



# Impact of Integrated Nutrient Management on Soil Micronutrients and Organic Matter Dynamics in Maize-mustard Crop Rotation in Himalayan Foothills

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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## ABSTRACT

**Aims:** The purpose of this research is to investigate the effects of inorganic fertilizers and organic manures on availability of micronutrients and organic matter in soils of rainfed agriculture in foothills of Himalayas.

**Place and Duration of Study:** Present study was conducted at Advance Centre for Rainfed Agriculture (ACRA), Rakh Dhiansar, Jammu from 2020 to 2022.

**Methodology:** In a long-term field experiment, we investigated the effects of 10 treatments on soil micronutrients, organic matter and their correlation under rain fed agriculture. Randomized block design was used with three replications. Following are the treatments: T<sub>1</sub> - Control, T<sub>2</sub> - 100% RDF of N,P,K through chemicals, T<sub>3</sub> - 50% RDF of N,P,K through chemicals, T<sub>4</sub>- 50% RD of N through crop residue, T<sub>5</sub> - 50% RD of N through FYM, T<sub>6</sub> -50% RDF of N,P,K through chemicals + 50% RDF of N through crop residues, T<sub>7</sub>- 50% RDF of N,P,K through chemicals + 50% RD of N through FYM, T<sub>8</sub> - FYM @ 10 ton/ha, T<sub>9</sub> - 100% RDF of N,P,K through chemicals + Zinc Sulphate @ 20kg/ha and T<sub>10</sub> - Farmer practice (FYM @ 4 ton/ha + 40kg urea /ha).

The micronutrients (Fe, Zn, Cu and Mn) showed maximum increase with the application of organic manures along with inorganic fertilizers over control in both surface and sub surface layers of the soil. However, in the sub-surface soil, there was less availability of these nutrients than the surface layer of the soil. The available Zn content was found maximum in the treatment T<sub>9</sub> getting 100% NPK + ZnSO<sub>4</sub> @ 20kg/ha over control. The treatment T<sub>8</sub> with the application of FYM @ 10 ton/ha recorded highest content of soil organic matter in surface soil. Positive and significant correlations were observed between soil organic matter and the micronutrient content of the soil. The INM practices proved very beneficial for increasing the sustainability of soil.

**Keywords:** Rainfed agriculture; INM; soil fertility; micronutrients and organic matter.

## 1. INTRODUCTION

“Maize (*Zea mays L.*) is one of the most adaptable developing crops, able to thrive in a wide range of agro-climatic conditions. After rice and wheat, it is the third most significant cereal in India. It plays an essential role in global agriculture as a source of food and fodder, as well as in agro-industries. In 1950-51, India produced 1.73 million metric tonnes of maize, which has climbed to 34.6 million metric tonnes in 2022-23, an almost 16-fold increase in production. In India, maize makes up almost 9% of the country's food supply” (Anonymous.,2018). “On the other hand, Indian mustard is the country's most important oilseed crop. Mustard productivity in J&K is 6.98 qha<sup>-1</sup>. It accounts for 23% of total oilseeds area and 23% of the total oilseeds production of the country. Chemical fertilizers plays very important role in increasing the production of mustard but their imbalance use reduce the soil quality and productivity. Both crops are highly nutrient requiring and heavily deplete soil nutrients and moisture. Multiple nutritional deficits arise as a result of poor recycling of organic sources” (Kumar., 2008).

“Agriculture today is concerned with long-term sustainability. Imbalance use of inorganic fertilisers and lack of organic fertilization are the

related causal factors for decline of soil properties” (Beshir and Abdulkerim, 2017). “In order to boost and maintain crop yield and sustainability, there is a need for effective and efficient techniques to halt the process of nutrient mining by returning nutrients to the soil. Integrated nutrient management (INM) is an age-old method of supplying secondary and micronutrients in addition to basic nutrients to meet crop nutrient requirements through organic sources. In addition to having a positive influence on soil health, INM is effective in restoring and maintaining soil fertility, crop yield, preventing primary, secondary and micronutrient deficiencies, improving nutrient use-efficiency and economizing fertiliser use” (Singh et al., 2012). “To increase N usage efficiency, soil organic carbon, crop production, and soil health, integrated nutrient management strategies entails the use of green manure (GM), crop residues, farmyard manure (FYM) and bio-fertilizers are proposed” (Liu et al. 2005). But in case of rainfed area and semi-arid area in which agriculture is totally dependent on rainfall, integrated nutrient management take a longer period of time to show its effect on fertility of soil. It may be due to harsh conditions of these areas. But it shows positive effect on improvement in soil fertility and crop productivity in these areas also.

In the past, fertilizer research in our country was mostly focused on the nutritional needs of specific crops, but there has recently been a shift in research priorities from individual crops to cropping systems that incorporate residual effects. The addition of inorganic with organic materials speeds up the mineralization process by lowering the C:N ratio. Organic manure releases nutrients slowly and steadily, resulting in fewer losses and higher nutrient use efficiency, whereas inorganic fertilizer releases nutrients quickly, resulting in more losses and poorer fertilizer use efficiency. In light of this, the overall goal of this research was to find the best integrated nutrient management strategies for the rainfed area of Jammu in maize-mustard crop rotation.

