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EFFECT OF GRADED LEVELS OF ESSENTIAL HEAVY METALS ON THE DRY 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) interval on dry 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 dry weight changes of different vegetative parameters *viz.*, dry weight of leaves (54.86 g and 62.90 g, respectively during 2018-19 and the pooled data analysis), dry weight of roots (15.73 g and 18.49 g respectively during 2018-19 and the pooled data analysis), dry weight of bulbs (27.80 g and 58.25 g respectively during 2018-19 and the pooled data analysis), the above ground dry biomass (74.80 g, 93.53 g and 84.16 g respectively during 2018-19, 2019-20 and the pooled data analysis) and the total dry biomass (95.46 g, 212.23 g and 145.03 g respectively during 2018-19, 2019-20 and the pooled data analysis) per plant.

Key words : $CuSO_4$, Heavy metals, $MnSO_4$, Dry leaf yield, Total biomass, Tuberose and $ZnSO_4$.

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 toxicity has 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 (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 dry weight changes of tuberose *cv.* 'Prajwal' as influenced by graded levels of different essential heavy metals *viz*., Mn, Cu and Zn.

Materials 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 dry weight changes of tuberose *cv.* 'Prajwal' as influenced by graded levels of essential heavy metals (Mn, Cu, Zn). Dry 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 dry biomass was calculated by weighing the dry weight of leaves, flower stalks and florets present on each plant and the total was expressed as grams per plant. Total dry biomass was calculated by weighing the dry 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 noticed in the dry weight of flowers 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 dry weight of flowers per plant (8.40 g, 19.20 g and 13.80 g, respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil during 2018-19, 2019-20 and the pooled data analysis. However, application of $ZnSO_4$ @ 200 mg kg^{-1} soil was found at par with the application of $ZnSO_4$ @ 400 mg kg^{-1} soil (8.23 g) with respect to dry weight of flowers per plant during 2018-19 only. Among the concentrations of $ZnSO_4$, application of $ZnSO_4$ @ 600 mg kg^{-1} soil recorded significantly lowest dry weight of flowers per plant. Application of graded levels of $MnSO_4$ and $CuSO_4$ recorded non-significant differences among their concentrations with respect to dry weight of flowers per plant in tuberose *cv.* 'Prajwal'. Among all the treatments, significantly lowest dry weight of flowers per plant was noticed in the untreated control plants (0.21 g, 1.45 g and 0.83 g respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of results, a substantive increase noticed in dry weight of flowers per plant of tuberose *cv.* 'Prajwal' by application of $ZnSO_4$ @ 400 mg kg^{-1} soil might be attributed to significant increase in the vegetative growth parameters of tuberose plant which have ultimately contributed to an increase in the number of flower spikes per plant and subsequently the number florets per spike due to influence of zinc in increasing the plant metabolism and enhanced biosynthesis of auxins in the plant thus increased the accumulation of nutrients and water from soil (Cakmak *et al.*, 1999). Shanker *et al.* (1999) opined that application of micronutrients have beneficial effects on the flower yield traits which might be attributed to activation of various enzymes in the plant system as well as efficient utilization of applied nutrients especially the zinc which enhanced the flower yield in sesamum. Similar kind of observation was also reported by Singaravel *et al.* (2001) in sesamum.

Significant variation was noticed among the intervals of observation recorded on dry weight of flowers per plant in tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Among the intervals, significantly highest dry weight of flowers per plant (7.64 g, 10.37 g and 9.00 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP, whereas significantly lowest dry weight of flowers per plant (1.31 g, 6.75 g and 4.03 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. The data with respect to dry weight of flowers per plant was found non-significant in the successive intervals in between the 90 to 180 DAP during both the years of study as well as in the pooled data analysis. The data

Table 1 : Influence of applied essential heavy metals (Cu, Mn, Zn) on dry flower yield plant^{-1} of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Dry flower yield 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	0.20	0.26	4.50	5.66	**2.65**	3.06	5.60	8.63	8.83	**6.53**	1.63	2.93	6.56	7.24	**4.59**
$MnSO_4$ 2000	1.16	0.20	4.93	7.83	**3.53**	6.36	0.00	5.66	6.23	**4.56**	3.76	0.10	5.29	7.03	**4.05**
$MnSO_4$ 3000	1.16	2.16	4.26	5.10	**3.17**	5.76	5.90	5.23	8.80	**6.42**	3.46	4.03	4.74	6.95	**4.80**
$CuSO_4$ 100	1.03	1.06	5.56	9.06	**4.18**	9.20	8.06	8.16	12.36	**9.45**	5.11	4.56	6.86	10.71	**6.81**
$CuSO_4$ 200	0.86	2.06	9.80	6.40	**4.78**	9.50	5.06	4.70	11.63	**7.72**	5.18	3.56	7.25	9.01	**6.25**
$CuSO_4$ 300	0.00	1.06	7.83	9.16	**4.51**	4.86	4.93	15.66	9.23	**8.67**	2.43	2.99	11.74	9.19	**6.59**
$ZnSO_4$ 200	3.03	2.70	16.06	11.13	**8.23**	5.53	15.80	15.23	15.50	**13.01**	4.28	9.25	15.64	13.31	**10.62**
$ZnSO_4$ 400	4.13	2.83	12.00	14.66	**8.40**	17.50	21.96	16.93	20.43	**19.20**	10.81	12.39	14.46	17.54	**13.80**
$ZnSO_4$ 600	1.53	0.93	4.53	6.53	**3.38**	5.76	5.76	8.04	8.73	**7.07**	3.65	3.34	6.28	7.63	**5.23**
Control	0.00	0.00	0.00	0.86	**0.21**	0.00	2.53	1.36	1.93	**1.45**	0.00	1.26	0.68	1.39	**0.83**
Mean	**1.31**	**1.33**	**6.95**	**7.64**		**6.75**	**7.56**	**8.96**	**10.37**		**4.03**	**4.44**	**7.95**	**9.00**	
Factor	**T**		**I**		**T × I**	**T**		**I**		**T × I**	**T**		**I**		**T × I**
SEm±	0.94		0.59		1.89	1.43		0.90		1.43	0.86		0.54		1.72
CD at 5%	2.66		1.68		NS	4.04		2.55		NS	2.43		1.53		NS

