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Zinc Toxicity and its Influence on Nutrient Uptake in Tea

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Abstract: An experiment was conducted using potted plants of the tea cultivar UPASI-9 to document the toxicity limits of zinc and to determine the toxic effects on tea plant and soil. There were nine treatments including an untreated control, where zinc was not added. Zinc acetate was applied to the soil in the pots to make eight treatments, containing 10, 25, 50, 100, 500, 750, 1000 and 2000 mg Zn kg^{-1} of soil. One-year-old plants of clone UPASI-9 were grown in these pots and the trial was continued for 136 days. The plants grown in soil containing 2000 mg Zn kg^{-1} died within 15 days, while the plants supplied with 1000 mg Zn kg^{-1} zinc died within 36 days after imposing treatments. The toxic limits of zinc were found to be 83, 170 and 660 mg kg^{-1} in leaf, stem and root, respectively. The typical toxicity symptoms were browning of leaves along the midrib starting from about 1.5 to 2.0 cm from the petiole towards the leaf tip and extending throughout the leaf. Addition of zinc increased the translocation of manganese to leaves, while it suppressed the uptake of magnesium. Although there is no report of antagonism between zinc and iron at the absorption sites of roots and during translocation process to stem, the leaf analysis indicated an antagonism. Absorption of phosphorus was also inhibited due to excessive zinc uptake. The soil urease activity went on increasing up to 500 mg kg^{-1} of zinc and then decreased drastically.

Key words: Zinc toxicity, uptake of Mg, Mn, P, Na, urease activity, critical toxicity limit

Introduction

Owing to the similarity in the ionic radius of zinc (Zn^{2+}) ions with those of Fe^{2+} and Mg^{2+}, these two ions are substituted by Zn^{2+} by isomorphous replacement in several mineral structures and hence the occurrence of zinc in the lithosphere is as high as 80 mg kg^{-1}. Zinc is reported to interact with soil organic matter to form both soluble and insoluble zinc complexes (Hodgson, 1969). The level of zinc in soil is very much related to the parent material. Soils originating from basic igneous rocks are high in zinc, while the soils derived from more siliceous parent materials are particularly low. Zinc is closely involved in the N-metabolism of the plant. It plays a vital role in the synthesis of nucleic acids and proteins and helps in the utilization of phosphorus and nitrogen. It is the only micronutrient whose deficiency is widespread and its correction has become a routine practice to maintain high productivity of tea in south India. As in other crops, the deficiency is characterised by very short internodes, chlorotic and small sickle shaped leaves and stunted axillary shoots. The correction is done through foliar application of mixture of zinc sulphate, magnesium sulphate, manganese sulphate, boric acid and naphthalene acetic acid (Verma and Palani, 1997). The expenditure involved in manpower to spray the mixture is much costlier than the cost of the chemicals. It is necessary to be well informed about zinc toxicity levels and the typical symptoms on tea leaves. While the zinc deficiency in tea is well recorded and recognized, there is no information on its toxicity symptoms in tea, particularly under south Indian conditions. Although zinc is very much needed for tea growth, higher concentration would retard

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growth and development of plants by interfering with certain metabolic process. Hyper-accumulation of zinc has been observed in many plants species (Baker and Walker, 1990; Verkleij and Schat, 1990). The toxic effect of zinc on other plants has also been reported by many researchers (Davis and Parkar, 1993; Taylor *et al*., 1991; Wheeler and Power, 1995). The main objectives of the present study are 1. To determine the distribution and accumulation of soil applied zinc, 2. To fix the critical toxic limit of the metal, 3. To find out the interaction of zinc with other essential elements in plant and soil and 4. to document its influence on soil urease activity.

Materials and Methods

A potted plant experiment was carried out with nine treatments including an untreated control in clone UPASI-9. About 4 kg of soil was filled in each pot to which zinc acetate was added externally in such a way that the soils contain 10, 25, 50, 100, 500, 750, 1000 and 2000 mg kg^{-1} of zinc. The experiment was conducted in triplicate. The soil used in this study was sandy loam in texture having 71% sand, 10% silt and 19% clay. The soil pH was 4.5 having 3.4% organic matter. One year old plants of clone UPASI-9 were grown in these pots for 136 days after which the plants were uprooted and separated into root, stem and leaves. A moisture meter (Theta meter type HH1) was used to maintain the soil moisture at 20%. Visual observation was taken for six days a week and the dead plants were separated out from the experiments as and when noticed.