## 2. MATERIALS AND METHODS

The trail region was in the Shivalik foothills of Jammu and Kashmir at 32°39' North latitude and 74°53' East longitude. with an elevation of 332 m above mean sea level, it is a sub-tropical rainfed area. The field experiment was conducted at of Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST), Jammu's Advance Centre for Rainfed Agriculture (ACRA), Rakh Dhiansar. The soil in the experimental region is alluvial with a sandy loam texture. In terms of soil taxonomy, the soil in the experimental region belongs to entisols order. In reaction, it is mildly acidic to neutral. The climatic conditions of the test site were sub-tropical in nature. The first summer is dry and hot, followed by a humid, hot monsoon and cold winter. The average low and high temperatures show significant fluctuations during the summer and winter seasons. During the months of May and June, temperatures often rise to 45 ° C and lower to 2 ° C at least in December and January winter. The average annual rainfall is between 1050 and 1115 mm, with about 75% dropping between June and September. Total rainfall and its distribution, on the other hand, vary widely.

The experiment was laid out in randomized block design with three replications. There were ten treatments used in this experiment which are following: T<sub>1</sub> - Control, T<sub>2</sub> - 100% RDF of N,P,K through chemicals, T<sub>3</sub> - 50% RDF of N,P,K through chemicals, T<sub>4</sub>- 50% RD of N through crop residue, T<sub>5</sub> - 50% RD of N through FYM, T<sub>6</sub> -50% RDF of N,P,K through chemicals + 50% RDF of N through crop residues, T<sub>7</sub>- 50% RDF of N,P,K through chemicals + 50% RD of N through FYM, T<sub>8</sub> - FYM @ 10 ton/ha, T<sub>9</sub> - 100% RDF of N,P,K through chemicals + Zinc Sulphate @

20kg/ha and T<sub>10</sub> - Farmer practice (FYM @ 4 ton/ha + 40kg urea /ha). The plot size was 5m x 3m and replicated three times. All agricultural management practices were followed during the growing season for both maize and mustard crops. The application of RDF fertilizer is done on each plant in rotation. The application of half the amount of nitrogen and the full amount of P and K fertilizer is done during sowing of maize and mustard. The remaining amount of nitrogen was used as a top dressing for both plants. FYM @ 10 t ha<sup>-1</sup> was applied before 15 days of sowing in the ground. After harvesting, the maize stalks were removed from the field to facilitate the planting of the next mustard crop. After the completion of the rotation of maize and mustard crops, soil samples were taken at two depths of 0-15cm and 15-30cm in small polythene bags. These samples were then analyzed to determine chemical properties of soil.

### 2.1 Methods Employed for Analysis

"Micronutrients were determined in the soil samples of experimental field by atomic absorption spectrophotometer method after extraction by DTPA" (Lindsay and Norvell, 1978). Different wavelengths were used for estimation of different micronutrients. Soil organic matter is calculated by estimating the soil organic carbon by the method of walkley and Black, 1934.

## 3. RESULTS

### 3.1 Available Iron

The various treatments of INM had made significant changes in the status of available iron in the surface layer(0-15cm) of soil after harvest of mustard crop as shown in the Table 1. The highest value of available iron(20.73 µg g<sup>-1</sup>) was obtained with the application of 50% RDF of N,P,K through chemicals + 50% RD of N through FYM(T<sub>7</sub>). It was at par with the treatments T<sub>6</sub>(20.33 µg g<sup>-1</sup>) receiving 50% RDF of N,P,K through chemicals + 50% RD of N through crop residues) and T<sub>8</sub>(19.50 µg g<sup>-1</sup>) receiving FYM @ 10 ton/ha. Substitution of 50% RD of N through crop residue in treatment T<sub>4</sub> and 50% RD of N through FYM in treatment T<sub>5</sub> were found to be at par with each other but these treatments recorded significantly superior values of available iron over treatments T<sub>2</sub>(16.03 µg g<sup>-1</sup>) and T<sub>9</sub>(16.20 µg g<sup>-1</sup>) in which only chemical fertilizers were used. The lowest available iron (13.43 µg g<sup>-1</sup>) was recorded in treatment T<sub>1</sub>(control) which was found to be statistically at

par with treatment T<sub>3</sub>(15.70  $\mu\text{g g}^{-1}$ ) receiving 50% RDF of N,P,K through chemicals.

In the sub-surface layer(15-30cm) of soil, the available iron at harvest of mustard crop was on the lower side as compared to surface layer(0-15cm) of soil in all the treatments but the trend was similar in both the layers (Table 1).

