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The effects of Zn, FYM and their combine application on soil physical and biological parameters under long-term rice based cropping systems in calcareous soil

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Abstract
The present investigation entitled, the effects of Zn, FYM and their combine application on soil physical and biological parameters under long-term rice based cropping systems in calcareous soil, was studied in an ongoing long-term experiment in the calcareous soil of Northern Bihar, at RPCAU Experimental Farm, Pusa Bihar, initiated in *Kharif* 1985, under AICRP micro, secondary and pollutant elements. The experiment comprises four different fertility levels *viz*.; control, NPK 50%, 100% and 150% of RDF (NPK), and six replications in a randomized block design (RBD), two cropping systems were followed *viz*., Rice-Wheat-Sorghum (R-W-S) and Rice-Mustard-Moong (R-M-M). The recommended doses of NPK for rice and wheat crops were 120:60:40, for the mustard and sorghum were 60:50:30 and for moong 20:50:30. After ten cropping cycles, zinc deficiency became serious in treatments receiving 150% of the RDF. Hence, Zn and FYM amendments were superimposed in four replications leaving the other two replications as such with no superimposition. The four superimposed treatments were 10 kg Zn/ha, 10kg Zn/ha + 5 t FYM/ha, 10 t FYM/ha and 10kg Zn/ha + 10 t FYM/ha. The superimposed treatments were applied in alternate years. In the current year (2020) the superimposed treatments were applied. Because of superimposition in four replications no replication was left for statistical analysis in RDF. Hence a paired t-test was used to compare the superimposed treatments. The present investigation was made in the 36th crop cycle after the harvest of the 106th rice crop in the year, 2020. The studies were made on some of the soil physical and biological parameters for both the crop rotations R-W-S and R-M-M.
Among the superimposed treatments the combined application of 10 kg Zn/ha with 10 t FYM/ha proved best both with regards to soil quality parameters and rice crop yield. The conjoint application of 10 kg Zn/ha with 10 t FYM/ha significantly improved the soil quality parameters, namely, available water capacity, mean weight diameters, active carbon, autoclave citrate extractable protein and soil respiration to the magnitude of 39.7%%, 16.9%, 16.9%, 10.5%, and 17.5%, respectively with respect to control in R-W-S cropping system while the same in R-M-M rotation stood at 56.1%, 17.7%, 18.2%, 11.9% and 22.9%. The paired t-test statistics revealed that the application of 10 t FYM/ha was significantly superior in improving soil physical (Mean weight diameter and Available water content) and biological (Active carbon, Autoclave citrate extractable protein and Soil respiration) properties than the application of 10 kg Zn/ha. The conjoint application of 10 kg Zn/ha with either 5 t FYM/ha or 10 t FYM/ha proved better with regard to soil properties and crop performance. Inclusion of Zn based fertilizer in calcareous soil is beneficial in the long-term conventional agriculture to maintain Zn balance in the soil. One of the notable findings from investigation was the application of NPK based fertilizer with FYM in long-term rice based cropping system positively influences soil physical and biological parameters in the calcareous soil environment.

Keywords: Active carbon; Autoclave citrate extractable protein; Available water capacity; Mean weight diameter; Superimposition

1. Introduction

Agricultural sustainability and soil resilience depend on soil physical and biological quality. Thus, achieving agricultural sustainability and restoring degraded soils depend on the knowledge of the effect of management practices on soil quality and soil-plant relationships. Enhancing soil quality in intensive agricultural systems is important to sustaining productivity and improving environmental quality. Long-term imbalanced fertilizer application has been reported to hamper the physical as well as biological health of soil. Application of organic manure not only supplies major and micro-nutrients but also improves physical, chemical, and biological properties of soil (Nanda *et al.*, 2016b) [23]. The Organic amendments increase soil aggregation and organic matter levels (Bandyopadhyay *et al*., 2010; Brar *et al.*, 2015) [2, 5]. The SOM components such as humic molecules and polysaccharides increased aggregate stability by binding mineral particles into aggregates and reduced their susceptibility to erosion by wind or water. The formation of stable aggregates enhances physical protection of SOM against microbial decomposition. Long-term fertilizer experiments (LTFEs) (Majhi *et al.*, 2019; Ram *et. al*., 2016) [18, 30] indicated a positive impact of additional supply of 100% NPK, farmyard manure (FYM), S and Zn on yield and soil properties. Long-term manure application promoted the formation of soil macro aggregates and increased aggregate stability (Li *et al*., 2010) [15]. The increase in aggregate stability likely enhances the soil resistance to erosion which is a major threat for crop production and agricultural sustainability. Addition of compost and manures, crop rotation, bio fertilizers, and cover crops not only increase soil organic matter but also improve soil physico-chemical and biological properties (Naresh *et al.*, 2018; Ouyang *et al.*, 2018) [24, 27]. The adequate use of organic matter often leads to an increase in the activity of various enzymes in soil (Majhi, 2017; Shahid *et al.*, 2013) [17, 34]**.** Several studies have reported that the continuous addition of organic manures, green manures, crop residues, and bio fertilizers in rice-wheat system improved soil physical properties, chemical properties and biological properties with respect to control treatments (Ghosh *et al.*, 2018) [9].

