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MODULATION OF TRANSLOCATION DYNAMICS FOR ESSENTIAL HEAVY METALS THROUGH COMBINED APPLICATION IN TUBEROSE *CV.* PRAJWAL

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ABSTRACT

The persistence and inherent toxicity of heavy metals position them as critical environmental contaminants. Anthropogenic driver specifically intensive mining, industrial discharge and modern agrochemical usage have accelerated the loading of these non-biodegradable elements into the soil matrix. This accumulation poses a significant risk to human health, as the soil-to-plant transfer interface serves as the primary conduit for heavy metals to enter the food chain. Translocation factor of Mn, Cu and Zn from soils were calculated in the present investigation based on the phytoremediation capability. Phytoremediation stands out as a sustainable, aesthetically favorable and low-cost strategy for soil decontamination using specialized flora. The present study evaluated the remedial potential of tuberose cv. 'Prajwal' across varying concentrations of $MnSO_4$, $CuSO_4$, $ZnSO_4$. Statistical validation via OPSTAT software revealed that metal accumulation was dose-dependent. Notably, manganese translocation increased linearly with $MnSO_4$ application rates. In contrast, peak accumulation for copper and zinc was observed at specific thresholds: $CuSO_4$ at 300 mg kg^{-1} and $ZnSO_4$ at 400 mg kg^{-1}. These high translocation factors across two years of study underscore the efficacy of 'Prajwal' as a robust phytoremediator for essential heavy metals.

Keywords **:** Translocation factor, Tuberose, Phytoremediation, $MnSO_4$, $CuSO_4$ and $ZnSO_4$

Introduction

Tuberose (*Polianthes tuberosa* L.) cv. 'Prajwal' is a key commercial flower, but its physiological response and nutrient partitioning, particularly regarding Manganese, Copper, and Zinc, require deeper understanding for optimized growth. This study examines how combined, graded levels of these metals impact the translocation factor, bridging a research gap in nutrient management and uptake mechanisms for this cultivar. Plants adopt various cellular mechanisms to avoid/minimize the detrimental effects of heavy metal toxicity in a variety of different ways. On exposure to heavy metals, plants initially try to prevent entry of metal in to the root cells by implementing avoidance strategy, thus restricting the uptake and transport of heavy metals in to the plant system. When heavy metals manage to enter the root cells, they are detoxified at intracellular level through processes like cell wall binding, plasma membrane exclusion, chelation and sequestration of heavy metals by ligands such as phytochelatins and metallothioneins, induction of heat shock proteins, biosynthesis of polyamines and production of anti-oxidants (Dalvi and Bhalerao, 2013; Bohra *et al*., 2015). Excess of heavy metals also activate oxidative stress defence mechanisms and the synthesis of stress related proteins in plants. This inherent ability of plants to tolerate and accumulate toxic contaminants can be explored to treat the metal contaminated areas efficiently. Phytoremediation refers to the technologies that use living plants to clean up soil, air and water contaminated with hazardous chemicals (Phyto = Plant + Remedy = Restoring balance). It is a cost-effective plant-based approach of remediation that takes advantage of ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in

their tissues. It is an *in-situ* remediation technology that utilizes inherent abilities of living plants. The mechanisms and efficiency of phytoremediation depend on the type of contaminant, bio-availability and soil properties. The root system provides an enormous surface area that absorbs and accumulates the water and nutrients essential for growth as well as other non-essential contaminants. Phytoremediation is a natural process carried out by plants in cleaning up and stabilization of contaminated soils and ground water. Phytoremediation is applicable to a broad range of contaminants including metals and radio-nuclides as well as organic compounds like chlorinated solvents, polychloro-biphenyls, polycyclic aromatic hydrocarbons, pesticides/ insecticides, explosives and surfactants. The Translocation Factor (TF) is a critical index in environmental science and plant physiology used to evaluate a plant's ability to move heavy metals from its roots to its aerial parts (shoots, leaves or flowers). In the context of your research on tuberose cv. 'Prajwal', it serves as the primary indicator of whether the plant is a "stabilizer" or an "extractor."