### 3.2 Available Zinc

At harvest of mustard crop, significant changes in the available zinc content were observed in the soil as shown in the Table 1. Available zinc status of surface soil under all the treatments remained above it's critical level in soil. In the surface layer(0-15cm) of soil, the treatment T<sub>9</sub>(100% RDF of N,P,K through chemicals + Zinc Sulphate @ 20 kg/ha) had recorded greatest value of available zinc(1.37  $\mu\text{g g}^{-1}$ )among all the treatments. It was at par with treatments T<sub>6</sub>(1.24  $\mu\text{g g}^{-1}$ ) comprising of 50% RDF of N,P,K through chemicals + 50% RD of N through crop residues and T<sub>8</sub>(1.25  $\mu\text{g g}^{-1}$ ) comprising of FYM @ 10 ton/ha. Addition of 50% of N through organic amendments(crop residues or FYM) in treatments T<sub>4</sub> and T<sub>5</sub> recorded superior values of available zinc (1.16  $\mu\text{g g}^{-1}$ ) and (1.04  $\mu\text{g g}^{-1}$ ), respectively over the treatments T<sub>2</sub>(0.97  $\mu\text{g g}^{-1}$ ) and T<sub>3</sub>(0.94  $\mu\text{g g}^{-1}$ ) in which only chemical fertilizers were applied. The lowest value of available zinc(0.90  $\mu\text{g g}^{-1}$ ) was recorded in treatment T<sub>1</sub>(control).

In the sub-surface layer(15-30cm) of soil, the available zinc showed same trend as in the surface layer(0-15cm) but the values were lower as compared to surface layer(0-15cm).The status of available zinc in the sub-surface layer(15-30cm) of soil in treatments T<sub>1</sub>, T<sub>2</sub>and T<sub>3</sub> were below critical level where as in all other treatments it was above critical level.In the sub-surface layer(15-30cm), the available zinc declined as compared to surface layer of soil.

### 3.3 Available Copper

Data depicted in Table 2 revealed significant effect of various treatments of INM on the status of available copper in the surface layer(0-15cm) of soil after the harvest of mustard. In the surface layer(0-15cm) of soil, available copper content ranged from 0.66  $\mu\text{g g}^{-1}$  to 0.87  $\mu\text{g g}^{-1}$  in various treatments of organic and inorganic fertilizers. The maximum content of available copper(0.87  $\mu\text{g g}^{-1}$ ) in soil was observed under the treatment(T<sub>7</sub>) receiving 50% RDF of N,P,K through chemicals + 50% RD of N through FYM which was significantly higher than that under control(T<sub>1</sub>). However, it(T<sub>7</sub>) was at par with all other treatments indicating positive effect of use of organics or inorganics separately or in combination on available Cu in the soil. The lowest available copper content was found in the treatment T<sub>1</sub> in which no nutrient source was applied.

**Table 1. Long-term effect of INM on available iron and zinc in soil**

Treatments	Available Fe ( $\mu\text{g g}^{-1}$ )		Available Zn ( $\mu\text{g g}^{-1}$ )	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T <sub>1</sub> Control	13.43	12.07	0.90	0.46
T <sub>2</sub> 100% RDF of N,P,K through chemicals	16.03	14.27	0.97	0.57
T <sub>3</sub> 50% RDF of N,P,K through chemicals	15.70	12.63	0.94	0.53
T <sub>4</sub> 50% RD of N through crop residue	17.73	14.87	1.16	0.72
T <sub>5</sub> 50% RD of N through FYM	18.50	16.20	1.04	0.67
T <sub>6</sub> 50% RDF of N,P,K through chemicals + 50% RD of N through Crop residues	20.33	16.93	1.24	0.89
T <sub>7</sub> 50% RDF of N,P,K through chemicals + 50% RD of N through FYM	20.73	18.43	1.21	0.87
T <sub>8</sub> FYM @ 10 ton/ha	19.50	16.70	1.25	0.94
T <sub>9</sub> 100% RDF of N,P,K through chemicals + Zinc Sulphate @ 20 kg/ha	16.20	15.27	1.37	0.94
T <sub>10</sub> Farmer practice (FYM @ 4 ton/ha + 40kg urea /ha)	16.05	14.15	1.02	0.65

In the sub-surface layer(15-30cm) of soil, same trend was observed in case of available copper but the values were on lower side as compared to surface layer(0-15cm). In the sub-surface layer(15-30cm), the treatment T<sub>7</sub> had significantly highest available copper(0.78 µg g<sup>-1</sup>) but it was statistically at par with the treatments T<sub>5</sub>(0.59 µg g<sup>-1</sup>), T<sub>6</sub>(0.62 µg g<sup>-1</sup>) and T<sub>8</sub>(0.73 µg g<sup>-1</sup>). However, the lowest value of available copper(0.39 µg g<sup>-1</sup>) was recorded in the treatment T<sub>1</sub>(control).

### 3.4 Available Manganese

Various combination of INM treatments significantly influenced the availability of manganese in the soil (Table 2). The treatment T<sub>8</sub> with the application of FYM @ 10 ton/ha recorded highest content of available manganese(23.37 µg g<sup>-1</sup>) in surface soil which was statistically at par with the treatments T<sub>7</sub> comprising of 50% RDF of N,P,K through chemicals + 50% RD of N through FYM and T<sub>6</sub> comprising of 50% RDF of N,P,K through chemicals + 50% RD of N through crop residues. The lowest available manganese (12.57 µg g<sup>-1</sup>) was recorded in treatment T<sub>1</sub>(Control) which was found to be at par with the treatment T<sub>10</sub>(15.30 µg g<sup>-1</sup>) comprising of FYM @ 4 ton/ha + 40kg urea/ha(Farmer practice).

