Electronic Supplementary Material (ESI) for Environmental Science: Nano.

SUPPORTING INFORMATION

Nano-based soil conditioners eradicate micronutrient deficiency: Soil physico-chemical and plant molecular responses

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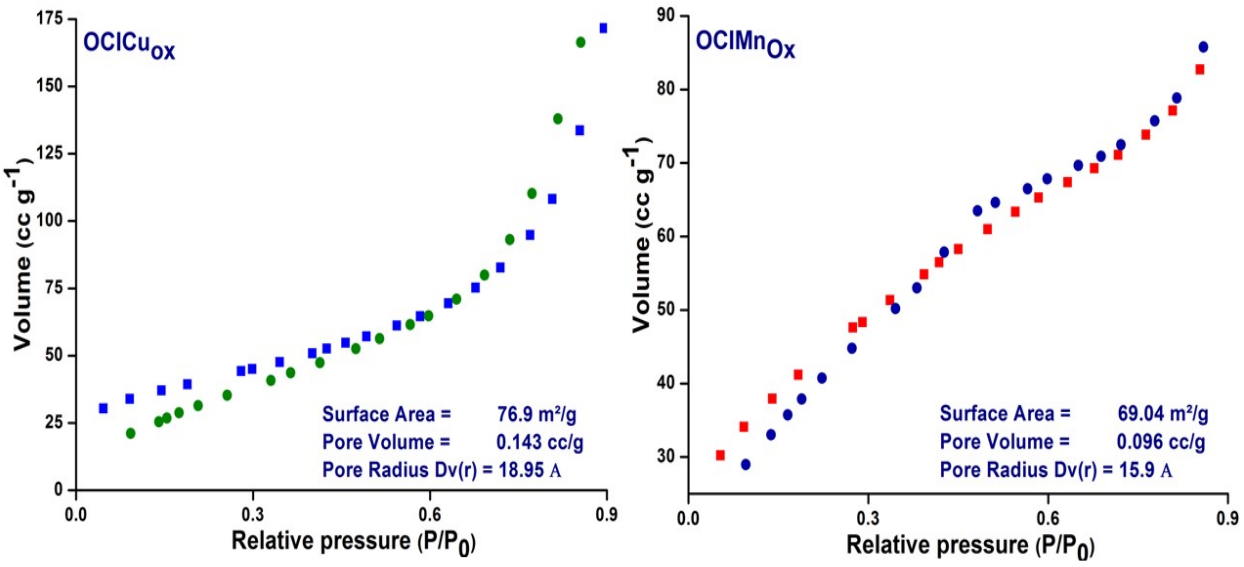


Figure 1S. BET plot for OCICu$_{ox}$ and OCIMn$_{ox}$

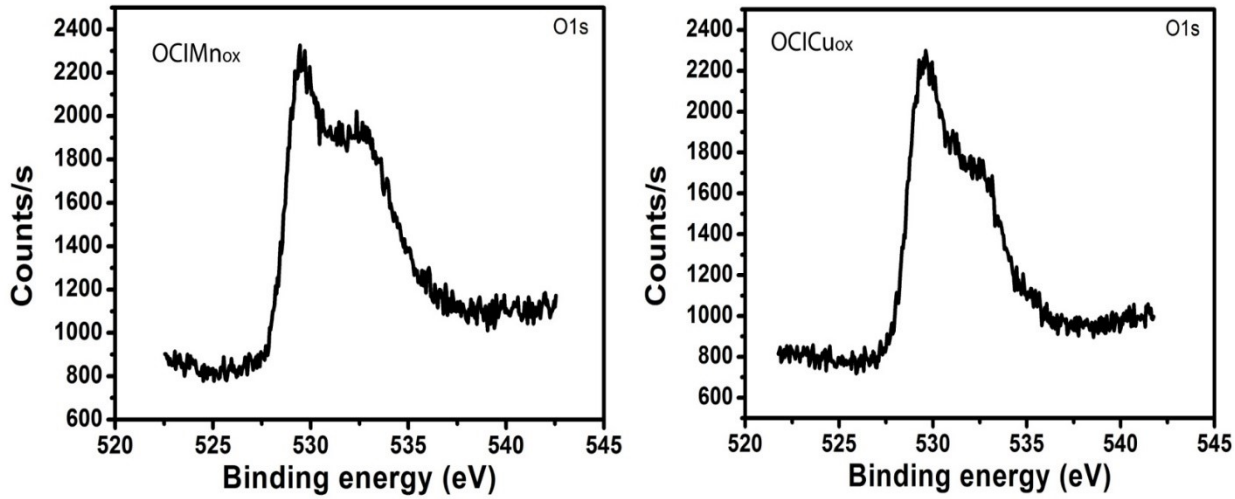
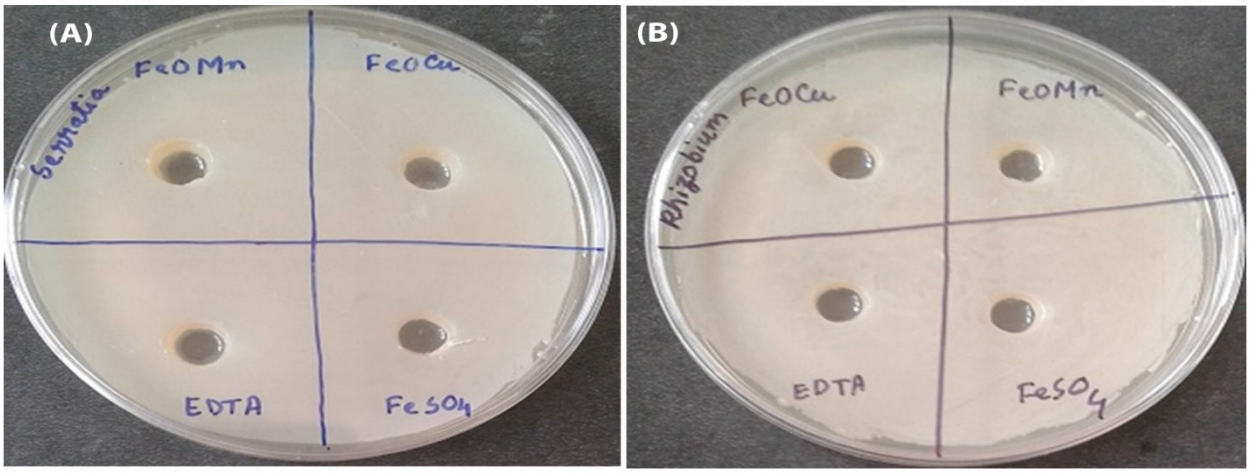