Zn deficiency is lead to nutritional and health problem in human populations where rice is the dominating staple food crop**.** Among nutrient deficiencies, Zn deficiency has been identified as a most serious agricultural issue in world. For instance, 43% of Indian soils and 20% of Jharkhand soils (Shukla *et al.*, 2014) [35] are deficient in zinc. Zinc is an essential element for normal growth and metabolism of plant plays an important role in membrane integrity, synthesis of carbohydrates, enzymes activation such as dehydrogenase, carbonic anhydrase, superoxide dismutase, alkaline phosphatase. The pH of soil makes large difference in the occurrence of Zn in the soil, Zn precipitation is a major cause of Zn deficiency in the soil. Zn associated with ligands, on exchanged sites of soil, bound by organic matter and occluded in oxides and hydroxides of Al and Fe (Havlin *et al*., 2005) [10]. Since, present investigation is in the calcareous soil, the availability of fertilizer Zn to plants decreases rapidly after application to soil due to surface adsorption, cation exchange, chelation, and precipitation (Jalali and Khanlari, 2008) [13]. In the calcareous soils, up to 90% of applied Zn fertilizer is adsorbed on soil colloids and precipitated. Therefore, Zn deficiency is a major problem in calcareous soil. The solubility and availability of Zn are highly dependent on pH, in addition to calcareousness, high pH of the soils also decreases the availability of Zn. Thus, the use of synthetic and organic source of Zn is crucial to create Zn balance in the soil system.

Long-term cultivation, fertilization could change the soil density, aggregation, and porosity, then change soil water retention characteristic and hydraulic conductivity. In particular, organic fertilizer could improve these physical properties, as a result, to improve soil moisture regime and penetrate resistance for crop growth, long-term experiment is a viable source to understand the imbalance in soil physical and biological properties, therefore the present study entitled "The effects of Zn, FYM and their combine application on soil physical and biological parameters under long-term rice based cropping systems in calcareous soil " was choose to draw some inference with the application of Zn and FYM with respect to soil physical and biological parameter in the long run**.**

2. Materials and Methods

2.1 Field site and experimental design

The current study was carried out as part of an ongoing field experiment on Micro-Secondary and Pollutant Elements in Soil and Plants under the auspices of the AICRP in RPCAU Pusa Bihar. The trial began in the month of *Kharif* 1985. The coordinates for the site are 25.9807988 0N, 85.6676792 0E. The testing location is 52 meters above sea level (MSL). The standard procedure followed in soil and crop studies and the details of field experiment are described below:

A long-term experiment was started in the nursery jhilli, the crop research Centre of Rajendra Agricultural University, Pusa, in *Kharif* 1985. The experiment comprised of four fertility levels, i.e., 0%, 50%, 100% and 150% RDF of NPK level for each crop [RDF of 120:60:40, (N:P2O5:K2O) kg/ha in rice and wheat crops], six replications in RBD experimental design. Two cropping systems *viz*; Rice-Wheat-Sorghum (R-W-S) and Rice-Mustard-Moong (R-M-M) were followed. Zinc sulphate was used before the experiment began. For both crop rotations, the soil was allowed to equilibrate with Zn for one month [(Zn content 3.2 ppm)], and then the rice crop was transplanted. Soil samples were taken before transplantation. All treatments under different replications were superimposed in alternate years with the sub-treatments after completing 10 cropping cycles, i.e., after harvesting 30 crops in each rotation, sub-treatment of 10 kg Zn/ha, 10 kg Zn/ha+5 t FYM/ha, 10 kg Zn/ha, 10 kg Zn/ha+10 t FYM/ha and no superimposition in R1, R2, R3, R4 and (R5 & R6) respectively.

The current research was conducted with 36th crop cycle i.e., after the harvest of 106^{th} rice crop. Rice variety (Rajshree) was planted for R-W-S and rice variety (Prabhat) for R-M-M cropping systems. On July 15th, 22-day-old mature rice seedlings (20 cm x 20 cm) were transplanted. Urea, DAP, and MOP were applied at 211 kg ha^{-1}, 130 kg ha^{-1}, and 100 kg ha^{-1}, respectively, in treatment T3. At the same time, 50 and 150 percent of the aforementioned fertilizers were applied in treatments T2 and T4. Half of urea was applied basally, and the remaining dose was top-dressed at tillering, panicle initiation, and flowering stages. DAP and MOP was applied in total basally.

The experimental field is located at subtropical zone. The monsoon rainfall in this region is not constant and 80% of the total rainfall (1300 mm) is received during the month of July-September. The mean maximum temperature ranges from 340C to 370C and minimum temperature ranges from 90C to 110C.