with respect to dry weight of flowers per plant in between the successive intervals of 270 to 360 DAP was also observed non-significant during 2019-20 and the pooled data analysis. However, the data with regard to dry weight of flowers per plant was found non-significant in between all the successive intervals of observation recorded during 2019-20.

The data pertaining to interaction effect between graded levels of essential heavy metal concentrations and the intervals of observation recorded with respect to dry weight of flowers per plant was found non-significant during 2018-19, 2019-20 and the pooled data analysis.

Significant variation was observed in the dry weight of leaves per plant in tuberose *cv.* 'Prajwal' (Table 2). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest dry weight of leaves per plant (31.06 g, 64.50 g and 47.50 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 zinc sulphate concentrations, application of $ZnSO_4$ @ 600 mg kg^{-1} soil recorded significantly lowest dry weight of leaves per plant during both the years of study as well as in the pooled data analysis. Soil application of $MnSO_4$ at 1000 mg kg^{-1} soil recorded significantly highest dry weight of leaves per plant among the $MnSO_4$ concentrations, whereas application of $MnSO_4$ at 2000 and 3000 mg kg^{-1} soil recorded non-significant differences in dry weight of leaves per plant in tuberose *cv.* 'Prajwal' during 2018-19, whereas soil application of $MnSO_4$ at 2000 mg kg^{-1} soil recorded significantly lowest dry weight of leaves per plant, but soil application of $MnSO_4$ at 1000 and 3000 mg kg^{-1} soil recorded non-significant differences with respect to dry weight of leaves per plant during 2019-20. Soil application of graded levels of $CuSO_4$ recorded non-significant differences among their concentrations with respect to dry weight of leaves per plant of tuberose *cv.* 'Prajwal' during 2018-19, whereas significant differences were noticed in dry weight of leaves per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of $CuSO_4$ during 2019-20. Soil application of $CuSO_4$ @ 100 mg kg^{-1} soil recorded significantly highest dry weight of leaves per plant in tuberose *cv.* 'Prajwal', whereas soil application of $CuSO_4$ @ 200 and 300 mg kg^{-1} soil recorded non-significant differences with respect to dry weight of leaves per plant in the pooled data analysis. Among all the treatments, untreated control plants recorded significantly lowest dry weight of leaves per plant (8.55 g, 23.46 g and 16.01 g respectively during 2018-19,

Table 2 : Influence of applied essential heavy metals (Cu, Mn, Zn) on dry leaf yield plant^{-1} of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Dry leaf yield 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	3.40	3.63	14.33	48.33	**17.42**	51.90	55.33	57.10	60.40	**56.18**	27.65	29.48	35.71	54.36	**36.80**
$MnSO_4$ 2000	3.30	3.50	23.20	31.53	**15.38**	37.46	41.00	44.70	46.96	**42.53**	20.38	22.25	33.95	39.25	**28.95**
$MnSO_4$ 3000	3.26	3.53	14.86	43.20	**16.21**	47.46	51.46	52.30	55.50	**51.68**	25.36	27.50	33.58	49.35	**33.95**
$CuSO_4$ 100	2.63	2.80	15.46	42.13	**15.75**	44.66	49.33	52.16	55.16	**50.33**	23.65	26.06	33.81	48.65	**33.04**
$CuSO_4$ 200	3.43	3.66	18.80	35.20	**15.27**	38.53	46.00	48.30	51.26	**46.02**	20.98	24.83	33.55	43.23	**30.65**
$CuSO_4$ 300	4.80	5.43	24.26	22.13	**14.15**	38.13	39.46	42.56	46.16	**41.58**	21.46	22.44	33.41	34.14	**27.86**
$ZnSO_4$ 200	2.80	3.33	32.26	35.53	**18.48**	58.93	60.00	63.70	65.36	**62.00**	30.86	31.66	47.98	50.44	**40.23**
$ZnSO_4$ 400	7.33	7.80	54.26	54.86	**31.06**	56.56	62.93	67.76	70.93	**64.50**	31.95	35.36	61.01	62.90	**47.80**
$ZnSO_4$ 600	4.30	4.63	15.13	23.80	**11.96**	28.26	34.26	39.93	41.43	**35.97**	16.28	19.45	27.53	32.61	**23.97**
Control	2.63	3.20	12.13	16.26	**8.55**	17.00	21.46	25.76	29.63	**23.46**	9.81	12.33	18.95	22.95	**16.01**
Mean	**3.79**	**4.15**	**22.46**	**35.29**		**41.89**	**46.12**	**49.43**	**52.28**		**22.84**	**25.14**	**35.94**	**43.78**	
Factor	T		I		T × I	T		I		T × I	T		I		T × I
SEm±	0.57		0.366		1.15	0.80		0.51		1.61	0.53		0.33		1.06
CD at 5%	1.63		1.03		3.26	2.27		1.44		NS	1.49		0.94		2.98