Figure 2S.XPS spectra broad peak of OCICu$_{ox}$ and OCIMn$_{ox}$



FeOMn= $OCIMn_{ox}$ FeOCu= $OCICu_{ox}$

Figure 3S – Evidence of non-inhibitory effects on beneficial soil microbes

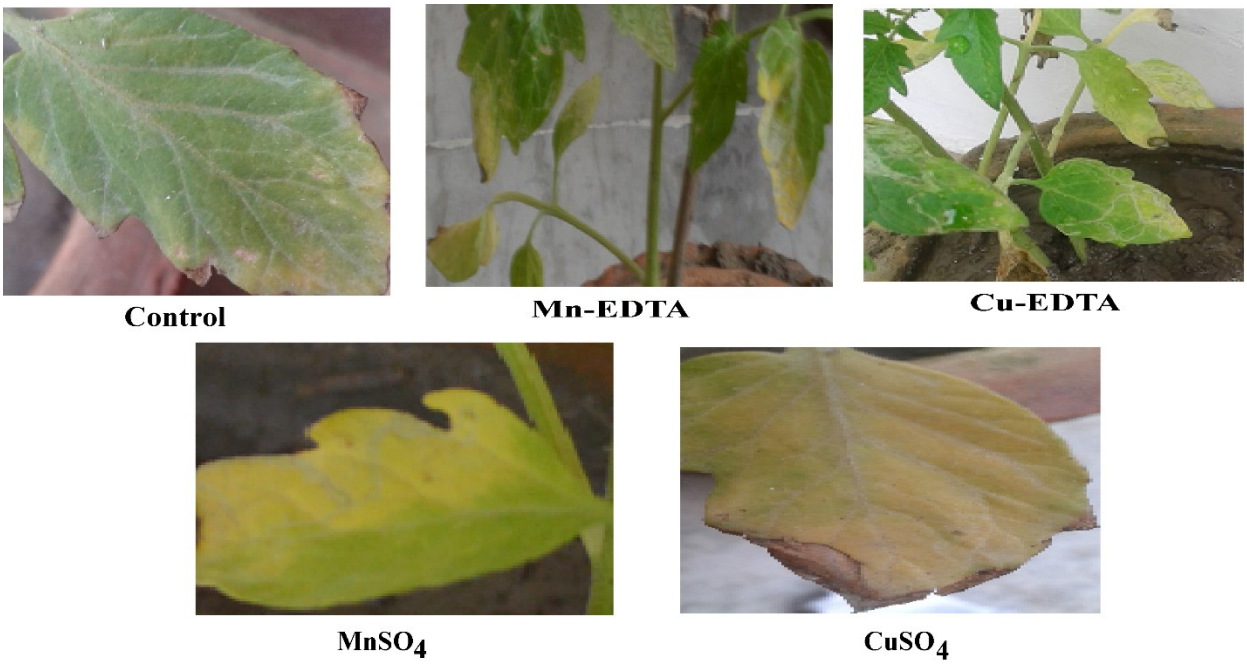


Figure 4S. Chorotic leaves of control, Mn-EDTA, Cu-EDTA, $MnSO_4$, and $CuSO_4$ treatments.

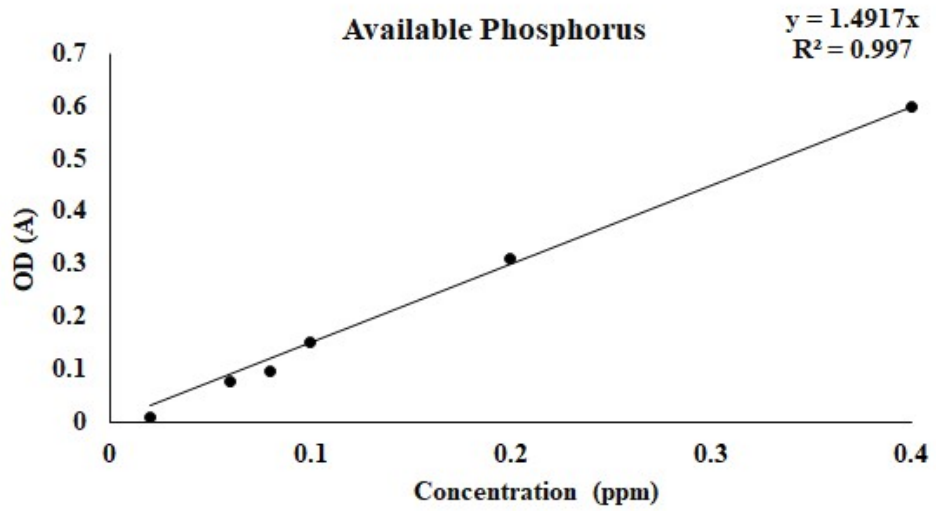


Figure 5S. Method detection limit (MDL) values for available phosphorus in UV-visible spectrophotometer

