ASSESSMENT OF SELECTIVE RETENTION SITES OF CADMIUM AND LEAD IN TOMATO
(*Lycopersicon esculentum* Mill.)

By

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THESIS

submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

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DECLARATION

I, K.Vanisri hereby declare that the thesis entitled " **Assessment of selective retention sites of cadmium and lead in tomato (*Lycopersicon esculentum* Mill.)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or society.

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CERTIFICATE

Certified that the thesis entitled " **Assessment of selective retention sites of cadmium and lead in tomato (*Lycopersicon esculentum* Mill.)**" is a record of research work done independently by Ms. K.Vanisri, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the under signed members of the Advisory Committee of Ms. K.Vanisri, a candidate for the degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled " **Assessment of selective retention sites of cadmium and lead in tomato (*Lycopersicon esculentum* Mill.)**" may be submitted by Ms. K.Vanisri, in partial fulfillment of the requirement for the degree.

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To my loving parents,

brother,

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and

Lord Sowdambika

CONTENTS

ABBREVIATIONS AND SYMBOLS USED

Abbreviations / Symbols	
Cd	Cadmium
CD	Critical Difference
ha	Hectare
kg	Kilogram
µg	Microgram
mg	Milligram
Pb	Lead
AAS	Atomic absorption spectrophotometer
T	Treatment
KAU	Kerala Agricultural University
DTPA	Diethylene triamine penta acetic acid
US	United States
mM	Millimolar
µM	Micromolar
g	Gram
ppm	Parts per million
EDTA	Ethylene diamine tetra acetic acid

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Introduction

1. INTRODUCTION

Heavy metals have been identified as one of the most dreaded pollutants, which make their silent entry into living systems particularly plants from soil, water and air. The possible sites of retention of these metals could be anything from roots, shoots and fruits and such retention normally causes concern to human health only if these parts turn economically important in the food chain. Small, but continuous ingestion of these metals into the human system in the long run is sure to impair the human health in different ways. The implication after the ingestion of metals in human being cannot be precisely predicted as several health factors predispose them. However, such exposures may lead to renal impairment, osteomalacia, plumbism and many other health problems associated with various heavy metals.

Among the toxic heavy metals that pose health hazards, cadmium and lead occupies prime position. Cadmium and lead pollutions of the environment are synonymous with civilization and these elements are even seen in nature as accessory minerals.

Tomato (*Lycopersicon esculentum* Mill.) enjoys a premier status among vegetables as it is widely consumed as raw as well as in the cooked form. Though it is known to be a rich source of vitamins and minerals, the same can turn as a potential indicator for heavy metal contamination, which necessarily means that it can be the best source of heavy metal contamination for any one right from new born to octogenarians if they are included in the food chain.

In Kerala, majority of the vegetables are being brought from other states, where different kinds of inputs with unknown etiology, particularly organic and inorganic sources are being used in the cultivation. If for any chance these sources offer contamination, the kind and nature of the contaminants definitely get reflected in the quality of the produce without affecting the external - internal quality as decided by taste or appearance. As long as there is no easy mechanism available for identifying such contamination and in the absence of any apparent manifestations in the produce regarding contamination, the quality of the vegetables is to be believed without any other concerns. In view of this contention, the ultimate consumer just cannot remain complacent particularly when these metals are seen bound to various elements in tissues like nitrogen, sulphur, oxygen *etc*. Inadvertent ingestion of such contaminated materials over a period of time, no doubt, is sure to pose serious health concerns.

The Agency for Toxic Substances and Disease Registry (part of the U.S. Public Health Services) has indicated that the major exposure of lead to the general population is mainly through fruits and grains, while that for cadmium the entry has been identified through the roots, edible leaves, fruits and seeds.

Since the selective retention sites in tomato are obscure and the behaviour of tomato under various levels of both cadmium and lead are not available, the ambiguity was cashed in the present study with following objectives

- To identify the selective retention sites of cadmium and lead in tomato plants.
- To quantify the selectively retained heavy metals in tomato at different levels of their application.
- To observe if the applied doses of cadmium and lead affect the normal growth and production in tomato including the possible manifestation of toxicity symptoms.

Review of literature

2. REVIEW OF LITERATURE

2.1 SOURCES OF HEAVY METALS IN SOILS

According to Tiller (1958), feldspars, micas, iron oxides and hydroxides, clay minerals and humus are the principal carriers of heavy metals.

Anderson (1976) analysed different samples of farmyard manure for possible heavy metal content and reported that under normal application rates, an annual input of 1-4g Cd ha^{-1} can be expected in soils.

Mortvedt and Giordano (1977) showed that concentrations of eight heavy metals (Zn, Cu, Cd, Cr, Mn, Ni, Pb and V) in phosphatic fertilizers not only varied with the source of rock phosphate but also with the P concentrations in them. According to them, heavy metals are mere contaminants in phosphate rocks and are generally related to the impurities usually seen as co-precipitates along with the phosphates at the time of application. The addition of phosphate or its cadmium equivalent as $CdCl_2$ in soil results in increased Cd content of the edible portion of vegetables (Ormrod, 1978).

Jaakkola *et al.* (1979) reported that vegetables grown on soil heavily treated with phosphate fertilizer might have constituted the main sources of cadmium pollution in soils and vegetables. Milberg *et al.* (1980) reported that gasoline combustion especially from vehicles is the primary cause of lead pollution in air and these lead particles reach the soil through dry and wet deposition.

Mortvedt and Osborn (1982) reported that analysis for Cd in Florida phosphate rock varied from 3 to 15 mg kg^{-1} and the contents were much lower when compared to western US deposits where the range went up to 130 mg kg^{-1}. Muramoto and Aoyama (1990) reported that some phosphate fertilizers and phosphorite contained high concentration of cadmium (4 to 77 $\mu g\ g^{-1}$) and were considered to be one of the main reasons for increasing Cd content in rice plants.

Singh *et al.* (1991) studied the Cd uptake by oats and carrot from atmosphere using isotopic dilution technique. They found that the total uptake of Cd by oat grains and carrot roots was about 50 and 20 per cent respectively. Further, they concluded that atmospheric contamination of cadmium could not be ignored in the heavy metal studies as it contributed significantly to the metal load in plants.

Jeng and Bergseth (1992) reported that the soils developed on parent materials such as black sedimentary, alum-shales showed significantly higher metal load especially Cd than those developed on other parent materials. The water-soluble fraction of Cd in soil had been reported to be enhanced with increased levels of phosphorus fertilization (Kaushik *et al.*, 1993). Alloway (1995) reported that mafic and ultramafic parent materials contain high levels of heavy metals than siliceous rocks.

He and Singh (1995) observed that when NPK fertilizer containing high Cd and lead or inorganic Cd salt when applied to soil, the DTPA and NH_4NO_3 extractable Cd from such soils maintained higher levels. Raaven and Loeppert (1997) analysed the trace element composition of fertilizers and soil amendments and estimated that farm yard manure supplies 0.7 $\mu g\ g^{-1}$ of Cd and 7.5 $\mu g\ g^{-1}$ of Pb. They also reported that DAP contains 4.6 $\mu g\ g^{-1}$ and 3.7 $\mu g\ g^{-1}$ of Cd and Pb respectively.

Agricultural soils next to major roadways contained approximately two or three times the concentration of total lead compared with the soils with no history of such contamination (Badawy *et al.*, 2002).

2.2 HEAVY METALS AND BIO-INDICATORS

According to Lehoczky *et al.* (1996) spinach was identified to be the most sensitive plant to Cd contamination as is able to accumulate Cd to a great extent especially when compared to garlic and corn. Significant decreases in the relative water content of plants were detected as the result of higher levels of Cd application (50 and 100 mg Cd kg^{-1} soil).

Jarvan (1998) conducted a study with lettuce, an indicator crop for major heavy metals at different pH levels from contaminated peat soils. According to him, Cd and Zn uptake in lettuce were higher at lower pH and lettuce leaves accumulated two to four times more heavy metals than tomato, cucumber and pepper fruits.

Verdoni *et al.* (2001) conducted a study with tomato plant to see whether fatty acid composition of leaves, cotyledons or roots could be used as an indicator of the bio-availability of heavy metals. They also wanted to assess the adverse effects of heavy metals on the growth and yield of plants. Accordingly, the plants were grown in metal contaminated soils. The study revealed that there was a significant change in the fatty acid composition in primary leaves, which was consequently indicated as positive relation in metal accumulation (Cd, Pb, Zn and Cu) by plants.

2.3 INFLUENCE OF pH ON BIO-AVAILABILITY OF HEAVY METALS

Reddy *et al.* (1995) conducted a study on activity of copper, zinc and lead in acidic environment. They had reported that when pH decreased from 6.6 to 2.4, the activity of Pb^{2+} increased resulting in higher availability.

Singh *et al.* (1995) conducted a greenhouse experiment with wheat, carrot and lettuce as test crops in soils containing naturally high concentration of metals at different pH levels (5.5, 6.5, 7.0 and 7.5). It was observed that the concentration of Cd in plant species decreased significantly with increasing pH levels especially between 5.5 and 6.5.

Brallier *et al.* (1996) conducted a study on plant uptake of metals in acidic soils, which had been amended with 500 t ha^{-1} municipal sewage sludge 16 years ago. The study revealed that, where crops like bush beans (*Phaseolus vulgaris* cv *seafarer*), cabbage (*Brassica oleracea* v. *capitata*), maize (*Zea mays*), potato (*Solanum tuberosum*) and tomato (*Lycopersicon esculentum* Mill.) showed lesser uptake of heavy metals from limed soils indicating the influence of pH in the bio-availability of heavy metals.

Sukreeyapongse *et al.* (2002) studied the pH dependent release of cadmium, copper and lead from natural and sludge-amended soils. They reported that as pH decreased, the rate of release of heavy metals increased. The sequence of release was observed to be in the order cadmium > lead > copper, thus expressing the order of metal lability in the soils.

2.4 HEAVY METALS AND THEIR BIOAVAILABILITY

Williams and David (1973) found plant species differed greatly in their ability to absorb cadmium and that vegetable crops generally recorded higher content of cadmium than cereals and grasses.

Pradeep (1993) conducted an experiment with main and residual crop of French bean on sewage sludge to study its effect of heavy metals on yield. From the study it was concluded that both main and residual crop resulted in the accumulated Cd and Pb. However, it was seen that the lead content in both crops were generally greater than the cadmium content. Quite contrary to the expectations, the residual crop of French bean accumulated more lead content than the main crop.

Ma-Guorui *et al.* (1996) conducted uptake studies with heavy metals like Pb and Cd on different vegetables. They observed that among the vegetables that they had tried, the Chinese mustard (*Brassica chinensis*) and Chinese cabbage absorbed more Pb while pea seedlings, coriander and spinach absorbed more Cd.

Logan *et al.* (1997) conducted a field experiment in a highly contaminated soil to measure the uptake of different heavy metals including Cd and Pb through raising different vegetable crops. It was observed that the uptake of heavy metals by the different crops were in the order: Zn > Cu > Ni > Cd > Pb. Among the vegetable crops studied, lettuce, bean and tomato were seen to accumulate more concentrations of metals than cabbage, potato and carrot.

Weir and Allen (1997) while assessing the uptake of heavy trace metals through chemical analysis of the edible portions of tomato and mustard (*Brassica juncea* L.) grown in contaminated soils, indicated that lead and cadmium levels in these plants were not high enough to warrant any health concerns and the levels were well within acceptable ranges.

Eissa and El-kassas (1999) compared the growth of different plants like strawberry, onion, wheat, clover, tomato, lettuce and cucumber in two soils, one from the industrially contaminated area and the other from a normal agricultural area in Egypt. Their study revealed that the plants grown in soils from the industrially contaminated area showed more Pb and Cd content than those grown on normal soils.

2.5 HEAVY METALS AND THEIR TRANSLOCATION IN PLANTS

Electron microscopic studies conducted by Malone *et al.* (1974) on corn plant exposed to Pb in hydroponic solution showed that the roots initially accumulated Pb as surface precipitation and subsequently held the same as Pb crystals in the cell wall. The concentration of Pb deposits usually occurred outside the plasmalemma of the cell wall. Similar deposits were also observed in other parts of the plant, mainly stem and leaves suggesting that Pb was transported and deposited in a similar manner.

Singh *et al.* (1995) conducted a greenhouse experiment in soils having inherently high concentration of metals to study the uptake behaviour of Cd especially by wheat and carrot. From the result it is concluded that when roots absorb cadmium from the soil, it got readily translocated to the upper parts of the plant retaining very less of it in the root portion. Accordingly, higher levels of Cd got accumulated in the vegetative parts than in roots in both the crops. However, it was also noted in their study that, though vegetative parts maintained higher concentration of Cd, seed of these plants contained very low concentration of the metal.

Lehoczky *et al.* (1996) conducted a pot culture experiment to study the effects of Cd in soil plant system with corn (*Zea mays* L.), garlic (*Allium sativum* L.) and spinach (*Spinacea oleracea* L.) as test crops. It was noted that in all crops studied, increase in concentration of cadmium in soil resulted in a corresponding increase of the metal in shoots. Compared to control, an assessment of Cd content of leaves and stems of corn revealed that there was a 30-fold increase in metal load in plants from an application of 10 mg Cd kg^{-1} soil. Similarly, 90-fold and 250-fold increase in metal load in plants with respect to control were observed in maize when Cd was applied at 50 and 100 mg Cd kg^{-1} soil respectively.

Hegedusova and Hegedus (2000) conducted an experiment with tomato to study the rate of transfer of Cd from soils as influenced by pH. They had applied Cd at the rate of 1 to 2 mg kg^{-1} in alkaline soils (pH 7.5) and observed that there was 3.5 to 4.0-fold increase in Cd content in fresh tomato fruits compared to control.

Gundersen *et al.* (2001) conducted a comparative study to observe the uptake of major trace elements including heavy metals in tomato fruits grown in three different substrates. Accordingly, they independently irrigated soil and rockwool with a normal nutrient solution. Further, in another set of rockwool media, they used a nutrient solution with elevated electrical conductivity. Results indicated that plants grown in soil media, maintained more concentration of Cd in tomato fruits and on comparison, it was more than 15 times higher than those grown in rockwool.

Shimachi *et al.* (2003) reported that a wetland herb called as smartweed (*Polygonum thunbergii*) accumulated high concentrations of Cd in its stems with a remarkably low content of it in the leaves. According to them, Cd accumulation in these plants occurred mainly in the nodes, junctions of petioles and vessels in stems, with minimal translocation in petioles. They further suggested that there exists a translocation inhibitory mechanism for Cd from stems to leaves.

Greger and Lofstedo (2004) conducted a study using 0.5 mM Cd nutrient solution by raising wheat varieties, bread wheat (*Triticum aestivum* L.) and durum wheat (*T. durum* Desf.) to investigate the reasons for the high accumulation of Cd in wheat grains. According to them, the Cd which got absorbed by roots was translocated to shoot portion and particularly to flag leaf and grain coats.

Wu *et al.* (2004) observed in a nutrient solution study that the cadmium concentrations noted in both functional leaves and petioles of cotton have direct relationship with the content of Cd in the medium.