In the sub-surface layer(15-30cm), there was reduction in the available manganese but pattern similar to that obtained in surface layer. In the sub-surface layer(15-30cm) of soil, the maximum available manganese(16.93 µg g<sup>-1</sup>) was recorded in treatment T<sub>8</sub> which was at par with the treatment T<sub>7</sub>(15.73 µg g<sup>-1</sup>). The lowest available manganese(6.90 µg g<sup>-1</sup>) was recorded in

treatment T<sub>1</sub>(Control) which was statistically at par with the treatment T<sub>10</sub>(8.27 µg g<sup>-1</sup>) receiving FYM @ 4 ton/ha + 40kg urea /ha(Farmer practice).

### 3.5 Soil Organic Matter

The organic carbon content (Table 2) in the surface layer(0-15cm) of soil was improved significantly with the application of different integrated nutrient treatments. In the surface layer(0-15cm) of soil, among all the treatments, the maximum accumulation of organic carbon(4.70 g kg<sup>-1</sup>) content was observed with the application of FYM @ 10 ton/ha in treatment T<sub>8</sub> which was found to be statistically at par with the treatment T<sub>7</sub>(4.1 9g kg<sup>-1</sup>) receiving 50% RDF of N,P,K through chemicals + 50% RD of N through FYM but superior to rest of the treatments. The treatment T<sub>6</sub> (50% RDF of N,P,K through chemicals + 50% RD of N through crop residues) showed higher build-up of organic carbon(3.58g kg<sup>-1</sup>) as compared to the application of 50% RD of N through crop residue in treatment T<sub>4</sub>(2.92g kg<sup>-1</sup>) and application of 50% RD of N through FYM in treatment T<sub>5</sub>(2.41g kg<sup>-1</sup>). The lowest amount of organic carbon(1.34 g kg<sup>-1</sup>) was recorded in treatment T<sub>1</sub>(control) plot which was statistically at par with the treatment T<sub>2</sub>(2.13g kg<sup>-1</sup>) receiving 100% RDF of N,P,K through chemicals, T<sub>3</sub>(1.95g kg<sup>-1</sup>) receiving 50% RDF of N,P,K through chemicals, T<sub>9</sub>(2.21g kg<sup>-1</sup>) receiving 100% RDF of N,P,K through chemicals + Zinc Sulphate @ 20 kg/ha and T<sub>10</sub>(1.87g kg<sup>-1</sup>) receiving FYM @ 4 ton/ha + 40kg urea /ha(Farmer practice).

**Table 2. Long-term effect of INM on available copper and manganese in soil**

Treatments	Available Cu (µg g <sup>-1</sup> )		Available Mn (µg g <sup>-1</sup> )		Soil Organic Matter(%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
	T <sub>1</sub> Control	0.66	0.39	12.57	6.90	0.23
T <sub>2</sub> 100% RDF of N,P,K through chemicals	0.73	0.44	17.33	10.37	0.37	0.32
T <sub>3</sub> 50% RDF of N,P,K through chemicals	0.73	0.41	15.97	8.67	0.34	0.28
T <sub>4</sub> 50% RD of N through crop residue	0.83	0.52	20.20	13.30	0.50	0.35
T <sub>5</sub> 50% RD of N through FYM	0.84	0.59	19.76	11.23	0.41	0.34
T <sub>6</sub> 50% RDF of N,P,K through chemicals + 50% RD of N through Crop residues	0.84	0.62	22.17	13.73	0.62	0.43
T <sub>7</sub> 50% RDF of N,P,K through chemicals + 50% RD of N through FYM	0.87	0.78	22.40	15.73	0.72	0.46
T <sub>8</sub> FYM @ 10 ton/ha	0.84	0.73	23.37	16.93	0.81	0.51
T <sub>9</sub> 100% RDF of N,P,K through chemicals + Zinc Sulphate @ 20 kg/ha	0.77	0.48	19.10	10.70	0.38	0.33
T <sub>10</sub> Farmer practice (FYM @ 4 ton/ha + 40kg urea /ha)	0.80	0.50	15.30	8.27	0.32	0.25

In the sub-surface layer(15-30cm) of soil, the lower organic carbon content was recorded than that in surface layer(0-15cm), but the trend was same among all the treatments in both the layers of the soil. The highest value of organic carbon ( $2.98 \text{ g kg}^{-1}$ ) was recorded in the treatment  $T_8$  which was at par with the treatments  $T_6$ ( $2.50 \text{ g kg}^{-1}$ ) and  $T_7$ ( $2.66 \text{ g kg}^{-1}$ ). The application of 50% N through crop residue in treatment  $T_4$ ( $2.03 \text{ g kg}^{-1}$ ) and 50% N through through FYM in treatment  $T_5$ ( $1.97 \text{ g kg}^{-1}$ ) showed superior values of organic carbon than that under sole application of 100% NPK through chemicals in treatment  $T_2$ ( $2.13 \text{ g kg}^{-1}$ ). The Treatment  $T_1$ (control) recorded lowest organic carbon ( $0.93 \text{ g kg}^{-1}$ ) in sub-surface soil layer.

