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RESEARCH PAPER

Influence of graded levels of essential heavy metals on the fresh weight changes of tuberose *cv.* 'Prajwal'

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Abstract : An experiment was conducted with graded levels of three different essential heavy metals *viz.,* $MnSO_4$(1000, 2000 and 3000 mg kg^{-1} soil), $CuSO_4$(100, 200 and 300 mg kg^{-1} soil) and $ZnSO_4$(200, 400 and 600 mg kg^{-1} soil) in addition to control *i.e.,*without external application of any essential heavy metals mentioned above. The experiment was carried out continuously for two years in polybag culture method and conducted with a Completely Randomized Design using three replications. The data recorded at every 90 days after planting (DAP) intervalon fresh weight changes of tuberose *cv.* 'Prajwal' during different phases of vegetative growth were analyzed using OPSTAT software and the least significant difference was used to differentiate the treatments. Analysis of results indicated that soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded a significant improvement in the fresh weight changes of different vegetative parameters *viz*., fresh weight of leaves (591.06, 807.66 and 699.36 g, respectively during 2018-19, 2019-20 and the pooled data analysis), fresh weight of flower stalks (37.33 g during 2018-19), fresh weight of roots (36.26 and 37.29 g, respectively during 2018-19 and the pooled data analysis), fresh weight of bulbs (86.60, 221.76 and 154.18 g, respectively during 2018-19, 2019-20 and the pooled data analysis), the above ground fresh biomass (377.43, 532.30 and 454.86 g, respectively during 2018-19, 2019-20 and the pooled data analysis) and the total fresh biomass (595.30, 996.50 and 795.90 g, respectively during 2018-19, 2019-20 and the pooled data analysis) per plant.

Key Words : $CuSO_4$, Heavy metals, $MnSO_4$, Fresh leaf yield, Total biomass, Tuberose, $ZnSO_4$

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INTRODUCTION

Contamination of soils with heavy metals is considered as one of the serious environmental concerns due to persistent nature of heavy metals as well as their bio-magnification potential in the soil. Presence of high concentrations of both essential and non-essential heavy metals are considered to affect the plant growth and development adversely and sometimes even lead to death under extreme conditions and thus heavy metal toxicityhas been considered as one of the major abiotic stresses leading to hazardous effects in plants as many of them were found toxic even at a very low-level concentrations in the soil. Industrial revolution has accelerated the biosphere with heavy metals all over the world. A common response of heavy metal toxicity on plants was excessive accumulation of reactive oxygen species

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(ROS) which can cause peroxidation of lipids, oxidation of proteins, inactivation of enzymes, DNA damage and/ or interact with other vital constituents of plant cells (Bohra *et al*., 2015). Certain heavy metals were found nutritionally essential for healthy growth of plant in very small quantities such as iron (Fe), copper (Cu), manganese (Mn), magnesium (Mg) and zinc (Zn). These metals were found required in specific amounts and their deficiencies or elevated concentrations will result in deleterious effects on plant growth and development and thus reduce plant productivity. Out of the several heavy metals of essential and non-essential nature, three essential heavy metals *viz.,* Mn, Cu and Zn were found required in trace amounts for better growth, development and metabolic activity of plants and thus, have been selected in the present investigation to identify their level of beneficial and toxic effects on the plant's metabolic activity under heavily accumulated condition in the soil. General metabolic functions and toxicity of these essential heavy metals on plant's growth and metabolism has been briefly discussed to show the basis for selection of tuberose plants to remove these elements from soil through the process of phytoremediation in the present investigation with the main objective to find out the fresh weight changes of tuberose *cv.* 'Prajwal' as influenced by graded levels of different essential heavy metals *viz.,*Mn, Cu and Zn.

Material and Methods

The present investigation was carried out during the period from *Rabi*-2018 to *Kharif*-2020 at the College of Horticulture, Dr. Y.S.R. Horticultural University, Anantharajupeta, Kadapa district of Andhra Pradesh. The experiment was laid out in a Completely Randomized Design (CRD) with factorial concept and replicated thrice. The experiment has consisted of 10 treatments *viz.,* T_1 = RDF+$MnSO_4$ @ 1,000 mg kg^{-1} soil, T_2 = RDF+$MnSO_4$ @ 2,000 mg kg^{-1} soil, T_3 = RDF+$MnSO_4$ @ 3,000 mg kg^{-1} soil, T_4 = RDF+$CuSO_4$ @ 100 mg kg^{-1} soil, T_5 = RDF+$CuSO_4$ @ 200 mg kg^{-1} soil, T_6 = RDF+$CuSO_4$ @ 300 mg kg^{-1} soil, T_7 = RDF+$ZnSO_4$ @ 200 mg kg^{-1} soil, T_8 = RDF+ $ZnSO_4$ @ 400 mg kg^{-1} soil, T_9 = RDF+ $ZnSO_4$ @ 600 mg kg^{-1} soil, T_{10} = Control (No RDF and no essential heavy metals application). The main objective of the investigation was to find out the fresh weight changes of tuberose *cv.* 'Prajwal' as influenced by graded levels of essential heavy metals (Mn, Cu, Zn). Fresh weight changes with respect to leaves, flower stalks, roots and bulbs of tuberose cv. 'Prajwal'was weighed by using an electronic balance with 1 milli gram precision and expressed as grams per plant. The above ground fresh biomass was calculated by weighing the fresh weight of leaves, flower stalks and florets present on each plant and the total was expressed as grams per plant. Total fresh biomass was calculated by weighing the fresh weights of root, bulb, leaf, stem and flower stalks present on each plant and the total was expressed as grams per plant. The data obtained was analyzed using OPSTAT software and the least significant difference was used to differentiate the treatment differences.