Table 1: Initial soil properties at the start of the experiment

Properties	Content	Method used
Sand (%)	64.1	(Bouyoucos, G.J., 1962) [4]
Silt (%)	24.5	
Clay (%)	11.4	
Textural Class	Sandy loam	International Pipette method (Page *et al.*, 1982) [28]
Soil aggregate (%)	36.1	
Bulk density (g cm^{-3})	1.45	
Particle density (g cm^{-3})	2.58	
Porosity (%)	43.72	
Water holding capacity (%)	34.1	
pH	8.59	1:2 soil water suspension
EC (dS m^{-1})	0.24	1:2 soil water suspension
Free $CaCO_3$ (%)	32.8	(Black *et al.*, 1965) [48]

2.2 The soil sampling

Soil samples were collected from four random locations within the plot at depths of 0-15 cm (surface soil) after the harvest of the rice crop. For the analysis of Mean weight diameter (MWD)/soil aggregation, Soil chunks weighing 1 kg were removed from the experimental area with a shovel. The soil chunks were air-dried, and small peds of uniform size (retained on 8 mm sieve) were extracted for further analysis. Soil sampling for biological parameter was done just after the harvest of rice crop and fresh sample air-dried in shade area for 3-4 days and then partially ground the sample with the help of wooden roller. The partially ground sample was sieve through 8 mm sieve for soil respiration analysis and the sample retaining in 8mm sieve is fully ground and sieve through 2 mm sieve for soil active carbon and autoclave extractable protein determination.

Table 2: Methodology used to find the soil quality parameters during present investigation

Sl. No.	Soil Parameters	Standard Protocol Followed
1	Soil aggregation (Mean Weight Diameter)	(Cambardella *et al.*, 1994) [49]
2	Available water capacity	(Reynolds *et al.*, 2008) [31]
3	Autoclaved Citrate Extractable(ACE) Protein	(Wright and Upadhyaya, 1996) [50]
4	Soil Respiration	(Zibilske, 1994) [51]
5	Active Carbon	(Weil *et. al.*, 2003) [52]

2.3 Data processing

Correlation and regression studies were conducted among soil quality parameters with rice yield and nutrient uptake as per standard procedure using SPSS 16. A Paired T-test to comparing two treatment means at a 5% level of significance.

3. Results

3.1 Soil Physical properties [Available water capacity (AWC) and Mean weight diameter (MWD)]

The available water capacity of soil of both the cropping system was estimated, with post-harvest soil samples. The soil water loss between 10 to 1500 kPa pressure was estimated and depicted in (Table 3a)., the value ranged from 0.18 cm^3/cm^3 to 0.57 cm^3/cm^3 in R-W-S and from 0.08 cm^3/cm^3 to 0.28 cm^3/cm^3 in R-M-M cropping systems, with increased in fertility levels. It was observed, the highest value was produced by the highest fertility levels with respect to control in both R-W-S and R-M-M cropping systems. The variation in the AWC in different superimposed treatments as depicted in (Table 3a, Figure no. 1a), for both R-W-S and R-M-M. The AWC was ranged from 0.32 cm^3/cm^3 to 0.50 cm^3/cm^3 in R-W-S and the values ranged from 0.15 cm^3/cm^3 to 0.24 cm^3/cm^3 in R-M-M. It was observed that the AWC was increased in all the treatments with respect to control. However, the application of 10 kg Zn/ha + 10 t FYM/ha found to be the superior over rest of the treatments in both R-W-S and R-M-M cropping systems. The test results are depicted in (Table 3b), for both R-W-S and R-M-M. Paired t-test revealed that combine application of 10 kg Zn/ha with 10 t FYM/ha or 5 t FYM/ha and 10 t FYM/ha alone are found significant. The application of 10 kg Zn/ha alone was found to be not sufficient to increased active carbon content therefore test value was non-significant in both R-W-S and R-M-M. The treatments in which FYM was combined the particular treatments produced significant results.

The MWD was estimated in the post-harvest soil sample of both R-W-S and R-M-M and the results are depicted in (Table 3a, Figure no. 1b), With an increase in fertility level the MWD varied between 2.20-3.20 mm in R-W-S and from 2.16-3.14 in R-M-M cropping system. Among the superimposed treatments, MWD varied in between 2.60-3.04 mm in R-W-S and from 2.54-2.99 mm in the R-M-M cropping system. As per the data, MWD increased with an increase in the fertility levels. The minimum value for the MWD was found in control for both the crop rotations and it stood at 2.20 mm and 2.16 mm for R-W-S and R-M-M rotation respectively. The maximum value was observed at the highest fertility level i.e. with the application of 150% of the recommended dose of fertilizer for both the rotations and the values observed were 3.20 mm and 3.14 mm for R-W-S and R-M-M rotation. The magnitude of increase in MWD was for both the rotations stood at 45.4%. Among the superimposed treatments, the maximum value for MWD was observed for the treatment receiving the conjoint application of both 10 kg Zn/ha and 10 t FYM/ha for both the crop rotations. However, the magnitude of increase over control was more in R-M-M rotation than R-W-S rotation. The paired t-test statistics revealed that FYM alone or FYM with either 5 kg Zn/ha or 10 kg Zn/ha was significantly effective in increasing the MWD over control in both the crop rotations. However, zinc alone was not able to increase MWD in either of the crop rotations. Application of 10 t FYM/ha proved significantly superior over the application of 10 kg Zn/ha in either of the two crop rotations (Table 3b). Application of 10 t FYM/ha improved MWD by 3.01% and 2.69% as compared with the application of 10 kg Zn/ha in R-W-S and R-M-M rotation, respectively.

