



# Influence of Integrated Nitrogen Management on Release Pattern of Zn, Fe, Mn and Cu under Different Soil Moisture Regimes

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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

A two-year incubation experiment (2015-2016 and 2016-2017) was conducted at College of Agriculture, CAU, Imphal - 04 to ascertain the effect of integrated nitrogen management on release patterns of nutrients overtime at different moisture regimes in soils. The experiment consisted of 12 treatments with three different soil moisture regimes: 40%, 60%, and 80% water-holding capacity. The Incubation study was conducted by discard method and the experiment was conducted in FRBD. Soil samples were collected at 30-day intervals to assess DTPA-extractable micronutrients. Analysis of the data of incubation study revealed that irrespective of different treatments, accumulation of available Fe and Mn gradually increased up-to 60<sup>th</sup> day of incubation, thereafter continued to decrease slowly up to the last stage of incubation. Comparatively, greater accumulation DTPA-extractable Zn, Cu was also observed at 60 % WHC followed by 40% and 80% WHC at different stages of incubation. Among the treatments, significantly higher concentration of available Zn and Mn was observed in T<sub>11</sub> followed by T<sub>6</sub>. Further, the data pointed out that statistically higher accumulation of DTPA extractable Cu in soil was perceived in T<sub>4</sub> followed by T<sub>11</sub> throughout the incubation period. The results indicate that Integrated Nitrogen management, particularly with moisture (60% WHC) and organic amendments will improve the soil availability potential of the micronutrients. They should be incorporated with organic & inorganic nutrient sources while managing soil moisture levels under integrated nitrogen management, to find better availability of micronutrients and improve uptakes, performance and long-term fertility of soils.

*Keywords: Integrated nitrogen management; WHC; moisture regime; DTPA – extractant; micronutrients.*

## 1. INTRODUCTION

Application of organic wastes as a source of organic matter is a common practice to improve soil properties (Baran, 2001). Distribution of trace elements between soil and solution is the key to evaluate the environmental impact of the metals. So, the efficient management of micronutrients (Zn, Fe, Mn and Cu) is vital to sustain the productivity of different crops and to maintain a healthy balance of nutrients in soils.

When organic materials are added to the soil mineralization to release nutrients slowly and the rate of nutrient mineralization increases as the plant grows. As the plant matures, it is expected that a good soil would have released adequate nutrients for optimum plant growth (Lekasi et al. 2005). Organic matter is an important secondary source of trace elements in soil. Most micronutrients are held tightly in complex organic compounds and may not be readily available to plants. However, they can be an important source of micronutrients when they are slowly released into a plant available form as organic matter decomposes (Choudhary et al. 2008)

However, limited information is available in Imphal, Manipur on how integrated Nitrogen Management influences the release patterns of micronutrients under varying soil moisture

regimes, especially over time during incubation. Understanding these dynamics is important to optimize nutrient availability and improve soil fertility. Therefore, this study aims to investigate the effect of integrated nitrogen management on the release patterns of micronutrients (Zn, Fe, Mn, and Cu) in soils subjected to different moisture levels. Soil samples were periodically collected and analyzed on 0th, 30th, 60th, and 90th days of incubation to determine nutrient release patterns under these conditions.

## 2. MATERIALS AND METHODS

An acid soil having the physico-chemical properties as presented in Table 1 was collected from the research field of College of Agriculture, CAU, Imphal, by taking several thin slices from the surface soil layer (0-20 cm) as outlined by Jackson (1973). Soil texture, pH, EC, Organic carbon, cation exchange capacity (CEC), available N,P,K and DTPA extractable - Zn, Fe, Mn, Cu were also determined following the standard procedure described by Jackson (1973); Lindsay and Norvell (1978).

The composite soils were air dried in shade, ground and passed through 2 mm sieve. The processed soils were stored in polyethylene bags and used for the experiment. Hundred grams of air dried soil was taken in each of a series of 100

mL beakers. Urea, Vermicompost and *Azolla* equivalent to the recommended dose of nitrogen for rapeseed-mustard were mixed thoroughly with the soil according to different treatments. *Azotobacter* was applied @ 2 kg per acre. Soils of each treatment were moistened to three different moisture regimes viz. 40% ( $W_1$ ), 60% ( $W_2$ ) and 80% ( $W_3$ ) of water holding capacity (WHC) and kept at room temperature throughout the experiment. The loss of moisture was replenished by periodic addition of sterile distilled water on every alternate day by difference in weight. The beakers were kept covered with black polythene sheets and incubated for a period of 90 days. Separate sets of treatments were maintained for each of the sampling stages.