Results and Discussion

Significant differences were observed among the graded levels of applied essential heavy metal concentrations on the fresh weight of leaves per plant of tuberose *cv.* 'Prajwal' (Table 1). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1}soil recorded significantly highest fresh weight of leaves per plant (310.50, 677.93 and 494.22 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil. Application of graded levels of $MnSO_4$ recorded a significant reduction in the fresh weight of leaves per plant with an increase in the concentration upto 2000 mg kg^{-1} soil, whereas a slight but significant increase in the fresh weight of leaves per plant was noticed with further increase in the concentration of $MnSO_4$ upto 3000 mg kg^{-1} soil. Application of graded levels of $CuSO_4$ recorded a significant increase in the fresh weight of leaves per plant with increased concentration of $CuSO_4$ during 2018-19, whereas an increase in the concentration of $CuSO_4$ has recorded a significant decrease in the fresh weight of leaves per plant upto 200 mg kg^{-1} soil and thereafter a further increase in the concentration of $CuSO_4$ upto 300 mg kg^{-1} soil recorded a significant increase in the fresh weight of leaves per plant during 2019-20 and the pooled data analysis. Among all the treatments, untreated control plants recorded significantly lowest fresh weight changes in the leaves per plant (49.88, 164.17 and 107.03 g, respectively during 2018-19, 2019-20 and the pooled data analysis). Influence of $MnSO_4$ and $CuSO_4$ at different concentrations on fresh weight of leaves per plant of tuberose *cv.* 'Prajwal' was found moderate in comparison to zinc sulphate concentrations and the untreated control plants during both the years of study as well as in the pooled data analysis. Based on the analysis of results with respect to application of graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1}soil recorded significantly highest fresh weight of leaves per plant during both the years of study as well as in the pooled data analysis. This might be attributed to the vital role of zinc in several of the physiological and biochemical processes in the plant thus, increased the production of vegetative growth in terms of leaf weight and ultimately encouraged the total fresh biomass of tuberose *cv.* 'Prajwal'. Patel *et al.* (2017) reported similar kind of observation in tuberose by foliar application of $ZnSO_4$ at 20 ppm concentration.

Significant differences were noticed among the intervals of observation recorded with respect to fresh weight of leaves per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations. Among the intervals of observation recorded, significantly highest fresh weight of leaves per plant (283.87, 414.09 and 348.98 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval, whereas significantly lowest fresh weight of leaves per plant (29.11, 330.75 and 179.93 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded during the initial 90 DAP interval. A gradual increase in the fresh weight of leaves per plant was noticed at each successive interval of observation. However, differences noticed in the fresh weight of leaves per plant between the successive intervals of 90 and 180 DAP were found at par with each other during 2018-19.

Significant differences were noticed in the interaction effects between graded levels of soil applied essential heavy metal concentrations and the intervals of observation recorded with respect tofresh weight of leaves per plant during 2018-19, 2019-20 and the pooled data analysis. Among the combination treatments, significantly highest fresh weight of leaves per plant (591.06, 807.66 and 699.36 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 360 DAP interval followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (538.00, 665.20 and 601.60 g, respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest fresh weight of leaves per plant (14.93, 151.26 and 83.10 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control plants at 90 DAP interval. Based on the analysis of results, it may be concluded that application of $ZnSO_4$ @ 400 mg kg^{-1} soil might have played a vital role in enhancing the vegetative growth of plant by an increase in the production of tryptophan, the precursor of auxin which encouraged the total fresh biomass of tuberose plant thus, resulted an increase in the fresh weight of leaves per plant. The present result was found in agreement with the earlier findings of Siddiqui *et al.* (2009) in

Table 1 : Influence of applied essential heavy metals (Cu, Mn, Zn) on fresh weight of leavesplant^{-1} of *Polianthes tuberose cv.* Prajwal