2019-20 and the pooled data analysis). Based on the analysis of results, it may be concluded that application of zinc sulphate at the rate of 400 mg kg^{-1} soil might have exerted the efficient translocation and utilization of nutrients as well as water from soil and thus activated various enzymes in the plant system which caused an increase in the dry weight of leaves per plant in tuberose *cv.* 'Prajwal'. Further, Zarmehri *et al.* (2013) reported an increase in the leaf area of maize by application of zinc sulphate which caused an increase in the leaf area and thus recorded an increase in the dry weight of leaf.

Significant differences were noticed among the intervals of observation recorded with respect to dry weight of leaves per plant of tuberose *cv.* 'Prajwal'. Among the intervals of observation recorded, significantly highest dry weight of leaves per plant (35.29 g, 52.28 g and 43.78 g, respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP, whereas significantly lowest dry weight of leaves per plant (3.79 g, 41.89 g and 22.84 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at the initial 90 DAP interval. Significant differences were noticed in the successive intervals of observation recorded with respect to dry weight of leaves per plant during both the years of study as well as in the pooled data analysis, except in between the successive intervals of 90 to 180 DAP during 2018-19, where non-significant difference was noticed with respect to dry weight of leaves per plant of tuberose *cv.* 'Prajwal'. A gradual increase in the dry leaf yield per plant was noticed in tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis which may be attributed to the accumulation of photo assimilates in the plant with the passage of time.

The data pertaining to interaction effect between graded levels of soil applied essential heavy metal concentrations and the intervals of observation recorded with respect to dry weight of leaves per plant was found significant during 2018-19 and the pooled data analysis. Among the combination treatments, significantly highest dry weight of leaves per plant (54.86 g and 62.90 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 and was found at par with the application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP (54.26 g and 61.01 g, respectively during 2018-19 and the pooled data analysis), whereas significantly lowest dry weight of leaves per plant (2.63 g and 9.81 g respectively during 2018-19 and the pooled data analysis) was recorded in the untreated control

Table 3 : Influence of applied essential heavy metals (Cu, Mn, Zn) on dry stalk yield plant^{-1} of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Dry stalk yield 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	0.18	0.30	3.53	6.66	**2.67**	2.46	4.96	7.06	7.60	**5.52**	1.32	2.63	5.29	7.13	**4.09**
$MnSO_4$ 2000	0.22	0.30	3.00	7.03	**2.63**	4.93	0.00	4.26	3.80	**3.25**	2.58	0.15	3.63	5.41	**2.94**
$MnSO_4$ 3000	0.12	0.50	3.46	4.20	**2.07**	6.73	6.80	5.20	10.63	**7.34**	3.42	3.65	4.33	7.41	**4.70**
$CuSO_4$ 100	0.10	0.23	3.53	6.13	**2.95**	6.66	7.00	5.80	10.20	**7.41**	3.38	3.61	4.66	8.16	**4.95**
$CuSO_4$ 200	0.14	0.40	4.56	2.73	**1.96**	6.46	3.30	2.60	10.06	**5.60**	3.30	1.85	3.58	6.39	**3.78**
$CuSO_4$ 300	0.00	0.36	3.93	6.00	**2.57**	2.66	3.26	7.33	6.40	**4.91**	1.33	1.81	5.63	6.20	**3.74**
$ZnSO_4$ 200	0.65	0.83	6.40	5.60	**3.37**	2.73	10.36	7.13	10.43	**7.66**	1.69	5.59	6.76	8.01	**5.51**
$ZnSO_4$ 400	0.70	1.00	7.93	8.53	**4.09**	10.46	9.66	11.16	12.03	**10.83**	5.58	5.33	9.54	10.28	**7.68**
$ZnSO_4$ 600	0.14	0.36	3.60	5.93	**2.51**	5.20	6.33	6.46	8.93	**6.73**	2.67	3.34	5.03	7.43	**4.62**
Control	0.00	0.00	0.00	3.33	**0.83**	0.00	2.40	5.40	2.03	**2.45**	0.00	1.20	2.70	2.68	**1.64**
Mean	**0.22**	**0.43**	**3.99**	**5.61**		**4.83**	**5.40**	**6.24**	**8.21**		**2.53**	**2.91**	**5.11**	**6.91**	
Factor		**T**	**I**	**T × I**			**T**	**I**	**T × I**			**T**	**I**	**T × I**	
SEm±		0.69	0.44	1.39			1.06	0.67	2.13			0.66	0.41	1.32	
CD at 5%		NS	1.24	NS			3.01	1.90	NS			1.86	1.18	NS	

plants at 90 DAP. The data recorded on interaction effect of dry weight of leaves per plant was found non-significant during 2019-20. Based on the analysis of results, a significant increase recorded in dry weight of leaves per plant in tuberose *cv.* 'Prajwal' might be attributed to the influence of zinc sulphate in increasing the vegetative growth parameters of tuberose *cv.* 'Prajwal' by efficient absorption of nutrients and water from soil as well as biosynthesis of auxins in the developing tissue of plant especially in the leaf. All these increased activities of physiological and biochemical might have contributed an increase in the metabolism of plant which in turn might have contributed an increase in the accumulation of more photo assimilates in the plant parts especially the leaves and flowers (Cakmak *et al.*, 1999). Similar kind of observation in tuberose was reported earlier by Patel *et al*. (2017) which is in line with the present result.