Kidd *et al.* (2004) conducted a hydroponic experiment to study the effect of heavy metals on the growth and accumulation by five populations of *Cistus ladanifer* L. subsp. *ladanifer*, which is generally considered as Cd tolerant. These plants were exposed to 0-2000 μM of heavy metal concentrations including Cd and Pb. It was reported that these plants accumulated more Cd in shoots (309 μg Cd g^{-1}) than roots. They further reported that these plants were not able to transport Pb from their roots to aerial parts.

2.6 INFLUENCE OF HEAVY METALS ON PLANT GROWTH

Cadmium accumulation in plants invariably results in direct effects especially in terms of growth retardation and lesion development (Ormrod, 1978).

Kastori *et al.* (1992) related the influence of heavy metals with water relations in sunflower (*Helianthus annus* L.) and they observed that under the influence of excess lead, cadmium, copper and zinc, there was an increase in number of stomata per leaf area with an accompanying decrease in size of stomata. The study also emphasized that excess concentrations of heavy metal significantly affected plant water status causing water deficit and subsequent metabolic changes in the plants.

Mechanism of inhibition of seed germination by heavy metals especially lead was studied by Mishra and Choudhuri (1997). According to them, inhibition of seed germination occurred due to the hydrolysis of starch by α- amylase. Navarro-Pedreno *et al.* (1997) reported that in tomato, the plant growth was adversely affected by the presence of cadmium, chromium and nickel. The heavy metal damages were particularly produced noted in roots and leaves. In leaves the damage was manifested as leaf chlorosis, which brought reduction in yield.

Khan *et al.* (1999) reported that the inhibitory effects of heavy metals were more pronounced on roots than the shoot. The heavy metals accumulation in the shoot may also lead to increase in phenolic compounds that may be responsible for inhibition of germination and growth.

Nair (1999) reported that in carrot, the tissue content of Pb and Cd was significantly higher in above ground parts when compared to control. Lead application at the rate of 80 mg Cd kg^{-1} of soil resulted in three-fold increase in tissue metal content compared to application of half dose in soil. It was also observed that the highest level of Cd application (80 mg Cd kg^{-1} soil) did not allow the plant to establish growth.

Cobb *et al.* (2000) conducted an experiment on vegetables (lettuce, radish, tomato and beans) to study the accumulation of heavy metals and in their study, it was reported that all the vegetables grown in mine wastes exhibited stunted growth and chlorosis. Further they reported that the survival of tomatoes in such soils was very poor compared to other plants.

Tomar *et al.* (2000) conducted a pot culture experiment to study the effect of enhanced lead levels in soil on growth and development of green gram (*Vigna radiata* L.). Lead was applied at different concentrations from 2.5 g to 7.5 g kg^{-1} soil. It was observed that with increase in Pb concentration in soil, there was a gradual decrease in plant height. Root growth, lateral root and root hair formation were all found to get strongly inhibited by enhanced lead concentration. At the highest concentration of Pb, shoot length and root length decreased by 41 per cent and 10 per cent respectively. There were significant changes in many biometric observations noted on these plants, which include, reduction in dry weight of roots, shoots and leaves. There was also a reduction in the number and size of roots, shoots, leaves and nodules of green gram.

Kim *et al.* (2000) conducted a study on characterization of cadmium tolerant carrot cells in response to cadmium stress. Accordingly, the carrot cells were induced in media containing Cd at different concentrations *viz.*, 20, 40, 80, 100 and 160 μM Cd. It was reported that at higher concentrations (160 μM Cd), there was no cell growth. The susceptible cells readily turned to brown colour at concentrations greater than 80 μM Cd after 1 day of induction. It was also observed that with the increase of the external Cd level, an increase of the internal Cd concentration was noted in both susceptible and tolerant cells.

Yemeni (2001) conducted a study on the seedling growth of *Vigna ambacensis* (a wild legume crop) with various heavy metals (Cd, Pb and Hg) at 9 different concentrations (0.05, 0.1, 0.5, 1.0, 2.0, 5.0, 10 and 50 mM). It was observed that the seed germination was markedly poor in all heavy metal treated seeds. It was also found that at 10 mM of Cd and Hg and at 50 mM of Pb, germination of seed was completely inhibited. The radicle and shoot length of *Vigna ambacensis* seedlings were significantly inhibited by lower concentrations of Cd, Pb and Hg.

Singh and Tiwari (2003) conducted a pot culture experiment to study the influence of cadmium toxicity in inducing changes in plant growth and metabolism of *Brassica juncea* L. plants. In their study, it was strangely observed that the lower and marginal levels of cadmium (100 and 250 ppm) improved the growth of mustard plants. But, higher levels of Cd (500 ppm) caused significant suppression in growth.

2.7 SELECTIVE RETENTION OF HEAVY METALS

Tobacco plants appeared to be good in the translocation of heavy metals, especially cadmium. Results of the experiment conducted by Mench *et al.* (1989) indicated that *Nicotiana tabacum* took 80 per cent of the total cadmium applied and transported to leaves while corresponding figures for *N. rustica* was 75 per cent. In contrast they had observed that in maize the root retained five times more Cd than its leaves.

Hsieh (1990) observed that rice grown in polluted soil containing 5.8 ppm Cd showed higher selective retention of Cd in roots than other plant parts. The content of Cd in roots ranged from 11 to 38 ppm while in the leaves and grain it was 1 to 7.5 ppm and 0.5 to 2.0 ppm respectively. Kubota *et al.* (1992) reported that in corn, zinc and copper were preferentially transferred to seed or grain while, cadmium and lead were selectively excluded from these plant parts.

In a study with heavy metals especially cadmium and lead, Kurumthottical (1995) reported that accumulation of Cd was more in the shoots of radish than in its roots. On the contrary, the concentration of lead was found to be higher in the roots than in the shoots.

Xue-Dongsen *et al.* (1995) conducted a study with tomato (*Lycopersicon esculentum* Mill.) and green beans (*Phaseolus vulgaris*) on nutrient solution culture containing Cd. When tomatoes and beans were supplied with 0-10 mg and 0-8 mg Cd L^{-1} respectively, they have observed that tomato roots accumulated more cadmium than its shoot part. Similarly in the green beans, it was observed that its roots recorded four times more cadmium than its shoot parts. However, it could be seen in the study that tomato roots retained 15 times more Cd than the roots of green beans under similar conditions.

Tung and Temple (1996) reported that soil-borne Pb accumulated primarily in the roots, although at high concentrations Pb accumulated at the ends of transpirational streams, particularly at hydathodes, trichomes and the terminal ends of xylem streams bringing contamination to other aerial parts of plants.

Lehoczky *et al.* (1996) reported that the cadmium content of garlic leaves was seven times higher in treatment receiving 100 mg Cd kg^{-1} soil than those leaves of the control plants. Whereas in bulbs, the same application of treatments resulted three fold increases in metal load than its corresponding leaves.

Ouariti *et al.* (1997a) while comparing the uptake of heavy metals in beans and tomato, observed that the accumulation of Cd in the roots was significantly higher than the corresponding shoots. However, tomato plants showed greater cadmium accumulation than beans.

Navarro-Pedreno *et al.* (1997) studied the retention pattern of the heavy metals especially Cd, Cr and Ni on tomato plant. It was observed that the roots preferentially retained Cr while, Ni and Cd were more readily transported to the leaves.

Jidesh and Kurumthottical (2000) reported higher selective retention of cadmium in the shoot portion of chilli plants than its root portions. According to them the roots of chillies retained more lead than shoots. While assessing the concentration of heavy metals in the edible portion (fruits), it was seen that fruits retained only very low content making it safe for human consumption.

Cobb *et al.* (2000) reported that tomato and beans when grown in hundred percent mine wastes, contaminated with heavy metals (Pb, Cd, As and Zn), it is seen that these heavy metals were mainly retained in the roots and little was translocated to fruits.

Shen *et al.* (2002) conducted a pot culture experiment with cabbage (*Brassica rapa* L. subsp. *chinensis*) to study the effect of EDTA on lead uptake from soil and consequent effect on plant growth. The shoot Pb concentration in cabbage reached 5010 and 4620 mg kg^{-1} dry matter with 7 days and 14 days after EDTA application respectively. These concentrations when compared against control were found to be 40-fold and 46-fold higher. It was also observed that Pb retention was relatively higher in cabbage shoots.

Wu *et al.* (2004) conducted a greenhouse hydroponic experiment with different concentrations of Cd (0, 0.1, 1.0 and 10.0 μM in nutrient solution) to study its accumulation pattern and site in three cotton genotypes (Simian 3, Zhongmian 16 and Zhongmian 16-2). In their study, it was found that Cd concentration in different parts generally increased with increasing Cd levels in nutrient solution. The reproductive part retained relatively less content of the metal when compared to vegetative part. The order of accumulation of Cd was as follows: root > petiole >

xylem > fruiting branch, leaf > phloem in vegetative parts and seed coat, seed nut > boll shell > fibre in reproductive parts.

2.8 HEAVY METALS AND YIELD OF CROPS

Mench *et al.* (1994) reported that plants need not necessarily show phyto-toxicity symptoms or yield reduction even when they take up heavy metals in appreciable quantities where such effects could normally be expected. Lehoczky *et al.* (1996) reported that in corn, garlic and spinach, biomass production decreased as Cd dose increased. In spinach, the maximum biomass reduction was noted when Cd was applied at the rate of 100 mg Cd kg^{-1} soil which was estimated to be about one-fourth of that recorded from control.

Ouariti *et al.* (1997b) reported that cadmium treatment had a greater depressive effect on shoot and root dry weight production in bean than tomato plants. Further, the biomass production (roots and primary leaves) was strongly depressed at high metal concentrations.

Ramachandran and D'Souza (1999) conducted pot culture experiments using sewage sludge and city compost to evaluate regular uptake of cadmium by the first crop of maize and the residual uptake of the metal with another successive maize crop (*Zea mays* L. var. Golden Bentham). They reported that there was a significant reduction in yield of maize shoots in both the crops of maize.

Nair (1999) conducted a pot culture experiment with carrot to study the effect of Cd and Pb from sewage and to see the effect of the same metals from the industrial effluents from Bangalore urban area. He reported that in carrot, the enrichment of soils with Cd and Pb at all levels decreased dry matter yield. It was also observed that the decline in dry matter yield was very conspicuous beyond 10 mg Cd kg^{-1}. It was also reported that carrot plants failed to establish when soils were enriched with 80 mg Cd kg^{-1} soil.

Material and Methods

3. MATERIALS AND METHODS

3.1 MATERIALS

In order to comply with the objective proposed in the study, it was necessary to have a pot culture experiment with two independent set of experiments. This necessitated the use of different materials including a good biomarker namely tomato. Various analyses were also necessitated during and after the study to completely comprehend the objectives. A brief presentation of the materials and methods employed in this context is presented under appropriate heads.

3.1.1 Heavy Metal Sources

Heavy metal sources in the study have been confined mainly to direct sources like water-soluble salts of cadmium and lead. However, there could be some inadvertent addition of heavy metal through indirect sources like fertilizers and organic matter.

3.1.1.1 Direct Sources of Cadmium and Lead

Chemically pure salts of cadmium and lead (cadmium chloride and lead nitrate respectively) served as the direct water-soluble sources of heavy metals for the study.

3.1.1.2 Indirect Sources of Cadmium and Lead

3.1.1.2.1 Fertilizer Sources

Out of the main fertilizer input sources like urea, Rajphos and muriate of potash (N, P and K), phosphatic fertilizers in particular are bound to contain some amount of heavy metals especially cadmium and lead, which usually get added to soil without much notice.

3.1.1.2.2 Organic Manure

Under certain conditions, cow dung may also harbour different heavy metals at low concentrations, which in all probability could act as indirect sources of the metal.

3.1.1.2.3 Soil

Bulk and sieved soil samples used in the study though collected from virgin area of vegetable research farm, Department of Olericulture, College of Horticulture, may provide traces of heavy metals as natural contaminants.

3.1.2 Planting Materials

Foundation seeds of tomato (*Lycopersicon esculentum* Mill.) variety Sakthi, which is resistant to bacterial wilt, were procured from the Department of Olericulture, College of Horticulture, Vellanikkara for being studied as the test crop.

3.2 METHODS

3.2.1 Lay Out and Experimental Design

The study was proposed as a pot culture experiment with tomato as an indicator crop. The experimental design was completely randomized with five treatments and four replications including control. Independent experiments were conducted to assess the different objectives.

3.2.2 Nursery Bed Preparation

The nursery site was selected in the vegetable research farm attached to the Department of Olericulture. The site was cleared and the soil was brought to fine tilth. Pre-calculated quantities of organic manure (cow dung) was mixed well with the surface soil. A raised nursery bed of size 0.5 m x 2.0 m was prepared and leveled for sowing the seeds.

3.2.3 Sowing of Seeds and Raising of Seedlings

Uniform sized healthy seeds of variety Sakthi were identified from the bulk seeds. Sufficient seeds were sown on the bed in lines to get required population. Later, the nursery bed was mulched with dried coconut leaves and carefully irrigated. The sowing of seeds was completed during the month of August 2003. Three days after sowing, most of the seeds germinated and on germination, the coconut leaves were removed to facilitate good growth. In order to provide further shade, twigs with sufficient leaves were placed along the border of the nursery bed. Required moisture levels in the nursery bed were maintained through need-based irrigation with de-ionized water. There was no external application of fertilizers to prevent excessive growth of seedlings in the nursery.

3.2.4 Treatments

In order to get a sensible comparison on the effect of cadmium and lead on the test crop, different treatments are proposed in the study. A brief description of different treatments applied is given below:

3.2.4.1 Experiments

Treatment No.	Experiment I – Cadmium		Experiment II – Lead	
	Cadmium levels (mg kg^{-1} of soil)	Concentration of Cd in pots (5 kg) after application (mg)	Lead levels (mg kg^{-1} of soil)	Concentration of Pb in pots (5 kg) after application (mg)
T_1	0.5	2.5	0.5	2.5
T_2	1.0	5.0	1.0	5.0
T_3	1.5	7.5	1.5	7.5
T_4	2.0	10.0	2.0	10.0
T_5	0.0	0.0	0.0	0.0

3.2.5 Preparation of Soil and Potting Mixture for Filling Pots

Uniform sized earthern pots of 7.0 kg capacity were selected. Sufficient quantity of virgin bulk soil was sieved through 2.0 mm sieve. Well-decomposed cow dung which was kept as dried and powdered was used as organic manure in the potting mixture. Sand, soil and cow dung were mixed in the ratio 1: 1: 1 to generate potting mixture. Five kilograms of the potting mixture was weighed and filled in earthern pots. Randomization of treatments was done and each pot was accordingly labeled and positioned in the field.

3.2.6 Fertilizer Application

Pre-calculated quantities of required fertilizers (urea, Rajphos and muriate of potash) based on the *Package of Practices recommendations: Crops* of Kerala Agricultural University (KAU, 2002) for tomato (75:40:25 kg N: P_2O_5: K_2O ha^{-1}) were carefully weighed, added and mixed well with the contents of each pot including that of control. Accordingly, fifty per cent of the recommended N and K and complete dose of phosphorus were applied as basal during transplanting and the balance 50 per cent in two splits, one 30 days after transplanting and the other 60 days after transplanting.

3.2.7 Application of Treatments

Fertilizer mixed potting mixture from each pot was emptied out on to separate polythene sheet of required size to facilitate further mixing of treatments. Depending upon the specificity of treatments necessitated in each pot, the pre-calculated quantities of heavy metal sources were added and mixed well. Later, these soils were carefully transferred to the corresponding pots.