Treatment (mg of element kg^{-1} soil)	Fresh weight of leaves plant^{-1}(g) 2018 - 2019					2019 - 2020					Pooled (2018-20)				
	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean
$MnSO_4$ 1000	16.60	18.20	143.66	386.40	141.21	355.66	374.33	398.26	462.00	397.56	186.13	196.26	270.96	424.20	269.38
$MnSO_4$ 2000	34.00	34.56	146.33	149.13	91.00	305.00	333.06	354.73	391.36	346.03	169.50	183.81	250.53	270.25	218.52
$MnSO_4$ 3000	29.00	29.43	43.33	315.33	104.27	317.46	326.53	342.43	366.26	338.17	173.23	177.98	192.88	340.80	221.22
$CuSO_4$ 100	25.60	26.00	112.66	169.40	83.41	325.53	328.53	359.16	385.23	349.61	175.56	177.26	235.91	277.31	216.51
$CuSO_4$ 200	25.86	26.16	65.00	231.93	87.23	271.93	285.86	305.10	327.06	297.48	148.90	156.01	185.05	279.50	192.36
$CuSO_4$ 300	16.26	16.63	247.66	250.26	132.70	288.60	293.70	327.13	375.16	321.14	152.43	155.16	287.40	312.71	226.92
$ZnSO_4$ 200	44.13	44.53	305.33	308.06	175.51	386.70	388.00	408.03	441.86	406.14	215.41	216.26	356.68	374.96	290.82
$ZnSO_4$ 400	55.73	57.23	538.00	591.06	310.50	597.03	641.86	665.20	807.66	677.93	326.38	349.55	601.60	699.36	494.22
$ZnSO_4$ 600	29.00	29.46	163.66	306.60	132.18	308.36	335.53	356.50	393.83	348.55	168.68	182.49	260.08	350.21	240.36
Control	14.93	15.06	39.00	130.53	49.88	151.26	154.93	159.96	190.56	164.17	83.10	85.00	99.48	160.55	107.03
Mean	29.11	29.72	180.46	283.87		330.75	346.23	367.65	414.09		179.93	187.98	274.05	348.98	
Factor	T		I		T × I	T		I		T × I	T		I		T × I
S.E.±	1.37		0.87		2.75	0.83		0.52		1.66	0.81		0.51		1.63
C.D. (P=0.05)	3.88		2.46		7.77	2.34		1.48		4.68	2.31		1.46		4.61

sunflowerand Tariq *et al.* (2013) in gladiolus.

Significant differences were recorded in the fresh weights of flower stalks per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations (Table 2). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1}soil recorded significantly highest fresh weight of flower stalks per plant (21.38, 57.24 and 39.31 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil and was found at par with the application of $ZnSO_4$ @ 600 mg kg^{-1} soil. Non-significant differences were noticed in the fresh weights of flower stalks per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of $MnSO_4$ and $CuSO_4$ during 2018-19, 2019-20 and the pooled data analysis.Significantly lowest fresh weight of flower stalks per plant was noticed in the untreated control plants (3.21, 9.83and 6.52 g, respectively during 2018-19, 2019-20 and the pooled data analysis). Dikshit (1961) and Sharma *et al.* (1974) reported that availability of Zn in soil might have played a key role in increasing the plant growth and fruit yield in citrus and sweet oranges, respectively.

Significant variation was noticed among the intervals of observation recorded with respect to fresh weights of flower stalks per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations. Significantly highest fresh weight of flower stalks per plant (20.09, 28.45 and 24.27 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval, whereas significantly lowest fresh weight of flower stalks per plant (2.43, 18.48 and 10.45 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at the initial 90 DAP interval during both the years of study as well as in the pooled data analysis. A gradual increase in the fresh weight of flower stalks per plant was recorded at each successive interval of observation recorded during both the years of study as well as in the pooled data analysis. However, non-significant differences were noticed in the intervals between 90 and 180 DAP during 2018-19, 2019-20 and the pooled data analysis with respect to fresh weight of flower stalks per plant. Further, non-significant differences were noticed with respect to fresh weight of flower stalks per plant in between the intervals 180 and 270 DAP during 2019-20 and in between the intervals 270 and 360 DAP in the pooled data analysis.

The data pertaining to interaction effects between graded levels of essential heavy metal concentrations and the intervals of observation recorded with respect to fresh weight of flower stalks per plant was found significant duringthe 1st year of study *i.e.,* 2018-19, whereas the data was found non-significant during 2nd year of study *i.e.,*2019-20 as well as in the pooled data analysis. Among the combination treatments, significantly

Table 2 : Influence of applied essential heavy metals (Cu, Mn, Zn) on fresh weight of flower stalksplant^{-1}of *Polianthes tuberose cv.* Prajwal

Treatment (mg of element kg^{-1} soil)	Fresh flower stalksyield plant^{-1}(g)														
	2018 - 2019					2019 – 2020					Pooled (2018-20)				
	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean
$MnSO_4$ 1000	0.93	1.50	12.00	13.13	6.89	8.80	16.80	25.20	22.93	18.43	4.86	9.15	18.60	18.03	12.65
$MnSO_4$ 2000	1.26	1.10	12.00	19.86	8.55	17.83	0.00	17.06	17.40	13.07	9.55	0.55	14.53	18.63	10.81
$MnSO_4$ 3000	2.30	4.26	11.00	12.53	7.52	16.40	17.23	12.86	25.33	17.95	9.35	10.74	11.93	18.93	12.73
$CuSO_4$ 100	1.20	2.70	11.33	32.06	11.82	21.03	21.23	20.90	31.13	23.57	11.11	11.96	16.11	31.59	17.69
$CuSO_4$ 200	1.36	3.60	11.33	10.46	6.68	24.13	11.76	12.20	34.00	20.52	12.75	7.68	11.76	22.23	13.60
$CuSO_4$ 300	4.00	3.90	8.66	11.20	6.94	12.20	12.30	27.93	23.63	19.01	8.10	8.10	18.29	17.41	12.97
$ZnSO_4$ 200	4.56	3.30	26.00	26.53	15.09	10.80	34.63	26.86	33.63	26.48	7.68	18.96	26.43	30.08	20.78
$ZnSO_4$ 400	6.33	9.23	32.66	37.33	21.38	56.63	58.40	56.23	57.73	57.24	31.48	33.81	44.44	47.53	39.31
$ZnSO_4$ 600	2.40	2.26	12.33	25.00	10.49	17.03	21.26	25.66	30.46	23.60	9.71	11.76	18.99	27.73	17.05
Control	0.00	0.00	0.00	12.86	3.21	0.00	8.93	22.13	8.26	9.83	0.00	4.46	11.06	10.56	6.52
Mean	2.43	3.18	13.73	20.09		18.48	20.25	24.70	28.45		10.45	11.71	19.21	24.27	
Factor	T		I	T × I		T		I	T × I		T		I	T × I	
S.E.±	2.19		1.38	4.38		3.73		2.36	7.46		2.18		1.38	4.37	
C.D. (P=0.05)	6.17		3.90	12.35		10.53		6.66	NS		6.16		3.90	NS	