Materials and Methods

The present investigation was carried out at the College of Horticulture, Dr. Y.S.R. Horticultural University, Anantharajupeta, Annamayya district of Andhra Pradesh, India. The location is situated at an altitude of 162 meters (531 feet) above the mean sea level. The geographical location was 13°59' North latitude and 79°19' East longitude. Poly bags of 12 kg capacity were used in the present investigation and bags were filled with 10 kg of virgin soil brought from uncultivated barren land. Soil was dried, grounded and sieved through 2 mm sieve and then 3 samples of soil were collected at random just before filling the poly bags. Further, regularly soil samples were collected from poly bags at every 90 days interval and the samples were used for analysis of essential heavy metals content present in the soil. The experimental material used for the present study was tuberose single type cultivar 'Prajwal'. 'Prajwal' also known as 'Arka Prajwal' is a cross between 'Shringar' x 'Mexican Single' varieties released by Indian Institute of Horticultural Research, Bangalore. It bears single type flowers on tall and stiff spikes. Pinkish red tinge is observed on the bud before opening. The variety has been reported as tolerant to high concentrations of heavy metals and has the ability to extract heavy metals from contaminated soils. The experiment was laid out in a completely randomized design with three replications under open field conditions as pot culture experiment. The experiment consisted of 10 treatments, *viz.*, T_1 = RDF+$MnSO_4$ @ 1,000 mg/ kg soil, T_2 = RDF+$MnSO_4$ @ 2,000 mg/kg soil, T_3 = RDF+$MnSO_4$ @ 3,000 mg/ kg soil, T_4 = RDF+$CuSO_4$ @ 100 mg/kg soil, T_5 = RDF+$CuSO_4$ @ 200 mg/kg soil, T_6 = RDF+$CuSO_4$ @ 300 mg/kg soil, T_7 = RDF+$ZnSO_4$ @ 200 mg/kg soil, T_8 = RDF+ $ZnSO_4$ @ 400 mg/kg soil, T_9 = RDF+ $ZnSO_4$ @ 600 mg/kg soil, T_{10} = Control (No RDF and no essential heavy metals). One bulb was planted in each poly bag and there were 300 plants in each replication. Poly bags of size 13" x 15" with 12 kg capacity were used in the present study. Poly bags were filled with 10 kg of growing medium containing red earth, sand and farmyard manure in the ratio of 2:1:1. Calculated quantities of heavy metals as per the concentration were incorporated into the growing medium just before filling the poly bags and all the poly bags were left over on polythene mulch sheet for ten days to get settle down the growing medium. Based on the calculated area of poly bag (12.56 m^2), NPK fertilizers were applied in the form of Urea @ 540 g, SSP @ 1570 g and MOP @ 410 g per annum of the crop growth period at every three months interval as per the recommended package of practice suggested by Dr. Y.S.R. Horticultural University, Venkataramannagudem, West Godavari district of Andhra Pradesh. A day before planting all the selected tuberose bulbs were soaked in carbendazim solution at a concentration of 0.1% for half an hour and the bulbs were dried in shade. Bulbs weighing about 40 g were planted at a depth of about 3-4 inches in soil filled in poly bags and watered with rose can immediately after planting. Five plants were randomly selected and tagged with a label in each replication of the treatment to record the non-destructive observations which include vegetative growth, physiological, floral and flower yield parameters. In case of destructive sampling, one plant at each stage of observation recording was removed carefully by tearing the polythene bag and removed the soil adhered to the root system of the plant, washed thoroughly with clean water to remove the soil particles adhered to the plant and dried in shade for recording the observations on growth analysis and estimation of heavy metals in different parts of the plant at regular intervals of 90 days *i.e.*, at 90, 180, 270 and 360 days after transplanting. Translocation factor is a measure of the ability of plants to transfer accumulated metals from the roots to the shoots. It represents the ratio of metal concentration in the shoots to the metal concentration in the roots explained by Cui *et al.*, (2007). He (2013) explained that hyper-accumulators were the plants suitable for use in phytoremediation and could be defined as plant with translocation factor value was higher than one.