3.2 Soil Biological properties [Active carbon (AC), autoclave citrate extractable(ACE) protein and soil respiration (SR)

The post-harvest soil sample after the harvest of rice crops of both the crop rotation were analyzed for AC. The AC content in the soil ranged from 157.18 mg/kg to 251.77 mg/kg in R-W-S and the value ranged from 142.90 mg/ha to 236.26 mg/kg, in R-M-M cropping system with increase in fertility levels. The highest value was observed with the application of 150% of the recommended NPK fertilizer for each crop. In the case of among superimposed treatments, the active carbon content ranged from 194.32 mg/kg to 227.13 mg/ha in R-W-S, and the value ranged from 180.14 mg/kg to 212.95 mg/kg in R-M-M cropping systems, as depicted in (Table 3a, Figure no. 1c) With respect to control, all the superimposed imposed treatments produced higher values. The combined application of 10 kg Zn/ha and 10 t FYM/ha proved too superior over all the other treatments. As**1.** per paired t test combined application of 10 kg Zn/ha with 10 t FYM/ha or 5 t FYM/ha and 10 t FYM/ha alone were found significant as shown in (Table 3b). The application of 10 kg Zn/ha alone was not sufficient to increase the AC content therefore, test value was non-significant in both R-W-S and R-M-M.

Autoclave citrate extractable(ACE) protein content is an indicator of protein like materials present in the organic matter results are depicted in (Table 3a, Table 3b). The subsequent mineralization of these materials released mineral nutrients for plant growth. The ACE protein content ranged from 1.15 mg/g to 1.57 mg/g in R-W-S, and the value ranged from 1.00 mg/g to 1.42 mg/g in R-M-M crop rotation with increased fertility levels. As per the data, ACE protein increased with an increase in fertility levels. The minimum value for the mean weight diameter was found in control for both the crop rotation, and it stood at 1.15 mg/g and 1.00 mg/g for R-W-S and R-M-M rotation, respectively. The maximum value was observed at the highest fertility level i.e. with the application of 150% of the recommended dose of fertilizer for both the rotations, and the values observed were 1.57 mg/g and 1.42 mg/g for R-W-S and R-M-M rotation. The magnitude of increase in ACE protein was 36.5% for R-W-S rotation and 42.0% for R-M-M rotation. Among the superimposed treatments, the maximum value for ACE protein was observed for the treatment receiving the conjoint application of both 10 kg Zn/ha and 10 t FYM/ha for both the crop rotations. However, the magnitude of increase over control was more in R-M-M rotation than R-W-S rotation. A percentage increase of 11.9 was observed in R-M-M rotation and for R-W-S rotation, it stood at 10.5%. The paired t-test statistics revealed that FYM alone or FYM with either 5 kg Zn/ha or 10 kg Zn/ha was significantly effective in increasing the ACE protein over control in both the crop rotations. However, zinc alone was not able to increase ACE protein in either of the crop rotations. Application of 10 t FYM/ha proved significantly superior over the application of 10 kg Zn/ha in either of the two crop rotations. Application of 10 t FYM/ha improved ACE protein by 3.65% and 5.83% as compared with the application of 10 kg Zn/ha in R-W-S and R-M-M rotation, respectively.

SR was analyzed with post-harvest soil of both the crop rotation and the value ranged from 0.58 mg/g/4days to 0.69 mg/g/4days in R-W-S and the value ranged from 0.46 mg/g/4days to 0.65 mg/g/4days in R-M-M cropping systems with increase in fertility levels. It was observed highest at highest fertility level *viz*; NPK 150% of RDF application. The magnitude of increase in soil respiration rate over control at the highest fertility level was 41.3% in R-M-M rotation and 18.9% in R-W-S rotation. Among the superimposed treatments, the maximum value for soil respiration was observed for the treatment receiving the conjoint application of both 10 kg Zn/ha and 10 t FYM/ha for both the crop rotations. However, the magnitude of increase over control was more in R-M-M rotation than R-W-S rotation. A percentage increase of 22.9 was observed in R-M-M rotation and for R-W-S rotation; it stood at 17.5% (Table 3a, Figure no. 1d**)**. The paired t-test statistics revealed that FYM alone or FYM with either 5 kg Zn/ha or 10 kg Zn/ha was significantly effective in increasing the soil respiration over control in both the crop rotations (Table 3b). Application of 10 t FYM/ha improved soil respiration by 12.0% and 7.84% as compared with the application of 10 kg Zn/ha in R-W-S and R-M-M rotation, respectively.