3.2.8 Transplanting

Sufficient numbers of forty-two days old and healthy seedlings were carefully uprooted from the nursery bed without any damage to the root system after repeated irrigation. The uprooted healthy seedlings were kept in de-ionized water for a short time before it is planted in the pots. From among the uprooted seedlings, uniformly sized seedlings were identified and transplanted in the pots at the rate of one seedling per pot. Immediately after transplanting, the pots were irrigated with de-ionised water and necessary shade was provided to pick up normal growth for the seedlings.

3.2.9 After Care

The plants were given with need-based irrigation with de-ionised water to maintain field capacity. Top dressing with fertilizers was given at the appropriate time. At the on-set of fruiting or whenever it was necessitated, staking was done. Care was taken to prevent any weed growth inside the pots.

3.2.10 Harvest and Processing of Fruits

All fruits were harvested at the respective turning point stage due to staggered ripening of fruits in treatments. After recording the fresh weight of the fruits, the same was properly labeled and kept for drying in the sun. After sufficient sun drying the fruits were oven dried at 70°C. Such oven dried fruits from each treatment was pooled, powdered, labeled and suitable quantity taken for analysis.

3.2.11 Collection and Processing of Plant Samples

Wherever fruiting took place in treatments and in such case, when 50 per cent of the fruits have reached the turning point stage, the harvesting time for plants have been fixed. On deciding the harvest of plants, the same was irrigated with de-ionized water for loosening the soil. The pots were inverted carefully on a clean polythene sheet and plants together with soil were emptied on to it. The adhering soil particles on the roots were physically removed with hand and the plants together with the entire root system recovered from the soil mass. Later, it was washed with running water to further clean the plant and finally washed well with distilled water. The fresh weights of the plants were recorded. Using a sharp steel knife each plant was separated into its respective root and shoot portions, properly tagged and kept in shade for drying. The air-dried plant samples were again dried in an oven at 70°C. After oven drying, each portion was chopped with a stainless steel cutter and powdered in a glass pestle and mortar.

3.2.12 Collection and Processing of Post Harvest Soil Samples

During the harvest of the crop the entire soil was emptied onto a polyethylene sheet. After complete recovery of the plant, especially the root system from the soil mass, the left over was dried in shade to drive off excess moisture. On sufficient drying, soil was mixed well and a representative sample drawn and stored in polythene cover with proper labeling.

3.2.13 Analysis of Pre-treatment Soil Samples

3.2.13.1 Available Cadmium and Lead

The DTPA extracts of pre-treatment soils were prepared using a soil solution ratio of 1: 2 and a reaction time of two hours (Lindsay and Norvell, 1978) and concentrations of Cd and Pb were determined by AAS (Perkin Elmer, Model 3110) as described by Page *et al.* (1982) by using the facilities available in the Department of Animal Nutrition, College of Veterinary and Animal Sciences, Mannuthy.

3.2.13.2 Soil Reaction (pH)

The pH of the soil samples was measured in a suspension of soil in water (1: 2.5) with the help of combined electrode assembly connected to a pH meter.

3.2.13.3 Electrolytic Conductivity (EC)

The electrolytic conductivity was measured in the supernatant liquid of the soil water suspension (prepared for measuring soil pH) with the help of solubridge and expressed in dS m^{-1} at 25°C.

3.2.13.4 Available Nitrogen

Available nitrogen in soil was estimated in a representative sample by alkaline permanganate method (Subbaiah and Asija, 1956).

3.2.13.5 Available Phosphorus

Available phosphorus in the representative soil sample was extracted using Bray No. 1 extractant (Bray and Kurtz, 1945) and the concentration of phosphorus in the extract was determined colorimetrically by using standard procedure outlined by Watanabe and Olsen (1965).

3.2.13.6 Available Potassium

Available potassium in the soil was extracted using neutral normal ammonium acetate, and K concentration in the extract was estimated using Elico flame photometer (Model, CL 22D).

3.2.13.7 Organic Carbon

The organic carbon content in the representative soil sample was estimated by employing wet oxidation method (Walkley and Black, 1934).

3.2.14 Analysis of Fertilizers and Organic Manures

Representative samples of all the fertilizer sources employed in the study *viz.*, urea, Rajphos, MOP and cow dung were extracted for the possible content of heavy metals like Cd and Pb using di-acid digest employing standard procedures and heavy metal contents estimated using an atomic absorption spectrophotometer (AAS).

3.2.15 Analysis of post-harvest Soil Samples

The post-harvest soil samples collected from different treatments were analyzed for available content of heavy metals like cadmium and lead using DTPA extract. These soils were also analyzed for the available content of nitrogen. phosphorus and potassium. The organic carbon status of the post-harvest soil samples was also estimated. The pH and EC of soils in all the treatment samples were also noted. All estimations and analysis done for post-harvest soil samples were based on standard procedures already described under analysis of pre-treatment soil samples.

3.2.16 Preparation of Plant Samples for Analysis

A suitably weighed quantity of ground plant material from each treatment, separately for the different plant part, *viz.*, root, shoot and fruit was taken in 100 ml conical flask and digested with di-acid mixture of HNO_3 – $HClO_4$ in 2:1 ratio on a hot plate as per the procedure outlined by Jackson (1958). The digested material was cooled, diluted with distilled water, filtered and made up to 100 ml and labeled properly.

3.2.17 Total Cadmium and Lead

The total contents of cadmium and lead in the different plant parts were estimated from the diluted digest for different treatments using AAS (Perkin Elmer, Model 3110).

3.2.18 Total Nitrogen

Nitrogen contents of the plant samples, especially from the three distinct portions were estimated from a suitable weight of respective plant part after digesting the same with single acid and by employing the microkjeldahl distillation method as described by Jackson (1958).

3.2.19 Total Phosphorus

The phosphorus content of plant parts from the different treatments in the di-acid digested material was determined colorimetrically by developing the phospho-molybdo-vanadate yellow complex in nitric acid system (Koenig and Johnson, 1942).

3.2.20 Total Potassium

Potassium content in the different plant parts was determined from the respective di-acid digested material using Elico flame photometer (Model, CL 22D).

3.2.21 Statistical Analysis

The data generated from the pot culture experiment were analyzed statistically using standard procedures described by Panse and Sukhatme (1978). A computer-aided analysis was carried out at the Department of Statistics, Kerala Agricultural University, Vellanikkara.

Results

4. RESULTS

In order to find out the major selective retention sites of cadmium and lead in tomato plant and to comply with the other objectives mentioned in the project, two separate pot culture experiments with five treatments and four replications were conducted. The various results obtained in the connection are summarized below.

4.1 CHEMICAL CHARACTERIZATION OF PRE-TREATMENT SOIL

The chemical characteristics of the soil used in the study are presented in Table1. The soil reaction of the pre-treatment soil was observed to be acidic (5.6). The electrolytic conductivity of the pre-treatment soil showed normal value (0.07 dS m^{-1}). Medium organic carbon status (1.2 %) was observed in the soil. The available nitrogen status of the soil was found to be 465.19 kg ha^{-1}. The Bray-extractable P in the pre-treatment soil indicated that the available phosphorus status of the soil is in the medium range (18.27 kg ha^{-1}). The available potassium content of the soil was estimated to be 123.20 kg ha^{-1}.

4.2 PHYSICAL CHARACTERISATION OF PRE-TREATMENT SOIL

The physical characteristics of pre-treatment soil are presented in the Table 2. The particle size analysis revealed that the texture of the soil as sandy loam and the soil was found to have the following composition: coarse sand 8.70, fine sand 35.7, silt 44.0 and clay 8.2 per cent.

4.3 CADMIUM AND LEAD IN BASIC INPUTS

The possible amount of cadmium and lead in the basic inputs were quantified before the commencement of the study and presented in the Table 3. The analysis of the soil (pre-treatment) for possible cadmium and lead content indicated their marginal presence in them. Accordingly, 0.03 and 0.01 $\mu g\ g^{-1}$ of cadmium and lead were detected respectively in pre-treatment soil. In cow dung

Table 1. Chemical characterisation of the pre-treatment soil

Parameters	Value	Rating
Soil reaction	5.60	Acidic
Electrolytic conductivity (dS m^{-1})	0.07	Normal
Organic carbon (%)	1.23	Medium
Available nitrogen (kg ha^{-1})	465.19	Medium
Available phosphorus (kg ha^{-1})	18.270	Medium
Available potassium (kg ha^{-1})	123.20	Low

Table 2. Textural analysis of the pre-treatment soil

Parameters	Particle size distribution (%)
Coarse sand	8.7
Fine sand	35.7
Silt	44.0
Clay	8.2
Texture	Sandy loam

Table 3. Cadmium and lead content in pre-treatment soil and basic inputs

Details of inputs	Cadmium (μg g^{-1})	Lead (μg g^{-1})
Soil	0.03	0.01
Organic manure	ND	0.001
Urea	ND	ND
Rajphos	35.0	91.0
Muriate of potash	0.0001	0.0004

ND – Not detectable

(which was used as component of potting mixture) the cadmium content was below detectable limit while the lead content in the same was assessed to be 0.001 μg Pb g^{-1}. In urea, the cadmium and lead content was below detectable limits. Rajphos, a rock phosphate source used in the experiment offered a heavy metal load of 35 μg cadmium and 91 μg lead per gram of the material. Muriate of potash also offered traces of cadmium and lead (0.0001 and 0.0004 μg g^{-1} respectively).

4.4 CHEMICAL CHARACTERIZATION OF POST-HARVEST SOIL SAMPLES TREATED WITH DIFFERENT LEVELS OF CADMIUM

Table 4 presents the chemical characteristics of the post harvest soil samples, which received varying levels of cadmium mainly through $CdCl_2$, a water-soluble source.

The soil reaction in different pots ranged from 5.6 to 6.2. The lowest value of 5.6 was recorded in the control pots while the highest value of 6.2 was observed in Treatment 4 that had received 2.0 mg Cd kg^{-1} soil. There was marginal but significant difference in soil reaction when the effect of various treatments was compared against control. However, there was no significant difference in pH between treatments that had offered 0.5, 1.0 and 1.5 mg Cd kg^{-1} soil.

The electrolytic conductivity of the soils, which received different levels of cadmium ranged between 0.14 and 0.25 dS m^{-1}. There was practically no significant difference in conductivity between any treatments even when it is compared against control.

The organic carbon and available nitrogen status of the soils as influenced by the different levels of application of cadmium is presented in table 4. From the results, it is clear that though there exists some marginal difference in the organic carbon content between treatments, none of them were found to be statistically superior. Though the results indicated some marginal variation between the available nitrogen status of soils that received varying levels of cadmium, these variations were not significant, even when they are compared with control.

Table 4. Chemical characterisation of post-treatment soil samples treated with different levels of cadmium

Metal level (mg kg $^{-1}$ soil)	Soil reaction	Electrolytic conductivity (dS m^{-1})	Organic Carbon (%)	Available Nitrogen (kg ha^{-1})	Available Phosphorus (kg ha^{-1})	**Available Potassium (kg ha^{-1})**
0.5	5.9	0.14	1.36	586.3	20.27	**233.8**
1.0	5.9	0.18	1.47	629.0	20.87	**232.4**
1.5	6.0	0.21	1.51	632.2	21.20	**247.7**
2.0	6.2	0.25	1.59	639.6	22.48	**262.3**
0.0	5.6	0.16	1.51	585.2	19.50	**229.5**
CD (0.05)	**0.2**	**NS**	**NS**	**NS**	**2.273**	**14.37**

*NS – Non significant

Table 5. Chemical characteristics of post-treatment soil samples treated with different levels of lead

Metal level (mg kg^{-1} soil)	Soil reaction	Electrolytic conductivity (dS m^{-1})	Organic Carbon (%)	Available Nitrogen (kg ha^{-1})	Available Phosphorus (kg ha^{-1})	**Available Potassium (kg ha^{-1})**
0.5	6.2	0.27	1.93	831.4	22.61	**184.8**
1.0	6.2	0.17	1.77	750.0	22.51	**193.2**
1.5	6.2	0.16	1.73	633.5	22.32	**201.6**
2.0	6.3	0.14	1.45	567.3	22.28	**168.0**
0.0	5.6	0.09	1.76	807.6	19.94	**189.0**
CD (0.05)	**0.17**	**0.10**	**0.26**	**80.46**	**1.811**	**52.02**

The available phosphorus content of the soils, though found to enhance with an increase in levels of cadmium addition, there was no statistical difference between them. However, the available phosphorus content from Treatment 4, where 2.0 mg Cd kg^{-1} soil had been added remained significant when compared against the control, maintaining the highest available phosphorus status of 22.48 kg ha^{-1}.

Table 4 provides the data on the available potassium status from different treatments, which received varying doses of cadmium with values ranging from 229.5 to 262.3 kg ha^{-1}. It has been observed that the available potassium status of soils from different treatment varied inconsistently without showing any specific trend with levels of addition. However, available potassium status noted in Treatment 3 and Treatment 4 varied significantly over the control.

4.5 CHEMICAL CHARACTERIZATION OF POST-HARVEST SOIL SAMPLES TREATED WITH DIFFERENT LEVELS OF LEAD

Table 5 presents the chemical characteristics of the post-harvest soil samples treated with different levels of lead. The soil reaction of the post harvest soil samples did not register any significant effect due to application of different levels of lead. The pH values ranged from 5.6 to 6.3 in various treatments. The control values when compared with the rest of the treatments, maintained significant difference.

The electrolytic conductivity of the soil was found to be normal with values ranging from 0.09 to 0.27 dS m^{-1} in different treated soils with varying levels of lead. There was no significant difference between any treatments including control, though there existed some marginal variations in the conductivity between them.

The organic carbon status of the soil from the different lead treated soils is presented in Table 5. The results indicate that there was a non-significant decrease in organic carbon content with increase in levels of lead application except in Treatment 4 particularly when compared against control. Accordingly, Treatment

1 recorded the highest organic carbon content of 1.93 per cent and Treatment 4 recorded 1.45 per cent.

The available nitrogen content of soils, which received four levels of lead application, did not show any significant difference particularly between control and lower levels (Treatment 1 and Treatment 2). However, when the same control values were compared against that from higher levels of application, the available nitrogen content remained significantly higher. The highest available nitrogen status of soils was recorded in Treatment 1 (831.4 kg ha^{-1}) while the lowest content of the available nitrogen (567.3 kg ha^{-1}) was recorded by Treatment 4.

Available phosphorus content in the soil, which received different levels of lead, did not produced any significant difference between any treatments. The range of available phosphorus registered in different treatments was between 19.94 and 22.61 kg ha^{-1}. Control pots however remained significantly lower values making all levels of metal application significant in enhancing the available phosphorus. The available phosphorus content in post-harvest soil from control pots was 19.94 kg ha^{-1}.

The different levels of lead application had no significant effect in enhancing the available potassium content in the post-harvest soil samples from any treatment even when they are compared against control. The range of available potassium recorded in various treatments varied between 168.0 and 201.6 kg ha^{-1}.