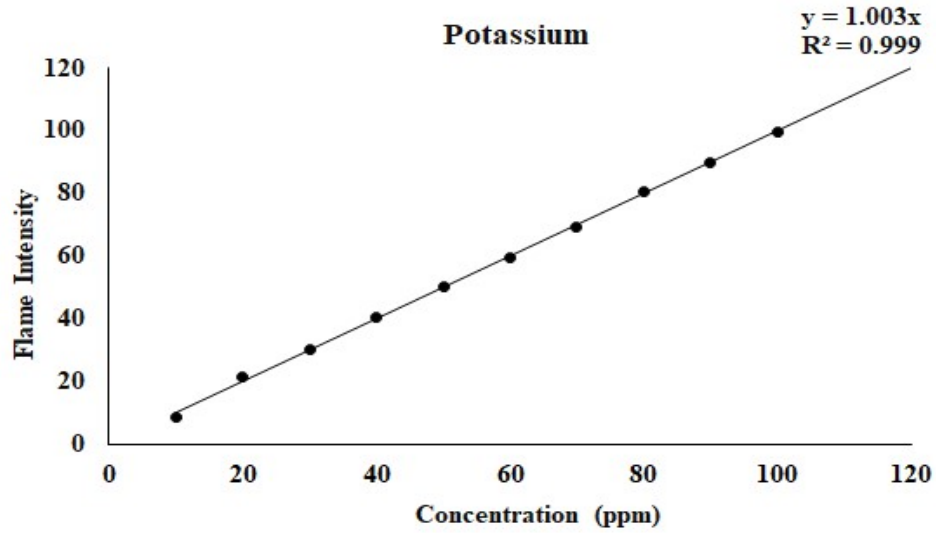


Figure 6S. Relative standard deviation (RSD) for potassium in flame photometer

Table 1S: Method detection limit (MDL) values for different instruments

Instrument	Parameter	Method Detection limit
UV-VIS spectrophotometer	Phosphorus (P)	0.5 ppm
Flame photometer	Potassium (K)	1 ppm
	Sodium (Na)	1 ppm
ICP-OES	Fe	0.01 ppm
	Mn	0.02 ppm
	Cu	0.01 ppm

Table 2S: Relative standard deviation (RSD) values for different attributes measured in various instruments

Instrument	Parameter/Attribute	Relative standard deviation
UV-VIS spectrophotometer	Phosphorus (P)	1.60%
Flame photometer	Potassium (K)	6.20%
	Sodium (Na)	4.70%
ICP-OES	Fe	5.20%
	Mn	3.80%
	Cu	4.60%

Table 3S. Physico-chemical characteristics of the test soil

Soil properties	Mean±stdev

pH	5.49±0.1
BD (g cc^{-1})	1.4±0.5
WHC (%)	60.5±5.6
TOC (%)	0.38±0.01
Available N (mg kg^{-1})	270.5±5.1
Available P (mg kg^{-1})	21.4±2.1
Available K (mg kg^{-1})	89.15±5.6
Fe (mg kg^{-1})	110.5±2.4
Mn (mg kg^{-1})	47.1±1.1
Cu (mg kg^{-1})	17.19±1.1

Table 4S-A: Impact of $OCIMn_{ox}$ and $OCICu_{ox}$ on bulk density (BD) and water holding capacity (WHC) of soil

Treatment	BD (g cc^{-1})			WHC (%)		
	0 D	45D	90D	0 D	45D	90D
Control	1.41±0.5	1.38±0.1	1.42±0.2	65.87±1.3	65.87±2.4	68.33±1.2
$(OCIMn_{ox})_{10}$	1.4±0.2	1.36±0.1	1.31±0.2	71.07±1.7	73.2±1.3	78.5±1.5
$(OCIMn_{ox})_{50}$	1.41±0.1	1.37±0.5	1.33±0.1	70.1±2.5	72.1±5.1	75.2±1.8
$(OCICu_{ox})_{10}$	1.39±0.5	1.37±0.4	1.30±0.1	70.6±2.1	72.9±1.2	77.2±2.3
$(OCICu_{ox})_{50}$	1.41±0.01	1.38±0.04	1.35±0.2	68.3±1.7	72.07±1.7	75.2±1.4
$Fe\text{-}EDTA_{10}$	1.39±0.01	1.38±0.02	1.43±0.01	60.8±0.6	55.6±0.3	52.09±0.5
$Fe\text{-}EDTA_{50}$	1.41±0.01	1.4±0.01	1.44±0.01	60.5±0.9	56.7±0.4	52.8±0.6
$Mn\text{-}EDTA_{10}$	1.39±0.01	1.38±0.02	1.43±0.01	60.9±0.6	56.06±0.4	52.1±0.7
$Mn\text{-}EDTA_{50}$	1.41±0.01	1.4±0.01	1.44±0.01	60.5±0.1	56.7±0.1	50.2±0.2
$Cu\text{-}EDTA_{10}$	1.4±0.1	1.38±0.1	1.44±0.3	62.56±1.6	53.15±2.1	51.5±1.6
$Cu\text{-}EDTA_{50}$	1.4±0.04	1.41±0.03	1.44±0.01	63.4±1	61±1.9	50.4±1.6
$FeSO_4$	1.41±0.01	1.37±0.02	1.46±0.02	61±1	55.5±1.5	54.3±1.5
$MnSO_4$	1.39±0.02	1.39±0.03	1.43±0.01	62±1	56±1.6	53.4±1.4
$CuSO_4$	1.38±0.2	1.4±0.2	1.45±0.4	60.4±0.2	55±0.2	51.4±0.2
P value	P(trt×day)<0.01			P(trt×day)<0.01		
LSD	LSD(day)=0.004			LSD (day)=0.37		
	LSD(trt)=0.01			LSD (trt)=0.79		

Table 4S-B: Impact of $OCIMn_{ox}$ and $OCICu_{ox}$ on pH, TOC , available N, and available P content in soil