4. Discussion

4.1 Soil physical properties [Available water capacity (AWC) and Mean weight diameter (MWD)]

Soil loss between 10kPa and 1500 kPa pressure using pressure plate apparatus, (Reynolds *et al.*, 2008) [31] to find the available water capacity (AWC) and wet sieving aggregate mean weight diameter (MWD) of soil. Soil aggregate stability is ascribed by mean weight diameter (MWD) and data recorded showed a significant effect of organic nutrient management on MWD (Meena *et al.*, 2020) [21]. The reason for significant increment in values may be by the addition of FYM and Zn as well as use of DAP instead of SSP as P source with 100% NPK significantly increased aggregate MWD compared to 100% NPK. Aggregate MWD increased significantly with increase in fertilizer application rate from 50% to 100% NPK, but no change in MDW from further addition of fertilizer to 150% NPK and infiltration rate and aggregate MWD were greater with integrated use of FYM along with 100% NPK compared to non-treated control (Brar *et al.*, 2015) [5]. The addition of FYM and VC along with crop residues and biofertilizers resulted in better soil aggregation as compared to other treatments which showed a close relationship between organic matter status of soil and aggregation (Meena *et al.*, 2020) [21]. The contents of AWC and MWD comparatively more in RWS than RMM the reason may be due to the FYM and inorganic fertilizer applications might have resulted in higher SOM due to increased root biomass and acted as a binding agent improved the aggregate MWD (Haynes *et al.*, 1998) [11], in which RWS in combination contribute more root biomass soil than RMM, higher biomass accumulation, aggregate stability and MWD under NPK + FYM lead to greater soil organic carbon and nitrogen stabilization in aggregates. The FYM and inorganic fertilizer applications might have resulted in higher SOM due to increased root biomass and acted as a binding agent which improved the aggregate MWD. The higher MWD in organically amended soil had shown the addition of fresh organic residues (Hydrolysable and water-soluble substrates) and available carbon resulted in the production of microbial polysaccharides that increase aggregate cohesion and enhanced the microbial activity in these soils and thus increased binding of aggregates (Karami *et al.*, 2012; Mitran *et al.*, 2018) [14, 22]. Increase in aggregate MWD with the application of nitrogenous fertilizers has been reported by (Subbian, *et al.*, 2000). Application of 10 t FYM/ha improved MWD by 3.01% and 2.69% as compared with the application of 10 kg Zn/ha in R-W-S and R-M-M rotation, respectively. Application of NPK 100% + FYM significantly increased MWD, reduced infiltration rate (Brar *et. al*., 2015) [5]. It has been shown that the addition of organic fertilizers improved soil properties such as aggregation, total porosity, pore size distribution, resistance to water and wind erosion, and reduced the bulk density (BD) (Celik *et al.*, 2004) [6], paired t-test revealed that combine application of 10 kg Zn/ha with 10 t FYM/ha or 5 t FYM/ha and 10 t FYM/ha alone are found significant. The application of 10 kg Zn/ha alone was found to be not sufficient to increased AWC and MWD content therefore test value was non-significant in both R-W-S and R-M-M. The treatments in which FYM was combined the particular treatments produced significant results. The field application of FYM and Zn as well as use of DAP instead of SSP as P source with 100% NPK significantly increased aggregate MWD compared to 100% NPK., and also the aggregate MWD increased significantly with increase in fertilizer application rate from 50% to 100% NPK, however, there was no change in MDW from further addition of fertilizer to 150% NPK (Brar *et al.*, 2015) [5]. The application of organic manure increase organic carbon content in soil which in turn improves the soil physico-chemical properties such as soil porosity, water holding capacity, soil aggregation and decreased bulk density, infiltration rate, (Naresh *et al.*, 2017) [25]. The application of 10 t FYM/ha + 5 t FYM/ha was at par with 10 t FYM/ha, hence, 10 t FYM/ha would be batter in order to minimize the cost of production as well as to improve AWC and MWD in long-term agriculture. Therefore, the application 10 t FYM/ha proved to be the best choice in maintaining the MWD in long-term agriculture in minimizing production cost according to the result of present investigation and the similar findings by (Naresh *et al.*, 2017 and Bassouny *et al.*, 2016) [25, 3]. The (Jaiswal *et al.*, 2020) [12] also worked on soil water retention, they have suggested available AWC by pressure plate apparatus helps to see the availability of water in soil and with additional soil physical properties it can be used for scheduling irrigation. Application of inorganic with organic fertilizer, reduced bulk density, increased water retention capacity, macro aggregates and mean weight diameter, (Pant *et al.*, 2018) [29].