The incubation study was conducted using the discard method, where separate sets of soil samples were prepared for each sampling interval (0th, 30th, 60th, and 90th days). Soil samples were periodically collected and analyzed on 0<sup>th</sup>, 30<sup>th</sup>, 60<sup>th</sup> and 90<sup>th</sup> days of incubation to determine the release pattern of nutrients under different moisture regimes in soil.

At each sampling time, the corresponding soil samples were removed from incubation and analyzed, preventing disturbance to the remaining samples and allowing accurate measurement of nutrient release over time. The experiment was carried out under Factorial Randomized Block Design (FRBD).

SPSS (Statistical Package for the Social Sciences) software was used for analysis of the data along with Microsoft Excel.

## 2.1 Treatment Details

- T<sub>0</sub>- Control
- T<sub>1</sub>-100 % RDN using chemical fertilizer Urea
- T<sub>2</sub>-100% using Vermicompost as N-source
- T<sub>3</sub>-100% using *Azolla* as N-source
- T<sub>4</sub>-75% RDN using (Urea) + 25% RDN using Vermicompost
- T<sub>5</sub>-75% RDN using (Urea) + 25% using *Azolla* + *Azotobacter*
- T<sub>6</sub>-50% RDN using (Urea) + 50% RDN using Vermicompost
- T<sub>7</sub>-50% RDN using (Urea) + 50% using *Azolla* + *Azotobacter*
- T<sub>8</sub>-25% RDN using (Urea) + 75% RDN using Vermicompost
- T<sub>9</sub>-25% RDN using (Urea) + 75% using *Azolla* + *Azotobacter*
- T<sub>10</sub>-100 % RDN using Vermicompost +100 %using *Azolla* + *Azotobacter*
- T<sub>11</sub>-100 % RDN using chemical fertilizer + 100 % RDN using Vermicompost + 100 % using *Azolla* + *Azotobacter*

\*RDN: Recommended Dose of Nitrogen

## 2.2 Moisture Regimes

- W<sub>1</sub>- 40% WHC (Water holding capacity)
- W<sub>2</sub>- 60% WHC (Water holding capacity)
- W<sub>3</sub>- 80% WHC (Water holding capacity)

Soil samples were periodically collected and analyzed on 0<sup>th</sup>, 30<sup>th</sup>, 60<sup>th</sup> and 90<sup>th</sup> days of incubation to determine the release pattern of nutrients under different moisture regimes in soil.

**Table 1. Initial soil characteristics of the incubation experiment**

Soil characteristics	Results
Textural class	Clayey soil
Sand (%)	8.24
Silt (%)	13.44
Clay (%)	78.32
pH (1:2.5 soil : water ratio)	5.40
EC (1:2.5 soil : water ratio, dsm <sup>-1</sup> )	0.28
CEC [cmol(p <sup>+</sup> ) kg <sup>-1</sup> ]	34.05
Organic carbon (%)	1.56
Available Nitrogen (Kg N ha <sup>-1</sup> )	389.39
Available Phosphorus (Kg P <sub>2</sub> O <sub>5</sub> ha <sup>-1</sup> )	57.71
Available potassium (Kg K <sub>2</sub> O ha <sup>-1</sup> )	252.67
DTPA extractable Zn (mg kg <sup>-1</sup> )	0.80
DTPA extractable Fe (mg kg <sup>-1</sup> )	94.38
DTPA extractable Mn (mg kg <sup>-1</sup> )	35.81
DTPA extractable Cu (mg kg <sup>-1</sup> )	0.96

## 2.3 Statistical Analysis

Data obtained from the experiments were statistically analyzed through analysis of variance techniques for comparing the treatment effects as described by Gomez and Gomez (1984). The significance of various effects was tested at 5% level of probability.

## 3. RESULTS AND DISCUSSION

### 3.1 DTPA-extractable Zinc (Zn)

Data shown in Table 2 represent the effect of INM and moisture regimes on DTPA-extractable zinc content in soil.