4.6 AVAILABLE CADMIUM IN POST-TREATMENT SOILS

The available cadmium content in the post-harvest soil samples, which had received varying doses of cadmium, is presented in Table 6 and Figure 1. An increase in available cadmium content was observed in all treatments when the same is compared with the pre-treatment soils. The maximum and minimum contents of available cadmium were identified with Treatments 4 and 5 respectively with a corresponding concentration 136.85 and 9.75 $\mu g\ pot^{-1}$. It had

Table 6. Available cadmium content in post-harvest soil samples

Metal level		Available Cd	
Treatments	(µg pot $^{-1}$)	(mg kg^{-1} soil)	(µg pot $^{-1}$)
T_1	2500	23.70	118.50
T_2	5000	25.35	126.75
T_3	7500	26.00	130.00
T_4	10000	27.37	136.85
T_5	0	1.95	9.75
CD (0.05)		**0.72**	**3.57**

Table 7. Available lead content in post-harvest soil samples

Metal level		Available Pb	
Treatments	(µg pot $^{-1}$)	(mg kg^{-1} soil)	(µg pot $^{-1}$)
T_1	2500	170.0	850.0
T_2	5000	304.1	1520.5
T_3	7500	423.5	2117.5
T_4	10000	535.5	2677.5
T_5	0	5.9	29.5
CD (0.05)		**5.5**	**27.7**

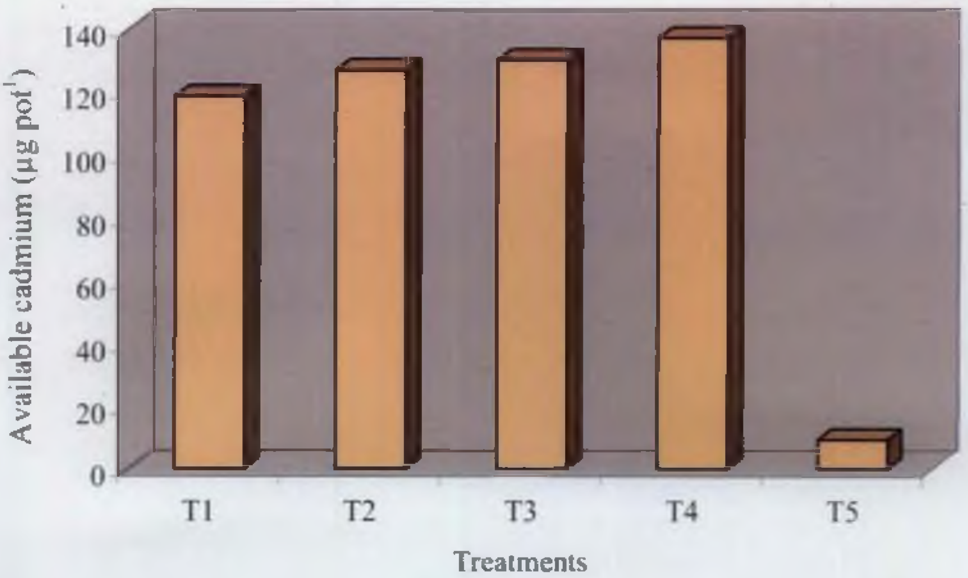

Fig 1. Available cadmium in post-treatment soil samples

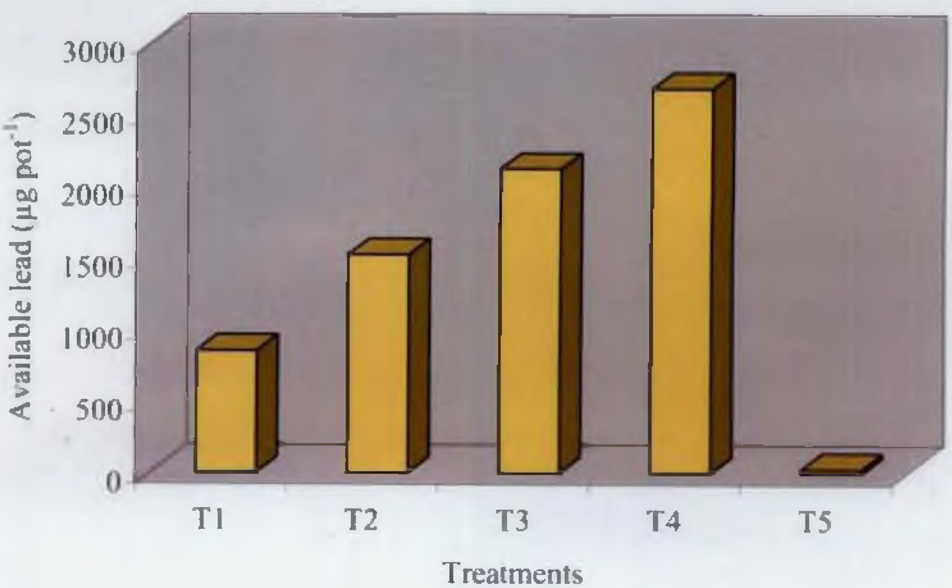

Fig 2. Available lead in post-treatment soil samples

been observed that there had been a corresponding significant increase in available cadmium levels in treatments with each successive enhancement in level of addition of cadmium.

4.7 AVAILABLE LEAD IN POST-TREATMENT SOILS

The available lead contents in post-harvest soil samples, which have received different levels of lead directly through water-soluble source of the metal are presented in Table 7 and Figure 2. Proportionately higher amounts of available lead have been recovered from soils where a corresponding enhancement in the levels of lead has been applied. Accordingly, the amount of available lead recovered from soils ranged from 29.5 to 2677.5 $\mu g\ pot^{-1}$. The lowest and the highest contents of available lead correspond to Treatment 5 (control) and Treatment 4 respectively, where Treatment 4 had physically received a maximum dose of 10,000 μg Pb pot^{-1}. In all other cases of addition of treatment, the recovery of available lead ranged between the extreme values indicated, with significant difference existing between one another.

4.8 NUTRIENT CONCENTRATIONS IN SHOOTS, ROOTS AND FRUITS OF TOMATO PLANTS AS AFFECTED BY DIFFERENT LEVLES OF CADMIUM APPLICATION

4.8.1 Total Nitrogen

Table 8 presents the results of analysis of total nitrogen from roots, shoot and fruits of tomato plant. From the table and Figure 3 it is obvious that fruits maintained relatively more nitrogen content than rest of its portions studied.

4.8.1.1 Root

The total nitrogen content in root portions of the plant can be discerned from the same table. Though the total nitrogen content in roots arising from different treatments ranged from 1.4 to 2.1 per cent, there had been significant variations in the values due to differences in the levels of addition of cadmium.

The roots of the control plants were observed to maintain the maximum content of nitrogen (2.1 per cent). It can be further seen from the table that as the levels of addition of cadmium increased, there was a corresponding increase in the nitrogen content of the roots, which appeared to be statistically significant

4.8.1.2 Shoot

While considering the shoot portion of the plant, all treatment except Treatment 4, (which received cadmium at the rate of 2 mg kg^{-1} soil) remained statistically on par maintaining more or less similar content of total nitrogen with values ranging between 1.6 and 3.1 per cent. However, the highest total nitrogen content of 3.1 per cent was recorded in Treatment 4 and this content of nitrogen was considered to be significantly superior to all other treatments including control.

4.8.1.3 Fruit

The absence of fruits at higher levels of addition of cadmium permitted no chance for comparison of nitrogen in fruits with lower levels of addition. Even at lower levels of addition of cadmium, the fruiting was negatively influenced by the enhancement in levels of addition (Table 20). In spite of an observed reduction in fruiting tendency at lower levels of treatments, the nitrogen contents of fruits were not that different to make any significant difference.

4.8.2 Total Phosphorus

Table 9 and Figure 4 present the total phosphorus content of roots, shoot and fruits of tomato plants, which received different levels of cadmium addition. Among the portions studied, the fruits contained relatively higher amounts of phosphorus, followed by shoots.

Table 8. Nitrogen content in roots, shoot and fruits of tomato plant treated with cadmium (%)

Metal level ($mg\ kg^{-1}$ soil)	Nitrogen content (%)		
	Root	Shoot	Fruit
0.5	1.4	1.8	3.4
1.0	1.6	1.7	3.1
1.5	1.8	1.8	0*
2.0	1.9	3.1	0*
0.0	2.1	1.6	3.1
CD (0.05)	**0.18**	**0.34**	**0.69**

* Absence of fruits

Table 9. Phosphorus content in roots, shoot and fruits of tomato plant treated with cadmium (%)

Metal level ($mg\ kg^{-1}$ soil)	Phosphorus content (%)		
	Root	Shoot	Fruit
0.5	0.31	0.44	0.71
1.0	0.35	0.46	0.73
1.5	0.37	0.47	0*
2.0	0.39	0.50	0*
0.0	0.26	0.40	0.80
CD (0.05)	**0.02**	**0.02**	**0.002**

* Absence of fruits

Table 10. Potassium content in roots, shoot and fruits of tomato plant treated with cadmium (%)

Metal level ($mg\ kg^{-1}$ soil)	Potassium content (%)		
	Root	Shoot	Fruit
0.5	0.12	0.14	0.55
1.0	0.16	0.16	0.56
1.5	0.17	0.19	0*
2.0	0.40	0.25	0*
0.0	0.11	0.14	0.54
CD (0.05)	**0.02**	**0.02**	**0.20**

* Absence of fruits

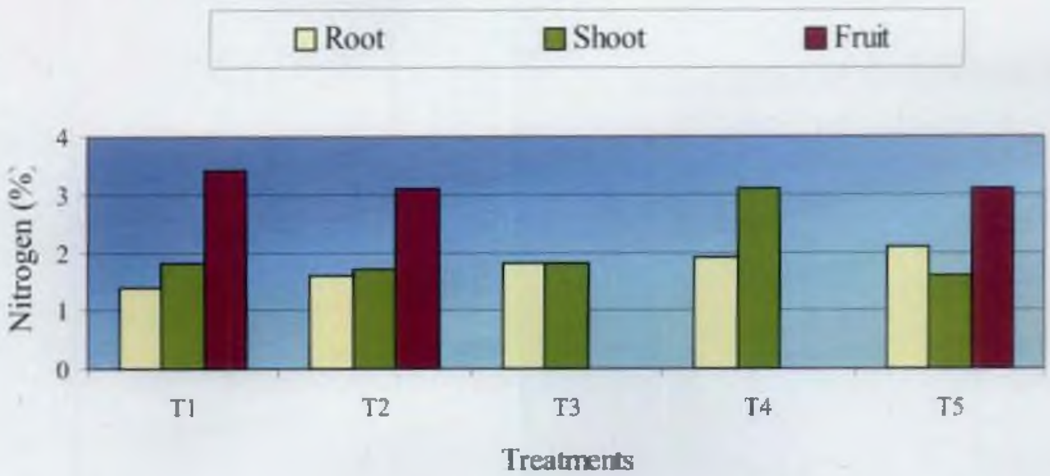

Fig 3. Nitrogen content in cadmium treated tomato plants

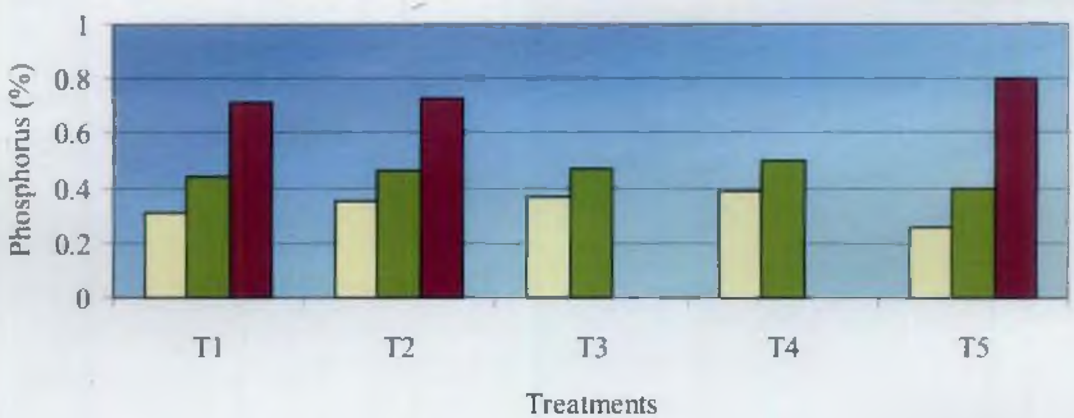

Fig 4. Phosphorus content in cadmium treated tomato plants

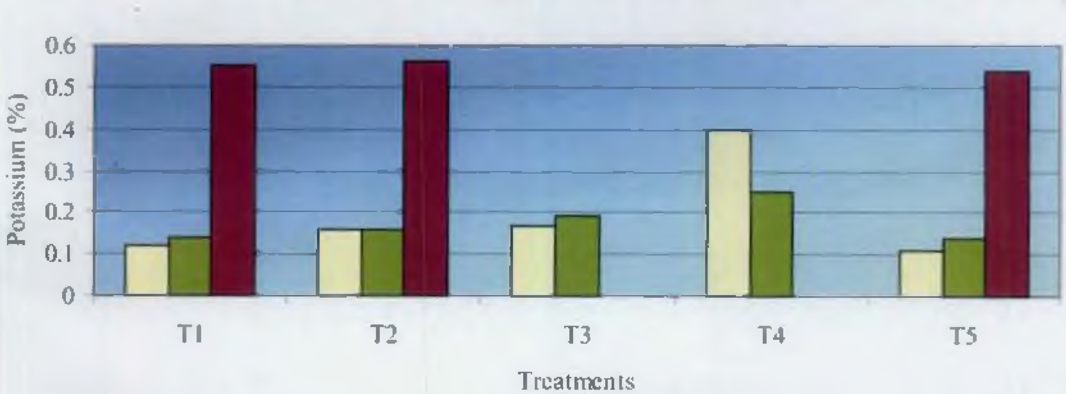

Fig 5. Potassium content in cadmium treated tomato plants

4.8.2.1 Root

The total phosphorus content in the roots of the tomato plant has been depicted in Table 9. In roots, the total phosphorus content increased proportionate to the increase in levels of addition of cadmium. Accordingly, Treatment 4 recorded the maximum content of phosphorus (0.39 per cent) and Treatment 5 (control) recorded the least content of 0.26 per cent total phosphorus. All the treatments including control could establish significant difference in the total phosphorus in the roots.

4.8.2.2 Shoot

In shoots, the totals phosphorus content increased proportionate to the increase in levels of addition of cadmium. Accordingly, Treatment 4 recorded the maximum content of phosphorus (0.50 per cent) and Treatment 5 (control) recorded the least content of 0.40 per cent total phosphorus. There was significant difference in the total phosphorus content in shoots between majority of the treatments including control. However, Treatment 2 and Treatment 3 which physically received 5,000 and 7,500 μg Cd pot^{-1} could not significantly bring about any apparent difference in the total phosphorus content in their shoots.

4.8.2.3 Fruit

Since higher concentrations of cadmium addition did not permit any fruiting in tomato, any comparison on the total phosphorus content between fruits which received lower and higher doses of phosphorus was not possible. Maximum total phosphorus was found in the fruits of tomato from control pots 0.80 per cent followed by Treatment 2 and Treatment 1 with 0.73 and 0.71 per cent respectively and there existed a significant difference between these treatments.

4.8.3 Total potassium

The total potassium contents of roots, shoot and fruits of tomato plant are presented in Table 10 and Figure 5. Among the plant parts, the fruits showed comparatively higher content of total potassium than the rest of the portions studied.