4.2 Active carbon (AC), Autoclave citrate extractable Protein (ACE) and Soil Respiration (SR)

Imbalanced fertilization may impact the physical, chemical, and biological attributes of soil quality in this system (Biswas *et al.*, 2017). Balance application of fertilizers in long term improves soil physical and biological attributes. Increase in active carbon (AC), autoclave citrate extractable (ACE) protein and Soil respiration (SR) content with increased in fertility seems to be due to larger accumulation of root biomass of crops, better soil physical and chemical environment. The decomposition of root biomass increased organic carbon content in the soil. Root contribute 24% of the total biomass of particular crop in general and has an advantageous role in the contribution of organic carbon to soil largely with particular crop choose for crop rotation in a season and their total carbon accumulation in soil where, shoots of crop plant are removed after the harvest (Mathew *et al.*, 2017) [20]. Therefore, it was observed that the increased in active carbon content since it is a labile fraction of organic carbon and readily available food source for microorganisms. Application of organic matter often leads to an increase in the activity of various enzymes in soil (Majhi *et al.*, 2021) [19] (Shahid *et al.*, 2013) [34]. Higher microbial respiration in 100% NPK + FYM treatment might be due to the favorable effect of FYM on bacterial population, FYM improves soil physical, chemical and biological properties. The long-term fertilizer nutrients and manure application also had a significant influence on basal respiration long-term application of manure influence SR (Liu. *et al.*, 2020) [16]. According to paired t test stats, the combined application of 10 kg Zn/ha with 10 t FYM/ha or 10 kg Zn/ha with 5 t/ha FYM found significant in AC, ACE protein and SR and the magnitude of increase in AC, AWC and SR was comparatively more in RWS than RMM. The fact attributes may the direct impact of FYM in organic carbon content in the soil basically AC, SR is directly related to the organic carbon content in the soil however, 10 kg Zn/ha alone found to be non-significant. This view is consistent with the observation of (Hao *et al.*, 2008) who observed that the microbial biomass was considerably greater in soils receiving farmyard manure along with NPK fertilizer than in plots receiving merely NPK fertilizer in three subtropical paddy soils. The experiments of (Sahoo *et al.*, 2019; Samal *et al.*, 2017), [32, 33] reported the comparative findings from their experiments. Majhi, (2017) [17], higher microbial respiration in 100% NPK + FYM treatment might be due to the favorable effect of FYM on bacterial population. The application of minerals NPK fertilizer with FYM improves carbon mineralization, readily extractable gomalin protein, and enzymatic activities in the soil (Choudhary *et al.*, 2021) [7]. The greater SR indicates a higher population of soil micro-organisms in the soil having high in organic matter. Tamilselvi *et al.*, (2015) [53] reported similar findings from their experiment conducted using integrated nutrient management (INM) with organic matter produced progressive result in terms of soil respiration. Minimum tillage with direct sowing of maize improved the protein content in the soil (Anna *et al.*, 2017) [1]. Continuous integrated uses of 100% NPK and 10 t FYM ha−1 over performed 100% NPK in terms of sustainability by improving the physical and biological properties of soil (Majhi *et al.*, 2019) [18].

Table 3a: Effect of long-term application of Zinc, FYM, NPK fertilizers and their combination on Soil AWC (cm^3/cm3), MWD (mm), AC (mg/kg), ACE (mg/g) & SR (mg CO_2/g soil/4 days), under R-W-S and R-M-M cropping system

Treat	10 kg Zn/ha		10 kg Zn/ha + 5 t FYM/ha		10 t FYM/ha		10 kg Zn/ha + 10 t FYM/ha		Control		Mean	
Available Water Capacity (AWC) cm^3/cm^3												
	RWS	RMM	RWS	RMM	RWS	RMM	RWS	RMM	RWS	RMM	RWS	RMM
Control	0.15	0.06	0.17	0.06	0.17	0.07	0.25	0.10	0.12	0.05	0.18	0.08
Low Fertility	0.25	0.12	0.31	0.14	0.28	0.13	0.53	0.24	0.21	0.10	0.34	0.16
Medium Fertility	0.48	0.23	0.53	0.25	0.52	0.25	0.60	0.28	0.44	0.21	0.53	0.26
High Fertility	0.52	0.25	0.55	0.27	0.56	0.27	0.65	0.34	0.52	0.25	0.57	0.28
Mean	0.35	0.17	0.39	0.18	0.38	0.18	0.50	0.24	0.32	0.15		
Mean Weight Diameter (MWD) mm												
Control	2.16	2.12	2.17	2.13	2.21	2.16	2.35	2.33	2.11	2.06	2.20	2.16
Low Fertility	2.42	2.36	2.54	2.48	2.48	2.42	3.08	3.03	2.31	2.26	2.57	2.51
Medium Fertility	2.99	2.93	3.09	3.04	3.09	3.02	3.25	3.20	2.90	2.84	3.06	3.00
High Fertility	3.08	3.03	3.17	3.14	3.17	3.11	3.49	3.42	3.09	3.03	3.20	3.14
Mean	2.66	2.61	2.74	2.70	2.74	2.68	3.04	2.99	2.60	2.54		