Result and Discussion

The analyzed data pertaining to influence of soil application of essential heavy metal concentrations and intervals of observation recorded on translocation factor of Zn in tuberose *cv.* 'Prajwal' were presented in Table 1. Significant differences were noticed among the graded levels of essential heavy metal concentrations with respect to translocation factor of Zn in tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Among the graded levels of essential heavy metal concentrations, soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil recorded significantly highest translocation factor of Zn in tuberose *cv.* 'Prajwal' (1.61, 0.91 and 1.27 respectively during 2018-19, 2019-20 and the pooled data analysis) followed by soil application of $ZnSO_4$ @ 600 mg kg^{-1} soil during both the years of study as well as in the pooled data analysis. Soil application of $MnSO_4$ @ 1000 mg kg^{-1} soil recorded significantly lowest translocation factor of Zn in tuberose *cv.* 'Prajwal' (0.64), whereas higher concentrations of $MnSO_4$ recorded non-significant differences in the translocation factor of Zn in tuberose *cv.* 'Prajwal' during 2018-19. However, soil application of higher concentration of $MnSO_4$ @ 3000 mg kg^{-1} soil recorded significantly lowest translocation factor of Zn in tuberose *cv.* 'Prajwal' (0.23) during 2019-20 and the lower concentrations of $MnSO_4$ were found at par with each other. The pooled data analysis of graded levels of $MnSO_4$ depicted a significant increase in the translocation factor of Zn in tuberose *cv.* 'Prajwal' with an increase in the concentration of $MnSO_4$ up to 2000 mg kg^{-1} soil and thereafter a significant decrease in the translocation factor of Zn was noticed. Soil application of graded levels of $CuSO_4$ recorded significant differences in the translocation factor of Zn in tuberose *cv.* 'Prajwal'. An increase in the concentration of $CuSO_4$ recorded a gradual decrease or non-significant changes in the higher concentrations of $CuSO_4$ with respect to translocation factor of Zn in tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis. Among all the treatments, significantly lowest translocation factor of Zn in tuberose *cv.* 'Prajwal' was observed in the untreated control plants (0.33, 0.15 and 0.24 respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of results, it may be concluded that except with the higher concentrations of $ZnSO_4$, the remaining heavy metal concentrations recorded marginal differences in the translocation factor of Zn in tuberose *cv.* 'Prajwal' even though significantly different between concentrations. Soil application of $ZnSO_4$ readily increased the availability of the metal in the soil solution thereby enhancing its absorption by plant roots and further translocated easily in to the site of action. Root-leaf and root-stem translocation values of >1 showed that metal concentration in leaves or stems was higher than in roots. It exhibited that roots had greater ability to absorb rather than accumulate the heavy metal. The translocation of materials in plants occurs via the vascular system or the xylem tissue. Its main function was to transport water, although heavy metals could also potentially be transported from roots to leaves. Moreover, the speed of heavy metal translocation may be influenced by the systems responsible for capillary action in plants.

Significant differences were noticed among the intervals of observation recorded with respect to the translocation factor of Zn in tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations during 2018-19, 2019-20 and the pooled data analysis. Among the intervals of observation recorded, significantly highest translocation factor of Zn in tuberose *cv.* 'Prajwal' (1.09, 0.54 and 0.81 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 180 DAP interval, whereas significantly lowest translocation factor of Zn in tuberose *cv.* 'Prajwal' (0.53, 0.34 and 0.43 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval during both the years of study as well as in the pooled data analysis. Based on the analysis of results, it may concluded that significantly highest translocation factor of Zn in tuberose *cv.* 'Prajwal' was noticed at 180 DAP interval and thereafter a significant decrease was noticed in the translocation factor till the end of the 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 translocation factor of Zn in tuberose *cv.* 'Prajwal' was found significant during 2018-19, 2019-20 and the pooled data analysis. Among the interaction effects, significantly highest translocation factor of Zn in tuberose *cv.* 'Prajwal' (3.73, 1.25 and 2.49 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 180 DAP interval followed by soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 270 DAP interval (1.87, 0.82 and 1.34 respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest translocation factor of Zn in tuberose *cv.* 'Prajwal' (0.00, 0.00 and 0.00 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control plants at 90 DAP

interval during 2018-19, 2019-20 and the pooled data analysis. Based on the analysis of results, it may be concluded that soil application of $ZnSO_4$ @ 400 mg kg^{-1} soil at 180 DAP interval recorded significantly highest translocation factor of Zn in tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis. The present result was found in close conformity with the earlier findings of An *et al.* (2006) in *Pteris vittata*, Mkumbo *et al.* (2012) in different crop species of gold mining area, Opaluwa *et al.* (2012) in different crop species grown on dump sites, Roongtanakiat (2009) in tomato, Subhashini *et al.* (2013) in weeds, flowering plants and grasses, Subhashini and Swamy (2014) and Subhashini and Swamy (2015) in *Canna indica* and Dotaniya *et al.* (2017) in spinach.