Significant variation was noticed in the data with respect to dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' (Table 3) during 2019-20 and the pooled data analysis. Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest dry weight of flower stalks per plant (10.83 g and 7. 86 g respectively during 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 during 2019-20 and the pooled data analysis. Application of $MnSO_4$ @ 3000 mg kg^{-1} soil recorded significantly highest dry weight of flower stalks per plant (7.34 g) and was found at par with the application of $MnSO_4$ @ 1000 mg kg^{-1} soil, whereas significantly lowest dry weight of flower stalks per plant was recorded by application of $MnSO_4$ @ 2000 mg kg^{-1} soil during 2019-20. However, non-significant differences were noticed in the pooled data analysis with respect to dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of $MnSO_4$. Soil application of graded levels of $CuSO_4$ recorded non-significant differences in the dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' during 2019-20 as well as in the pooled data analysis. Among all the treatments, significantly lowest dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' was recorded in the untreated control plants (2.45 g and 1.64 g during 2019-20 and the pooled data analysis respectively). Based on the analysis of results, it was evident that soil application of graded levels of $ZnSO_4$ recorded significant increase in the dry weight of flower stalks in tuberose *cv.* 'Prajwal' which might be attributed to an increase in the total biomass of the plant in the

Table 4 : Influence of applied essential heavy metals (Cu, Mn, Zn) on dry root yield plant^{-1} of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Dry root yield 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	1.40	3.66	7.73	9.06	**5.46**	9.96	15.66	16.73	17.30	**14.91**	5.68	9.66	12.23	12.61	**10.04**
$MnSO_4$ 2000	1.60	1.73	6.46	7.13	**4.23**	7.73	10.73	12.16	13.20	**10.95**	4.66	6.23	9.31	9.65	**7.46**
$MnSO_4$ 3000	0.40	2.90	5.60	11.26	**5.04**	16.46	17.73	19.13	19.40	**18.18**	8.43	10.31	12.36	13.55	**11.16**
$CuSO_4$ 100	1.20	1.43	10.20	11.73	**6.14**	16.73	18.40	18.86	19.50	**18.37**	8.96	9.91	14.53	14.96	**12.09**
$CuSO_4$ 200	1.40	1.66	6.20	14.43	**5.92**	9.66	12.53	13.26	13.86	**12.33**	5.53	7.09	9.73	11.49	**8.46**
$CuSO_4$ 300	0.66	2.03	7.66	8.30	**4.66**	8.50	10.40	11.43	12.83	**10.79**	4.58	6.21	9.55	9.95	**7.57**
$ZnSO_4$ 200	2.73	3.60	7.80	11.46	**6.40**	17.06	18.60	19.30	21.20	**19.04**	9.89	11.10	13.55	14.66	**12.30**
$ZnSO_4$ 400	1.46	2.83	12.86	15.73	**8.22**	19.00	21.30	22.46	23.76	**21.63**	10.23	12.06	17.66	18.49	**14.61**
$ZnSO_4$ 600	1.46	1.66	6.60	8.33	**4.51**	16.36	17.16	18.40	18.93	**17.71**	8.91	9.41	12.50	12.95	**10.94**
Control	0.26	1.73	6.46	8.10	**4.14**	9.40	12.20	12.93	14.23	**12.19**	4.83	6.96	9.70	10.28	**7.94**
Mean	**1.26**	**2.32**	**7.75**	**10.55**		**13.09**	**15.47**	**16.47**	**17.42**		**7.17**	**8.89**	**12.11**	**12.85**	
Factor		**T**	**I**		**T × I**		**T**	**I**		**T × I**		**T**	**I**		**T × I**
SEm±		0.24	0.15		0.49		0.35	0.22		0.70		0.22	0.14		0.44
CD at 5%		0.69	0.44		1.39		1.00	0.63		NS		0.62	0.39		1.25

present study. Srinivasan and Velu (1982) explained the positive effect of Zn on increasing the content of chlorophylls and thus recorded a significant increase in the rate of photosynthesis in tuberose thereby enhanced the accumulation of photosynthates in the plant and thus recorded an increase in the total dry weight of flowers per plant in ground nut. Khije (1972) and Malewar *et al.* (1993) also reported similar kind of observation in different crops.

Significant differences were noticed among the intervals of observation recorded with respect to dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations. Among the intervals, significantly highest dry weight of flower stalks per plant (5.61 g, 8.21 g and 6.91 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP, whereas significantly lowest dry weight of flower stalks per plant (0.22 g, 4.83 g and 2.53 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. However, the data with respect to dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' was found non-significant in between the successive intervals of observation at 90 to 180 DAP during both the years of study as well as in the pooled data analysis.