NS = Non-significant

highest fresh weight of flower stalks per plant (37.33 g) was recorded by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 360 DAP intervaland was found at par with the application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (32.66 g) during 2018-19, whereas significantly lowest fresh weight of flower stalks per plant (0.00 g) was recorded in the untreated control plants at the initial 90 DAP interval during 2018-19. Increase in the fresh weight of flower stalks per plant in tuberose *cv.* 'Prajwal' might be attributed to increased dry matter accumulation in the plant by availability of required nutrient elements to the plant. Further, application of $ZnSO_4$ @ 400 mg kg^{-1} soil might have enhanced the activity of apical meristem in the plant thus, an increase in the weight of fresh flower stalks might have recorded. Similar kind of observation was also reported by Verma *et al*. (2000) in carnation, Humaid (2001) in rose and El-Naggar (2005) in gladiolus.

Significant differences were noticed in the fresh weight of roots per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations (Table 3). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest fresh weight of roots per plant (22.40, 39.43 and 29.77 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil. Among the manganese sulphate concentrations, application of $MnSO_4$ @ 1000 and 3000 mg kg^{-1} soil recorded non-significant differences in the fresh weight of roots per plant during 2018-19, whereas significant reduction in the fresh weight of roots per plant of tuberose *cv.* 'Prajwal' was noticed with an increase in the concentration upto 2000 mg kg^{-1} soil and thereafter significant increase in the fresh weight of roots per plant was noticed with the application of $MnSO_4$ @ 3000 mg kg^{-1} soil. Among the $CuSO_4$ concentrations, application of $CuSO_4$ @ 100 and 300 mg kg^{-1} soil recorded non-significant differences in their fresh weight of roots per plant during 2018-19 as well as 2019-20, but non-significant differences were noticed with the pooled data analysis with respect to the fresh weight of roots per plant by soil application of graded levels of $CuSO_4$. Among all the treatments, significantly lowest fresh weight of roots per plant was noticed in the untreated control plants (7.62, 18.62 and 10.45 g, respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of results, it may be concluded that soil application of different concentrations of $ZnSO_4$ recorded significantly more vigorous growth in the roots of tuberose *cv.* 'Prajwal' than the other essential heavy metal concentrations and in comparison, to the untreated control plants. Mousavi (2011) proposed that soil application of $ZnSO_4$ might have played a key role in the stabilization of structures of RNA and DNA in the plant system and thus their active role in the biosynthesis of growth promoting hormones such as IAA and gibberellins promoted the root growth of tuberose *cv.* 'Prajwal' by

Table 3: Influence of applied essential heavy metals (Cu, Mn, Zn) on fresh weight of rootsplant^{-1}of *Polianthes tuberose cv.* Prajwal

Treatment (mg of element kg^{-1} soil)	Fresh weight of rootsplant^{-1} (g)														
	2018 - 2019					2019 - 2020					Pooled (2018-20)				
	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean
$MnSO_4$ 1000	6.63	7.26	17.33	23.60	13.70	25.60	26.53	27.70	31.33	27.79	16.11	16.42	22.51	24.49	19.88
$MnSO_4$ 2000	13.30	13.63	15.53	18.93	15.34	19.26	21.83	26.00	27.23	23.58	16.28	16.86	20.76	21.69	18.89
$MnSO_4$ 3000	3.33	7.05	16.66	29.66	14.17	32.23	33.53	34.56	36.36	34.17	17.78	18.78	25.61	28.57	22.68
$CuSO_4$ 100	10.73	14.60	19.00	19.46	15.94	22.80	24.80	33.33	33.86	28.69	16.76	17.93	26.16	26.36	21.80
$CuSO_4$ 200	6.16	6.60	15.33	26.86	13.73	27.93	29.13	34.06	34.63	31.43	17.05	17.37	24.70	27.11	21.55
$CuSO_4$ 300	3.96	9.26	22.33	22.76	14.57	26.20	26.63	31.56	32.70	29.27	15.08	16.22	26.95	27.25	21.37
$ZnSO_4$ 200	10.70	13.03	24.33	30.80	19.71	31.73	36.66	38.50	38.93	36.45	21.21	22.67	31.41	32.79	27.02
$ZnSO_4$ 400	8.70	13.00	31.66	36.26	22.40	36.93	38.30	40.40	42.10	39.43	22.81	23.94	36.03	37.29	30.01
$ZnSO_4$ 600	9.46	9.73	22.66	25.13	16.74	26.80	28.40	29.63	29.86	28.67	18.13	18.50	26.15	26.68	22.36
Control	2.43	3.53	9.00	15.53	7.62	16.00	16.90	19.90	21.70	18.62	9.21	9.61	14.45	16.11	12.34
Mean	7.54	9.76	19.38	24.89		26.54	28.27	31.56	32.87		17.04	17.83	25.47	26.83	
Factor	T		I		T × I	T		I		T × I	T		I		T × I
S.E.±	0.53		0.34		1.07	0.59		0.37		1.19	0.41		0.26		0.82
C.D. (P=0.05)	1.51		0.95		3.03	1.68		1.06		N/A	1.16		0.73		2.33

application of $ZnSO_4$ @ 400 mg kg^{-1} soil which might be considered as an optimum dose for proper plant growth and development.