In general, irrespective of different treatments and moisture regimes, DTPA-extractable zinc gradually decreased throughout the incubation period. The decrease in DTPA-extractable zinc in soil might be due to immobilization because of applied organic sources (Angelova et al., 2013). Closer investigation of the data revealed that significantly greater accumulation of DTPA-extractable zinc was observed at 60% WHC followed by 40% and 80% WHC at different stages of incubation. It signified that DTPA-extractable zinc content in soil decreased with increasing moisture level. Application of organic matter combined with saturated moisture regime brought about decrease in zinc content suggesting immobilization and the antagonistic effect of increased concentration of extractable iron, manganese and phosphorus (Halder and Mandal, 1979).

The data further revealed that application of either chemical fertilizers or organic manures or in conjunction of both the sources increased DTPA-extractable zinc in soil over untreated control. Similar results were also reported earlier by other investigators (Dhaliwal et al., 2012, Lakshmi et al., 2013a; Baishya et al., 2015; Zeid et al., 2015 and Jat and Singh, 2017). Irrespective of moisture regimes, statistically higher accumulation of DTPA-extractable zinc was recorded in combined application of inorganic and organic N sources than inorganic fertilizers alone. Similar findings were also given by Swarup and Yaduvanshi (2000) and Balwinder et al. (2008).

Similar findings were also provided by Swarup and Yaduvanshi (2000) and Balwinder et al. (2008). This suggests that the combined application of organic and inorganic N sources

promotes the release of nutrients from organic sources thereby increasing the pool of nutrients along with inorganic sources (Gautam et al., 2013). Abdul Salam and Subramanian (1988) also reported that the interaction between Zn and N was synergistic.

Comparing among the different treatments, significantly higher DTPA-extractable zinc in soil was recorded in T<sub>11</sub> at different periods of incubation followed by T<sub>4</sub> showing parity with T<sub>6</sub> and T<sub>8</sub> on 90<sup>th</sup> day of incubation. In the case of 30<sup>th</sup> and 60<sup>th</sup> day, comparatively higher zinc was maintained in T<sub>11</sub> followed by T<sub>5</sub> and T<sub>8</sub>.

There was a significant interaction between treatments and moisture on the 90<sup>th</sup> day of incubation.

### 3.2 DTPA-extractable Iron (Fe)

Data regarding the changes in the amount of soil DTPA-extractable iron as influenced by INM and moisture regimes are given in Table 3. Irrespective of different treatments and moisture regimes, an increase in the concentration of DTPA extractable Fe was observed with the addition of different N sources. The amount of DTPA extractable Fe increased rapidly to a maximum on 60<sup>th</sup> day of incubation, then gradually declined till the end of the experiment under different moisture regimes (40%, 60% and 80% WHC). The result was at parity with the work of Safarzadeh et al. (2018).

The production of organic and inorganic acids during the degradation of organic fertilizers contributed to a decrease in soil pH, which in turn increased the availability of elements in the rhizosphere (Lakshmi et al., 2013b; Baishya et al., 2015; Zeid et al., 2015; Patel and Tiwari, 2018).

The decrease in DTPA extractable Fe indicated immobilization due to application of organic sources (Angelova et al., 2013). Closer examination of the data revealed that significantly greater accumulation of DTPA-extractable Fe was observed at 80% WHC followed by 60% and 40% WHC at different stages of incubation. Irrespective of different moisture regimes, results pointed out that significantly higher accumulation of DTPA extractable Fe was noticed in the entire N treated soils than untreated control at different stages of incubation.