The analyzed data pertaining to the influence of soil application of essential heavy metal concentrations and intervals of observation recorded on translocation factor of Mn in tuberose *cv.* 'Prajwal' were presented in Table 2. Significant variation was recorded among the graded levels of essential heavy metal concentrations with respect to translocation factor of Mn in tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Among the graded levels of essential heavy metal concentrations, soil application of graded levels of $MnSO_4$ recorded significantly higher translocation factor of Mn in tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis. An increase in the concentration of $MnSO_4$ recorded a significant increase in the translocation factor of Mn in tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Similar kind of trend as observed with graded levels of $MnSO_4$ with respect to the translocation factor of Mn in tuberose *cv.* 'Prajwal' was noticed by soil application of graded levels of $CuSO_4$ during both the years of study as well as in the pooled data analysis. Soil application of graded levels of $ZnSO_4$ recorded a significant decrease in the translocation factor of Mn in tuberose *cv.* 'Prajwal' with an increase in the concentration of $ZnSO_4$ during both the years of study as well as in the pooled data analysis. However, non-significant differences were noticed with respect to translocation factor of Mn in between the higher concentrations of $ZnSO_4$ during 2018-19. Among all the treatments, significantly lowest translocation factor of Mn in tuberose *cv.* 'Prajwal' (0.20, 0.05 and 0.13 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded with untreated control plants. Based on the analysis of results, it may be concluded that translocation factor of Mn in tuberose *cv.* 'Prajwal' was found increased with an increase in the concentration of $MnSO_4$ and $CuSO_4$, but a decrease in the translocation factor of tuberose *cv.* 'Prajwal' was noticed with an increase in the concentration of $ZnSO_4$ during both the years of study as well as in the pooled data analysis. Similar kind of result was reported in tomato by Roongtanakiat (2009).

Significant variation was noticed among the intervals of observation recorded with respect to the translocation factor of Mn in tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations during 2018-19, 2019-20 and the pooled data analysis. Among the intervals of observation recorded, significantly highest translocation factor of Mn in tuberose *cv.* 'Prajwal' (0.76, 0.82 and 0.79 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 90 DAP interval, whereas significantly lowest translocation factor of Mn in tuberose *cv.* 'Prajwal' (0.39, 0.38 and 0.39 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval during both the years of study as well as in the pooled data analysis. Based on the analysis of results, it may be concluded that a significant reduction was noticed in the translocation factor of Mn in tuberose *cv.* 'Prajwal' with progress of the experiment 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 with respect to the translocation factor of Mn in tuberose *cv.* 'Prajwal' was found significant during 2018-19, 2019-20 and the pooled data analysis. Among the interaction effects, significantly highest translocation factor of Mn in tuberose *cv.* 'Prajwal' (2.67, 4.87 and 3.77 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by soil application of $MnSO_4$ @ 3000 mg kg^{-1} soil at 180 DAP interval followed by soil application of $MnSO_4$ @ 3000 mg kg^{-1} soil at 270 DAP interval (2.54, 4.75 and 3.64 respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest translocation factor of Mn in tuberose *cv.* 'Prajwal' (0.00, 0.00 and 0.00 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control plants at 360 DAP interval 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 $MnSO_4$ recorded significantly higher values of translocation factor of Mn in tuberose *cv.* 'Prajwal' in comparison to other essential heavy metal concentrations between 180 to 270 DAP intervals during both the years of study as well as in the pooled

data analysis, whereas many of the remaining treatments recorded significantly lower values of translocation factor of Mn in tuberose *cv.* 'Prajwal' during the same period.