	pH			TOC (%)			Available N (mg kg^{-1})			Available P (mg kg^{-1})		
	0 D	45D	90D	0 D	45D	90D	0 D	45D	90D	0 D	45D	90D
Control	5.49±0.1	5.5±0.1	5.51±0.2	0.44±0.06	0.62±0.05	0.69±0.02	279.07±4.2	286.5±1.8	294.7±2.4	24.77±0.8	30.95±1.1	26.5±1.1
$(OCIMn_{ox})_{10}$	5.5±0.1	5.58±0.1	5.64±0.1	0.5±0.04	0.83±0.05	1.1±0.06	285.6±9.6	378.6±7.8	385.3±5.6	26.2±1.1	48.1±1.2	78.8±1.4
$(OCIMn_{ox})_{50}$	5.53±0.1	5.59±0.1	5.63±0.1	0.53±0.02	0.81±0.03	1.03±0.05	281.9±8.3	373.6±9.4	378.8±10.4	25.1±1.1	43.9±1.3	64.9±1.4
$(OCICu_{ox})_{10}$	5.49±0.1	5.57±0.1	5.63±0.2	0.5±0.3	0.81±0.3	1.08±0.7	284.7±4.5	360.8±9.8	383.4±8.6	25.9±1.4	42.7±1.3	74.7±1.1
$(OCICu_{ox})_{50}$	5.52±0.5	5.59±0.5	5.62±0.4	0.49±0.02	0.78±0.01	1.03±0.03	281.9±4.7	356.5±4.7	377.6±4.9	24.98±1.8	39.7±1.9	59.2±1.4
$Fe\text{-}EDTA_{10}$	5.43±0.2	5.4±0.5	5.46±0.4	0.38±0.12	0.61±0.12	0.71±0.1	278.6±4.7	276.1±5.4	285.9±6.1	21.19±0.5	22.9±0.4	25.6±0.5
$Fe\text{-}EDTA_{50}$	5.46±0.2	5.43±0.3	5.48±0.4	0.43±0.14	0.59±0.1	0.65±0.05	282.6±11.7	284.7±6.7	279.8±5.7	21.7±1.1	20.64±0.8	24.85±0.9
$Mn\text{-}EDTA_{10}$	5.40±0.2	5.42±0.3	5.43±0.1	0.41±0.14	0.6±0.15	0.60±0.08	273.7±8.5	278.3±11.4	279.5±8.1	20.1±0.8	21.54±0.9	23.64±0.8
$Mn\text{-}EDTA_{50}$	5.45±0.3	5.47±0.1	5.5±0.2	0.4±0.15	0.56±0.1	0.61±0.06	275.7±8.1	271.2±4.6	266.1±11.1	21.71±1.1	19.56±0.8	23.9±0.9
$Cu\text{-}EDTA_{10}$	5.41±0.4	5.45±0.4	5.43±0.2	0.41±0.16	0.60±0.12	0.58±0.08	278.6±4.7	285.8±7.4	286.8±10.5	23.86±0.8	21.58±0.8	18.97±0.9
$Cu\text{-}EDTA_{50}$	5.41±0.1	5.43±0.2	5.45±0.5	0.40±0.07	0.6±0.1	0.59±0.06	270.9±4.5	275.2±9.8	272.8±10.4	21.6±0.8	22.5±0.9	24.4±0.7
$FeSO_4$	4.61±0.1	4.38±0.1	4.33±0.1	0.45±0.06	0.63±0.1	0.61±0.06	271.2±4.8	275.2±5.7	278.9±5.6	21.9±1.1	21.11±0.8	22.28±.8
$MnSO_4$	5.40±0.2	5.41±0.1	5.42±0.2	0.44±0.05	0.64±0.12	0.6±0.05	272.7±4.8	278±4.6	265.3±4.8	22.7±0.8	22.1±0.9	20.7±1.2
$CuSO_4$	5.40±0.2	5.42±0.3	5.41±0.3	0.43±0.02	0.61±0.01	0.58±0.01	273.4±5.4	278.7±2.3	264.5±3.4	21.8±1.1	20.75±1.1	21.48±1.2
p value	P(trt×day)<0.01			P(trt×day)<0.01			P(trt×day)<0.01			P(trt×day)<0.01		
LSD	LSD(day)=0.022			LSD (day)=0.01			LSD (day)=1.92			LSD (day)=0.08		
	LSD(trt)=0.04			LSD (trt)=0.02			LSD (trt)=4.08			LSD (trt)=0.16		

Table 4S-C: Impact of $OCIMn_{ox}$ and $OCICu_{ox}$ on available K, DTPA extractable Fe, Mn, and Cu in soil

	Available K (mg kg^{-1})			Fe (mg kg^{-1})			Mn (mg kg^{-1})			Cu (mg kg^{-1})		
	0 D	45 D	90 D	0 D	45D	90D	0 D	45D	90D	0 D	45D	90D
Control	102.3±3.2	225±4.1	261.8±5	122.5±2	125.5±5.4	127.7±5.4	48.7±3.4	35.5±1.1	29.5±1.2	19.15±0.5	28.7±0.8	22.5±0.5
$(OCIMn_{ox})_{10}$	106.1±4	300.7±3.2	411±4	128.6±4.6	144.4±6.7	158.4±5.7	81.4±3.42	146.5±5.4	145±3.4	14.5±0.9	11.5±1	17.8±1.1
$(OCIMn_{ox})_{50}$	107.2±5.6	298.8±4	394.6±6	124.6±3.7	147.1±3.4	161.4±3.5	83.6±1.1	172.5±1.4	168.4±2.1	16.5±0.6	12.5±0.8	20.6±0.8
$(OCICu_{ox})_{10}$	108.6±4.3	300.4±3	408.4±5	126.2±2.8	141.2±2.5	156.22±2.6	17.4±0.2	25.8±0.8	22.4±0.9	58.15±1.1	107±2.4	114.1±3.4
$(OCICu_{ox})_{50}$	107.7±3	288±5	384±6	125.4±3.4	145.6±3.7	159.6±3.4	19.4±1.4	26.5±1.6	23.4±1.2	63.56±2.4	124.25±3.8	123.8±3.8
$Fe\text{-}EDTA_{10}$	105.1±4	183.9±3.6	208.4±5	118.1±2.8	89.5±2.4	72.8±2.7	24.5±1.1	25.4±1.2	20.4±1.5	15.8±0.4	11.5±0.6	21.5±0.9
$Fe\text{-}EDTA_{50}$	100.8±6	178.9±3.7	209.5±6	121.5±2.8	94.7±2.7	75.9±2.6	28.4±0.5	20.8±2.4	16.4±3.5	17.2±0.2	12.4±0.9	24.5±0.9
$Mn\text{-}EDTA_{10}$	100.1±4	152.2±4	211.8±7	81.7±3.4	71.5±3.4	48.5±4.1	55.6 ±0.4	68.7±1.6	89.4±1.8	15.4±0.8	14.5±0.9	11.5±1.1
$Mn\text{-}EDTA_{50}$	101.8±3	161±5	200.1±5	83.8±3.6	69.5±3.5	54.4±3.2	64.9±0.4	77.4±1.4	98±2.1	16.8±0.4	13.5±0.5	9.7±0.8
$Cu\text{-}EDTA_{10}$	102.8±4	160.7±5	221.6±6	69.7±2.8	59.5±3.4	51.5±3.7	22.4±0.8	24.6±2.4	20.9±3.4	45.7±0.7	76.6±0.6	97.6±0.7
$Cu\text{-}EDTA_{50}$	101.5±4	163.8±6	218.5±6	78.8±4.8	66.1±4.6	56.5±4.3	24.8±0.5	23.5±0.8	21.4±1.1	56.56±1.1	104.25±1.6	108.6±1.4
$FeSO_4$	101.8±4	120.7±6	165.6±4	163.7±2.8	189.5±4	171.5±3.7	10.4±0.8	8.6±0.5	8.9±4	12.7±0.6	13.6±0.9	11.6±0.7
$MnSO_4$	102±4	211.5±5	205.5±5	83.3±3.4	79.8±3.1	66.4±2.8	28.4±0.8	38.7±2.5	46.86±3.8	11.5±0.8	12.1±0.8	14.5±0.7
$CuSO_4$	103.5±3	217.5±4	208.4±5	84.5±0.3	80.5±0.3	67.8±0.2	10.4±0.9	24.6±1.1	12.5±1.1	48.9±1	82.4±2.4	79.8±3.2
p value	P(trt×day)<0.01			P(trt×day)<0.01			P(trt×day)<0.01			P(trt×day)<0.01		
LSD	LSD (day)=0.10			LSD (day)=0.43			LSD (day)=0.32			LSD (day)=0.21		
	LSD (trt)=2.9			LSD (trt)=0.83			LSD (trt)=0.74			LSD (trt)=0.56		