The separated soil samples were air dried and passed through 2 mm sieve (Klose and Tabatabai, 2000). The separated vegetative parts were oven dried at 60°C and made into homogeneous powder. About 1 g from every plant part was digested with $HNO_3/HClO_4$ mixture (Haunter *et al*., 1987) and analyzed for Zn, Fe, P, Mn, Mg and Na (Bhargava and Raghupathi, 2001) using atomic absorption spectrophotometer (GBC AA model). The metal standards used in this study were traceable to NIST (National Institute for Standards and Technology). Statistical analysis was carried out by the standard method (Gomez and Gomez, 1984).

The soil urease activity was determined at the end of the experiment (136 days after imposing treatments) using the method developed by Tabatabai (1982), which consists of incubation of 5 g of soil with 40% moisture in a wide mouth polythene bottle at 35°C. The incubation was done in triplicate. After 2 hr, the incubation medium was removed from the incubator and urease activity was measured (Tabatabai, 1982). The activity was expressed in terms of ammonium nitrogen formed per gram of soil per hour.

Results and Discussion

Based on the visual observations, the typical toxicity symptoms appeared to be browning of leaf, which started along the mid-rib starting from about 1.5 to 2.0 cm from the petiole towards the leaf tip and expanding throughout the leaf at later stages. The toxicity symptoms started appearing over the plant on the 8th day of imposing treatments. Depression in growth was noted from 25th day onwards due to 1000 and 750 mg kg^{-1} treatments. The symptoms appeared first on the bottom most leaves, which gradually spread to the upper part of the plant. The affected leaves turned brown, became wilted and due to loss of turgor hung down from petioles. The bottom leaves was the first to shed due to toxicity. The plants established on the soil containing 2000 mg Zn kg^{-1} died within 15 days, while the plants supplied with 1000 mg Zn kg^{-1} died within 36 days after imposing treatments. The plants raised under 750 mg Zn kg^{-1} showed severe toxicity symptoms like leaf browning and scorching. The surviving plants were uprooted and separated into root, stem and leaf after 136 days of experimentation and analyzed for Zn and the results are given in Fig. 1. It shows that the concentration

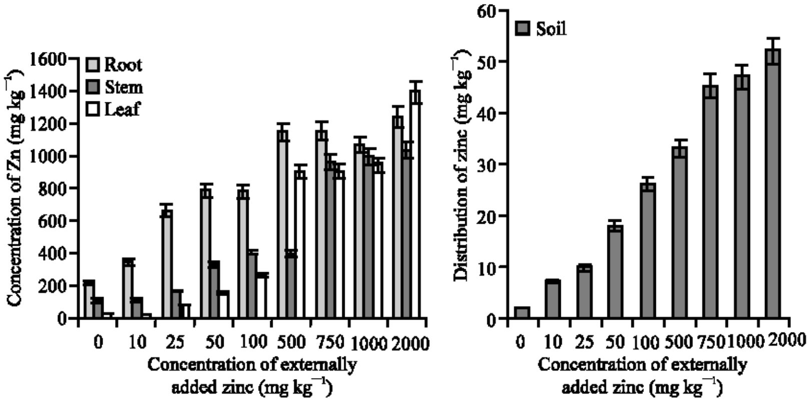

Fig. 1: a) Absorption and distribution of zinc to various plant parts, b) levels of available zinc in soil after 136 days of external addition. The error bars represent the relative standard deviation

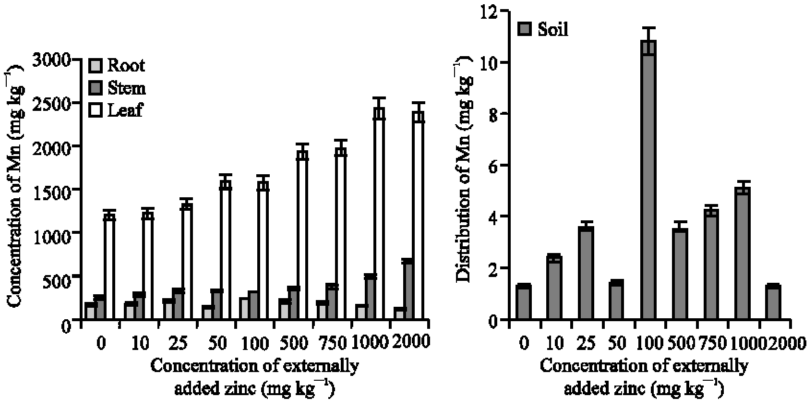

Fig. 2: Influence of externally added Zn a) on Mn uptake by various plant parts, b) on distribution of Mn in soils. The error bars represent the relative standard deviation