The analyzed data pertaining to the influence of soil application of essential heavy metal concentrations and intervals of observation recorded on translocation factor of Cu in tuberose *cv.* 'Prajwal' were presented in Table 3. Significant variation was recorded among the graded levels of essential heavy metal concentrations with respect to translocation factor of Cu in tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. Among the graded levels of essential heavy metal concentrations, soil application of graded levels of $CuSO_4$ recorded significantly higher translocation factor of Cu in tuberose *cv.* 'Prajwal' during 2018-19, 2019-20 and the pooled data analysis. An increase in the concentration of $ZnSO_4$ recorded a significant increase in the translocation factor of Cu in tuberose *cv.* 'Prajwal' up to 400 mg kg^{-1} soil and thereafter a significant decrease in the translocation factor of Cu in tuberose *cv.* 'Prajwal' was noticed during both the years of study as well as in the pooled data analysis. Similar kind of trend as observer with graded levels of $ZnSO_4$ was noticed with the soil application of graded levels of $MnSO_4$ with respect to the translocation factor of Cu in tuberose *cv.* 'Prajwal' up to 2000 mg kg^{-1} soil and thereafter a significant decrease in the translocation factor of Cu in tuberose *cv.* 'Prajwal' was noticed during both the years of study as well as in the pooled data analysis. Among all the treatments, significantly lowest translocation factor of Cu in tuberose *cv.* 'Prajwal' was noticed in the untreated control plants (0.12, 0.13 and 0.12 respectively during 2018-19, 2019-20 and the pooled data analysis). Based on the analysis of results, it may be concluded that among the essential heavy metal concentration, soil application of graded levels of $CuSO_4$ recorded significantly higher translocation factor of Cu in tuberose *cv.* 'Prajwal' during both the years of study as well as in the pooled data analysis. The present result was found in close conformity with the earlier findings of Roongtanakiat (2009) in tomato, Mellem *et al.* (2012) in *Amaranthus dubius*, Mkumbo *et al.* (2012) in *Sporobolus spp., Launea cornuta, Tagetes minuta, Blotiella glabra* crop species of gold mining area, Opaluwa *et al.* (2012) in *Zea mays, Hibiscus sabdarifa, Abelmuschus esculentus, Amaranthus dubius, Arachis hypogea* crop species grown on dump sites, Rahman *et al.* (2013a) in amaranth and Indian mustard.

Significant variation was noticed among the intervals of observation recorded with respect to the translocation factor of Cu in tuberose *cv.* 'Prajwal' by soil application of graded levels of essential heavy metal concentrations during 2018-19, 2019-20 and the pooled data analysis. Among the intervals of observation recorded, significantly highest translocation factor of Cu in tuberose *cv.* 'Prajwal' (0.83, 0.51 and 0.67 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 90 DAP interval, whereas significantly lowest translocation factor of Cu in tuberose *cv.* 'Prajwal' (0.28, 0.05 and 0.16 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded at 360 DAP interval during both the years of study as well as in the pooled data analysis. Based on the analysis of results, it may be concluded that with the progress of the experiment, the translocation factor of Cu in tuberose *cv.* 'Prajwal' got reduced significantly 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 translocation factor of Cu in tuberose *cv.* 'Prajwal' was found significant during 2018-19, 2019-20 and the pooled data analysis. Among the interaction effects, significantly highest translocation factor of Cu in tuberose *cv.* 'Prajwal' (3.01, 1.30 and 2.15 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded by soil application of $CuSO_4$ @ 300 mg kg^{-1} soil at 90 DAP interval followed by soil application of $CuSO_4$ @ 300 mg kg^{-1} soil at 180 DAP interval (2.97, 0.98 and 1.97 respectively during 2018-19, 2019-20 and the pooled data analysis), whereas significantly lowest translocation factor of Cu in tuberose *cv.* 'Prajwal' (0.00, 0.00 and 0.00 respectively during 2018-19, 2019-20 and the pooled data analysis) was recorded in the untreated control at 360 DAP interval 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 $CuSO_4$ recorded significantly highest translocation factor of Cu during the initial 90 DAP to 180 DAP interval during the 1st year of study *i.e.,* 2018-19 and thereafter a significant decrease was noticed in the translocation factor of Cu in tuberose *cv.* 'Prajwal' even during 2nd year of study *i.e.,* 2019-20.