Significant differences were noticed among the intervals of observation recorded with respect to fresh weight of roots per plant of tuberose *cv.* 'Prajwal' by application of graded levels of essential heavy metal concentrations. Among the intervals, significantly highest fresh weight of roots per plant (24.89, 32.87and 26.83 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval, whereas significantly lowest fresh weight of roots per plant (7.54, 26.54 and 17.04 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the initial 90 DAP interval during both the years of study as well as in the pooled data analysis. A gradual and significant increase in the fresh weight of roots per plant was recorded at each successive interval of observation recorded during 2018-19, 2019-20 and the pooled data analysis.

The data pertaining to interaction effects between graded levels of essential heavy metal concentrations and the intervals with respect to fresh weight of roots per plant was found significant duringthe 1st year of study *i.e.,* 2018-19 and the pooled data analysis, but the data was found non-significant during the 2nd year of study *i.e.,* 2019-20. Significantly highest fresh weight of roots per plant (36.26 and 37.29 g, respectively during 2018-19 and the pooled data analysis) was recorded by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 360 DAP interval followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (31.66 and 36.03 g, respectively during 2018-19 and the pooled data analysis), whereas significantly lowest fresh weight of roots per plant (2.43 and 9.21 g, respectively during 2018-19 and the pooled data analysis) was recorded in the untreated control plants at the initial 90 DAP interval. Fageria (2002) observed significant increase in the fresh root yield of rice crop by soil application of $ZnSO_4$ and attributed that soil application of Zn might have played a key role in the regulation of auxin production in rice plants. Fageria (2002) further reported that, apart from increasing the auxin production in plants, Zn possesses the ability to increase the cation exchange capacity of plant roots and thus, promote the absorption of essential nutrients in the plant system. Thus, soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil increased the fresh root yield per plant in tuberose *cv.* 'Prajwal' and the overall growth and development of plant. The present results were found in close conformity with the earlier findings of Yadav (1990) who reported significant increase in the fresh root yield of pearl millet due to soil application of $ZnSO_4$. Further, similar kind of observation by application of Zn was also reported by Maliwal *et al.* (1985); Jat (1990); Sharma (1992) and Dwivedi *et al.* (2001) in different crops.

Significant differences were noticed in the fresh weight of bulbs per plant of tuberose *cv.* 'Prajwal' by

Table 4 : Influence of applied essential heavy metals (Cu, Mn, Zn) on fresh weight of bulbsplant^{-1}of *Polianthes tuberose cv.* Prajwal

Treatment (mg of element kg^{-1} soil)	Fresh weight of bulbsplant^{-1}(g)														
	2018 - 2019					2019 - 2020					Pooled (2018-20)				
	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean
$MnSO_4$ 1000	15.10	24.73	44.00	44.46	32.07	105.13	113.33	120.40	123.03	115.47	60.11	69.03	82.20	83.75	73.77
$MnSO_4$ 2000	25.66	34.56	36.33	45.93	35.62	75.60	85.73	103.70	113.66	94.67	50.63	60.14	70.01	79.79	64.14
$MnSO_4$ 3000	15.06	17.90	27.33	43.80	26.02	148.96	149.90	154.10	163.63	154.14	82.01	83.90	90.71	103.71	90.08
$CuSO_4$ 100	18.86	16.06	44.66	48.33	31.97	125.60	132.40	135.43	153.33	136.69	72.23	74.23	90.05	100.83	84.33
$CuSO_4$ 200	17.56	21.23	23.96	42.00	26.18	132.60	135.00	139.33	142.43	137.34	75.08	78.11	81.65	92.21	81.76
$CuSO_4$ 300	13.10	32.53	54.33	66.46	41.60	73.46	84.13	95.16	103.80	89.13	43.28	58.33	74.75	85.13	65.37
$ZnSO_4$ 200	26.93	27.86	56.33	64.66	43.94	157.26	164.86	185.56	204.26	177.98	92.09	96.36	120.94	134.46	110.96
$ZnSO_4$ 400	42.33	64.26	84.33	86.60	69.38	207.66	213.13	216.73	221.76	214.82	124.99	138.69	150.53	154.18	142.09
$ZnSO_4$ 600	24.00	25.53	45.00	47.86	35.59	56.26	57.46	68.70	71.73	63.53	40.13	41.50	56.85	59.80	49.57
Control	8.56	22.66	25.66	34.13	22.75	45.53	56.33	59.60	62.60	56.01	27.04	39.50	42.63	48.36	39.38
Mean	20.71	28.73	44.19	52.42		112.80	119.22	127.87	136.02		66.76	73.98	86.03	94.22	
Factor	T		I		T × I	T		I		T × I	T		I		T × I
S.E.±	0.50		0.31		1.00	0.72		0.46		1.45	0.43		0.27		0.87
C.D. (P=0.05)	1.40		0.89		2.81	2.05		1.30		4.11	1.23		0.78		2.46