The data pertaining to interaction effect between graded levels of soil applied essential heavy metal concentrations and the intervals of observation recorded with respect to dry weight of flower stalks per plant of tuberose *cv.* 'Prajwal' was found non-significant during 2018-19, 2019-20 and the pooled data analysis.

Significant differences were noticed in the data with respect to dry weight of roots per plant of tuberose *cv.* 'Prajwal' (Table 4). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest dry weight of roots per plant (8.22 g, 21.63 g and 14.61 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 zinc sulphate concentrations, application of $ZnSO_4$ @ 600 mg kg^{-1} soil recorded significantly lowest dry weight of roots per plant. Application of $MnSO_4$ @ 1000 mg kg^{-1} soil recorded significantly highest dry weight of roots per plant (5.46 g) among the $MnSO_4$ concentrations and was found at par with the application of $MnSO_4$ @ 3000 mg kg^{-1} soil (5.04 g), whereas application of $MnSO_4$ @ 2000 mg kg^{-1} soil recorded significantly lowest dry weight of roots per plant (4.23 g) during 2018-19. However, application of $MnSO_4$ @ 3000 mg kg^{-1} soil recorded significantly highest dry weight of roots per plant (18.18 g and 11.16 g respectively during 2019-20 and the pooled data analysis), whereas application of $MnSO_4$ @ 2000 mg kg^{-1} soil recorded significantly lowest dry weight of roots per plant (10.95 g and 7.46 g respectively during 2019-20 and the pooled data analysis). Among the $MnSO_4$ concentrations, application of $MnSO_4$ @ 1000 mg kg^{-1} soil recorded moderate values with respect to dry weight of roots per plant during 2019-20 and the pooled data analysis. Soil application of graded levels of $CuSO_4$ recorded decreasing dry weight of roots per plant of tuberose *cv.* 'Prajwal' with increasing concentration of $CuSO_4$ during both the years of study as well as in the pooled data analysis. Among all the treatments, significantly lowest dry weight of roots per plant was recorded in the untreated control plants (4.14 g, 12.19 g and 7.94 g respectively during 2018-19, 2019-20 and the pooled data analysis).

Significant differences were noticed among the intervals of observation recorded with respect to dry weight of roots per plant of tuberose *cv.* 'Prajwal' during both the years of study as well as in the polled data analysis. Among the intervals, significantly highest dry weight of roots per plant (10.55 g, 17.42 g and 12.85 g respectively during 2018-19, 2019-20 and the pooled data analysis) was noticed at 360 DAP, whereas significantly lowest dry weight of roots per plant (1.26 g, 13.09 g and 7.17 g respectively during 2018-19, 2019-20 and the pooled data analysis) was noticed at 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 dry weight of roots per plant was noticed during the successive intervals of observation recorded.

The data pertaining to interaction effect between graded levels of soil applied essential heavy metal concentrations and the intervals with respect to dry weight of roots per plant was found significant during 1st year of study *i.e.*, 2018-19 and the pooled data analysis, but the data was found non-significant during 2nd year of study *i.e.*, 2019-20. Among the combination treatments, significantly highest dry weight of roots per plant (15.73 g and 18.49 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 followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP (12.86 g and 17.66 g respectively during 2018-19 and the pooled data analysis), whereas significantly lowest dry weight of roots per plant (0.26 g and 4.83 g respectively during 2018-19 and the pooled data analysis) was recorded in the untreated control plants at the initial 90 DAP. From the result, it was evident that soil application of graded levels of $ZnSO_4$ recorded significant increase in the dry weight of roots per plant in comparison with other treatments which might be attributed to the enhanced physiological activities in the plant system. Sofy (2015) observed that wheat plants treated with Zn recorded a significant increase in dry weight of roots in comparison to the plants grown without application of Zn.

Significant differences were noticed in the dry weight of bulbs per plant of tuberose *cv.* 'Prajwal' (Table 5). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest dry weight of bulbs per plant (21.85 g, 83.72 g and 51.87 g respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil, whereas among the zinc sulphate concentrations, significantly lowest dry weight of bulbs per plant (12.46 g, 46.25g and 29.17 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded with the application of $ZnSO_4$ @ 600 mg kg^{-1} soil. Soil application of graded levels of $MnSO_4$ recorded decreasing dry weight of bulbs per plant with increasing concentration of $MnSO_4$ during 2018-19. Soil application of $MnSO_4$ @ 3000 mg kg^{-1} soil recorded significantly highest dry weight of bulbs per plant (41.02 g and 25.19 g respectively during 2019-20 and the pooled data analysis) and was found at par with the application of $MnSO_4$ @ 1000 mg kg^{-1} soil during the pooled data analysis, whereas application of $MnSO_4$ @ 1000 and 2000 mg kg^{-1} soil recorded non-significant differences in between the concentrations during 2019-20. However, the pooled data analysis recorded significantly decreasing trend in the dry weight of bulbs per plant up to $MnSO_4$ @ 2000 mg kg^{-1} soil and an increase in the dry weight of bulbs per plant was noticed by application of $MnSO_4$ @ 3000 mg kg^{-1} soil. Soil application of $CuSO_4$ recorded increasing trend in the dry weight of bulbs per plant by increasing concentration of $CuSO_4$ during 2018-19, whereas a decreasing trend in the dry weight of bulbs per plant with increasing concentration of $CuSO_4$ was noticed during 2019-20. The pooled data analysis has revealed that increasing trend in the dry weight of bulbs per plant was noticed up to the application of $CuSO_4$ @ 200 mg kg^{-1} soil and thereafter a decreasing trend was noticed in the dry weight of bulbs per plant with the application of $CuSO_4$ @ 300 mg kg^{-1} soil and was found significantly lowest dry weight of bulbs per plant among the copper sulphate concentrations. Among all the treatments, significantly lowest dry weight of bulbs per plant was recorded in the untreated control plant (6.35 g, 27.03 g and 16.43 g respectively during 2018-19, 2019-20 and the pooled data analysis).