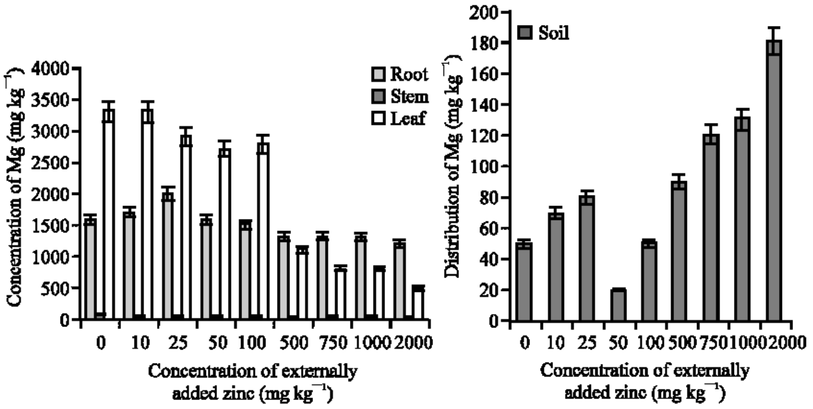

Fig. 3: Influence of externally added Zn a) on Mg uptake by various plant parts, b) on distribution of Mg in soils. The error bars represent the relative standard deviation

Table 1: Correlation Co-efficient (r) worked out between zinc and other elements in various plant parts

	Zinc in leaf	Zinc in root	Zinc in Soil	Zinc in Stem	Zinc treatment
Iron in leaf	-0.913**	-0.932**	-0.914**	-0.912**	-0.798**
Iron in root	0.845**	0.945**	0.910**	0.898**	0.763*
Iron in soil	0.851**	0.662	0.664	0.892**	0.958**
Iron in stem	0.888**	0.820**	0.815**	0.945**	0.924**
Magnesium in leaf	-0.976**	-0.927**	-0.804**	-0.914**	-0.859**
Magnesium in root	-0.862**	-0.731*	-0.792*	-0.797*	-0.749**
Magnesium in soil	0.882**	0.683*	0.676*	0.826**	0.927**
Magnesium in stem	-0.769*	-0.915**	-0.834**	-0.856**	-0.693*
Manganese in leaf	0.944**	0.895**	0.857**	0.935**	0.878**
Manganese in root	-0.239	-0.037	0.006	-0.290	-0.482
Manganese in soil	-0.039	0.153	0.490	0.089	-0.167
Manganese in stem	0.850**	0.715*	0.705*	0.813**	0.963**
Sodium in leaf	0.911**	0.836**	0.872**	0.968**	0.939**
Sodium in root	0.624	0.653	0.799**	0.825**	0.693*
Sodium in soil	0.297	0.531	0.314	0.287	0.336
Sodium in stem	0.867**	0.787*	0.777*	0.933**	0.920**
Phosphorus in leaf	0.225	-0.033	-0.030	0.117	0.515
Phosphorus in root	-0.816**	-0.576	-0.658	-0.833**	-0.931**
Phosphorus in soil	-0.949**	-0.781*	-0.74*	-0.854**	-0.99**
Phosphorus in stem	0.653	0.438	0.518	0.678*	-0.805**
Zinc in leaf		0.894**	0.817**	0.898**	0.931**
Zinc in root			0.857**	0.834**	0.747*
Zinc in soil				0.866**	0.726*
Zinc in stem					0.871*

* Significant at 5% level; ** Significant at 1% level

of zinc was higher in root and stem than that of leaf, when the concentration of applied zinc was 100 mg kg^{-1} or lesser. However, the zinc concentration in leaf was higher or almost equal to its concentration estimated in root and stem.