**Table 2. Effect of INM and moisture regimes on DTPA extractable Zn (mg kg<sup>-1</sup>) in soil**

Treatment	Incubation days															
	0				30				60				90			
	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean
T <sub>0</sub>	0.85	0.85	0.85	0.85	0.65	0.65	0.61	0.64	0.59	0.58	0.55	0.57	0.40	0.41	0.38	0.40
T <sub>1</sub>	0.86	0.87	0.87	0.87	0.68	0.68	0.67	0.68	0.60	0.62	0.58	0.60	0.42	0.46	0.43	0.44
T <sub>2</sub>	0.86	0.87	0.86	0.86	0.71	0.72	0.69	0.71	0.62	0.63	0.63	0.63	0.44	0.43	0.43	0.43
T <sub>3</sub>	0.85	0.86	0.85	0.85	0.69	0.69	0.66	0.68	0.60	0.61	0.59	0.60	0.43	0.44	0.42	0.43
T <sub>4</sub>	0.87	0.86	0.85	0.86	0.70	0.71	0.68	0.70	0.63	0.63	0.62	0.63	0.47	0.50	0.46	0.48
T <sub>5</sub>	0.88	0.88	0.86	0.87	0.73	0.75	0.71	0.73	0.66	0.67	0.64	0.66	0.46	0.48	0.45	0.46
T <sub>6</sub>	0.87	0.87	0.86	0.87	0.71	0.72	0.70	0.71	0.65	0.66	0.64	0.65	0.46	0.49	0.46	0.47
T <sub>7</sub>	0.87	0.88	0.87	0.87	0.70	0.71	0.69	0.70	0.63	0.65	0.62	0.63	0.45	0.47	0.44	0.45
T <sub>8</sub>	0.88	0.88	0.86	0.87	0.72	0.75	0.71	0.73	0.66	0.68	0.65	0.66	0.47	0.49	0.45	0.47
T <sub>9</sub>	0.85	0.85	0.85	0.85	0.71	0.74	0.70	0.72	0.65	0.65	0.64	0.65	0.46	0.48	0.45	0.46
T <sub>10</sub>	0.86	0.87	0.86	0.86	0.70	0.72	0.69	0.70	0.62	0.62	0.61	0.62	0.45	0.44	0.45	0.45
T <sub>11</sub>	0.87	0.88	0.87	0.87	0.75	0.77	0.74	0.75	0.68	0.70	0.67	0.68	0.51	0.54	0.50	0.52
Mean	0.86	0.87	0.86		0.70	0.72	0.69		0.63	0.64	0.62		0.45	0.47	0.44	
Source	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>
T	0.004			0.007	0.003			0.007	0.002			0.005	0.002			0.004
W	0.001			0.002	0.001			0.002	0.001			0.001	0.000			0.001
T X W	0.011			0.022	0.010			0.020	0.007			0.014	0.006			0.012

**Table 3. Effect of INM and moisture regimes on DTPA extractable Fe (mg kg<sup>-1</sup>) in soil**

Treatment	Incubation days															
	0				30				60				90			
	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean
T <sub>0</sub>	93.00	94.32	95.90	94.41	94.35	95.98	96.00	95.44	97.10	96.54	97.30	96.98	84.25	84.50	84.86	84.54
T <sub>1</sub>	93.50	94.69	96.10	94.76	95.56	96.00	97.99	96.52	99.25	99.65	99.07	99.32	85.52	86.10	86.54	86.05
T <sub>2</sub>	94.00	95.00	96.35	95.12	106.10	108.25	109.25	107.87	116.56	114.00	113.52	114.69	109.25	107.52	106.68	107.82
T <sub>3</sub>	94.52	95.63	95.62	95.26	105.50	108.35	108.90	107.58	114.00	114.56	116.25	114.94	105.54	105.98	107.65	106.39
T <sub>4</sub>	95.10	95.40	95.00	95.17	110.20	111.20	113.00	111.47	119.52	120.21	120.69	120.14	111.00	112.56	112.95	112.17
T <sub>5</sub>	95.00	94.89	95.65	95.18	105.52	107.00	109.98	107.50	111.58	112.56	114.56	112.90	105.80	106.35	108.23	106.79
T <sub>6</sub>	94.25	95.00	96.50	95.25	109.89	109.20	111.00	110.03	117.56	117.90	118.00	117.82	108.25	110.25	110.00	109.50
T <sub>7</sub>	94.68	94.68	96.23	95.20	107.50	108.25	110.25	108.67	115.35	116.00	116.52	115.96	107.00	108.00	108.96	107.99
T <sub>8</sub>	95.10	95.00	96.12	95.41	110.00	110.85	111.20	110.68	118.20	119.25	120.65	119.37	110.65	111.52	110.65	110.94
T <sub>9</sub>	95.00	95.10	95.69	95.26	108.52	110.00	111.65	110.06	117.00	117.69	118.32	117.67	108.25	110.20	109.56	109.34
T <sub>10</sub>	95.00	95.31	95.00	95.10	106.00	110.32	110.00	108.77	113.25	117.98	118.20	116.48	106.30	109.89	111.20	109.13
T <sub>11</sub>	94.68	95.00	96.20	95.29	112.45	112.69	113.50	112.88	121.54	121.98	122.00	121.84	111.56	112.00	113.50	112.35
Mean	94.49	95.00	95.86		105.97	107.34	108.56		113.41	114.03	114.59		104.45	105.41	105.90	
Source	SE(d) ±		CD <sub>0.05</sub>		SE(d) ±		CD <sub>0.05</sub>		SE(d) ±		CD <sub>0.05</sub>		SE(d) ±		CD <sub>0.05</sub>	
T	1.15		2.30		0.58		1.16		0.91		1.81		0.35		0.70	
W	0.29		0.58		0.15		0.29		0.23		0.45		0.09		0.17	
T X W	3.46		6.91		1.75		3.49		2.72		5.43		1.05		2.10	