Table 5S: Effect of $OCIMn_{ox}$ and $OCICu_{ox}$ on shift of pH, P, Fe, Mn, and Cu content in KH_2PO_4 solution

Attributes	Treatment	Days				
		24 hrs	**48 hrs**	**7 day**	**14 day**	**21 day**
pH	$OCIMn_{ox}$	6.84±0.05	6.83±0.05	6.85±0.04	6.86±0.05	6.87±0.5
	$OCICu_{ox}$	6.5±0.1	6.48±0.04	6.56±0.04	6.57±0.05	6.6±0.8
	Fe-EDTA	4.43±0.2	4.42±0.2	4.35±0.2	4.32±0.2	4.28±0.2
	Mn-EDTA	4.29±0.01	4.25±0.01	4.11±0.2	4.05±0.2	4.01±0.1
	Cu-EDTA	4.38±0.2	4.33±0.2	4.25±0.1	4.16±0.3	4.09±0.2
	$FeSO_4$	2.64±0.15	2.56±0.15	2.41±0.15	2.32±0.12	2.05±0.11
	$MnSO_4$	3.56±0.01	3.44±0.02	3.37±0.01	3.28±0.01	3.1±0.01
	$CuSO_4$	2.68±0.01	2.51±0.01	2.45±0.02	2.41±0.01	2.35±0.01
Avl P (mg L^{-1})	$OCIMn_{ox}$	84.45±2.8	85.24±1.9	82.78±1.6	82.66±2.4	86.54±2.2
	$OCICu_{ox}$	68±1.1	65±2.3	72±1.8	75±2.4	78±2.5
	Fe-EDTA	2.51±0.01	2.31±0.05	1.98±0.05	1.86±0.01	1.67±0.02
	Mn-EDTA	5.86±1.2	4.17±1.1	3.54±0.5	2.19±0.25	0.89±0.4
	Cu-EDTA	2.65±2.4	4.82±3.1	3.11±2.8	2.55±2.4	1.11±2.7
	$FeSO_4$	28.86±2.1	12.56±1.5	8.56±1.6	9.57±1.8	4.79±1.8
	$MnSO_4$	18.7±0.7	11.4±1.2	10.5±0.8	8.9±0.2	6.8±0.1
	$CuSO_4$	19.5±1.2	15.6±1.4	12.5±2.1	9.56±1.4	7.6±2.1
Fe (mg L^{-1})	$OCIMn_{ox}$	56.8±1.5	75±1.5	186.7±1.6	211.4±1.6	225±1.6
	$OCICu_{ox}$	34.2±1.2	46.8±1.2	71±1.6	93.8±1.5	115.6±8
	Fe-EDTA	22.4±1.5	61.85±1.8	47.8±2.1	80.64±2.8	87.21±2.7
	$FeSO_4$	264.5±7.5	271±6.9	275±6.3	286±6.5	305±6.8
Mn (mg L^{-1})	$OCIMn_{ox}$	42.86±0.3	62.5±0.1	81.03±0.1	108.79±2.4	145.2±2.5
	Mn-EDTA	37.5±0.02	52.4±0.03	73.42±0.01	98.77±0.2	120.64±0.1
	$MnSO_4$	34.18±0.2	47.07±0.9	56±0.16	68±0.07	75±0.5
Cu (mg L^{-1})	$OCICu_{ox}$	105.2±1.5	116.1±1.4	123.7±2.4	126.9±2.4	139.8±2.1
	$CuSO_4$	126±1.3	117.8±1.4	133.5±1.7	137.8±2.1	138.5±2.1
	Cu-EDTA	63.13±1.2	77.05±1.14	83.95±1.1	95.13±1.1	85.06±1.1

pH	**Avl P**	**Fe**	**Mn**	**Cu**
p(trt)<0.01	p(trt)<0.01	p(trt)<0.01	p(trt)<0.01	p(trt)<0.01
p(day)<0.01	p(day)<0.01	p(day)<0.01	p(day)<0.01	p(day)<0.01
p(trt×day)<0.01	p(trt×day)<0.01	p(trt×day)<0.01	p(trt×day)<0.01	p(trt×day)<0.01
LSD(trt)=0.01	LSD(trt)=0.13	LSD(trt)=0.62	LSD(trt)=0.49	LSD(trt)=0.80