Applied zinc has positive correlation with zinc content of leaf, root, soil and stem (Table 1). Zinc toxicity interfered with Mn and Mg uptake of leaves. Addition of zinc increased the translocation of Mn to leaves (Fig. 2), while it suppressed the magnesium uptake by leaves (Fig. 3). White *et al*. (1974) reported the increased translocation of Mn to upper portion of soybean due to increased zinc levels. Zinc is reported to interfere at the loading site of the roots and decrease the rate of translocation, particularly when zinc is antagonistic with an element (Rout and Das, 2003). From our observation, an important point is revealed that zinc is antagonistic to Mg, when the level of the former is high. The higher the concentration of applied zinc, higher was its accumulation in leaf, stem and root. This is contrary to the literature available that soil applied zinc accumulates at the collar region of the tea plants (Verma and Palani, 1997). The rate of soil applied zinc has got positive and significant correlation with the zinc content of leaf ($r = 0.87$, $p = 0.01$), stem ($r = 0.87$, $p = 0.01$) and root ($r = 0.75$, $p = 0.05$). The relationship for applied zinc with manganese content of leaf and stem was linear and positive ($r = 0.86$, $p = 0.01$; $r = 0.73$, $p = 0.05$, respectively), which confirms the synergism between zinc and manganese (Verma and Palani, 1997). Based on this study it is concluded that zinc toxicity can cause chlorosis and browning of leaf. Those plants which received 25 mg kg^{-1} and more zinc have shown very light, moderate and severe toxicity symptoms were selected and analyzed for zinc content in various parts (Fig. 1). The minimum value of zinc in leaf, stem and root was found to be 83, 170 and 660 mg kg^{-1}. Hence these values could be considered as critical toxic limits. It can even become fatal when the concentration of zinc is more than double the prescribed limits. Even though there are reports on accumulation of Ca due to increased zinc addition (Baker, 1978), in our studies, no such trend was observed (data not given).

It has been reported that zinc interferes with Fe uptake, when excessive Zn is supplied (Chaney, 1993). This problem is expected to be more in acid soils. In our studies (Table 1) iron content

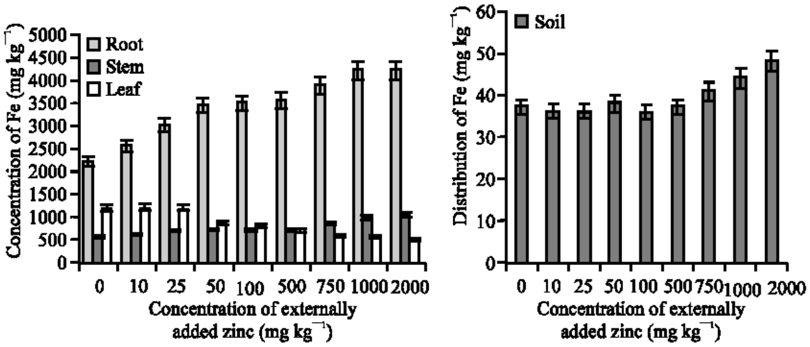

Fig. 4: Influence of externally added Zn a) on Fe uptake by various plant parts, b) on distribution of Fe in soils. The error bars represent the relative standard deviation

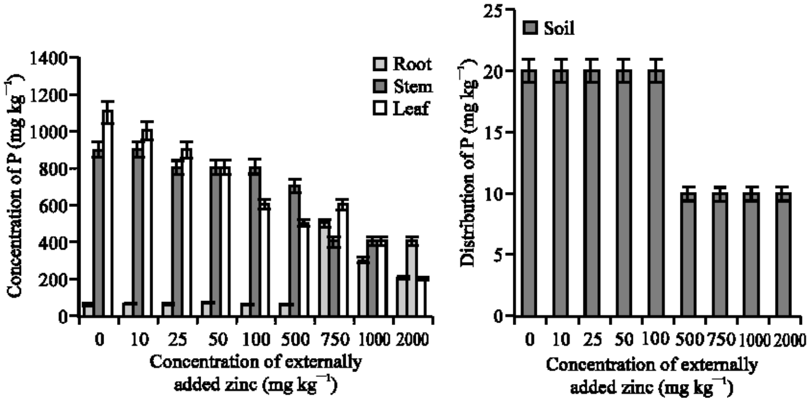

Fig. 5: Influence of externally added Zn a) on P uptake by various plant parts, b) on distribution of P in soils. The error bars represent the relative standard deviation