4.8.3.1 Root

The total potassium content in roots of plants that received 2.0 mg Cd kg^{-1} soil recorded the highest value of 0.40 per cent followed by Treatment 3 which received Cd at 1.5 mg kg^{-1} soil (0.17 %). Though the content of total potassium maintained in the roots of control and that of Treatment 1, established marginal differences, they were not significant enough to highlight any treatment difference.

4.8.3.2 Shoot

In shoots, Treatment 4 recorded the highest total potassium content of 0.25 per cent and it is observed from the results that all higher levels of addition of cadmium, especially Treatments 3 and 4 resulted in significant enhancement of total potassium content in shoots. However, lower levels of addition of cadmium, particularly, Treatments 1 and 2 were incapable of making any significant influence in the enhancement of total potassium in the respective shoots although there existed some marginal variations in the total potassium.

4.8.3.3 Fruit

Since higher concentrations of cadmium addition in soil did not permit any fruiting in tomato, any comparison on the total potassium content in fruits especially between lower and higher levels of cadmium was not possible. Compared to Treatment 1, where the lowest level of cadmium had been added to soil, Treatment 2 had registered marginally higher potassium content with practically no significant difference existing between them. On comparing the potassium content of those fruits from lower levels of application of cadmium with control, there was no significant difference.

4.9 NUTRIENT CONCENTRATIONS IN SHOOTS, ROOTS AND FRUITS OF TOMATO PLANTS AS AFFECTED BY DIFFERENT LEVLES OF LEAD APPLICATION

4.9.1 Total Nitrogen

Table 11 and Figure 6 present the results of analysis of total nitrogen from roots, shoot and fruits of tomato plant, which have received different levels of lead. From the table it is evident that fruits in general maintained relatively higher nitrogen than rest of its portions studied.

4.9.1.1 Root

The total nitrogen content observed in the roots of tomato plants treated with different levels of lead is presented in Table 11. From the table, it could be seen that control pots recorded the highest total nitrogen content of 2.43 per cent followed by Treatment 1 with 1.83 per cent. From the results it could be noted that the enhancement in the levels of lead application had marginally decreased the total nitrogen content, although the observed decrease was statistically not significant.

4.9.1.2 Shoot

Shoot portions of all treatments except Treatment 1 (which received lead at the rate of 0.5 mg kg^{-1} soil) maintained the higher content of total nitrogen. There was inconsistent trend in total nitrogen content with marginal difference in those treatments where lead has been applied at the rate of 1.0, 1.5 and 2.0 mg kg^{-1} soil especially when compared to control. However, these values failed to maintain any statistically significant difference at higher levels of lead. Accordingly, the total nitrogen content recorded by various treatments in shoots in the decreasing order is as follows: Treatment 3 (2.35 %) followed by Treatment 5 (2.29 %), Treatment 2 (2.21 %) and Treatment 4 (2.12 %).

Table 11. Nitrogen content in roots, shoot and fruits of tomato plant treated with lead (%)

Metal level (mg kg^{-1} soil)	Nitrogen content (%)		
	Root	Shoot	Fruit
0.5	1.83	1.37	2.48
1.0	1.31	2.21	2.75
1.5	1.31	2.35	2.50
2.0	1.52	2.12	2.38
0.0	2.43	2.29	3.37
CD (0.05)	**0.23**	**0.22**	**0.43**

Table 12. Phosphorus content in roots, shoot and fruits of tomato plant treated with lead (%)

Metal level (mg kg^{-1} soil)	Phosphorus content (%)		
	Root	Shoot	Fruit
0.5	0.30	0.45	0.76
1.0	0.31	0.46	0.77
1.5	0.38	0.48	0.78
2.0	0.40	0.49	0.79
0.0	0.27	0.39	0.76
CD (0.05)	**0.01**	**0.02**	**0.02**

Table 13. Potassium content in roots, shoot and fruits of tomato plant treated with lead (%)

Metal level (mg kg^{-1} soil)	Potassium content (%)		
	Root	Shoot	Fruit
0.5	0.13	0.14	0.55
1.0	0.14	0.15	0.52
1.5	0.14	0.16	0.48
2.0	0.15	0.16	0.52
0.0	0.15	0.14	0.52
CD (0.05)	**0.002**	**0.01**	**NS**

*NS – Non significant

Fig 6. Nitrogen content in lead treated tomato plants

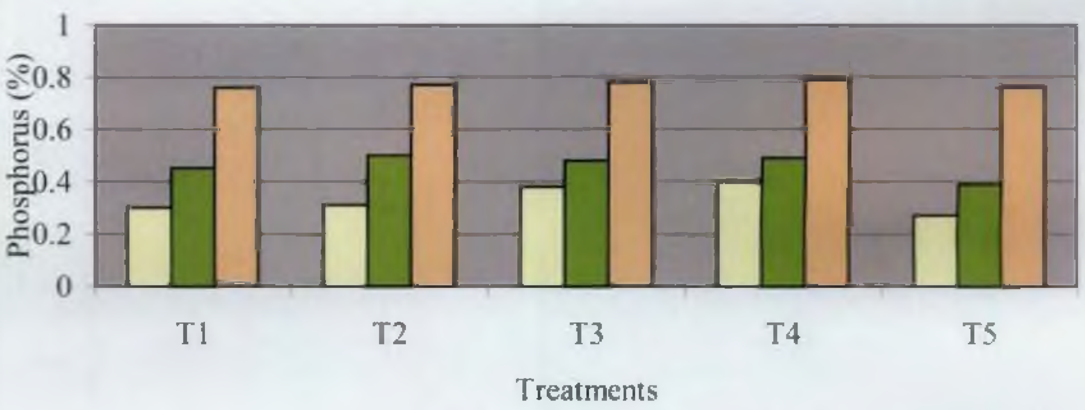

Fig 7. Phosphorus content in lead treated tomato plants

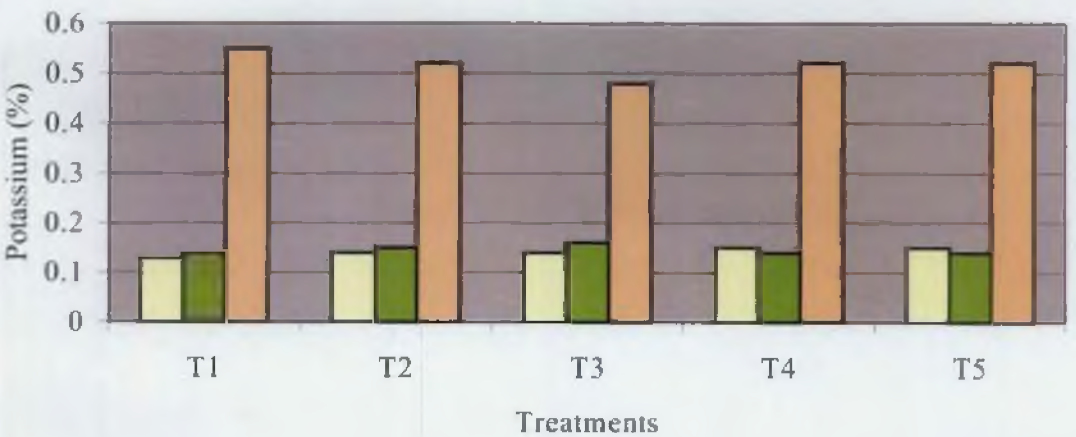

Fig 8. Potassium content in lead treated tomato plants

4.9.1.3 Fruit

The total nitrogen content of the tomato fruits obtained from different levels of lead application indicated that maximum content of nitrogen was noted in the control (3.37 per cent) and the lowest content of nitrogen (2.38 per cent) from those pots which received highest levels of lead application (2.0 mg kg^{-1} soil). The total nitrogen content observed from other treatments (which provided lead between control and 2.0 mg kg^{-1}) was found to decrease significantly with enhancement in the levels of lead application. However, all such treatments remained ineffective in altering the nitrogen content in fruits.

4.9.2 Total phosphorus

The total phosphorus contents in the roots, shoot and fruits of tomato plant treated with different levels of lead were computed and presented in Table12 and Figure 7. From the table it could be inferred that the fruits maintained relatively higher concentration of total phosphorus than other plant parts.

4.9.2.1 Root

The total phosphorus content observed in the roots of tomato plants was found to get enhanced with the enhancement in the levels of addition of lead. Accordingly, those plants which received the maximum dose of lead (2.0 mg kg^{-1} soil) maintained the highest content of total phosphorus (0.40 per cent) followed by Treatments 3, 2 and 1 with total phosphorus content of 0.38, 0.31 and 0.30 per cent respectively. The lowest level of total phosphorus content in roots was recorded in control (0.27 per cent). From the results it is evident that all enhanced levels of lead application had significantly increased the total phosphorus content in the roots of tomato plants.

4.9.2.2 Shoot

In shoots, the highest level of total phosphorus (0.49 %) and lowest level of phosphorus (0.39 %) had been observed from those treatments, which provided maximum amount of lead and control respectively. The other treatments, which provided 0.5, 1.0, 1.5 and 2.0 mg Pb kg^{-1} soil, helped the shoots to maintain relatively higher amount of total phosphorus content, particularly in accordance with the enhancement in the levels of lead application. When the Treatments 1 and 2 were compared independently with Treatment 2 and 3, Treatment 3 appeared to be superior to Treatment 1 in providing enhanced total phosphorus in shoots.

4.9.2.3 Fruit

The total phosphorus content in tomato fruits arising from different treatments, which received varying levels of lead, is presented in Table 12. Results indicate that all the four different levels of lead application significantly enhanced the total phosphorus content in fruits especially at higher levels of application. Application of Treatment 4 (where 2.0 mg Pb kg^{-1} soil had been applied) resulted in the highest level of total phosphorus in fruits (0.79 per cent) followed by Treatments 3, 2 and 1 with a respective content of 0.78, 0.77 and 0.76 per cent. When the Treatments 1 and 2 were compared independently with Treatment 2 and 3, Treatment 3 appeared to be superior to Treatment 1 in providing enhanced total phosphorus in fruits. However, there was no significant difference between the Treatment 1 and control in varying the content of total phosphorus in fruits.

4.9.3 Total potassium

The total potassium content in the roots, shoot and fruits of tomato plant treated with different levels of lead is provided in the Table 13. In tomato, among the different plant parts studied, the fruits maintained comparatively higher content of total potassium than the rest of the portions.

4.9.3.1 Root

The potassium content in the roots of tomato plants, which received different levels of lead, indicated an increase with a corresponding increase in level of lead application. The potassium content of roots, at the all levels of application of treatment, maintained significant difference even when they are compared against the control. It is further noted that the observed enhancement in root potassium was in accordance with increase in the levels of addition of lead. There was no observed difference in the potassium content of roots of tomato between control and Treatment 4 as they maintained similar content (0.15 per cent). However, between the lower levels of application of lead (0.5 and 1.0 mg kg^{-1} soil), the roots maintained significant difference in total potassium.

4.9.3.2 Shoot

The total potassium content in the shoots of tomato plants which received different levels of lead ranging from 0.5 to 2.0 mg kg^{-1} soil, maintained marginal but significant increase in total potassium especially between lower and higher levels of application of lead. Application of treatments at the rate of 1.5 and 2.0 mg Pb kg^{-1} soil resulted in more or less same content of total potassium (0.16 per cent) in the shoots of tomato plants. Similarly, application of treatment at the rate of 0.5 mg Pb kg^{-1} soil and control could not bring any change in the content of total potassium (0.14 per cent) in the shoots.

4.9.3.3 Fruit

Table 13 depicts the potassium content in fruits of tomato plants where lead had been applied to soil at different levels. Though there are some marginal and non-significant variations in the observed content of potassium in tomato fruits, the trend noted between levels of application of lead and potassium content in fruits remained totally inconsistent.

4.10 DRY MATTER YIELD OF TOMATO PLANTS TREATED WITH CADMIUM

The dry matter yield of tomato, especially with respect to its roots, shoot and fruits as influenced by different levels of cadmium application is presented in the Table 14 and Figure 9. From the table it is seen the fruits contributed maximum dry matter yield when compared to shoot and root portions of tomato.

Table 14. Dry matter yield of tomato plant treated with cadmium (g pot $^{-1}$)

Metal level (mg kg^{-1} soil)	Dry matter yield (g pot $^{-1}$)		
	Root	Shoot	Fruit
0.5	2.491	9.656	14.980
1.0	1.077	6.598	3.995
1.5	0.544	1.691	0*
2.0	0.131	0.708	0*
0.0	4.152	15.18	17.180
CD (0.05)	**1.41**	**6.27**	**11.48**

* Absence of fruits

Table 15. Dry matter yield of tomato plant treated with lead (g pot $^{-1}$)

Metal level (mg kg^{-1} soil)	Dry matter yield (g pot $^{-1}$)		
	Root	Shoot	Fruit
0.5	3.493	11.17	16.97
1.0	2.893	12.11	16.31
1.5	2.776	12.69	18.54
2.0	2.608	13.62	19.50
0.0	3.455	17.16	16.18
CD (0.05)	**NS**	**5.15**	**NS**

*NS – Non significant

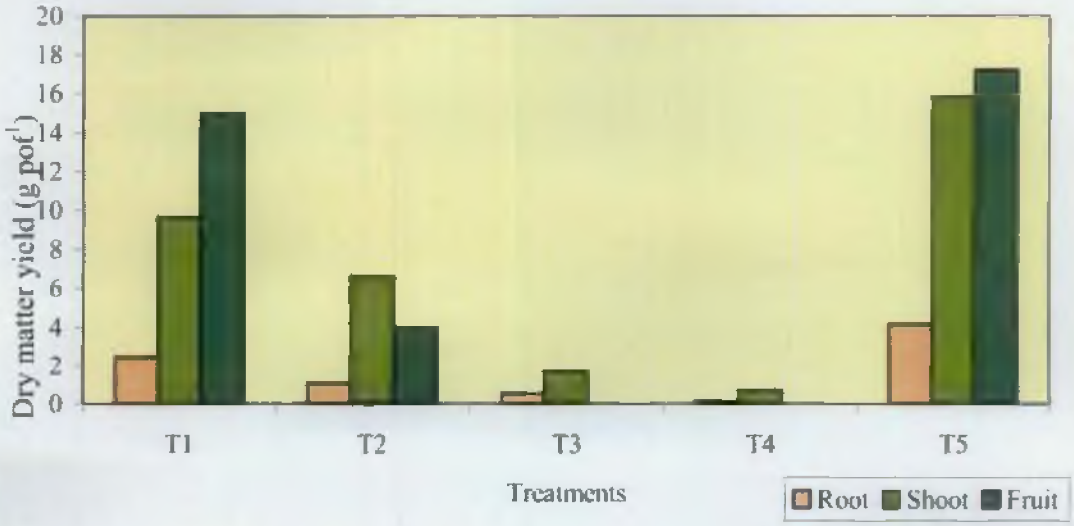

Fig 9. Dry matter yield of cadmium treated tomato plants

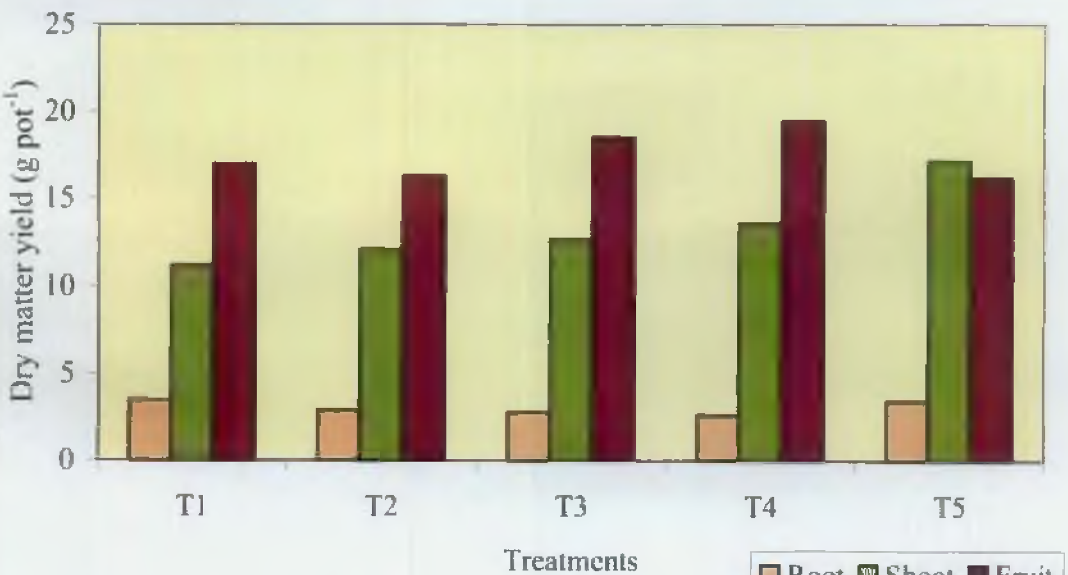

Fig 10. Dry matter yield of lead treated tomato plants

4.10.1 Root

In roots, the highest quantity of dry matter yield (4.152 g pot^{-1}) was recorded in control (Treatment 5) followed by Treatment 1 (2.491 g pot^{-1}), where the lowest level of cadmium (0.5 mg Cd kg^{-1} soil) had been applied. In the case Treatment 5 and 1, the dry matter yield remained significantly higher when compared to that obtained from the rest of the treatments. Again it is clear from the results, that further enhancement in the levels of application of cadmium over 0.5 mg Cd kg^{-1} in soil could not bring about any significant change in the root dry matter yield. However, there was no difference in dry matter yield obtained from those treatments, which received cadmium doses ranging from 1.0 and 2.0 mg kg^{-1} soil.