Conclusion

Based on the analysis of these results, it may be concluded that tuberose *cv.* 'Prajwal' can be classified as a potential phytoextractor of all the three essential heavy metals employed in the present investigation

viz., Mn, Cu and Zn from soil. Thus, tuberose *cv.* 'Prajwal' can be recommended to cultivate successfully in the soils affected with essential heavy metals especially in the mining base areas of Kadapa district to remediate the soils from these essential heavy metals without much difficulty.

Table 1 : Influence of soil applied essential heavy metals (Mn, Cu and Zn) on translocation factor of zinc in *Polianthes tuberosa cv.* 'Prajwal

Treatment (mg of element kg^{-1} soil)	Translocation factor of Zn														
	2018-2019					2019-2020					Pooled (2018-2020)				
	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	0.36	0.76	0.97	0.47	0.64	0.78	0.50	0.44	0.06	0.44	0.57	0.63	0.70	0.26	0.54
$MnSO_4$ 2000	1.67	0.1	0.14	0.92	0.70	0.45	0.63	0.65	0.21	0.48	1.06	0.36	0.39	0.56	0.59
$MnSO_4$ 3000	0.50	1.84	0.22	0.27	0.71	0.32	0.21	0.28	0.13	0.23	0.41	1.02	0.25	0.20	0.47
$CuSO_4$ 100	1.14	0.82	0.23	0.74	0.73	0.44	0.94	0.19	0.69	0.56	0.79	0.88	0.21	0.71	0.64
$CuSO_4$ 200	0.43	0.71	0.30	0.78	0.56	0.50	0.30	0.62	0.38	0.45	0.46	0.50	0.46	0.58	0.50
$CuSO_4$ 300	0.78	0.24	0.98	0.03	0.51	0.75	0.46	0.51	0.24	0.49	0.76	0.35	0.74	0.13	0.49
$ZnSO_4$ 200	0.19	0.73	0.18	0.71	0.45	0.26	0.28	0.23	0.19	0.24	0.22	0.50	0.20	0.45	0.34
$ZnSO_4$ 400	0.58	3.73	1.87	0.38	1.61	0.81	1.25	0.82	0.78	0.91	0.69	2.49	1.34	0.58	1.27
$ZnSO_4$ 600	0.92	0.97	1.23	0.87	1.00	0.66	0.65	0.54	0.62	0.61	0.79	0.81	0.88	0.74	0.80
Control	0.00	0.98	0.27	0.09	0.33	0.00	0.23	0.28	0.11	0.15	0.00	0.60	0.27	0.10	0.24
Mean	0.66	1.09	0.64	0.53		0.49	0.54	0.45	0.34		0.57	0.81	0.54	0.43	
Factor	T		I		T × I	T		I		T × I	T		I		T × I
SEm±	0.012		0.008		0.025	0.017		0.011		0.035	0.011		0.007		0.021
CD at 5%	0.035		0.022		0.070	0.049		0.031		0.098	0.030		0.019		0.060

Table 2 : Influence of soil applied essential heavy metals (Mn, Cu and Zn) on translocation factor of manganese in *Polianthes tuberosa cv.* Prajwal.