soil application of graded levels of essential heavy metal concentrations (Table 4). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest fresh weight of bulbs per plant (69.38, 214.82 and 142.09 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil. Among the graded levels of $MnSO_4$ and $CuSO_4$, the response of heavy metal concentrations was found non-rhythmic without any specific pattern with respect to fresh weight of bulbs per plant of tuberose *cv.* 'Prajwal', but the differences were found significantly notable even though the differences were non-rhythmic, as the plant's response with the soil applied heavy metals was non-responsive due to slow mobility or immobile nature of the concerned heavy metals. Among all the treatments, significantly lowest fresh weight of bulbs per plant was noticed in the untreated control (22.75, 56.01 and 39.38 g, respectively during 2018-19, 2019-20 and the pooled data analysis).

Significant differences were noticed among the intervals of fresh weight of bulbs per plant in tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations. Among the intervals, significantly highest fresh weight of bulbs per plant (52.42, 136.02 and 94.22 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was observed at 360 DAP interval, whereas significantly lowest fresh weight of bulbs per plant (20.71, 112.80 and 66.76 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was noticed at the initial 90 DAP interval. A gradual and significant increase in the fresh weight of bulbs per plant of tuberose *cv.* 'Prajwal' was noticed at each successive interval of observation during both the years of study as well as in the pooled data analysis.

The data pertaining to interaction effects between graded levels of essential heavy metal concentrations and the intervals of observation recorded with respect tofresh weight of bulbs per plant was found significant during 2018-19, 2019-20 and the pooled data analysis. Among the combination treatments, significantly highest fresh weight of bulbs per plant (86.60, 221.76 and 154.18 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by application of $ZnSO_4$ @ 400 mg kg^{-1}soilat 360 DAP interval followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (84.33, 216.73 and 150.53 g, respectively during 2018-19, 2019-20 and the pooled data analysis),whereas significantly lowest fresh weight of bulbs per plant (8.56, 45.53 and 27.04 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was noticed in the untreated control plants at 90 DAP interval. Based on the analysis of results, it may be concluded that soil application of graded levels of $ZnSO_4$ recorded significant increase in the fresh weight of bulbs per plant in tuberose *cv.* 'Prajwal' might be attributed to the increase in the contents of formation of chlorophylls thus, increased the rate of photosynthesis and also helped in increasing the

Table 5 : Influence of applied essential heavy metals (Cu, Mn, Zn) on above ground fresh biomass plant^{-1}of *Polianthes tuberose cv.* Prajwal

Treatment (mg of element kg^{-1} soil)	Above ground fresh biomass plant^{-1}(g)														
	2018 - 2019					2019 - 2020					Pooled (2018-20)				
	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean
$MnSO_4$ 1000	31.10	42.70	185.33	113.66	93.19	191.33	207.16	417.30	453.90	317.42	111.21	124.93	301.31	283.78	205.30
$MnSO_4$ 2000	35.90	45.10	149.33	164.26	98.64	266.36	267.26	476.63	483.26	373.37	151.13	156.18	312.98	323.76	236.01
$MnSO_4$ 3000	38.06	38.23	143.33	151.06	92.67	195.86	206.90	214.90	237.16	213.70	116.96	122.56	179.11	194.11	153.18
$CuSO_4$ 100	26.20	28.60	164.33	184.40	100.88	219.73	284.76	296.20	309.23	277.48	122.96	156.68	230.26	246.81	189.17
$CuSO_4$ 200	37.83	38.63	83.33	248.03	101.95	251.43	254.50	366.20	386.53	314.66	144.63	146.56	224.76	317.28	208.30
$CuSO_4$ 300	25.16	35.40	82.66	182.66	81.47	192.26	195.73	246.86	252.73	221.89	108.71	115.56	164.76	217.70	151.68
$ZnSO_4$ 200	36.50	38.16	160.00	182.76	104.35	328.40	356.33	385.13	389.06	364.73	182.45	197.24	272.56	285.91	234.54
$ZnSO_4$ 400	61.10	67.43	316.73	377.43	205.67	384.73	395.53	506.00	532.30	454.64	222.91	231.48	411.36	454.86	330.15
$ZnSO_4$ 600	29.10	31.36	113.66	161.10	83.80	227.83	246.43	305.76	326.73	276.68	128.46	138.90	209.71	243.91	180.24
Control	19.00	21.33	33.66	75.76	37.43	105.50	111.13	135.66	163.20	128.87	62.25	66.23	84.66	119.48	83.15
Mean	33.99	38.69	143.23	184.11		236.34	252.57	335.06	353.41		135.16	145.63	239.14	268.76	
Factor	T		I		T × I	T		I		T × I	T		I		T × I
S.E.±	1.04		0.66		2.08	0.82		0.51		1.63	0.73		0.46		1.47
C.D. (P=0.05)	2.94		1.86		5.89	2.31		1.46		4.62	2.08		1.31		4.16