**Table 4. Effect of INM and moisture regimes on DTPA extractable Mn (mg kg<sup>-1</sup>) in soil**

Treatment	Incubation days															
	0				30				60				90			
	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean
T <sub>0</sub>	33.25	34.00	34.21	33.82	31.25	31.00	31.25	31.17	30.54	30.00	30.95	30.50	25.36	26.10	28.52	26.66
T <sub>1</sub>	34.20	34.10	34.20	34.17	34.12	34.10	34.16	34.13	32.56	33.10	32.56	32.74	29.54	30.00	30.20	29.91
T <sub>2</sub>	35.65	35.66	34.52	35.28	50.52	52.35	53.00	51.96	52.35	53.65	58.10	54.70	40.62	41.25	47.21	43.03
T <sub>3</sub>	35.45	36.45	35.21	35.70	48.24	50.10	50.23	49.52	51.35	52.35	53.40	52.37	42.12	43.00	44.18	43.10
T <sub>4</sub>	36.54	36.00	35.85	36.13	49.63	49.69	49.52	49.61	55.25	56.25	53.25	54.92	44.89	45.52	44.25	44.89
T <sub>5</sub>	36.89	35.24	35.00	35.71	48.65	48.85	49.98	49.16	51.23	51.35	52.00	51.53	42.00	42.65	43.25	42.63
T <sub>6</sub>	35.54	35.48	34.56	35.19	50.95	51.00	49.65	50.53	55.25	57.00	56.23	56.16	45.23	45.00	46.00	45.41
T <sub>7</sub>	34.26	34.95	35.10	34.77	48.66	50.23	51.26	50.05	52.10	53.00	54.50	53.20	42.20	43.00	43.65	42.95
T <sub>8</sub>	34.00	36.00	34.56	34.85	51.20	51.98	52.00	51.73	54.23	55.35	57.00	55.53	44.65	43.56	46.30	44.84
T <sub>9</sub>	35.65	34.98	35.23	35.29	50.00	50.23	50.65	50.29	52.35	53.89	55.23	53.82	43.50	44.32	44.56	44.13
T <sub>10</sub>	36.25	36.10	35.64	36.00	52.30	52.38	52.65	52.44	53.00	56.96	57.90	55.95	43.56	46.00	48.24	45.93
T <sub>11</sub>	35.50	36.54	35.60	35.88	53.40	53.78	54.10	53.76	55.60	57.21	58.13	56.98	48.65	48.90	50.10	49.22
Mean	35.27	35.46	34.97		47.41	47.97	48.20		49.65	50.84	51.60		41.03	41.61	43.04	
Source	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>
T	0.15			0.29	0.20			0.39	0.21			0.42	0.18			0.36
W	0.04			0.07	0.05			0.10	0.05			0.11	0.05			0.09
T X W	0.44			0.87	0.59			1.18	0.63			1.27	0.55			1.09

The result showed similarity with earlier works of Patel and Tiwari (2018) and Safarzadeh et al. (2018). Further perusal of the data showed that integration of inorganic and organic N sources resulted in significantly higher amounts of DTPA extractable Fe than inorganic treated soil (T<sub>1</sub>). Enhancement in Fe content in integrated treatments might be due to gradual release of nutrients from organic sources which increased the nutrients to the soil along with inorganic source and made it available to the soil (Helgason et al., 2007; Baitilwake et al., 2012 and Gautam et al., 2013).