Active Carbon (AC) mg/kg												
Control	153.8	139.1	157.7	143.8	165.5	150.4	159.0	146.1	149.9	135.1	157.1	142.9
Low Fertility	183.2	167.9	210.6	195.8	194.5	179.0	221.7	207.5	177.6	164.4	197.5	182.9
Medium Fertility	226.6	210.4	247.6	233.1	229.6	213.3	255.8	241.1	221.7	207.5	236.2	221.1
High Fertility	245.4	228.9	260.8	246.0	252.5	235.9	272.1	257.1	228.1	213.5	251.7	236.2
Mean	202.2	186.5	219.2	204.67	210.5	194.6	227.1	212.95	194.3	180.1		
Autoclave Citrate Extractable Protein (ACE) mg/g												
Control	1.12	0.96	1.19	1.03	1.13	0.98	1.21	1.06	1.12	0.97	1.15	1.00
Low Fertility	1.37	1.21	1.38	1.23	1.46	1.31	1.46	1.29	1.34	1.17	1.40	1.24
Medium Fertility	1.43	1.26	1.48	1.32	1.50	1.34	1.57	1.42	1.39	1.23	1.48	1.31
High Fertility	1.55	1.38	1.58	1.44	1.61	1.46	1.64	1.49	1.48	1.34	1.57	1.42
Mean	1.37	1.20	1.41	1.25		1.27	1.47	1.32	1.33	1.18		
Soil Respiration (SR) mg CO_2/g soil/4 days												
Control	0.53	0.46	0.61	0.48	0.61	0.47	0.65	0.49	0.53	0.41	0.58	0.46
Low Fertility	0.54	0.46	0.62	0.53	0.62	0.50	0.65	0.58	0.54	0.45	0.60	0.50
Medium Fertility	0.59	0.51	0.66	0.53	0.66	0.54	0.67	0.57	0.57	0.51	0.63	0.53
High Fertility	0.65	0.61	0.71	0.67	0.71	0.68	0.73	0.70	0.65	0.57	0.69	0.65
Mean	0.58	0.51	0.65	0.55	0.65	0.55	0.67	0.59	0.57	0.48		

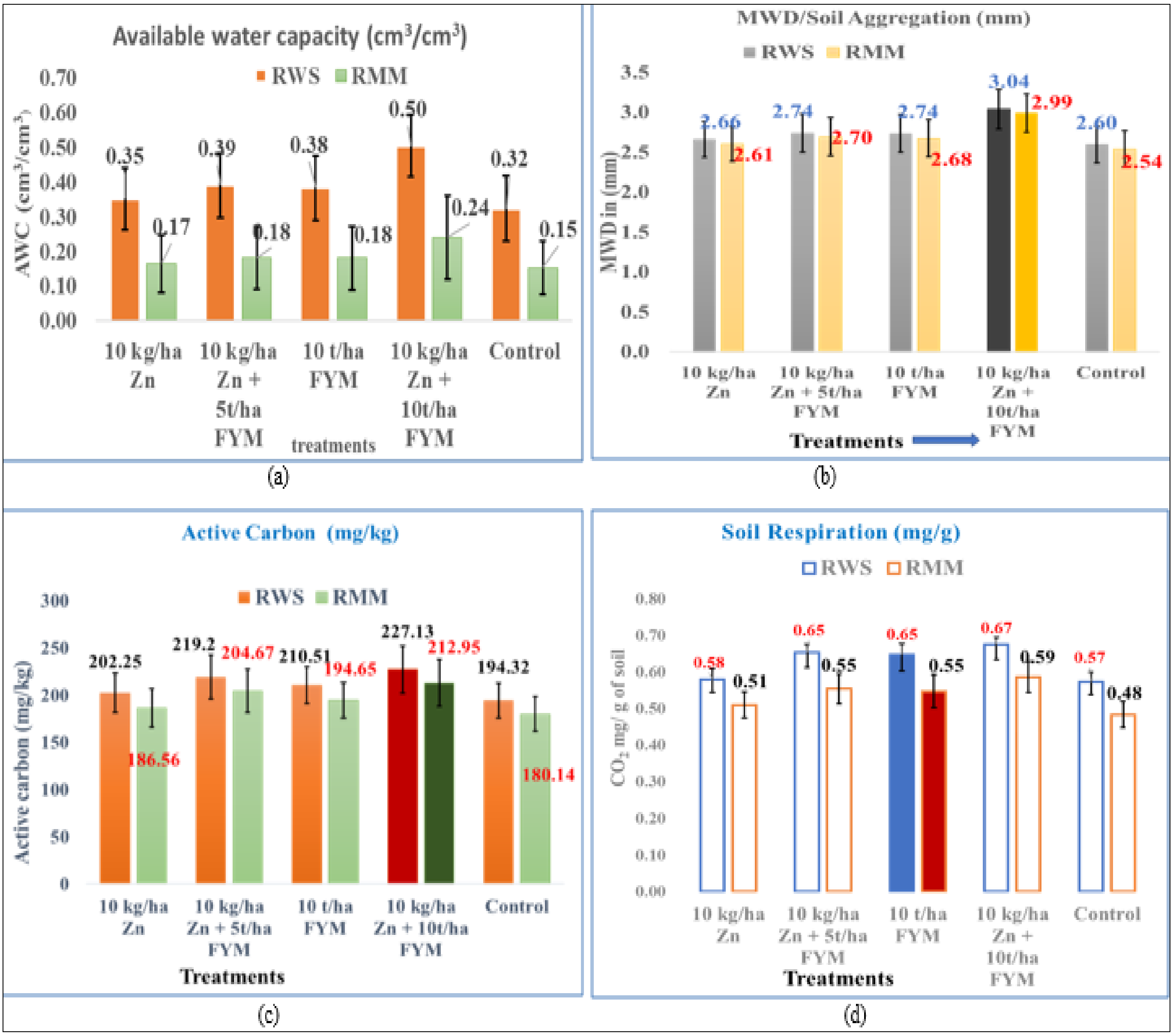

Fig 1: Effect of long-term application of Zn, FYM and their combination on AWC(a), MWD(b), AC(c) and SR(d), under R-W-S and R-M-M cropping systems