4.10.2 Shoot

Maximum dry matter yield of tomato shoot (15.18 g pot^{-1}) was noted in control pot. It is seen from the results that wherever cadmium had been applied, there was reduction in dry matter yield, particularly in proportion with the enhancement in doses of cadmium. Accordingly there was a gradual significant decrease in yield with 0.5, 1.0, 1.5 and 2.0 mg Cd kg^{-1} soil and the lowest shoot dry matter yield of 0.708 g pot^{-1} was recorded in Treatment 4.

4.10.3 Fruit

The dry matter yield of tomato fruits from soils, which received different levels of cadmium has been presented in Table 14. The control plants, which received practically no addition of cadmium source, recorded the highest fruit dry matter yield (17.18 g pot^{-1}). Since the higher levels of application of cadmium *viz.*, 1.5 and 2.0 mg kg^{-1} failed to produce any fruiting in tomato, the possibility of comparison of dry matter yield confines only to that produced from the applications of 0.5 and 1.0 mg Cd kg^{-1} soil. Accordingly the lowest dry matter yield of fruits was noted from Treatment 2 (3.995 g pot^{-1}) with apparent significant difference in yield existing between the control and Treatment 2.

4.11 DRY MATTER YIELD OF TOMATO PLANTS TREATED WITH LEAD

Table 15 and Figure 10 represents the dry matter yield of tomato plants from different levels of application of lead particularly in terms of roots, shoot and fruits. The fruit and root portions of the plant in general contributed the maximum and minimum share of dry matter yield respectively in tomato.

4.11.1 Root

The lead content of roots of tomato plants, which received varying levels of the metal in soil, is presented in Table 15. From the results it is clear that different levels of lead application could not bring about any change in the root dry matter production. Accordingly, there was no significant difference in the dry matter yield of roots produced from either the control or other treatments.

4.11.2 Shoot

The highest dry matter yield of shoot (17.16 g pot^{-1}) was found to be associated with control. This was followed by a lower, but significant dry matter yield in Treatment 4, where the highest dose of lead (2.0 mg kg^{-1} soil) had been applied. However, the lowest shoot dry matter yield was observed in Treatment 1 where the lowest dose of 0.5 mg Pb kg^{-1} soil had been applied. Enhancement in the levels of addition of lead in soil though found to increase the shoot dry matter yield, the observed increase was not significantly different from one another except Treatment 1.

4.11.3 Fruit

The dry matter yield of fruits, obtained from varying levels of application of lead in soil has been depicted in Table 15. Though the fruit dry matter yield was found to get enhanced with incremental doses of application of the metal in soil, the observed increase remained insignificant with respect to the levels of metal application.

4.12 UPTAKE OF CADMIUM IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANT

The cadmium uptake in roots, shoot and fruits of tomato plants as influenced by the different levels of application of the metal was computed from the tissue concentration of the metal and corresponding dry matter yield and the same is presented in Table 16 and Figure 11. In general, it is seen that all portions of the plant maintained fairly good concentration of the metal irrespective of the treatments. At lower levels of application of treatments, the shoot portion of the plant selectively maintained higher uptake of cadmium than other plant parts. However, at higher levels of application of the metal, roots are seen to harbour relatively more uptake of cadmium than other plant parts.

4.12.1 Root

Table 16 presents the details of cadmium uptake by roots of tomato from soils where varying levels of cadmium had been added. At higher levels of cadmium application (Treatments 3 and 4), the uptake of the metal was found to be maximum in the root portion and the uptake directly varied with the enhancement in treatment levels. The corresponding computed uptake of cadmium for Treatment 4 and 3 were 3650 and 3142 μg Cd pot^{-1} respectively. However, lower levels of application of the metal, especially when treated with 2,500 and 5,000 μg Cd pot^{-1} have not permitted any significant uptake of the metal by the root portion. Control plants recorded the lowest cadmium uptake (66.10 μg pot^{-1}).

4.12.2 Shoot

In tomato shoots, at lower concentration, the maximum cadmium uptake (3564 μg pot^{-1}) was noted in the Treatment 2 where 5,000 μg Cd pot^{-1} had been applied followed by Treatment 1 (2,500 μg Cd pot^{-1}). The computed uptake of cadmium from Treatment 1 was 1527.0 μg pot^{-1} and when this was compared with that from Treatment 2 there was significant difference. At higher concentrations of cadmium application (7,500 and 10,000 μg Cd pot^{-1}), the uptake was relatively

Table 16. Cadmium uptake in roots, shoot and fruits of tomato plant (µg pot^{-1})

Metal level (mg kg^{-1} soil)	Cadmium uptake (µg pot^{-1})			Cadmium content (µg g^{-1})		
	Root	Shoot	Fruit	Root	Shoot	Fruit
0.5	561.9	1527.00	437.5	2.25	1.58	0.29
1.0	620.9	3564.00	521.5	5.76	5.40	1.31
1.5	3142.0	874.00	0*	57.75	5.16	0*
2.0	3650.0	826.60	0*	278.62	11.67	0*
0.0	66.1	78.87	167.7	0.15	0.05	0.09
CD (0.05)	**114.8**	**250.0**	**13.19**			

* Absence of fruits

Table 17. Lead uptake in roots, shoot and fruits of tomato plant (µg pot^{-1})

Metal level (mg kg^{-1} soil)	Lead uptake (µg pot^{-1})			Lead content (µg g^{-1})		
	Root	Shoot	Fruit	Root	Shoot	Fruit
0.5	650.2	898.2	904.1	1.86	0.80	0.53
1.0	1071.0	1831.0	2062.0	3.70	1.51	1.26
1.5	1272.0	1884.0	2588.0	4.58	1.48	1.39
2.0	1745.0	2212.0	2933.0	6.69	1.62	1.50
0.0	512.4	497.6	637.2	1.48	0.29	0.39
CD (0.05)	**36.91**	**323.2**	**254.1**			

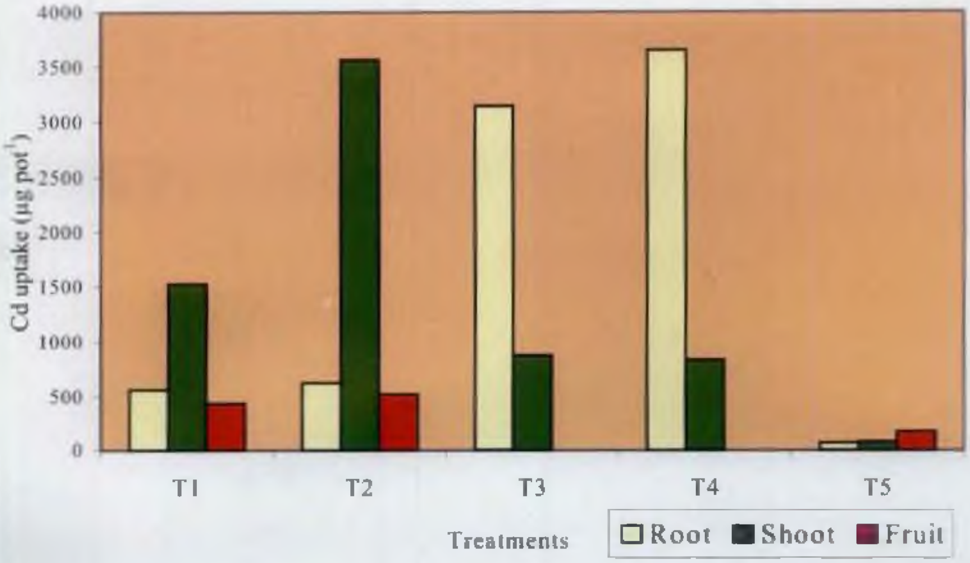

Fig 11. Cadmium uptake by tomato root, shoot and fruit portions

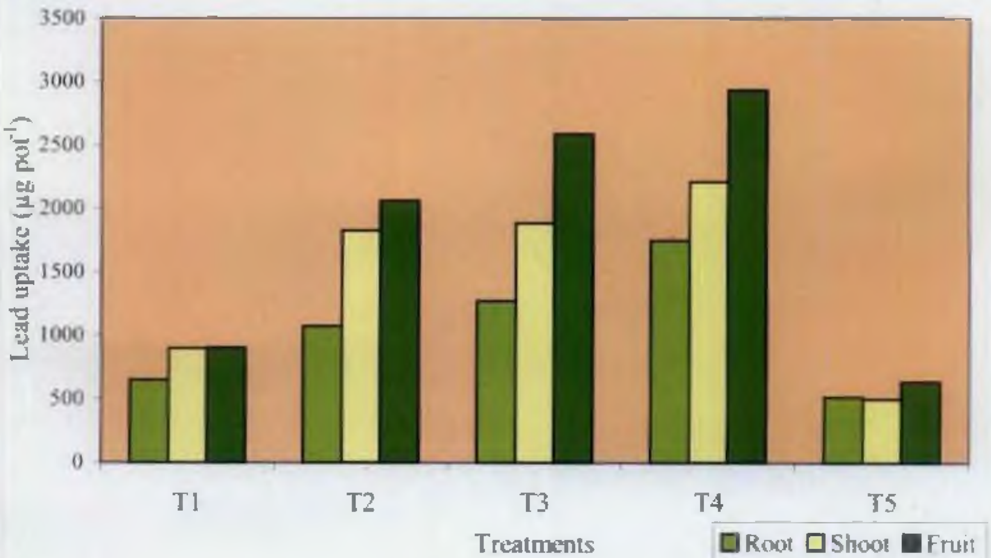

Fig 12. Lead uptake by tomato root, shoot and fruit portions

lower and the computed figures for uptake from Treatment 3 and 4 were 874.0 and 826.6 μg pot^{-1} respectively with no significant difference existing between them. The least uptake of cadmium was noted in control (78.87 μg pot^{-1}) and this remained inferior to all the other treatments with respect to uptake of the metal.

4.12.3 Fruit

In the case of tomato, there was absolutely no fruiting at higher levels of application of cadmium, permitting computation of uptake of metal, only from lower levels of application. Hence cadmium uptake could be noted in fruits only from Treatments 1 and 2. Among these treatments, maximum Cd uptake (521.5 μg pot^{-1}) was noted from those plants which received Treatment 2 (5,000 μg Cd pot^{-1}) followed by Treatment 1 with an uptake of 437.5 μg pot where 2,500 μg Cd pot^{-1} had been applied. Tomato fruits from control pots maintained the least uptake of cadmium. All levels of application of cadmium, which permitted, fruiting in tomato, had maintained significant difference in uptake of the metal in them.

4.13 UPTAKE OF LEAD IN SHOOTS, ROOTS AND FRUITS OF TOMATO PLANTS

The uptake of lead in roots, shoot and fruits of tomato plant was computed from both the tissue concentration of the metal and corresponding dry matter yield. The results of the same are presented in Table 17 and Figure 12. In general, it could be discerned that tomato fruits recorded relatively more uptake of lead than other plant parts while roots held comparatively low amount of lead.

4.13.1 Root

Though the least uptake of lead was noted in roots compared to other portions of the plant, there was a definite pattern of uptake of lead by the roots. Accordingly, it was observed that as the levels of application of lead in soil were enhanced, there was a corresponding increase in the uptake of the metal by the roots. Treatment 4, where 10,000 μg of lead had been applied per pot, a maximum uptake of 1745 µg Pb pot^{-1} was observed in the root portion of the plant. On the contrary, the lowest uptake of 512.40 µg Pb pot^{-1} was observed in the root portion of the control plants. The uptake of the metal by roots from other treatments, which received intermediate levels of lead application in soil, was significantly different from one another.

4.13.2 Shoot

In shoots, the highest uptake of lead was found to be in those tomato plants where the maximum dose of lead (10,000 µg Pb pot^{-1}) had been applied. Accordingly, treatment 4 recorded the highest uptake (2212.0 µg pot^{-1}) followed by Treatment 3 and the least concentration of 497.6 µg pot^{-1} was noted in control, with each uptake remaining significantly different from one another. The uptake from the rest of treatments maintained values between these extremes (Treatment 4 and Treatment 5) with significant difference existing between them. The uptakes of lead by Treatments 3 and 2 were computed to be 1884 and 1831 µg pot^{-1} respectively with no significant difference, but when the uptake of Treatment 1 and that from Treatment 2 are compared, they differed significantly.

4.13.3 Fruit

A similar trend as observed in the root and shoot portions of the plant with respect to the uptake of lead is clearly visible for the fruit portion also, though the fruits maintained the highest uptake of lead when compared to the other portions of the plant. Highest uptake of lead in fruit portions (2933.0 µg pot^{-1}) of the tomato plants were computed from Treatment 4 where 10,000 µg Pb pot^{-1} had been applied. The lowest uptake of lead by the fruits (637.2 µg pot^{-1}) was noted from control. The uptake from the rest of treatments maintained values between Treatment 4 and control with significant difference existing among them. The uptake of lead by Treatments 3, 2 and 1 in fruits was computed to be 2588.0, 2062.0 and 904.1 µg pot^{-1} respectively indicating a significant difference between them.