Among the different treatments, significantly greater accumulation of DTPA extractable Fe was found in T<sub>11</sub> throughout the study followed by T<sub>4</sub> which was at par with T<sub>8</sub> on 30<sup>th</sup> day of incubation but T<sub>11</sub> was at par with T<sub>4</sub> on 60<sup>th</sup> and 90<sup>th</sup> days of incubation followed by T<sub>8</sub> and T<sub>6</sub>.

### 3.3 DTPA-extractable Manganese (Mn)

Perusal of the data Table 4 showed that a similar trend of DTPA extractable Mn in soil was observed under different moisture regimes (40%, 60% and 80% WHC). The trend showed an increase rapidly to a maximum up to 60<sup>th</sup> day followed by a gradual decline till the end of the experiment excepting T<sub>0</sub> and T<sub>1</sub> presenting decreasing trend till the end of the experiment. The decline might be due to immobilization because of added organic sources (Angelova et al., 2013). Analysis of the data showed that significantly higher DTPA extractable Mn content in soil was observed at higher moisture regime i.e. 80% WHC followed by 60% and 40% at different days of incubation. Irrespective of moisture regimes, an increase in the concentration of DTPA extractable Mn was observed with the addition of organic sources at different levels. Application of organics might have increased the water soluble plus exchangeable and easily reducible fractions of Mn. According to Das and Mandal (1986), organic matter addition enhances the initial decrease in redox potential and increases water soluble and exchangeable Mn<sup>2+</sup> in soil.

Further study of the data observed that single or combined application of different inorganic and organic N sources at different levels gave significantly greater amounts of DTPA extractable Mn in soil as compared to untreated control. The results were supported by Swarup and Yaduvanshi (2000); Garai et al. (2014); Baishya et al. (2015) and Zeid et al. (2015). However, integration of inorganic and organic N

sources resulted in significantly higher concentration of DTPA extractable Mn in soil than inorganically treated soil (T<sub>1</sub>) (Balwinder et al., 2008). Comparing among the different treatments, statistically higher DTPA extractable Mn accumulation was recorded in T<sub>11</sub> followed by T<sub>10</sub> which was statistically similar with T<sub>6</sub> on 30<sup>th</sup> and 90<sup>th</sup> days of incubation. However, comparatively higher DTPA extractable Mn concentration was maintained in T<sub>11</sub> which was statistically similar with T<sub>6</sub> and T<sub>10</sub> on 60<sup>th</sup> day of incubation. There was an interaction effect between treatments and moisture on the 60<sup>th</sup> and 90<sup>th</sup> day of incubation.

### 3.4 DTPA-extractable Copper (Cu)

Data on the effect of INM and moisture regimes on DTPA extractable Cu content in soil are presented in Table 5. Irrespective of different treatments and moisture regimes, there was a declining trend in soil DTPA extractable Cu with increase in the period of experiment under different moisture regimes (40%, 60% and 80% WHC). Similar finding was also observed by Chaudhary et al. (2011). The decrease in DTPA-extractable Cu in soil might be due to immobilization by humic substances from applied organic sources (Angelova et al., 2013). Critical analysis of the data revealed that a significantly higher amount of DTPA extractable Cu was accumulated in soil treated with 60% WHC followed by 40% WHC from 30<sup>th</sup> day onwards up to 60<sup>th</sup> day of incubation. However, at the end of the experiment, accumulation at 40% WHC was significantly greater than 60% WHC.

Further perusal of the data revealed that irrespective of different moisture levels and sampling days, significantly higher accumulation of DTPA extractable Cu in soil was found in different inorganic and organic N sources treated soil than untreated control. This is in correlation with the results of Balwinder et al. (2008); Dhaliwal et al. (2012); Baishya et al. (2015); Zeid et al. (2015) and Jat and Singh (2017). Comparing the data between combined application of inorganic and organic N sources and sole application of inorganic fertilizer, it was observed that a significantly higher amount of DTPA extractable Cu in soil was recorded in integration of inorganic and organic N sources than sole application. The presence of organic matter may increase the availability of Cu in soils owing to the formation of soluble complexing agents thereby decreasing the fixation of Cu in soils (Prasad, 1981 and Lakshmi et al., 2013b).