Significant differences were noticed among the

Table 5 : Influence of applied essential heavy metals (Cu, Mn, Zn) on dry bulb yield plant^{-1} of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Dry bulb yield 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	10.70	11.93	16.03	17.93	**14.15**	33.26	35.70	37.40	38.46	**36.20**	21.98	22.71	27.71	28.19	**25.14**
$MnSO_4$ 2000	8.60	12.23	12.73	15.70	**12.31**	27.73	35.13	37.63	39.73	**35.05**	18.16	20.37	25.18	27.71	**22.85**
$MnSO_4$ 3000	5.46	6.46	8.66	19.66	**10.06**	36.33	39.93	42.86	44.96	**41.02**	20.89	21.81	25.76	32.31	**25.19**
$CuSO_4$ 100	5.30	6.36	13.26	15.66	**10.15**	46.63	48.86	51.36	53.30	**50.04**	25.96	26.62	32.31	34.48	**29.84**
$CuSO_4$ 200	6.40	6.63	16.06	24.66	**13.44**	45.40	48.93	51.43	52.76	**49.63**	25.90	26.65	33.75	38.71	**31.25**
$CuSO_4$ 300	6.73	11.06	19.53	20.10	**14.35**	36.53	45.66	48.66	51.16	**45.50**	21.63	24.32	34.10	35.63	**28.92**
$ZnSO_4$ 200	6.43	13.53	17.33	20.20	**14.37**	56.73	59.93	62.06	63.83	**60.64**	31.58	33.64	39.69	42.01	**36.73**
$ZnSO_4$ 400	15.26	18.46	25.86	27.80	**21.85**	75.60	84.60	86.00	88.70	**83.72**	45.43	47.87	55.93	58.25	**51.87**
$ZnSO_4$ 600	8.63	9.73	15.46	16.03	**12.46**	44.33	45.66	47.10	47.93	**46.25**	26.48	26.96	31.28	31.98	**29.17**
Control	4.16	4.50	7.20	9.56	**6.35**	23.60	26.73	27.90	29.90	**27.03**	13.88	14.57	17.55	19.73	**16.43**
Mean	**7.77**	**10.09**	**15.21**	**18.73**		**42.61**	**47.11**	**49.24**	**51.07**		**25.19**	**26.55**	**32.32**	**34.90**	
Factor		T	I		T × I		T	I		T × I		T	I		T × I
SEm±		0.47	0.30		0.95		0.77	0.48		1.53		0.42	0.26		0.85
CD at 5%		1.34	0.84		2.61		2.15	1.36		NS		1.20	0.75		2.40

intervals of observation with respect to dry 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 dry weight of bulbs per plant (18.73 g, 51.07 g and 34.90 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP, whereas significantly lowest dry weight of bulbs per plant (7.77 g, 42.61 g and 25.19 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 and significant increase in the dry weight of bulbs per plant of tuberose 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 to dry weight of bulbs per plant was found significant during 1st year of study *i.e.*, 2018-19 and the pooled data analysis, but the data was found non-significant during 2nd year of study *i.e.*, 2019-20. Among the combination treatments, significantly highest dry weight of bulbs per plant (27.80 g and 58.25 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 followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP (25.86 g and 55.93 g respectively during 2018-19 and the pooled data analysis), whereas significantly lowest dry weight of bulbs per plant (4.16 g and 13.88 g respectively during 2018-19 and the pooled data analysis) was noticed in the untreated control plants at 90 DAP. Significant increase recorded in the dry weight of bulbs per plant in tuberose *cv.* 'Prajwal' by soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil might be attributed to the key role played by Zn element in the cell division and cell enlargement as well as active role played in many of the physiological activities in the plant system. Similar kind of observation was also reported earlier in onion by Meena and Singh (1998). Further, Abedin *et al.* (2012) and Gamelli *et al.* (2000) reported significant increase in the dry weight of bulb per plant in onion by application of Zn.