Table 18. Mean biometric observations of cadmium treated tomato plants 68 days after sowing

Metal level (mg kg $^{-1}$ soil)	No. of leaves	Leaf length (cm)	No. of branches	No. of trusses	Plant height (cm)
0.5	9.5	11.6	2.00	2.50	27.8
1.0	9.0	9.3	1.00	2.25	24.0
1.5	7.3	6.9	0.25	0.25	21.0
2.0	7.0*	6.5*	0*	0*	20.8*
0.0	9.0	13.7	2.75	3.25	31.3
CD (0.05)	**NS**	**3.63**	**1.32**	**1.32**	**7.35**

* - Data recorded 3 days after transplanting
NS- Non significant

Table 19. Mean biometric observations of lead treated tomato plants 68 days after sowing

Metal level (mg kg $^{-1}$ soil)	No. of leaves	Leaf length (cm)	No. of branches	No. of trusses	Plant height (cm)
0.5	10.3	14.7	2.5	3.25	31.3
1.0	11.8	14.9	3.8	4.00	36.0
1.5	13.0	15.0	4.3	4.25	37.3
2.0	14.8	15.7	4.8	6.50	39.5
0.0	11.8	13.2	3.3	5.00	37.8
CD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**

*NS- Non significant

4.14 BIOMETRIC OBSERVATIONS OF TOMATO PLANTS TREATED WITH CADMIUM

The biometric observations on tomato plants *viz.*, number of leaves, number of branches, leaf length, number of trusses and plant height after 26 days of imposing varying treatments are presented in Table 18.

4.14.1 Number of leaves

The number of leaves ranged between 7.0 and 9.5 from different treatments. Maximum numbers of leaves (9.5) was seen in Treatment 1 and minimum (7.0) in Treatment 4 with practically no significant difference existing between them.

4.14.2 Leaf length

The length of tomato leaves as influenced by different levels of application of cadmium is presented in Table 18. From the table it is seen that the control plants maintained maximum length of leaves in the absence of any metal. Wherever cadmium metal had been added, there was a reduction in the length and this reduction in length was not having any statistical difference especially at higher levels of addition of cadmium.

4.14.3 Number of branches

The number of branches produced by tomato plants consequent to the different levels of application of cadmium is depicted in Table 18. From the results it is seen that the control plants produced the maximum number of branches (2.75). followed by those plants (2.00), which received Treatment 1. It is further seen that additions of cadmium had significantly decreased the presence of branches in tomato especially at lower levels (Treatment 1 and 2). At higher levels of addition of cadmium particularly at 1.5 mg Cd kg^{-1} soil (Treatment 3) failed to produce any significant branching. At the highest level of addition of cadmium, the question of branching did not arise as that treatment did permit the plant to establish only for a shorter period of time (3 days) compared to the longevity of the rest of the plants.

4.14.4 Number of trusses

The number of trusses (fruiting branches) as influenced by different levels of application of cadmium is presented in Table 18. It was seen that higher levels of application in general could not produce fruiting branches and the lower levels of application of treatments particularly treatment 1 and 2 could not impart any change in the reduction of fruiting branches and the same was comparable with control. However, in treatment 3, there was only minimum production (0.25) of fruiting branches, which remained significantly inferior to those treatments, which produced branches (treatments 1,2 and 5). At the highest level of addition of cadmium, the question of fruiting branches did not arise during the three days of its existence inside the pot.

4.14.5 Plant height

Compared to all other treatments, control plants recorded the highest plant height (31.3 cm) and it was noted that all addition of cadmium significantly decreased the plant height, the decrease in height becoming more conspicuous with higher levels of addition. However, those plants which received lower levels of addition of cadmium (0.5 and 1.0 mg Cd kg^{-1} soil) did not differ much among themselves (27.8 – 24.0 cm) and remained more or less on par with control.

4.15 BIOMETRIC OBSERVATIONS OF TOMATO PLANTS TREATED WITH LEAD

The biometric observations of tomato plants *viz.*, number of leaves, leaf length, number of branches, number of trusses and plant height observed after 26 days of imposing varying treatments are presented in Table 19.

4.15.1 Number of leaves

The number of leaves of tomato plants as influenced by different levels of lead application ranged between 10.3 and 14.8. The highest number of leaves (14.8) was seen produced by tomato plants which received the highest level of lead application (2.0 mg Pb kg^{-1} soil) and the least number of leaves by Treatment 1 with practically no significant difference existing between them.

4.15.2 Leaf length

The leaf length of tomato plants, which received different levels of lead, is presented in Table 19 and it is seen that the length of leaves increased with an increase in the level of application of lead in soil. The maximum leaf length (15.7 cm) was recorded in Treatment 4 and the minimum (13.2 cm) in control, which did not receive any external addition of lead. Although other treatments had produced leaves with difference in the length, the observed difference had no significant effect on the addition of lead.

4.15.3 Number of branches

The number of branches produced by the tomato plants treated with lead at different levels in soil is presented in Table 19. In all the cases, the number of branches produced by tomato plants treated by lead exceeded the corresponding values recorded by control plants. Even then, there was no significant difference between the numbers of branches produced by any level of lead tried particularly when compared against the control. The maximum number of branches (4.8) has been recorded from Treatment 4 while the minimum number of branches (2.5) by those tomato plants, which received Treatment 1.

4.15.4 Number of trusses

The number of fruiting branches (trusses) consequent to the application of lead at various levels is depicted in Table 19. From the table, it could be seen that

Table 20. Yield of tomato plants treated with different levels of cadmium

Metal level (mg kg^{-1} soil)	Yield (g pot^{-1})
0.5	120.1
1.0	46.5
1.5	0*
2.0	0*
0.0	292.8
CD (0.05)	**36.65**

* Absence of fruits

Table 21. Yield of tomato plants treated with different levels of lead

Metal level (mg kg^{-1} soil)	Yield (g pot^{-1})
0.5	163.0
1.0	190.3
1.5	229.0
2.0	243.5
0.0	253.3
CD (0.05)	**NS**

*NS - Non significant

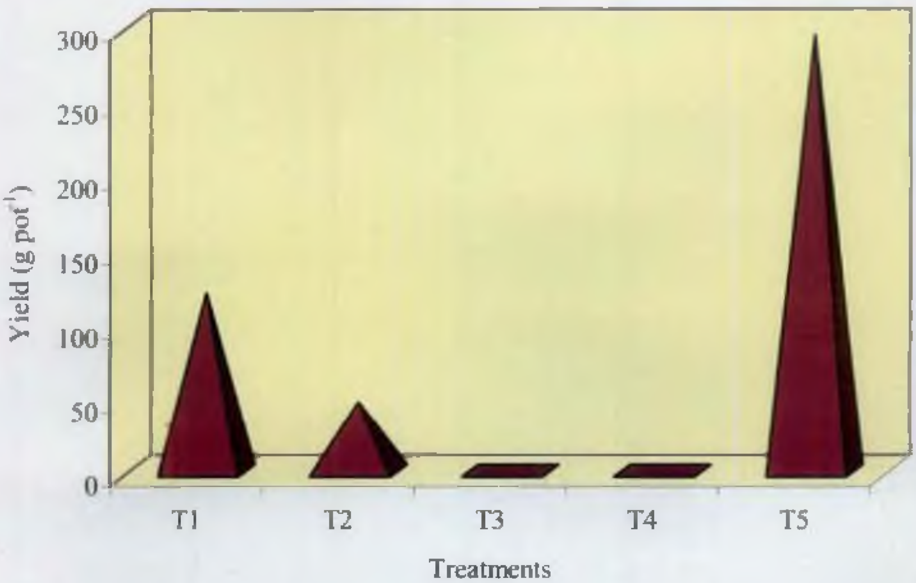

Fig 13. Yield of tomato plants treated with cadmium

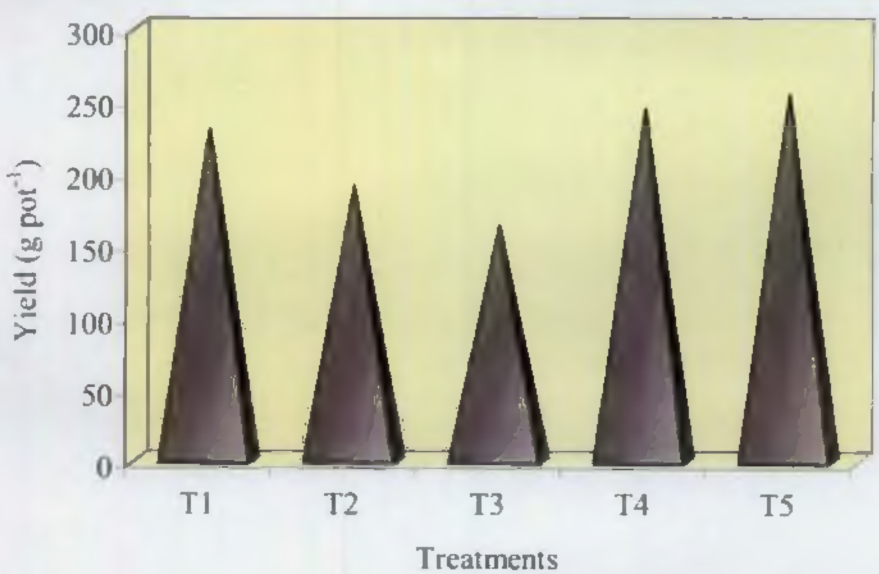

Fig 14. Yield of tomato plants treated with lead

there existed no significant difference in the number of trusses produced by the tomato plants from any treatment. Further, it is observed that the number of fruiting branches increased with a corresponding increase in the level of lead application, though the observed increase was non-significant. Application of 2.0 mg Pb kg^{-1} soil resulted in the production of maximum number of fruiting branches (6.50), while treatment 1 where lead had been applied at the rate of 0.5 mg kg^{-1} soil resulted in the nonsignificantly lower production of trusses (3.25) which again remained more or less on par with control.

4.15.5 Plant height

The height of tomato plants, which received varying levels of lead ranged between 31.3 and 39.5 cm. The maximum plant height (39.5 cm) was recorded in Treatment 4 while the minimum (31.3 cm) in Treatment 1 with no significance difference. Comparison of plant height from any lead treatments with that of control could not bring any significant change.

4.16 YIELD OF TOMATO PLANTS TREATED WITH CADMIUM

Table 20 and Figure 13 present the yield of tomato plants, which had received different levels of cadmium. The highest yield (292.8 g pot^{-1}) was obtained from the control pot. Compared to control, the yields of tomato plants from Treatment 1 and 2 were significantly lower. Accordingly, the yield recorded from Treatment 1 and 2 were 120.1 and 46.50 g pot^{-1} respectively. As the plants which received higher doses of cadmium, especially Treatment 3 (1.5 mg kg^{-1} soil), failed to produce any fruits, the yield from that is totally ruled out. Similarly, at the highest level of cadmium addition in soil (2.0 mg kg^{-1} soil) did not permit any successful establishment of the plant, with result, the question of fruiting has also been ruled out. Hence, no yield could be recorded from plants, which received higher doses of cadmium (Treatments 3 and 4). Among the different treatments which permitted fruiting, the plants fruited in the order $T_5 > T_1 > T_2$.

Plate 1. Influence of 1.0 mg Cd kg^{-1} and above on the development of browning on stem (Initial stage)

Plate 2. Browning symptoms on stem (at 1.0 mg Cd kg^{-1} soil and its higher doses) (Advanced stage)

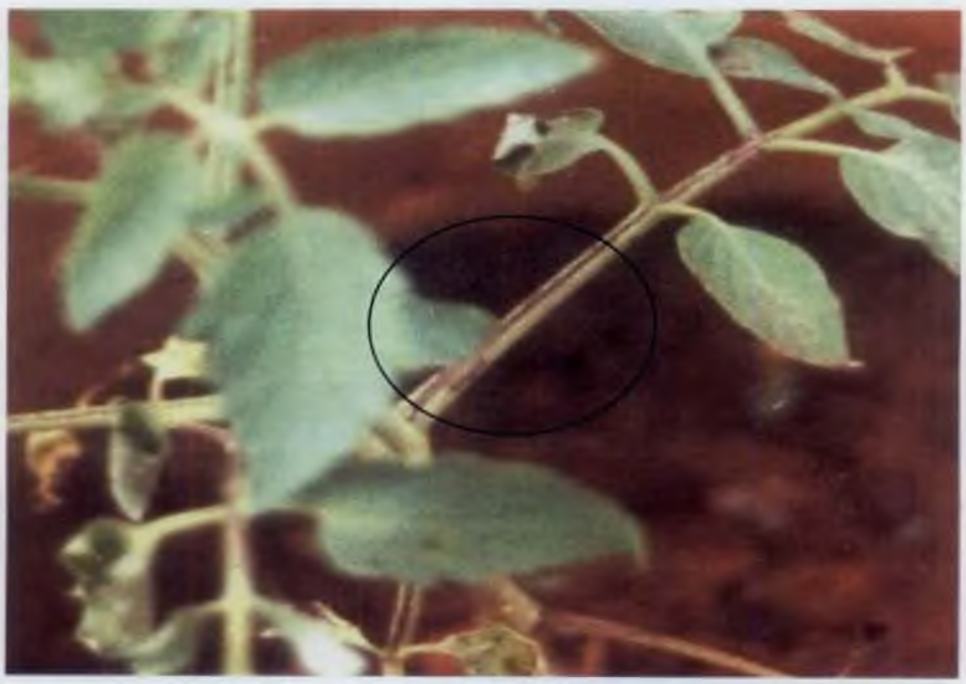

Plate 3. Browning and splitting of the leaf rachis (at 1.5 mg Cd kg^{-1} soil)

4.17 YIELD OF TOMATO PLANTS TREATED WITH LEAD

The yield of tomato plants treated with lead at varying levels of addition in soil is depicted in Table 21 and Figure 14. Though there was no significant difference in the yield of tomato plants between the different treatments, it was observed that there was a nonsignificant increase in the yield of tomato which increased with enhancement in addition of lead levels. Among all the various treatments, control recorded the highest yield (253.3 g pot^{-1}) followed by Treatment 4 (243.5 g pot^{-1}) which received the highest level of lead addition in soil. However, the lowest yield of 163.0 g pot^{-1} was recorded by Treatment 1 which received the lowest level of lead application (0.5 mg kg^{-1} soil).

4.18 GENERAL SYMPTOMS OBSERVED ON TOMATO PLANTS TREATED WITH CADMIUM

In tomato plants cadmium had been applied at different doses starting from 0.5 to 2.0 mg kg^{-1} soil. But visible symptoms were observed only on those treatments where cadmium had been supplied at the rate of 1.5 and 2.0 mg kg^{-1} soil. The plants, which received 2.0 mg Cd kg^{-1} soil, permitted only three days of growth in such pots with complete drying up (Plate 9). However, in this case, splitting was observed in the collar region of the plant (Plate 8). Hence visible symptoms could only be noticed with those plants, which received 1.5 mg Cd kg^{-1} soil. However, in this case, gradual symptoms were particularly manifested in the shoot portions of the plant. A brief description of visible symptoms, which appeared in the shoot portions of the plant particularly 25 days after transplanting the same in treated soils, is summarized below.

1. Prominent reduction in leaf area and length has been noticed for those leaves, which had emerged after transplanting at 1.0 and 1.5 mg Cd kg^{-1} soil.