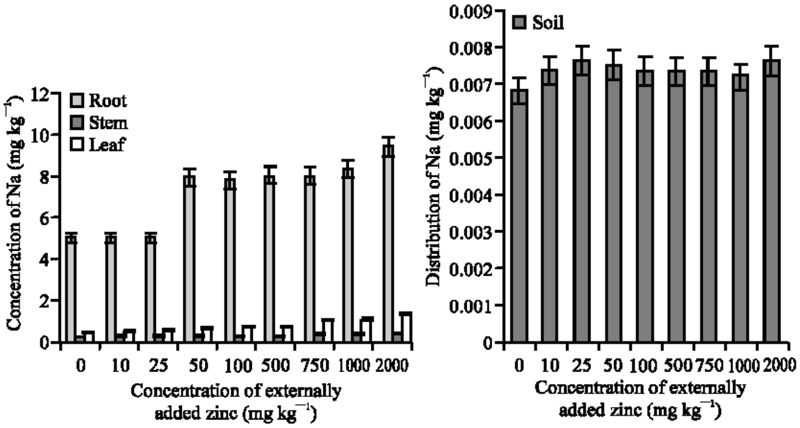

Fig. 6: Influence of externally added Zn a) on Na uptake by various plant parts, b) on distribution of Na in soils. The error bars represent the relative standard deviation

of leaf has shown negative correlation constantly with zinc content of various plant parts as well as soils (Fig. 4). Similar kind of observation has been recorded many times in other ongoing research

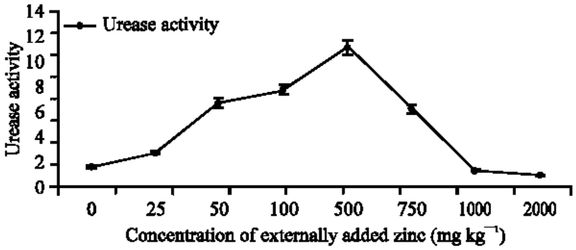

Fig. 7: Influence of externally added Zn on urease activity. The error bars represent the relative standard deviation

experiments (data not published). However, this is the first time that the antagonism between iron and zinc is quantitatively recorded and analyzed statistically in tea. On the other hand, the iron content estimated in root, soil and stem have shown positive correlation with zinc content of various plant parts and soil as well. Based on these observations it is presumed that there is no antagonism between iron and zinc at the absorption sites of roots and its transformation to stem portions, although accumulation in leaf is antagonistic to each other.

It is clear from the results that the addition of zinc reduced the phosphorus availability in soils (Fig. 5). The antagonism between zinc and phosphorus has already been reported in other crops like maize and wheat (Zhimini *et al*., 1999). However, such reports are not available on tea. A more clear antagonism between zinc and phosphorus was observed as evidenced by the root sample analysis (Table 1). When the concentration of externally added zinc was kept high, the concentration of phosphorus estimated in the root sample was lower (Fig. 5). It is probable that zinc reacts with phosphorus to form zinc phosphate, which is insoluble (Singh and Mittal, 1986; Arora and Singh, 2003; Montilla *et al*., 2003). We conclude that both P and Zn are mutually antagonistic in tea, whenever either of these elements exceeds some threshold value within the root. Similar kind of trend was also noticed in the case of leaf and stem. The correlation analysis carried out between zinc and phosphorus content of leaf, stem, root and soil (Table 1) was confirmatory to the above facts ($r = -0.86$, $p = 0.01$; $r = -0.86$, $p = 0.01$; $r = -0.93$, $p = 0.01$; $r = -0.80$, $p = 0.01$, respectively)

Sodium was another element showing a relationship with zinc (Fig. 6). The correlation coefficients were positive and significant for sodium content of stem with zinc content in all the parts; similarly, the sodium content of leaf was significant at $p = 0.01$ with zinc content of leaf, root, stem and soil (Table 1).

The activity of urease was reported to be influenced by zinc absorption (Bowen and Shuqing, 1999). The results of the attempt made in the current study are depicted in Fig. 7. It is obvious that the activity of urease, responsible for converting plant in available form of urea into available ammonium and nitrate form, increases upto 500 mg kg^{-1} zinc. The activity was inhibited greatly when the concentration of added zinc was 750 mg kg^{-1} and above.

Conclusions

The study clearly indicated that, like any other plants, the tea plants are also susceptible to zinc toxicity. Although the applied zinc is not fully accumulated in the collar region of the tea plant, as it was believed until now, a major portion is held back within the stem and root portion. Hence a critical cost economics should be worked out based on the percentage utilization and use efficiency of zinc by tea plant before making any recommendation on soil application of zinc.

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