rate of nitrogen metabolism and auxin production which ultimately improved the whole biomass of the plant. An increase noticed in the fresh weight of bulbs of tuberose *cv.* 'Prajwal' was found slower during the early stages of plant growth and thereafter found faster at later stages of plant growth. Slower rate of growth recorded in the fresh weight of bulbs at the early stage of crop growth might be attributed to lower temperatures and short days which led to poor morphology and bulb development in the plant. As the number of leaves and roots increased on the plant with passage of time to longer days with an increase in the temperature promoted the bulb development in tuberose. Further, as per the observations of Satbir *et al.* (1989) in onion, it might be attributed that an increase recorded in the fresh weight of bulbs per plant in tuberose *cv.* 'Prajwal' might be due to soil application of Zn which might have mobilized reserve food material to the sink through increased activity of hydrolyzing and oxidizing enzymes. The present results were also found in agreement with the earlier findings of Baghel and Sarnaik (1988); Alam *et al.* (2010), Ballabh and Rana (2012) and Ballabh *et al.* (2013) in onion.

Significant differences were noticed in the above ground fresh biomass per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations (Table 5). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest above ground fresh biomass per plant (205.67, 454.64 and 330.15 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil. Non-significant differences were noticed in between the concentrations of $MnSO_4$ @ 1000 and 3000 mg kg^{-1}soil with respect to above ground fresh biomass per plant in tuberose *cv.* 'Prajwal' during 2018-19, whereas significant differences were noticed in the above ground fresh biomass per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of $MnSO_4$ during 2019-20 and the pooled data analysis. Non-significant differences were noticed in between the concentrations of $CuSO_4$ at 100 and 200 mg kg^{-1} soil with respect to the above ground fresh biomass per plant of tuberose *cv.* 'Prajwal' during 2018-19, whereas significant differences were noticed in the above ground fresh biomass per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of $CuSO_4$ during 2019-20 and the pooled data analysis. Among all the treatments, significantly lowest above ground fresh biomass per plant was noticed in the untreated control plants of tuberose *cv.* 'Prajwal' (37.43, 128.87and 83.15 g, respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of results, it may be concluded that soil application of graded levels of $ZnSO_4$ recorded a significant increase in the above ground fresh biomass per plant in tuberose *cv.* 'Prajwal' in comparison to other essential heavy metal concentrations and the untreated control. Derakshani *et al.* (2011) and Yilmaz *et al.* (1997) reported that foliar application of Zn recorded significant

Table 6 : Influence of applied essential heavy metals (Cu, Mn, Zn) on total fresh biomass plant^{-1}of *Polianthes tuberose cv.* Prajwal

Treatment (mg of element kg^{-1} soil)	Total fresh biomass plant^{-1}(g) 2018 - 2019					2019 - 2020					Pooled (2018-20)				
	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean	I_{90}	I_{180}	I_{270}	I_{360}	Mean
$MnSO_4$ 1000	52.16	64.53	225.33	284.90	156.73	305.23	534.70	634.70	796.16	567.69	178.70	299.61	430.01	540.53	362.21
$MnSO_4$ 2000	66.53	72.40	134.00	224.56	124.37	348.23	354.90	362.70	562.70	407.13	207.38	213.65	248.35	393.63	265.75
$MnSO_4$ 3000	53.93	72.56	173.66	277.60	144.43	356.23	364.73	370.03	470.03	390.25	205.08	218.65	271.85	373.81	267.34
$CuSO_4$ 100	37.63	65.96	185.00	294.50	145.77	335.93	442.16	452.53	652.53	470.78	186.78	254.06	318.76	473.51	308.27
$CuSO_4$ 200	57.63	63.70	152.33	273.60	136.81	394.96	404.06	413.00	515.00	431.75	226.30	233.88	282.66	394.30	284.28
$CuSO_4$ 300	75.86	79.83	235.66	256.33	161.92	338.40	386.26	404.33	514.66	410.91	207.13	233.04	319.99	385.49	286.41
$ZnSO_4$ 200	52.73	63.50	163.33	415.36	173.73	513.53	533.00	553.96	755.30	588.94	283.13	298.25	358.64	585.33	381.33
$ZnSO_4$ 400	106.93	125.83	455.36	595.30	320.85	765.66	784.00	835.03	996.50	845.29	436.30	454.91	645.19	795.90	583.07
$ZnSO_4$ 600	45.53	53.50	187.00	213.06	124.77	384.90	394.66	405.60	506.93	423.02	215.21	224.08	296.30	360.00	273.89
Control	32.60	46.30	64.33	117.50	65.18	176.00	183.06	206.00	215.00	195.01	104.30	114.68	135.16	166.25	130.09
Mean	58.15	70.81	197.60	295.27		391.90	438.15	463.78	598.48		225.03	254.48	330.69	446.87	
Factor	T		I	T × I		T		I	T × I		T		I	T × I	
S.E.±	0.76		0.48	1.53		0.80		0.50	1.60		0.49		0.31	0.98	
C.D. (P=0.05)	2.15		1.36	4.31		2.26		1.43	4.52		1.39		0.88	2.78	

increase in the growth of aerial parts of plant in comparison to the underground roots based on the estimation of root to shoot ratios in costmary and wheat, respectively.