Table 5. Effect of INM and moisture regimes on DTPA extractable Cu (mg kg<sup>-1</sup>) in soil

Treatment	Incubation days															
	0				30				60				90			
	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	Mean
T <sub>0</sub>	0.95	0.93	0.94	0.94	0.60	0.61	0.57	0.59	0.55	0.53	0.53	0.54	0.45	0.43	0.43	0.44
T <sub>1</sub>	0.94	0.94	0.96	0.95	0.63	0.64	0.60	0.62	0.59	0.55	0.57	0.57	0.49	0.45	0.44	0.46
T <sub>2</sub>	0.93	0.93	0.95	0.94	0.65	0.64	0.62	0.64	0.60	0.61	0.59	0.60	0.51	0.47	0.45	0.48
T <sub>3</sub>	0.95	0.93	0.94	0.94	0.68	0.70	0.65	0.68	0.62	0.64	0.60	0.62	0.50	0.48	0.46	0.48
T <sub>4</sub>	0.95	0.95	0.95	0.95	0.75	0.76	0.72	0.74	0.68	0.66	0.64	0.66	0.56	0.55	0.50	0.54
T <sub>5</sub>	0.94	0.94	0.95	0.94	0.73	0.63	0.61	0.66	0.60	0.60	0.59	0.60	0.48	0.48	0.45	0.47
T <sub>6</sub>	0.93	0.95	0.94	0.94	0.70	0.71	0.70	0.70	0.62	0.61	0.60	0.61	0.51	0.49	0.47	0.49
T <sub>7</sub>	0.95	0.96	0.93	0.95	0.67	0.69	0.64	0.67	0.61	0.63	0.61	0.62	0.51	0.47	0.45	0.48
T <sub>8</sub>	0.93	0.95	0.95	0.94	0.65	0.65	0.65	0.65	0.60	0.63	0.59	0.61	0.52	0.50	0.47	0.50
T <sub>9</sub>	0.94	0.92	0.94	0.93	0.65	0.64	0.63	0.64	0.61	0.61	0.58	0.60	0.50	0.51	0.46	0.49
T <sub>10</sub>	0.94	0.93	0.94	0.94	0.63	0.64	0.60	0.62	0.59	0.62	0.58	0.60	0.47	0.48	0.45	0.47
T <sub>11</sub>	0.93	0.93	0.96	0.94	0.65	0.75	0.70	0.70	0.62	0.65	0.62	0.63	0.53	0.51	0.49	0.51
Mean	0.94	0.94	0.95		0.67	0.67	0.64		0.61	0.61	0.59		0.50	0.49	0.46	
Source	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>	SE(d) ±			CD <sub>0.05</sub>
T	0.004			0.007	0.003			0.005	0.003			0.005	0.002			0.004
W	0.001			0.002	0.001			0.001	0.001			0.001	0.000			0.001
T X W	0.011			0.022	0.008			0.016	0.008			0.015	0.005			0.011

A significant positive correlation between organic matter and exchangeable Cu was also recorded by Grewal et al. (1969). Again, the result pointed out that statistically higher accumulation of DTPA extractable Cu in soil was perceived in T<sub>4</sub> followed by T<sub>11</sub> throughout the incubation period. There was a significant interaction effect between treatments and moisture on the 60<sup>th</sup> and 90<sup>th</sup> day of incubation.

#### 4. CONCLUSION

The study demonstrated that both integrated nutrient management (INM) and moisture regime impacted soil micronutrient availability. In this study, DTPA-extractable Zn and Cu were normally declined because of immobilization processes largely related to both organic amendments and moisture regimes. Fe and Mn availability increased from 0 to 60 days, but subsequently declined. The alterations to the moisture regimes would seem as though to change the availability of micronutrients in soil. Utilizing a nutrient source which included both organic and inorganic nutrient sources allowed for greater availability of these micronutrients in soil compared to inorganic fertilizers alone or control (conventional) treatment.

Among the treatments, T<sub>11</sub> had the greatest amount of available Zn and Mn than all other treatments, with T<sub>6</sub> and T<sub>4</sub> having the highest extractable Cu, followed by T<sub>11</sub>. This would suggest combining inorganic fertilizers, organic manures and bio-fertilizers enhances the status of soil micronutrients.

In conclusion, development of environmentally friendly organic materials, with inorganic fertilizers are important for maintaining soil health, enhancing soil quality, improving crop yield, and enhancing nutrient use efficiencies; and the INM results stimulated with micronutrients extractability.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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