Table 6S: Variation of Mn and Cu in different pH solutions of $OCIMn_{ox}$ and $OCICu_{ox}$

Treatment	Mn (mg L^{-1})				Cu (mg L^{-1})			
	2 hours	24 hours	48 hours	72 hours	2 hours	24 hours	48 hours	72 hours
$OCIMn_{ox}$ pH4	6.1±0.08	7.85±0.5	9.81±0.8	10.38±1.1	BDL	BDL	BDL	BDL
$OCIMn_{ox}$ pH 7	10.12±0.23	14.89±1.2	21.46±1.4	22.45±1.2	BDL	BDL	BDL	BDL
$OCIMn_{ox}$ pH 9	15.56±0.4	18.95±1.1	16.01±2.1	19.35±1.5	BDL	BDL	BDL	BDL
$OCICu_{ox}$ pH4	BDL	BDL	BDL	BDL	2.5±0.01	3.4±0.01	4.2±0.05	5.87±0.5
$OCICu_{ox}$ pH 7	BDL	BDL	BDL	BDL	6.1±0.2	8.74±0.5	9.26±1	9.98±0.8
$OCICu_{ox}$ pH 9	BDL	BDL	BDL	BDL	5.4±0.11	6.67±0.5	7.78±0.5	8.74±0.8
Fe-EDTA pH4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Fe-EDTA pH 7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Fe-EDTA pH 9	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Mn-EDTA pH4	2.6±0.2	4.18±0.4	6.2±0.5	8.34±0.05	BDL	BDL	BDL	BDL
Mn-EDTA pH 7	7.1±0.15	8.17±0.1	16.78±1.1	17.74±0.20	BDL	BDL	BDL	BDL
Mn-EDTA pH 9	7.65±0.18	9.64±0.1	12.76±0.8	15.74±0.05	BDL	BDL	BDL	BDL
Cu-EDTA pH 4	BDL	BDL	BDL	BDL	1.9±0.1	2.3±0.4	3.6±0.5	4.51±0.04
Cu-EDTA pH 7	BDL	BDL	BDL	BDL	5.9±0.2	7.89±0.8	8.28±0.8	10.47±0.8
Cu-EDTA pH 9	BDL	BDL	BDL	BDL	4.9±0.21	5.64±0.5	6.28±0.6	7.89±0.8
$FeSO_4$ pH4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
$FeSO_4$ pH 7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
$FeSO_4$ pH 9	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
$MnSO_4$ pH4	6.8±0.11	8.74±0.05	9.71±0.5	10.34±1.1	BDL	BDL	BDL	BDL
$MnSO_4$ pH 7	15.6±0.1	17.5±1.1	20.41±1.1	21.45±1.4	BDL	BDL	BDL	BDL
$MnSO_4$ pH 9	18.67±0.3	20.51±1.3	19.9±1.4	20.25±1.6	BDL	BDL	BDL	BDL
$CuSO_4$ pH4	BDL	BDL	BDL	BDL	2.6±0.13	3.52±0.4	5.43±0.5	5.89±0.5
$CuSO_4$ pH 7	BDL	BDL	BDL	BDL	6.5±0.11	8.89±0.8	9.4±1	10.14±0.8
$CuSO_4$ pH 9	BDL	0.01±0.01	0.01±0.01	BDL	5.8±0.11	6.98±1	8.29±0.8	8.89±.7
P value	P(trt)<0.01	P(trt)<0.01	P(trt)<0.01	P(trt)<0.01	P(trt)<0.01	P(trt)<0.01	P(trt)<0.01	P(trt)<0.01
LSD	LSD=1.05	LSD=1.5	LSD=1.63	LSD=1.01	LSD=0.46	LSD=0.56	LSD=0.53	LSD=0.49

*BDL: Below detection limit of the instrument

Table 7S: Correlation statistics between pH, Available N, Available P, Available K, Fe, Mn, and Cu of different types of soil; photosynthetic rate, chlorophyll content, and hill activity of tomato leaves under various treatment

	Soil in lab-scale study					
	pH	P	Fe	Mn	Cu	
Aqueous media	0.72*	0.83**	0.67*	0.92**	0.95**	
	Photosynthetic rate		Hill reaction			Chlorophyll
Photosynthetic rate			0.82**			0.95**
Hill reaction	0.82**					0.75*
Chlorophyll	0.95**		0.75*			

* $p<0.05$; ** $p<0.01$

Table 8S: Effect on Catalase activity, Lipid peroxidation, Super oxide dismutase, Photosynthetic rate, Hill activity, Chlorophyll content, total protein content and shelf life in tomato leaves treated with $OCIMn_{ox}$ and $OCICu_{ox}$

	Attributes							
Treatment	Catalase (ml $min^{-1}g^{-1}$)	Lipid peroxidation (µM g^{-1})	Super oxide dismutase (min^{-1} mg $^{-1}$)	Photosynthetic rate (µM CO_2 m^{-2} s^{-1})	Hill activity (µM hr^{-1})	Chlorophyll (mg g^{-1})	Total protein (mg ml^{-1})	Shelf life(g)
Control	6.2±0.5	0.073±0.011	34.08±0.12	20.59±1.5	4126±56	38.01±5.4	1.13±0.001	54.8±0.26
$OCIMn_{ox}$	5.3±1.2	0.013±0.005	11.17±0.31	45.83±4.5	5221±48	54.6±2.5	2.28±0.05	30.1±0.24
$OCICu_{ox}$	5.3±1.5	0.008±0.001	10.85±0.08	32.76±1.5	5035±78	45.2±2.4	1.99±0.011	28.5±0.64
Fe-EDTA	5.3±1.4	0.108±0.01	31.77±0.29	26.03±2.1	4136±48	40.15±1.8	1.71±0.002	45.5±0.45
Mn-EDTA	5.3±1.4	0.134±0.005	50.15±0.83	22±1.6	3897±38	39.66±1.9	1.25±0.001	47.5±0.53
Cu-EDTA	5.3±1.1	0.167±0.008	35.41±0.11	21±1.8	3884±37	41.6±2.9	1.18±0.001	49.5±0.45
$FeSO_4$	8±1.1	0.128±0.005	21.66±0.15	23.79±2.7	4768±65	41.56±3.7	1.18±0.002	38±0.54
$MnSO_4$	6.8±0.8	0.172±0.009	27.31±2.5	20±1.4	3564±41	39.56±3.7	1.11±0.002	34.9±0.33
$CuSO_4$	6.2±1	0.144±0.012	48.97±0.86	21±1.6	3379±35	39.6±2.7	1.15±0.001	39.1±0.31
p value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	0.58	0.007	0.76	0.61	26.8	0.17	0.03	0.75