Table 3b: Paired t-test statistics for the effect of long-term application of Zinc, FYM and their combination on Soil AWC, MWD, AC, ACE, & SR, under R-W-S and R-M-M cropping system

SL. No.	Pair Member	AWC		MWD		AC		ACE		SR	
		t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.	t-value	Sig.
Rice-Wheat-Sorghum (RWS)											
1	Control – 10 kg Zn/ha	-2.52	0.086	-2.35	0.100	-2.54	0.085	-2.46	0.091	-1.13	0.340
2	Control – (10 kg Zn + 5t FYM/ha)	-4.84	0.017	-3.55	0.038	-4.20	0.025	-5.95	0.010	-11.62	0.001
3	Control – 10t FYM/ha	-5.99	0.009	-5.12	0.014	-4.79	0.017	-3.35	0.044	-4.34	0.023
4	Control – (10 kg Zn + 10t FYM/ha)	-4.21	0.024	-3.86	0.031	-3.98	0.028	-6.30	0.008	-18.27	0.000
5	10 kg Zn/ha – (10 kg Zn + 5t FYM/ha)	-4.05	0.027	-3.32	0.045	-3.40	0.043	-3.81	0.032	-11.88	0.001
6	10 kg Zn/ha – 10t FYM/ha	-6.35	0.008	-5.70	0.011	-4.03	0.027	-3.39	0.043	-4.09	0.026
7	10 kg Zn/ha – (10 kg Zn + 10t FYM/ha)	-3.86	0.031	-3.57	0.038	-3.54	0.038	-7.77	0.004	-10.02	0.002
8	(10 kg Zn + 5t FYM/ha) – 10t FYM/ha	1.75	0.178	0.30	0.781	1.48	0.236	-0.55	0.619	0.40	0.715
9	(10 kg Zn + 5t FYM/ha) – (10 kg Zn + 10t FYM/ha)	-3.37	0.043	-3.34	0.044	-3.43	0.042	-3.55	0.038	-3.71	0.034
10	10t FYM/ha – (10 kg Zn + 10t FYM/ha)	-3.16	0.051	-2.84	0.066	-2.11	0.125	-2.54	0.085	-1.55	0.218
Rice-Mustard-Moong (RMM)											
1	Control – 10 kg Zn/ha	-2.66	0.076	-2.82	0.067	-2.14	0.122	-2.49	0.088	-1.92	0.151
2	Control – (10 kg Zn + 5t FYM/ha)	-4.10	0.026	-4.29	0.023	-4.45	0.021	-6.96	0.006	-3.63	0.036
3	Control – 10t FYM/ha	-5.59	0.011	-5.40	0.012	-4.28	0.023	-3.34	0.044	-3.83	0.031
4	Control – (10 kg Zn + 10t FYM/ha)	-4.69	0.018	-4.11	0.026	-4.29	0.023	-6.05	0.009	-5.56	0.012
5	10 kg Zn/ha – (10 kg Zn + 5t FYM/ha)	-3.78	0.032	-3.39	0.043	-3.64	0.036	-4.49	0.021	-3.87	0.031
6	10 kg Zn/ha – 10t FYM/ha	-6.88	0.006	-5.95	0.010	-4.05	0.027	-3.69	0.034	-3.58	0.037
7	10 kg Zn/ha – (10 kg Zn + 10t FYM/ha)	-3.95	0.029	-3.73	0.034	-3.82	0.032	-6.73	0.007	-4.32	0.023
8	(10 kg Zn + 5t FYM/ha) – 10t FYM/ha	0.27	0.808	1.22	0.310	1.70	0.188	-0.58	0.603	0.78	0.495
9	(10 kg Zn + 5t FYM/ha) – (10 kg Zn + 10t FYM/ha)	-3.61	0.036	-3.42	0.042	-3.85	0.031	-3.83	0.031	-3.34	0.044
10	10t FYM/ha – (10 kg Zn + 10t FYM/ha)	-3.03	0.056	-3.15	0.051	-2.37	0.098	-1.82	0.166	-2.82	0.067

5. Conclusion

The combined application of 10 kg Zn/ha along with 10 t FYM/ha in alternate years proved best for the rice crop with respect to soil physical, biological qualities. The application of 10 kg Zn/ha alone or 10 t FYM/ha alone did not influence rice crop performance. However, better soil physical and biological properties were observed with the application of 10 t FYM/ha alone than 10 kg Zn/ha. As per the data of present investigation, the combine application of 10 kg Zn/ha with 10 t FYM/ha, significantly increased all the soil physical and biological parameters *viz*; Available water capacity, Mean weight diameter, Active carbon, Autoclave citrate extractable protein and Soil respiration. One of the notable findings from investigation was the application of NPK based fertilizer with FYM in long-term rice based cropping system positively influences soil physical and biological parameters. Inclusion of Zn based fertilizer in calcareous soil is beneficial in the long-term conventional agriculture to maintain Zn balance in the soil.

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