Treatment (mg of element kg^{-1} soil)	Translocation factor of Mn														
	2018-2019					2019-2020					Pooled (2018-2020)				
	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	0.36	0.11	0.31	0.20	**0.24**	0.30	0.46	0.28	0.09	**0.28**	0.33	0.28	0.29	0.14	**0.26**
$MnSO_4$ 2000	2.66	0.46	2.48	0.22	**1.45**	1.11	1.14	1.12	0.62	**0.99**	1.88	0.80	1.80	0.42	**1.22**
$MnSO_4$ 3000	0.81	2.67	2.54	0.15	**1.54**	4.73	4.87	4.75	0.36	**3.67**	2.77	3.77	3.64	0.25	**2.61**
$CuSO_4$ 100	0.01	0.01	0.02	0.04	**0.02**	0.14	0.14	0.08	0.13	**0.12**	0.07	0.07	0.05	0.08	**0.07**
$CuSO_4$ 200	1.08	0.18	0.51	0.04	**0.45**	0.28	0.24	0.24	0.42	**0.29**	0.68	0.21	0.37	0.23	**0.37**
$CuSO_4$ 300	0.51	0.20	0.25	2.22	**0.79**	0.28	0.27	0.25	0.61	**0.35**	0.39	0.23	0.25	1.41	**0.57**
$ZnSO_4$ 200	0.34	1.84	0.14	0.17	**0.62**	0.55	0.34	0.52	0.50	**0.52**	0.44	1.09	0.33	0.33	**0.55**
$ZnSO_4$ 400	0.50	0.95	0.28	0.31	**0.51**	0.52	0.34	0.34	0.72	**0.49**	0.51	0.64	0.31	0.51	**0.49**
$ZnSO_4$ 600	0.97	0.35	0.12	0.64	**0.52**	0.21	0.16	0.15	0.37	**0.21**	0.59	0.25	0.13	0.50	**0.37**
Control	0.45	0.22	0.14	0.00	**0.20**	0.08	0.08	0.07	0.00	**0.05**	0.26	0.15	0.10	0.00	**0.13**
Mean	**0.76**	**0.69**	**0.67**	**0.39**		**0.82**	**0.79**	**0.78**	**0.38**		**0.79**	**0.75**	**0.72**	**0.39**	
Factor	**T**		**I**		**T × I**	**T**		**I**		**T × I**	**T**		**I**		**T × I**
SEm±	0.004		0.004		0.008	0.005		0.003		0.01	0.003		0.002		0.006
CD at 5%	0.012		0.007		0.023	0.014		0.009		0.028	0.008		0.005		0.017

Table 3 : Influence of soil applied essential heavy metals (Mn, Cu and Zn) on translocation factor of copper in *Polianthes tuberosa cv.* 'Prajwal.

Treatment (mg of element kg^{-1} soil)	Translocation factor of Cu														
	2018-2019					2019-2020					Pooled (2018-2020)				
	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	0.29	0.04	0.48	0.03	**0.21**	0.30	0.30	0.20	0.04	**0.21**	0.30	0.17	0.34	0.04	**0.21**
$MnSO_4$ 2000	0.76	0.61	0.42	0.41	**0.55**	0.79	0.69	0.12	0.06	**0.42**	0.78	0.65	0.27	0.24	**0.49**
$MnSO_4$ 3000	0.36	0.13	1.13	0.26	**0.47**	0.12	0.23	0.01	0.01	**0.09**	0.24	0.18	0.57	0.14	**0.57**
$CuSO_4$ 100	0.20	0.11	0.34	0.28	**0.23**	0.35	0.38	0.04	0.07	**0.21**	0.27	0.24	0.19	0.17	**0.22**
$CuSO_4$ 200	2.27	1.24	0.22	0.49	**1.05**	0.94	0.93	0.16	0.10	**0.53**	1.60	1.08	0.19	0.29	**0.79**

$CuSO_4$ 300	3.01	2.97	0.57	0.46	**1.75**		1.30	0.98	0.95	0.09	**0.83**		2.15	1.97	0.76	0.27	**1.29**
$ZnSO_4$ 200	0.64	0.20	0.03	0.36	**0.30**		0.40	0.37	0.18	0.04	**0.25**		0.52	0.28	0.10	0.20	**0.27**
$ZnSO_4$ 400	0.30	0.33	1.68	0.41	**0.68**		0.30	0.33	0.58	0.03	**0.31**		0.30	0.33	1.13	0.22	**0.50**
$ZnSO_4$ 600	0.30	0.40	0.60	0.10	**0.32**		0.34	0.34	0.32	0.11	**0.28**		0.32	0.37	0.46	0.11	**0.32**
Control	0.26	0.16	0.06	0.00	**0.12**		0.23	0.26	0.02	0.00	**0.13**		0.24	0.21	0.04	0.00	**0.12**
Mean	**0.83**	**0.61**	**0.55**	**0.28**			**0.51**	**0.48**	**0.25**	**0.05**			**0.67**	**0.55**	**0.40**	**0.16**	

Factor	**T**	**I**	**T × I**		**T**	**I**	**T × I**		**T**	**I**	**T × I**
SEm±	0.004	0.002	0.008		0.005	0.003	0.009		0.002	0.001	0.005
CD at 5%	0.01	0.007	0.020		0.013	0.008	0.026		0.007	0.004	0.013

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