Significant variation was noticed in the data of above ground dry biomass per plant of tuberose *cv.* 'Prajwal' (Table 6). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest above ground dry biomass per plant (45.46 g, 85.15 g and 64.34 g respectively during 2018-19, 2019-

20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil, whereas application of $ZnSO_4$ @ 600 mg kg^{-1} soil recorded significantly lowest (25.75 g, 62.54 g and 44.22 g respectively during 2018-19, 2019-20 and the pooled data analysis) above ground dry biomass per plant, among the concentrations of $ZnSO_4$. Soil application of graded levels of $MnSO_4$ recorded a significantly decreasing trend in the above ground dry biomass per plant during 2018-19, 2019-20 and the pooled data analysis with increasing concentration of $MnSO_4$. However, non-significant differences were noticed in the $MnSO_4$ applied at 2000 and 3000 mg kg^{-1} soil during 2018-19 only. Soil application of graded levels of $CuSO_4$ recorded a significantly increasing trend in the above ground dry biomass per plant during 2018-19, 2019-20 and the pooled data analysis with increasing concentration of $CuSO_4$. However, non-significant differences were noticed in the $CuSO_4$ applied at 100 and 200 mg kg^{-1} soil during 2018-19 only with respect to above ground dry biomass per plant. Among all the treatments, untreated control plants recorded significantly lowest above ground dry biomass per plant (9.81 g, 46.05 g and 27.10 g respectively during 2018-19, 2019-20 and the pooled data analysis). These results were found in agreement with the earlier findings of Rehman (1992) who reported an increase in the accumulation of dry matter after anthesis in sesame.

Significant differences were noticed among the intervals of observation recorded with respect to the above ground dry biomass per plant of tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Among the intervals, significantly highest above ground dry biomass per plant (46.43 g, 73.37 g and 59.90 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP, whereas significantly lowest above ground dry biomass per plant (7.12 g, 59.41 g and 33.26 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at the initial 90 DAP interval. Based on the analysis of results, it may be concluded that a gradual and significant increase in the above ground dry biomass per plant of tuberose *cv.* 'Prajwal' was noticed 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 to above ground dry biomass per plant of tuberose *cv.* 'Prajwal' was found significant during both the years of study as well as in the pooled data analysis. Among the combination treatments, significantly highest above

Table 6 : Influence of applied essential heavy metals (Cu, Mn, Zn) on the above ground dry biomass yield $plant^{-1}$ of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Above ground dry biomass yield $plant^{-1}$ (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	6.50	7.70	42.40	54.53	**27.78**	66.16	74.70	82.20	84.36	**76.85**	36.33	38.27	62.30	69.45	**51.58**
$MnSO_4$ 2000	3.60	12.96	26.20	42.86	**21.40**	62.63	73.83	78.06	80.16	**73.67**	33.11	37.22	52.13	61.51	**45.99**
$MnSO_4$ 3000	7.36	9.63	24.73	43.70	**21.35**	55.23	63.03	65.33	67.70	**62.82**	31.30	33.30	45.03	55.70	**41.33**
$CuSO_4$ 100	3.66	4.66	27.80	30.20	**16.58**	55.56	58.13	61.50	63.53	**59.68**	29.61	30.32	44.65	46.86	**37.86**
$CuSO_4$ 200	4.40	5.46	18.66	44.20	**18.18**	57.03	63.13	65.43	68.66	**63.56**	30.71	32.14	42.05	56.43	**40.33**
$CuSO_4$ 300	4.56	5.56	35.56	39.53	**21.30**	54.53	62.86	72.23	73.73	**65.84**	29.55	31.41	53.90	56.63	**42.87**
$ZnSO_4$ 200	13.60	16.53	47.26	56.33	**33.43**	73.16	78.60	81.36	82.76	**78.97**	43.38	45.05	64.31	69.54	**55.57**
$ZnSO_4$ 400	17.60	25.26	64.20	74.80	**45.46**	76.86	81.93	88.26	93.53	**85.15**	47.23	49.77	76.23	84.16	**64.34**
$ZnSO_4$ 600	7.43	8.50	33.66	53.40	**25.75**	57.36	61.86	63.90	67.03	**62.54**	32.40	35.50	48.78	60.21	**44.22**
Control	2.46	3.20	8.80	24.80	**9.81**	35.56	45.93	50.46	52.26	**46.05**	19.01	21.23	29.63	38.53	**27.10**
Mean	**7.12**	**9.95**	**32.92**	**46.43**		**59.41**	**66.40**	**70.87**	**73.37**		**33.26**	**35.42**	**51.90**	**59.90**	
Factor	**T**		**I**		**T × I**	**T**		**I**		**T × I**	**T**		**I**		**T × I**
SEm ±	0.58		0.36		1.16	0.61		0.38		1.22	0.40		0.25		0.81
CD at 5%	1.63		1.03		3.27	1.72		1.08		3.44	1.14		0.72		2.29

ground dry biomass per plant (74.80 g, 93.53 g and 84.16 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 followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP, whereas significantly lowest above ground dry biomass per plant (2.46 g, 35.56 g and 19.01 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control plants at 90 DAP.