## 4. DISCUSSION

### 4.1 Available Iron

The significant changes in available iron were observed under various treatments of INM in the soil. "The treatment receiving 50% organic amendments along with 50% inorganic fertilizers recorded highest accumulation of available iron in the surface soil. Addition of organic only recorded higher content of available iron in soil as compared to use of inorganics only. The conjoint application of organic and inorganic sources of nutrients increased available iron, reason that the organic acids that are released during the mineralization of FYM makes organic chelates leading to prevention of adsorption, fixation and precipitation of iron and solubilization of the already precipitated iron in the soil" (Selvi et al. 2003; Parven et al. 2020). Walia et al., 2010 also reported "maximum increase in available iron with the incorporation of 100% NPK through chemicals + 50% N through FYM in rice wheat cropping system". Mann et al.,(1978) also observed "an increase in available iron with the application of FYM only in soil. The lowest available iron( $13.43 \mu\text{g g}^{-1}$ ) was recorded under control because there was no addition of nutrient sources and continuous cropping. In the sub-surface layer of soil, the quantity of available iron was low as compared to surface soil. This might be due to the fact that lower accumulation of the SOM in sub-surface soil resulted in less organic chelates". Kher (1993) also noted depth wise reduction in available iron under maize wheat cropping system.

### 4.2 Available Zinc

The application of 100% RDF of N,P,K through chemicals along with zinc sulphate @ 20 kg/ha in

the treatment  $T_9$  significantly increased the available zinc in the soil over other treatments. Meshram et al., (2016) also reported that the application of 100% NPK with Zn considerably raised the levels of available zinc in the soil. "The application of crop residues along with inorganic sources of nutrients in treatment  $T_6$  and only FYM in treatment  $T_8$  also contributed to the increase in zinc content in the soil. This might be due to the improvement in zinc mobilization and prevention of fixation of zinc by the process of complexation" (Banerjee et al. 2011; Walia et al. 2010). No any marked difference in the available zinc content in the soil was found in treatments in which only inorganic fertilizers were applied. These results were in line with the findings of Parven et al., (2020). The lowest available zinc was found in the treatment  $T_1$  in which continuous cropping without any addition of fertilizer depleted the available zinc and reduced its amount from the soil. In the sub-surface layer(15-30cm), the available zinc declined as compared to surface layer of soil. This might be due to low SOM in sub-surface soil resulting in less complexation, less mobilization of zinc but more fixation of zinc in the soil.

### 4.3 Available Copper

The available copper was significantly influenced under various treatments of integrated nutrient management. The maximum content of available copper in soil was observed under the treatment( $T_7$ ) receiving 50% RDF of N,P,K through chemicals + 50% RD of N through FYM which was significantly higher than that under control( $T_1$ ). "The increase in available copper in  $T_7$  may be ascribed to increase in SOM with the addition of FYM along with chemical fertilizers. As the SOM increases, the organic chelates also increase in the soil that prevents the fixation, precipitation and adsorption of the copper ions and enhances the solubilization of already present copper content in the soil by making it in the available form" (Walia et al. 2010; Dhaliwal et al. 2019; Mali et al. 2014). Prasad and Sinha (2000) also observed "the positive increase in available copper with the addition of different levels of fertilizers along with organic manures. In the sub-surface layer(15-30cm), the available copper was reduced as compared to surface layer that might be due to the lower SOM at this depth". The lowest SOM led to more fixation and adsorption of copper content in the soil. The findings of Kumar et al., (1996) were in agreement with our results.