Significant differences were noticed among the intervals of data recording with respect to the above ground fresh biomass per plant in tuberose *cv.* 'Prajwal'. Among the intervals, significantly highest above ground fresh biomass per plant (184.11, 353.41and 268.76 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval, whereas significantly lowest above ground fresh biomass per plant (33.99, 236.34 and 135.16 g, respectively during 2018-19, 2019-20 and the pooled data) was recorded at the initial 90 DAP interval. A gradual and significant increase in the above ground fresh biomass per plant of tuberose *cv.* 'Prajwal' was noticed at each successive interval of observation recorded during both the years of study as well as in the pooled data analysis.

The data pertaining to interaction effects between graded levels of essential heavy metal concentrations and the intervals of observation recorded with respect toabove ground fresh biomass per plant of tuberose *cv.* 'Prajwal' was found significant during 2018-19, 2019-20 and the pooled data analysis. Among the combination treatments, significantly highest above ground fresh biomass per plant (377.43, 532.30 and 454.86 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by application of $ZnSO_4$ @ 400 mg kg^{-1}soilat 360 DAP interval followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (316.73, 506.00 and 411.36 g, respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest above ground fresh biomass per plant (19.00, 105.50 and 62.25 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control plants at 90 DAP interval. Crop productivity is the rate at which a crop accumulate biomass which depends primarily on the rate of photosynthesis that convertslight energy into chemical energy by green tissues. Slaton *et al.* (2005) reported that soil and foliar application of micronutrients exhibited positive effects on grain yield of rice and attributed that it might be due to an increase in the leaf area and chlorophyll content in leaves which in turn led to an increase to capture the solar radiation thus an increase in the rate of photosynthesis was noticed in plants which ultimately resulted into an increase in the accumulation of more dry matter leading to enhanced values of growth parameters and yield contributing characters thereby recorded higher grain yield. The present result was also found in close agreement with the earlier findings of Khattak *et al.* (2015) and Ghoneim (2016), respectively in wheat and rice.

Significant differences were noticed in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations (Table 6). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest total fresh biomass per plant (320.85, 845.29 and 583.07 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil. Among the $ZnSO_4$ concentrations, application of $ZnSO_4$ @ 600 mg kg^{-1} soil recorded significantly lowest total fresh biomass per plant (124.77, 423.02 and 273.89 g, respectively during 2018-19, 2019-20 and the pooled data analysis). Significant decrease in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' was noticed by application of increasing concentrations of $MnSO_4$ upto 2000 mg kg^{-1} soil and thereafter a significant increase in the total fresh biomass per plant was noticed at 3000 mg kg^{-1} soil application during 2018-19 and the pooled data analysis, whereas a significant decrease in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' was noticed with increasing concentrations of $MnSO_4$ during 2019-20. Significant decrease in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' was noticed by application of increasing concentrations of $CuSO_4$ upto 200 mg kg^{-1} soil and thereafter a significant increase in the total fresh biomass per plant was noticed at 300 mg kg^{-1} soil application during 2018-19, whereas a significant decrease in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' was noticed with increasing concentrations of $CuSO_4$ during 2019-20 and the pooled data analysis. Among all the treatments, significantly lowest total fresh biomass per plant was recorded with the untreated control plants (65.18, 195.01 and 130.09 g, respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of results, it was evident that soil application of graded levels of $ZnSO_4$ recorded significantly highest vegetative growth in comparison to other treatments thus, recorded an increase in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis. Soil application of Zn played a vital role in increasing the fresh weight of plants due to increased content of tryptophan production in the plant, the precursor of auxin. The present results were found in accordance with the earlier findings of Mona *et al.* (2002) and Balakrishnan (2005) in marigold, Nag and Biswas (2003) in tuberose, Tariq *et al.* (2013) in gladiolus and Pal *et al.* (2016) in gerbera.

Significant differences were noticed among the intervals of observation recorded in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations. Among the intervals, significantly highest total fresh biomass per plant (295.27, 598.48 and 446.87 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval, whereas significantly lowest total fresh biomass per plant (58.15, 391.90 and 225.03 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at the initial 90 DAP interval. A gradual and significant increase in the total fresh biomass per plant of tuberose *cv.* 'Prajwal' was noticed with each successive interval of observation recorded during both the years of study as well as in the pooled data analysis.

The data pertaining to the interaction effects between graded levels of essential heavy metal concentrations and the intervals of observation recorded with respect tototal fresh biomass per plant was found significant during 2018-19, 2019-20 and the pooled data analysis. Significantly highest total fresh biomass per plant (595.30, 996.50 and 795.90 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by application of $ZnSO_4$ @ 400 mg kg^{-1} soilat 360 DAP interval followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (455.36, 835.03 and 645.19 g, respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest total fresh biomass per plant was noticed in the untreated control plants (32.60, 176.00 and 104.30 g, respectively during 2018-19, 2019-20 and the pooled data analysis) at 90 DAP interval. Based on the analysis of results, it was evident that application of $ZnSO_4$ @ 400 mg kg^{-1} soil might have activated many of the enzymes *viz.,* catalase, peroxidase, alcohol dehydrogenase, tryptophan synthase, carbonic dehydrogenase as well as Zn might have involved in the synthesis of chlorophylls thus, activated various physiological processes in the plant system thereby an enhancement in the growth and development might have been recorded in tuberose *cv.* 'Prajwal' hence, a significant increase in the total fresh biomass per plant was recorded. Munikrishnappa *et al.* (2002) recorded similar kind of observation with respect to increased total fresh weight of plant in tuberose *cv.* 'Single' by application of Zn.

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