Table 9S-A: qRT-PCR using *GS2*, *GOGAT*, *NR*, and *Fd* gene-specific primers where *gapdh* served as an internal control

Treatment	Attributes			
	Fd	*GOGAT*	*GS2*	*NR*
Control	1±0.1	1±0.1	1±0.01	1±0.01
$OCIMn_{ox}$	9.92±0.9	1.35±0.07	2.04±0.35	6.92±0.1
$OCICu_{ox}$	4.75±0.6	1.82±0.15	1.46±0.09	9.06±0.2
Fe-EDTA	0.05±0.001	0.005±0.001	0.55±0.05	0.38±0.3
$FeSO_4$	0.57±0.07	0.26±0.03	0.55±0.05	0.88±0.3
p value	<0.01	<0.01	<0.01	<0.01
LSD	0.05	0.03	0.04	0.03

Table 9S-B: Activity of GS, GOGAT, and NR enzyme in tomato leaves under various treatments

Treatment	Attributes		
	GOGAT ($nM\ min^{-1}mg^{-1}$)	GS ($\mu M\ min^{-1}\ g^{-1}$)	NR ($g\ hr^{-1}$)
Control	16.09±1.2	0.17±0.01	31.78±1.2
$OCIMn_{ox}$	16.2±0.5	0.195±0.02	68.34±2.4
$OCICu_{ox}$	18.49±0.5	0.178±0.01	55.9±1.1
Fe-EDTA	11.02±0.5	0.136±0.01	25±1.1
$FeSO_4$	14.17±0.4	0.134±0.01	34±1.4
p value	<0.01	<0.01	<0.01
LSD	0.05	0.01	0.6

Table 10S: Effect of OCICuox and OCIMnox on uptake of N, P, Fe, Mn, Cu, and Yield of tomato plant grown in micronutrient leached and natural soil

Treatments	Uptake N (%)	Uptake P (mg kg^{-1})	Uptake Fe (mg kg^{-1})	Uptake Mn (mg kg^{-1})	Uptake Cu (mg kg^{-1})	Yield (g $plant^{-1}$)
Control	2.44±0.2	28.5±4.5	3.3±0.6	0.48±0.01	0.12±0.01	14.9±3.4
$OCIMn_{ox}$	6.81±0.1	108.5±11.4	48.3±2.6	4.8±0.05	0.08±0.03	38.9±4.6
$OCICu_{ox}$	6.39±0.4	106.4±15.4	41.4±5.4	0.11±0.01	2.8±0.01	37.5±2.6
Fe-EDTA	2.45±0.3	41.52±1.7	28.54±1.1	0.15±0.01	0.11±0.01	11.08±1.3
Mn-EDTA	2.65±0.1	34.59±1.1	22.57±1.6	2.8±0.06	0.05±0.01	12.54±1
Cu-EDTA	3.03±0.2	39.09±1.4	25.17±1.2	0.11±0.05	1.5±0.01	10.25±1.1
$FeSO_4$	3.11±0.1	34.58±1.8	53.18±3.4	0.21±0.05	0.08±0.01	8.97±1.1
$MnSO_4$	3.03±0.4	39.19±2.1	28.6±1.2	1.5±0.09	0.06±0.01	10.41±1.1
$CuSO_4$	2.98±0.2	33.56±1.5	32.2±1.7	0.16±0.01	1.2±0.05	11.5±1.1
p value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	0.72	0.95	0.21	0.05	0.06	0.2

Table 11S: Effect of $OCIMn_{ox}$ and $OCICu_{ox}$ on relative seed germination (RSG), relative root growth (RRG), and germination index (GI) of tomato (Badshah *F1 hydbrid*).

Treatment	Attributes		
	RSG (%)	RRG (%)	GI (%)
Control	91±7.5	68±5	61.88±4.8
$(OCIMn_{ox})_{10}$	166.67±24.5	131±15	218.3±36
$(OCIMn_{ox})_{20}$	135±17	134±27	180.9±30
$(OCIMn_{ox})_{50}$	134±18	101±31	135.34±24
$(OCICu_{ox})_{10}$	159±21	125±12	198.75±14
$(OCICu_{ox})_{20}$	131±18.54	105±14	137.55±15
$(OCICu_{ox})_{50}$	108±14	95±4.6	102.6±13
$(FeSO_4)_{50}$	63±10	45±4.5	28.35±5.2
$(Fe\text{-}EDTA)_{50}$	45±8.5	36±3.4	16.2±5.3
p value	<0.01	<0.01	<0.01
LSD	0.86	0.82	1.08

Table 12S: Activity of catalase, reduced glutathione (GSH), glutathione S transferase (GST), super oxide dismutase (SOD), earthworm biomass and body length in earthworms exposed to $OCIMn_{ox}$ and $OCICu_{ox}$ (mean±stdev)