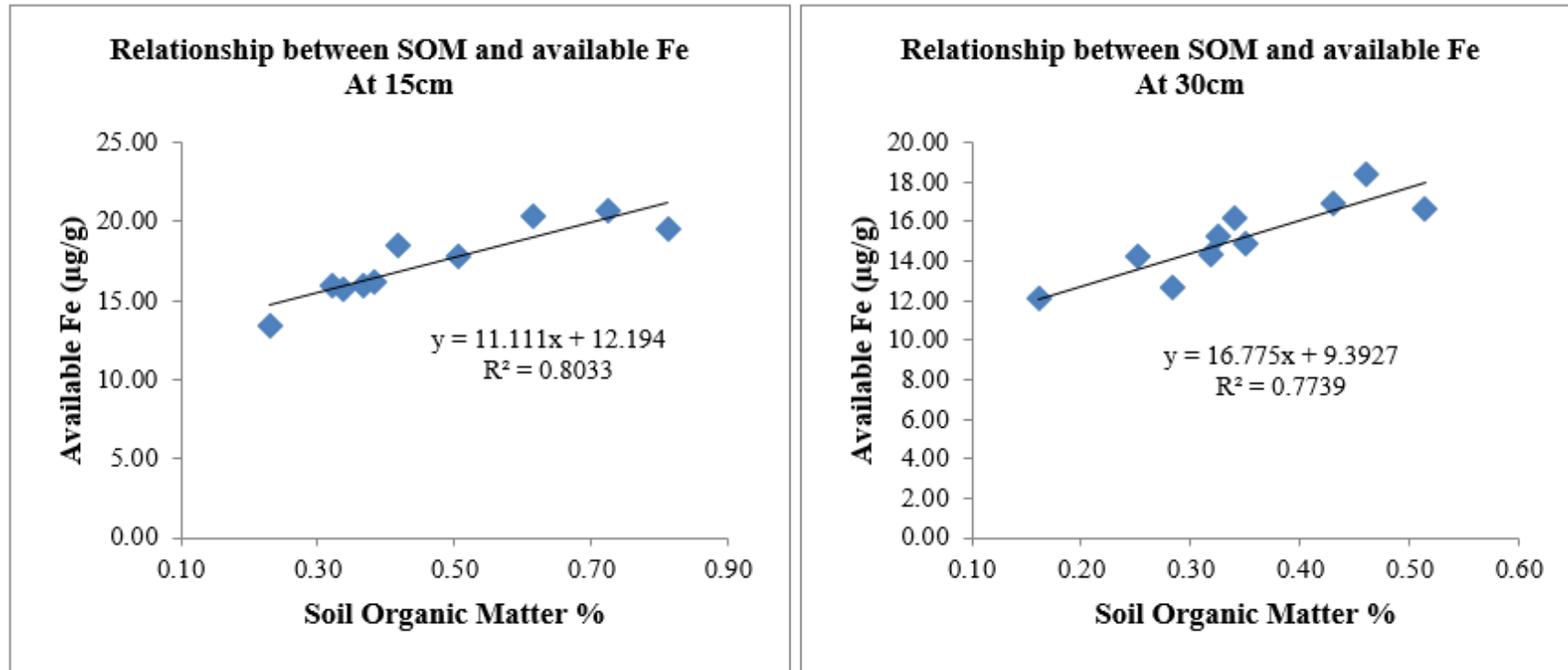


Fig. 1. Relationship between soil organic matter and available iron in surface and sub- surface layer of soil

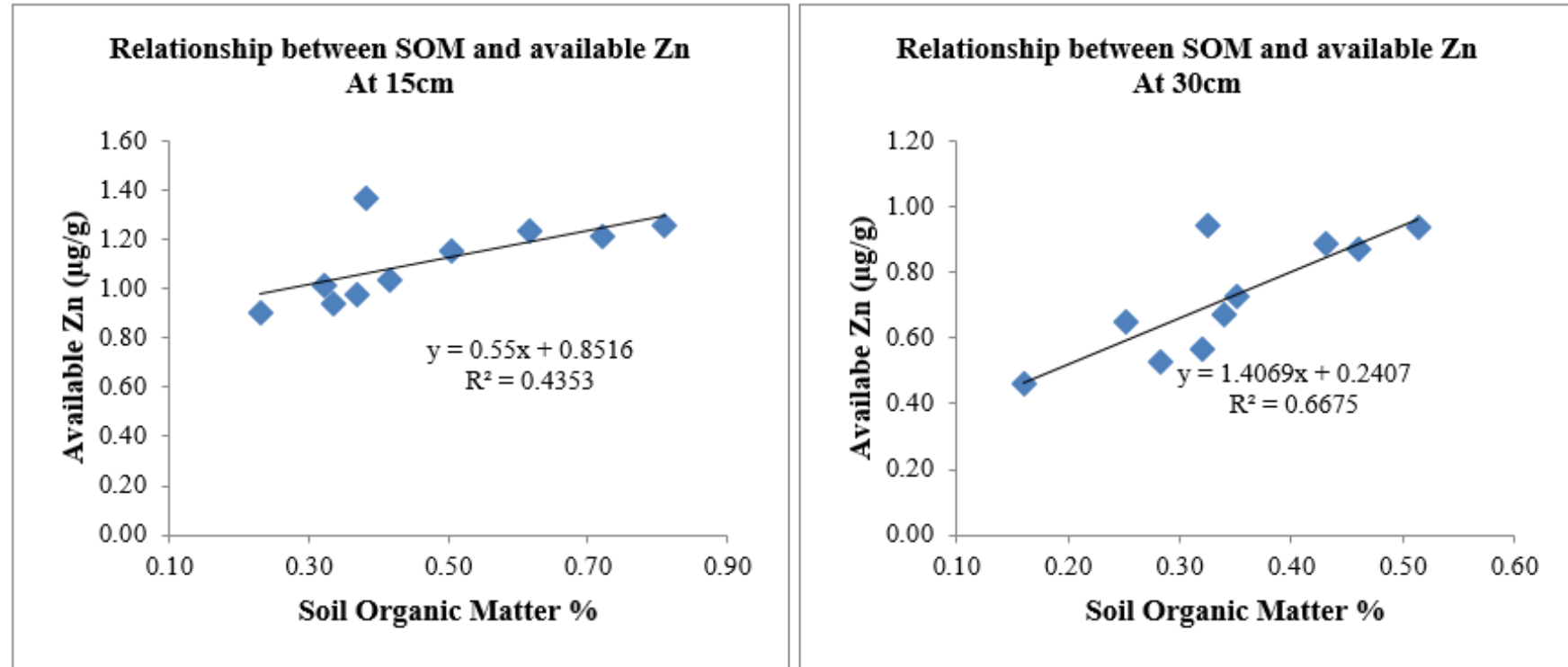


Fig. 2. Relationship between soil organic matter and available zinc in surface and sub- surface layer of soil