Significant differences were noticed in the analyzed data of total dry biomass yield per plant by soil application of graded levels of essential heavy metal concentrations (Table 7). Among the graded levels of essential heavy metal concentrations, application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest total dry biomass yield per plant (61.57 g, 187.05 g and 118.92 g respectively during 2018-19, 2019-20 and the pooled data analysis) followed by application of $ZnSO_4$ @ 200 mg kg^{-1} soil, whereas application of $ZnSO_4$ @ 600 mg kg^{-1} soil recorded significantly lowest total dry biomass yield per plant, among the $ZnSO_4$ concentrations. Among the $MnSO_4$ concentrations, application of $MnSO_4$ @ 1000 mg kg^{-1} soil recorded significantly lowest total dry biomass yield per plant (34.34 g, 129.75 g and 77.60 g respectively during 2018-19, 2019-20 and the pooled data), whereas application of $MnSO_4$ @ 3000 mg kg^{-1} soil recorded significantly highest total dry biomass yield per plant (37.35 g, 131.12 g and 80.57 g respectively during 2018-19, 2019-20 and the pooled data analysis). Among the concentrations of $CuSO_4$, application of $CuSO_4$ @ 100 mg kg^{-1} soil recorded significantly highest total dry biomass yield per plant (40.03 g, 128.55 g and 80.45 g respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest total dry biomass yield per plant was recorded by application of $CuSO_4$ @ 300 mg kg^{-1} soil (32.21 g, 126.21 g and 73.82 g respectively during 2018-19, 2019-20 and the pooled data analysis) and was found at par with the application of $CuSO_4$ @ 200 mg kg^{-1} soil. Among all the treatments, untreated control plants recorded significantly lowest total dry biomass yield per plant (18.60 g, 45.44 g and 30.23 g respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of data, it was evident that soil application of graded levels of $ZnSO_4$ recorded significant increase in the total dry biomass yield per plant in tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis. Thalooth *et al.* (2006) observed significant increase in the total dry biomass yield per plant in mung bean by application of Zn which might be attributed to enhanced metabolic activity in the plant as well as an increase noticed in the contents

Table 7 : Influence of applied essential heavy metals (Cu, Mn, Zn) on total dry biomass yield $plant^{-1}$ of *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Total dry biomass yield $plant^{-1}$ (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	14.56	21.80	46.00	55.00	**34.34**	105.86	128.46	132.16	152.53	**129.75**	60.21	66.17	89.08	94.95	**77.60**
$MnSO_4$ 2000	14.96	17.66	41.66	67.80	**35.52**	94.46	106.63	116.26	135.83	**113.30**	54.71	57.68	78.96	88.10	**69.86**
$MnSO_4$ 3000	14.46	18.06	42.00	74.90	**37.35**	120.83	124.56	135.26	143.83	**131.12**	67.65	69.11	88.63	96.92	**80.57**
$CuSO_4$ 100	16.90	17.56	48.00	77.66	**40.03**	115.66	126.73	132.00	136.96	**128.55**	66.28	68.62	90.00	96.92	**80.45**
$CuSO_4$ 200	16.80	17.40	31.66	63.00	**32.91**	116.30	125.46	129.46	143.00	**127.84**	66.55	68.50	80.56	89.53	**76.28**
$CuSO_4$ 300	11.90	18.86	44.33	56.56	**32.21**	91.10	127.20	132.66	153.90	**126.21**	51.50	60.11	88.50	95.18	**73.82**
$ZnSO_4$ 200	18.03	23.46	54.00	74.33	**42.45**	114.70	129.60	137.80	168.20	**137.57**	66.36	70.43	95.90	106.04	**84.68**
$ZnSO_4$ 400	24.93	41.10	84.80	95.46	**61.57**	158.06	184.40	193.53	212.23	**187.05**	91.50	99.99	139.16	145.03	**118.92**
$ZnSO_4$ 600	14.46	17.90	45.33	53.93	**32.90**	76.73	115.56	118.56	123.60	**108.61**	45.60	54.04	81.95	84.67	**66.56**
Control	8.63	9.30	22.00	34.46	**18.60**	38.96	42.53	46.63	53.63	**45.44**	23.80	24.64	34.31	38.20	**30.23**
Mean	**15.56**	**20.31**	**45.97**	**65.31**		**103.27**	**121.11**	**127.43**	**142.37**		**59.41**	**63.92**	**86.70**	**93.55**	
Factor	**T**		**I**	**T × I**		**T**		**I**	**T × I**		**T**		**I**	**T × I**	
SEm ±	0.77		0.49	1.55		0.81		0.51	1.62		0.56		0.35	1.12	
CD at 5%	2.19		1.38	4.37		2.29		1.45	4.58		1.58		1.00	3.16	

of chlorophyll pigments which ultimately enhanced the rate of photosynthesis.

Significant differences were noticed among the intervals of observation recorded with respect to the total dry biomass yield per plant of tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Among the intervals, significantly highest total dry biomass yield per plant (65.31 g, 142.37 g and 93.55 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP, whereas significantly lowest total dry biomass yield per plant (15.56 g, 103.27 g and 59.41 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at the initial 90 DAP interval. A significant and gradual increase in the total dry biomass yield per plant was recorded with the passage of time 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 to total dry biomass yield per plant was found significant during 2018-19, 2019-20 and the pooled data analysis. Among the combination treatments, significantly highest total dry biomass yield per plant (95.46 g, 212.23 g and 145.03 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 followed by application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP (84.80 g, 193.53 g and 139.16 g respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest total dry biomass yield per plant (8.63 g, 38.96 g and 23.80 g respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control plants recorded at 90 DAP. Significant increase recorded in the total dry biomass yield per plant in tuberose *cv.* 'Prajwal' by soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil might be attributed to the biosynthesis of tryptophan, the precursor of auxin and the active role played in carbohydrate and nitrogen metabolism of the plant. Frossard *et al.* (2000) also expressed similar kind of opinion while working on different crop species. Taliee and Sayadian (2000) recorded similar kind of result with respect to total dry biomass yield per plant in chickpea by application of Zn in soil.

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