Treatment	Catalase (U mg^{-1} min^{-1})		GSH (nM mg^{-1})		GST (min^{-1} mg^{-1})		SOD (min^{-1} mg^{-1})		Earthworm biomass (g)		Body length (cm)	
	10 day	30 day	10 day	30 day	10 day	30 day	10 day	30 day	10 day	30 day	10 day	30 day
$(OCIMn_{ox})_{10}$	52.01±2.8	19.29±0.95	114.08±5.9	20.88±1	121.99±6.9	43.01±4.13	43.79±2.2	24.53±1.3	0.4±0.02	0.7±0.04	5.8±0.3	10±0.5
$(OCIMn_{ox})_{50}$	94.01±4.8	24.68±1.4	138.58±6.2	21.89±1.1	190.32±9.8	62.95±3.1	56.66±2.8	30.74±1.5	0.35±0.02	0.58±0.03	5.6±0.26	8.5±0.4
$(OCICu_{ox})_{10}$	36.69±1.9	15.85±0.8	119.01±6.3	20.58±1	185.47±10	52.71±2.4	46.01±2.3	15.02±0.8	0.37±0.02	0.67±0.03	5.6±0.28	7.5±0.4
$(OCICu_{ox})_{50}$	11.09±0.58	20.42±1	122.59±6.3	26.72±1.3	169.57±8.6	82.44±4.1	67.29±3.4	33.15±1.7	0.35±0.03	0.53±0.03	5.5±0.23	7.1±0.4
$(FeSO_4)_{10}$	581.48±28.5	314.08±16.1	206.46±9.8	168.91±8.6	1428.79±68	240.38±12	381.63±20.1	472.84±23.8	0.32±0.02	0.35±0.02	5.2±0.28	5.8±0.3
$(FeSO_4)_{50}$	765.32±37.1	346.97±17.6	370.65±19.2	176.44±8.8	2617.53±110	280.39±14	473.56±23.9	366.38±18.5	0.31±0.03	0.34±0.02	5.2±0.29	5.9±0.3
Control	211.48±11.4	57.32±2.9	83.31±4.3	42.06±2.1	154.04±7.7	72.78±3.5	69.23±3.5	66.91±3.5	0.33±0.03	0.39±0.03	5.1±0.22	6±0.3
P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	0.162	8.85	0.469	0.907	15.78	1.99	7.594	9.26	0.0004	0.04	0.092	0.102

SI-A (for section 2.2.2.2.): Microbial analytical procedure

Soil microbial health was assessed by the growth of soil bacteria following serial dilution technique as reported by Parmer and Schimdt [38]. At first, air dried soil samples (1 g) were thoroughly mixed in 10 ml of sterile deionized water for 15min with the help of a vortex machine and serially diluted from 10^{-1} to 10^{-6}. Then, 0.1 ml of aliquots was inoculated in previously prepared nutrient agar (NA) containing petriplates in a laminar air flow chamber to ensure aseptic condition. Subsequently, the petriplates were incubated in an incubator for 24h at 37 ^{o}C to promote bacterial growth. After incubation, the colonies appeared in the petriplates were enumerated by means of a colony counter and approximate number of bacterial load was estimated by the formula given below:

$$No.\ of\ bacteria\ ml^{-1} = \frac{No.\ of\ colonies\ \times dilution}{Amount\ plated}$$

Siderophore producing bacterial growth was also assessed. Siderophores are secondary metabolites produced by diverse groups of soil microorganisms; they play a vital in sustaining Fe availability in soils, specifically under nutrient deficient conditions [40]. Hence, 1 g of soil samples under various treatments were aseptically submerged in 10 ml of sterilized distilled water and homogenized in vortex for 10-15 s and supernatants (100 µl) were collected. Eventually, the samples were serially diluted (10^{-3} to 10^{-4} times) and inoculated on CAS agar petri-dishes for isolating siderophore producing bacterial strains from different soil samples. The CAS agar plates were prepared according to the method of Louden et al. [41]. We also added griseofulvin (200 µg ml^{-1}) with CAS agar plates to avoid fungal contaminations. After 48h of incubation at 28 °C, single colonies with maximum halo zones were identified, counted, and purified by

repeated streaking for 5 to 6 generations on CAS agar plates. These pure siderophore producing bacterial strains were again spotted on the CAS agar plates and incubated at 28 °C for 72h. Siderophore production potential of the isolates was qualitatively evaluated on the basis of the development of orange zones around the bacterial colonies.

SI-B for 2.2.2.3 (Plant analyses)

Details of qRT-PCR techniques

The qRT-PCR was conducted with gene specific primers of *Fd*, *NR*, *GS2*, and *GOGAT*. Initially, TRI reagent, Isopropanol and DEPC treated water were used for extraction of total RNA. From this total RNA, 2 µg of sample was used in qRT-PCR in a total volume of 20 µL with gene specific primers of the specified genes. The standard conditions maintained in qRT-PCR are as follows: initial activation step (95 °C, 15 min), cycling step (denaturation at 95 °C, 30 s; annealing at 55 °C,30 s; extension at 72 °C, 30 s, 40 cycles), melt curve analysis (55–60 °C, 15 s, 40 cycles). GAPDH served as a house keeping gene.

The sequences of the primers are given below:

Fd (forward primer): AAGAAAGCCGGCTGTGACTA

Fd (reverse primer): ACTGGCCATGCAAGTAATCC

NR (forward primer): TTACAACTCCGTGCCATGAA

NR (reverse primer): TCCATGTCTCTCCTCCATCC

GS2 (forward primer): GAATCTATCCCTTCGCCACA

GS2 (reverse primer): CCTTGCCTTCCTTCTCAGTG

GOGAT (forward primer): ACGAGGAGCTCGGTAGTGAA

GOGAT (reverse primer): GCACCTGAGACAATGCAGAA

SI-C (for section 2.2.3): Formulas for deriving relative shoot growth (RSG), relative root growth (RRG), and germination index (GI) in treated tomato seeds

$$RSG\ (\%) = \frac{Number\ of\ seeds\ germinated\ with\ treatments}{Number\ of\ seeds\ germinated\ in\ distilled\ water} \times 100$$

$$RRG\ (\%) = \frac{Mean\ root\ length\ of\ seeds\ receiving\ treated\ solutions}{Mean\ root\ length\ of\ seeds\ receiving\ distilled\ water} \times 100$$

$$GI(\%) = \frac{RSG \times RRG}{100}$$

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