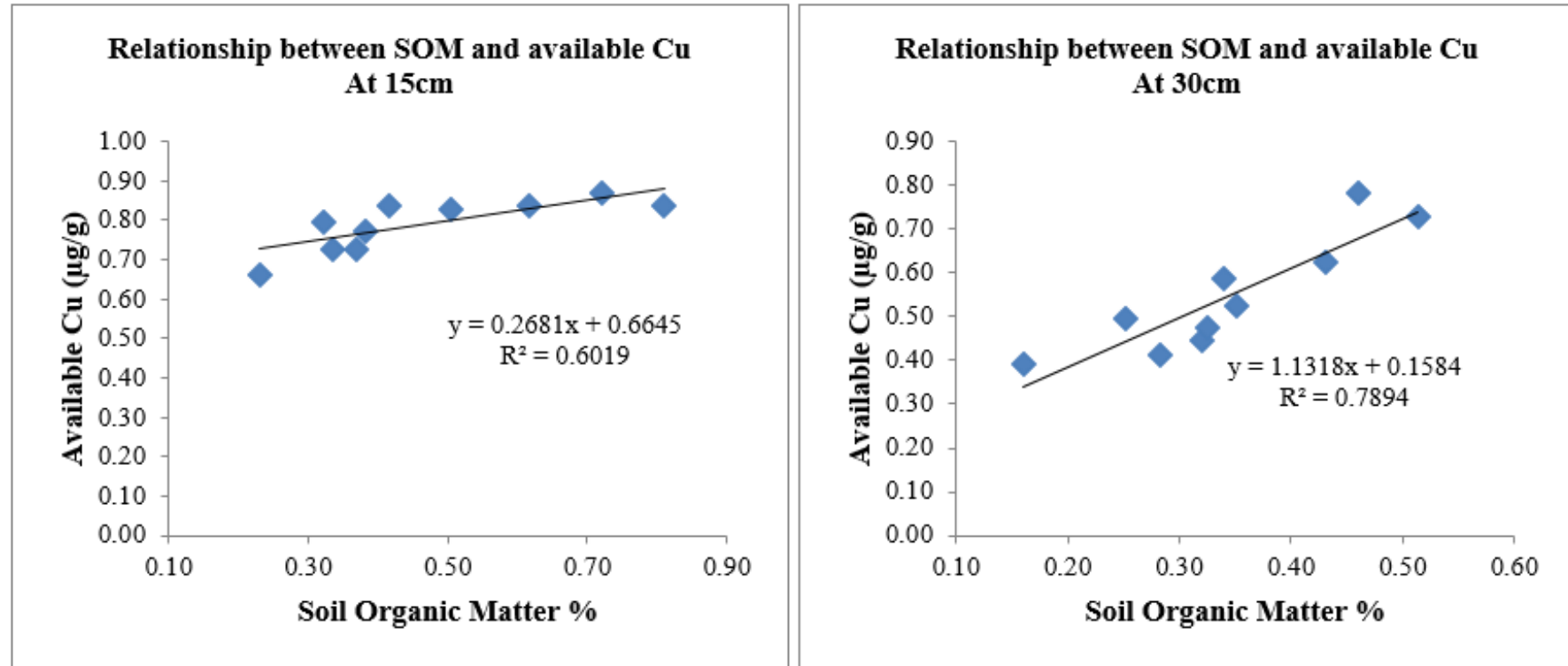


Fig. 3. Relationship between soil organic matter and available copper in surface and sub- surface layer of soil

