harvest.

The higher dehydrogenase activity at panicle initiation stage was likely due to high C input in the soil in the form of root mass that enhanced microbial activity (Maurya *et al.*, 2011).

At initial stage, the highest DHA (416.31, 425.21 µg TPF g^{-1} day^{-1}) in *kharif* 2016 and 17 and (420.16, 427.69 µg TPF g^{-1} day^{-1}) in *rabi* 2017 and 18 was recorded in the treatment T_7 and it was significantly superior over other treatments but it was on par with treatment T_{12} (FYM @ 10t/ha) and lowest dehydrogenase activity was observed in control (T_1) (Table 9 and 10).

At tillering satge, the dehydrogenase activity ranged from 274.89 to 424.29 in *Kharif*, 2016; 265.19 to 434.91in *Kharif*, 2017; 265.19 to 429.19 in *Rabi*, 2017 and 270.13 to 435.62 µg TPF g^{-1} day^{-1} in *Rabi*, 2018. The highest dehydrogenase activity was observed with treatment T_7 and it was significantly superior over other treatments but however it was on par with treatment T_{10}, T_{11} and T_{12} and lowest dehydrogenase activity was observed in control (T_1) in both the seasons and both the years of study.

At panicle initiation stage & harvest stage, the highest dehydrogenase activity in both the years of study in *kharif* and *rabi* was observed in T_7 (100% RD of NPK+FYM @ 10 t ha^{-1} + $ZnSO_4$) and it was significantly superior over other treatments but however it was on par with T_{10}, T_{11} and T_{12} and the lowest dehydrogenase activity was observed in control (T_1) and it was on par with T_8 (50% NPK).

Addition of organic sources might have created environment conducive for formation of humic acid, stimulated the activity of soil micro-organisms resulting in an increase in DHA of the soil (Bajpai *et al.*, 2006).

At all the stages of crop growth during *kharif*, *rabi* 2016-17 and 2017-18 among the inorganic treatments, the treatment T_6 (100% RDF %+ $ZnSO_4$) recorded the highest dehydrogenase activity and it was significantly superior over other inorganic treatments but however it was on par with treatment T_2 (100% NPK).

Significant increase in enzyme activity at panicle initiation stage due to addition of organics might be due to increased bacterial population (Pauscal *et al.,* 1998).

Highest enzyme activity in the soils applied with FYM could be attributed to the fact that it was more decomposed and was used as readily available source of carbon and energy for proliferation of microorganisms.

The increase in dehydrogenase activity in submerged soils was attributed to the increase in population of anaerobic microorganisms. There was a shift in soil microflora from predominantly aerobic to facultative and obligatory anaerobic ones once the soil is flooded. This shift from aerobic to anaerobic microorganisms was found to cause an increase in dehydrogenase activity (Lee *et al.*, 2004).

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