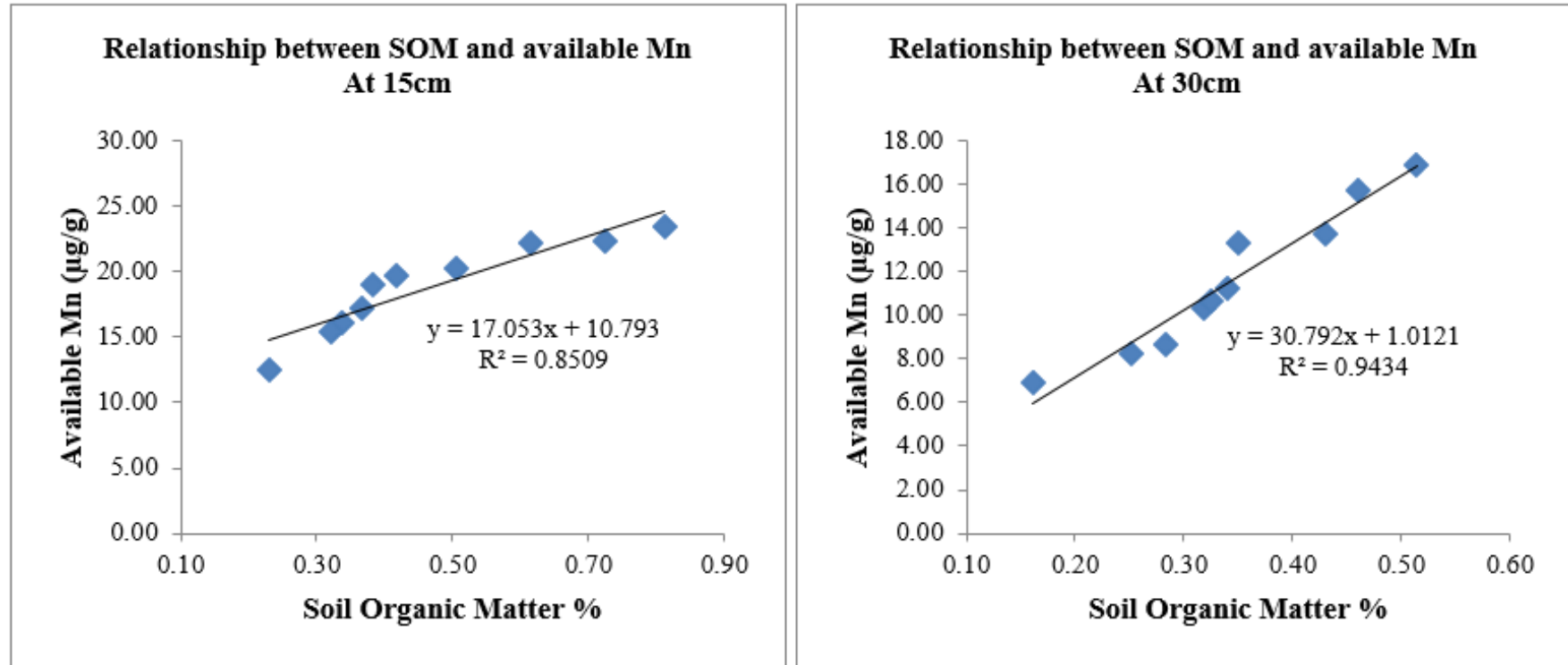


Fig. 4 Relationship between soil organic matter and available manganese in surface and sub- surface layer of soil

#### 4.4 Available Manganese

Various combination of INM treatments significantly influenced the availability of manganese in the soil. The treatment T<sub>8</sub> with the application of FYM @ 10 ton/ha recorded highest content of available manganese in soil which was statistically at par with the treatments T<sub>7</sub> comprising of 50% RDF of N,P,K through chemicals + 50% RD of N through FYM and T<sub>6</sub> comprising of 50% RDF of N,P,K through chemicals + 50% RD of N through crop residues. There was no marked difference in available manganese in soil in treatments T<sub>8</sub>, T<sub>7</sub> and T<sub>6</sub>. "The higher available manganese content in soil under these treatments might be due to chelating action of organic manures. During the decomposition of organic manures, many organic acids released reduces the fixation and adsorption of manganese by making complexes with clay and other compounds. Also increased SOM under these treatments help in solubilization of fixed manganese in the soil" (Walia et al. 2010; Dhaliwal et al. 2019; Mali et al.2014). Similar results were observed by Lal and Mathur (1989). The lowest available manganese(12.57 µg g<sup>-1</sup>) in soil was found in the treatment T<sub>1</sub> due to no addition of any organic or inorganic source in the soil. This might be due to less SOM and less complexation process at this depth. These results were in confirmation with the findings of Singh et al., (1990).

#### 4.5 Soil Organic Matter

Application of FYM alone @ 10ton/ha(T<sub>8</sub>) or use of 50% RD of NPK through chemicals and rest of N through crop residues/FYM recorded appreciable increase in O.C as compared to all other treatments. The maximum accumulation of O.C was observed in treatment T<sub>8</sub> receiving FYM@ 10ton/ha which was significantly higher as compared to rest of treatments except T<sub>7</sub> receiving 50% RDF of NPK through chemicals along with 50% N through FYM. The decomposition and mineralization of organic manures induced higher accumulation of SOC(Walia et al. 2010; Prakash et al. 2007; Das et al. 2016). Bhattacharyya et al., 2010 also reported that the soil treated with FYM+NPK recorded higher organic carbon over the soil treated with NPK alone. Similar results were also reported by Hati et al., (2006). The lowest SOC was observed in the treatment T<sub>1</sub> control which might be due to continuous cropping without any addition of organic manures that

results in the depletion of SOC(Manna et al., 2006). In the sub-surface layer(15-30cm), the SOC content decreases but the pattern was similar as in the surface layer. The lower SOC in the sub-surface layer might be due to less SOM as compared to surface layer of soil. These results were in agreement with the findings of Ghosh et al., (2017).

### 5. RELATIONSHIP STATUS BETWEEN SOIL PROPERTIES AND SOIL ORGANIC MATTER

In both the surface and sub-surface layers of soil, a positive and significant correlation was found between the micronutrients Fe (Fig. 1), Zn (Fig. 2), Cu (Fig. 3) and Mn (Fig. 4) and soil organic matter. Bhatt et al., (2017) also reported the same findings in his study.

### 6. CONCLUSION

From the present investigation, it is concluded that the long term INM practices shows great potential in increasing the fertility of the soil in rainfed areas. The addition of different treatments of INM enhanced the chemical properties of the soil. The availability of micro (Fe, Zn, Cu, Mn) nutrients and soil organic matter increased with the substitution of only organic manures or conjointly with inorganic fertilizers in both surface and sub surface layers of soil over control. However, in the subsurface soil, there was less improvement in chemical properties as compared to the surface layer of the soil. This might be due to less accumulation of SOM in the sub-surface layer than the surface layer. The maximum increase in available zinc was found with the application of zinc sulphate @20kg/ha along with 100% NPK in the soil. Positive and significant correlations were observed between soil organic matter and the nutrient content of the soil. Thus, this study signified that the integrated use of chemical fertilizers and manures are ecological important for increasing the soil sustainability and fertility in maize mustard crop rotation under rainfed agriculture.

### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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