2. Subsequent internodes remain relatively short at 1.5 mg Cd kg^{-1} soil, when compared to the same from lower doses.

Plate 4. Drying of the leaves (1.0 mg Cd kg^{-1} soil and its higher doses) in established plants

Plate 5. Browning of leaf midribs (2.0 mg Cd kg^{-1} soil) within few days after transplanting

Plate 6. Incidence of circular cracks at the shoulder region (at 0.5 mg Cd kg^{-1} soil)

Plate 7. Development of cracks in fruits (1.0 mg Cd kg^{-1} soil)

3. Older leaves which remained with the plant at the time of transplanting completely drooped off (observed at 0.5, 1.0 and 1.5 mg Cd kg^{-1} soil).

4. Initial yellowing of young emerging leaves, which on subsequent growth got recovered (observed at 1.0 mg Cd kg^{-1} soil) (Plate 10).

5. Scorching or burned appearance starts particularly from the leaf tips (observed at 1.0 and 1.5 mg Cd kg^{-1} soil) (Plate 4).

6. As growth advanced initial browning and necrotic spots have been noticed along the internodal region of the main stem (observed at 1.0 and 1.5 mg Cd kg^{-1} soil) (Plate 1 and 2).

7. Subsequently, leaf rachis of those leaves already established in the affected internodal region shows brown necrotic spots with splitting of rachis especially from the nodal region, which proceeds towards the tip (observed at 1.0 and 1.5 mg Cd kg^{-1} soil) (Plate 3).

8. During this stage, inter-veinal chlorosis gets initiated in the particular leaf with gradual increase in the necrosis of the leaf lamina and midrib, resulting in inward curling. And in no time drying of the entire leaf occurs from tip towards the base of the leaf (Plate 4).

9. By this time, the lower leaves exhibit similar necrotic symptoms and inter-veinal chlorosis gradually ending in the death of those leaves.

10. Flower buds from the affected plants were small and yellow instead of green and over a short period of time these buds turned necrotic and aborted and hence no fruiting.

11. It is seen that enhancement of cadmium levels particularly between 0.5 and 1.0 mg kg^{-1} soil resulted in a considerable reduction in the weight of fruits (Plate 11).

Plate 8. Incidence of stem splitting (1.0 and 1.5 mg Cd kg^{-1} soil)

Plate 9. Fate of tomato plants in soils (2.0 mg Cd kg^{-1} soil) few days after transplanting

Plate 10. Incidence of chlorosis in leaves (at 1.0 and 1.5 mg Cd kg^{-1} soil)

1.0 mg Cd kg^{-1} soil

0.5 mg Cd kg^{-1} soil

Plate 11. Comparison of fruit size under different levels of Cd

Plate 12. Comparison of growth under similar levels (1.5 mg kg^{-1} soil) lead (A) and cadmium (B)

Plate 13. Incidence of double fruits (1.5 mg Pb kg^{-1} soil)

Plate 14. Splitting of fruits (1.5 mg Pb kg^{-1} soil)

12. Appearance of circular cracks at the shoulder region at 0.5 mg Cd kg^{-1} soil (Plate 6).

4.19 GENERAL SYMPTOMS OBSERVED ON TOMATO PLANTS TREATED WITH LEAD

As a part of the experiment, tomato plants have been transplanted after 42 days of growth, to soils, loaded with different doses of lead starting from 0.5 to 2.0 mg kg^{-1} soil. But visible symptoms were observed only on those treatments where lead had been applied at the rate of 1.5 and 2.0 mg kg^{-1} soil. The visible symptom that could be noticed on the tomato plants from such treatments was mostly restricted to the fruits which appeared one month after transplanting, where different types of malformations could be observed. The plants, particularly the shoot portion indicated luxuriant growth on receipt of various treatments.

1. In some initially formed fruits, which received higher doses of lead, star-shaped cracks appeared at the base of the immature fruits and these cracks remained all through the growth of the fruit (Plate 14).

2. Double fruits from a single calyx were another observation, which were not seen towards the later fruiting from the same plant (Plate 13).

3. Initially formed fruits appeared to be pumpkin-shaped rather than oval shaped.

4. Seeds formation in those fruits developed from Treatments 3 and 4 (1.5 and 2.0 mg Pb kg^{-1} soil) had either no seeds or seeds which are totally brown.

5. On the shoot portion, all levels of lead application imparted abnormal luxuriant growth of plants equating them to that growth obtained in control (Plate 12).

Discussion

5. DISCUSSION

5.1 CHEMICAL CHARACTERISATION OF PRE-TREATMENT SOIL

The pre-treatment soil used for the study was identified to have an acidic pH (5.6) and normal electrolytic conductivity 0.07 dS m^{-1}. The assessment of organic carbon content also indicated a medium level. The available nutrient contents of soil, especially for nitrogen and phosphorus were found to have medium status. However, the available potassium content of the soil was estimated to be low (Table 1). From the above results it is clear that the virgin soil collected for the study is neither very rich in fertility nor having any abnormal problems.

5.2 PHYSICAL CHARACTERISTICS OF THE PRE-TREATMENT SOIL

From the particle size distribution of the soil (Table 2), the soil texture was found to be sandy loam. Mortvedt and Beaton (1995) indicated that wherever sand portions dominated among the other separates, soils exhibited relatively low cation exchange capacity and coupled with the acidic nature of soil, there remained every chance for enhanced uptake of metallic ions compared to that from a similar texture existing in the alkaline range. In the present study, the texture and the pH of the soils remained more or less ideal for the enhanced uptake upholding the contentions of Mortvedt and Beaton (1995).

5.3 CADMIUM AND LEAD CONTENT IN PRE-TREATMENT SOIL AND BASIC INPUTS

As expected, the basic inputs used for the study also contributed cadmium and lead in varying quantities to the soil, though their contributions remained small. The bulk soil material used for the study provided marginal quantities of 0.03 μg Cd and

0.01 μg Pb g^{-1} soil (Table 3). The traces of heavy metals observed in the uncultivated soil could possibly be attributed to their inherent presence in the soil. A similar apprehension has already been raised by Tiller (1958). Further possibility of its presence could be traced from the clay minerals, iron oxides and hydroxides, which are also believed to be the principal carriers of heavy metals according to Alloway (1995)

Well-decomposed cow dung though expected to be free of any heavy metal, it offered a mild presence of lead to the tune of 0.001 μg g^{-1} of manure (Table 3). While preparing the potting mixture, the same cow dung shared approximately one-third weight (1.6 kg) of the potting mixture. Based, on a rough computation of the metal load particularly lead in pots, from an approximate quantity of 1.6 kg cow dung, it could be seen that each pot was silently provided with lead in this manner to the tune of 1.66 mg. However, in the current study, the incidence of lead in cow dung is not an isolated occurrence, since Raaven and Loeppert (1997) had already reported the presence of lead in cowdung.

Analysis of fertilizer urea revealed practically no presence of cadmium and lead. However, Rajphos, a rock phosphate source, contributed substantial load of cadmium (35.0 μg g^{-1}) and lead (91.0 μg g^{-1}) to soil tagging this source as the single largest input offering heavy metals to soil. This is truer when the contributions of cadmium and lead are compared against that from other inputs other than the direct sources of heavy metals (Table 3). Hansen and Tjell (1982); Kurumthottical (1995) and Jidesh (1998) have already identified rock phosphate fertilisers as potential materials, for the indirect supply of heavy metals in soil. Muriate of potash also served as an external, but marginal sources of cadmium and lead addition in soil by supplying 0.0001 μg Cd g^{-1} and 0.0004 μg Pb g^{-1} of the fertilizer material.

5.4 CHEMICAL CHARACTERISATION OF THE POST-TREATMENT SOIL SAMPLES TREATED WITH DIFFERENT LEVELS OF CADMIUM

The soil reaction of the post-harvest soil increased significantly (Table 4) in the acidic range towards neutral pH (5.6 – 6.2). The increase in soil reaction was directly in accordance with the increase in levels of application of cadmium. The possible increase in pH observed in post-harvest soils, might have been due to the hydrolysis of the residual metal, which remained in the post-harvest soils.

The electrolytic conductivity of the post-harvest soils, though observed to get increased with the enhancement in levels of cadmium concentration in soil, it was non-significant (Table 4). However, Mishra and Choudhuri (1996) reasoned this increase in electrolytic conductivity due to leakage of electrolytes from the plants.

The organic carbon status of the soil from different treatments which permitted varying levels of addition of cadmium in soil (0.5 – 2.0 mg kg^{-1} soil) could not bring about any change in its status. Accordingly, with any level of addition of cadmium in soil, the organic carbon content remained quite unaffected even when they are compared against the control (Table 4).

The observed range of available nitrogen (585.2 and 639.6 kg ha^{-1}) in the post-harvest soil, though did not differ significantly between many treatments (2, 3 and 4), appeared significantly superior when compared to control and Treatment 1 (Table 4). Application of same quantity of nitrogen in all pots including control and the inability of the plant to differentially extract the nitrogen from the treated pots must have been a possible reason for a non-significant range of available nitrogen in soil.

The available phosphorus status in the soil (Table 4), which received varying levels of cadmium, though indicated a general increase in phosphorus content with all treatment in the increasing order, only the highest dose of addition of cadmium (Treatment 4) remained significantly different when compared to rest of the treatments. While other treatments, which permitted lower levels of addition of cadmium, resulted in non-significant difference in available phosphorus content among themselves. The available phosphorus in the post-harvest soil samples ranged between 19.50 – 22.48 kg ha^{-1}. The reason for this observed trend could be due to two facts. Firstly, the failure to support plant life at highest dose of cadmium application also means indirectly that this treatment did not permit phosphorus uptake by plants, necessarily leaving most of the applied quantity in soil. This situation is ought to make significantly higher level of available phosphorus in post-harvest soils. Secondly, the non-significantly different levels of available phosphorus observed within other treatment pots including control could be due to the fact that these levels of cadmium, which permitted different growth rate of tomato plants, also must have permitted differential uptake of supplied phosphorus necessarily making corresponding depletion from its sources.

Though the available potassium content of the post-harvest soil samples ranged between 229.5 and 262.3 kg ha^{-1}, the highest amount of available potassium was recovered from Treatment 4 (Table 4). The absence of any plants in Treatment 4 to utilize any potassium might have been the reason for the observation of higher available potassium in that treatment. All treatments except treatment 4 which permitted variable growth in plant also must have allowed varying uptake of potassium from the added sources of potassium. This sort of differential uptake of potassium in plants naturally must have left different levels of available potassium in soil, leading to the current variations, where the available potassium status remained significantly different from one another.

5.5 CHEMICAL CHARACTERISATION OF POST-TREATMENT SOIL SAMPLES TREATED WITH DIFFERENT LEVELS OF LEAD

The significant increase in soil reaction (5.6 – 6.3) has been observed over control in the acid range for different treatment in the post-harvest soil samples, perhaps might have been due to a possible formation of metal hydroxides in the soil which in all probability must have ensured an enhancement in pH (Table 5).

The electrolytic conductivity of the soil where different levels of lead had been added resulted in a non-significant decrease in conductivity with an increase in levels of application of treatments probably on account of the low activity of the metal ions at higher concentrations (Table 5). However, the observed enhancement in conductivity from different treatments when compared to control in all probability might be due to the presence of ions from the heavy metal source.

The significantly low organic carbon content observed in Treatment 4 (Table 5) where maximum quantity of lead had been applied which also permitted luxuriant growth of tomato, might be due to the rapid utilization of organic sources. The relatively lower levels of additions of lead in many treatments, justify the higher establishments of organic carbon status, presumably on account of lower utilization by such plants. In this context the report of Patel *et al.* (2004) suggesting a positive correlation in the utilization of organic matter and the metal content. This appears to be a better reason for the depletion and retention of organic carbon sources in the experiment.

The. available nitrogen status of the soil, which received different levels of lead, was in the range 567.3 – 831.4 kg ha^{-1} (Table 5). As the levels of application of lead increased, there was a significant reduction in the available nitrogen status of the soil. The visible increase in vegetative growth of plants with enhancement in the application of lead levels possibly should have been a more valid reason for better utilization of available nitrogen from soils. This further reasons for the high content of available nitrogen in soil at lower levels of application of lead, wherein the growth and development of the plant was not that good as observed at higher doses.

The available phosphorus status in the soil (Table 5) decreased with an increase in the levels of application of lead, which ranged from 19.94 kg ha^{-1} to 22.61 kg ha^{-1}. The observed decrease in the available phosphorus content in post-harvest soil samples with enhancement in the levels of application of lead in all possibility be due to the higher uptake of phosphorus from soils. The higher uptake must have occurred indirectly by reducing the fixation rates of phosphorus through enhancement in soil pH initiated through higher levels of lead application in soil.

The available potassium status of the post-treatment soil, which received varying levels of lead, varied from 168.0 kg ha^{-1} to 201.6 kg ha^{-1} (Table 5). Application of lead at all doses, might have not seriously interfered with the plants absorption of potassium from soils though same quantities of potassium added in different treatments reasons well for the observed non-significant increase in the available potassium status in the soil. In view of this explanation, the better growth and yield observed in Treatment 4 where maximum lead had been applied further reasons for the low content of available potassium.

5.6 AVAILABLE CADMIUM IN POST-HARVEST SOIL SAMPLES

The available cadmium content in the post-harvest soil samples (Table 6), which received different levels of cadmium, increased with increase in treatment levels with values touching up to 136.85 μg pot^{-1} in the highest level of addition. The availability of cadmium from other pots, which received lower levels, also registered proportionate and significant reduction indicating that plants were not able to absorb the entire quantity of the metal supplied. This trend in absorption also revealed that absorption of cadmium by tomato is directly proportional to the metal load in the rhizosphere. This contention is further upheld in control pots with the least availability of cadmium 9.75 μg pot^{-1}. The presence of this meagre quantity of cadmium in control pots should be construed as the major contribution from rock phosphate.

5.7 AVAILABLE LEAD CONTENT IN POST-HARVEST SOIL SAMPLES

The available lead content in the post-harvest soil samples (Table 7), which received different levels of lead, increased with increase in treatment levels with values touching up to 2677.5 μg pot^{-1} in the highest level of addition. The availability of lead from other pots, which received lower levels, also registered proportionate and significant reduction indicating that plants were not able to absorb the entire quantity of the metal supplied as seen in the case of cadmium. This trend in absorption by tomato plants also revealed that absorption of lead is directly proportional to the metal load in the rhizosphere. The presence of the least amount of lead in control pots (29.5 μg pot^{-1}) is also in full support of the above contention. The presence of this comparatively meagre quantity of lead in control pots should be construed as the contributions from rock phosphate in particular and to a lesser extent from organic manure.

5.8 NITROGEN CONTENT IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS TREATED WITH CADMIUM

5.8.1 Roots

The suppressing effect of cadmium in the absorption of nitrogen by the root portions of the tomato plants was very much evident from the different levels of application .(Table 8). The significantly higher content of nitrogen was retained by roots where higher levels of cadmium had been applied and vice versa at lower levels of application. Higher levels of cadmium must have created some root membrane damage, possibly through increased cell permeability and later on leading to final cell damage. Survival of the plants for not more than three days in pot with higher levels of application of cadmium might have occurred due to such damage. A similar observation had been recorded by Jeana and Choudhuri (1982) where they had noted higher permeability of tissues through membrane damage in aquatic plants, when treated with lead and mercury.

5.8.2 Shoot

The nitrogen content in the shoots was observed to get marginally increased in almost all levels of application of cadmium except Treatment 4, where the increase in nitrogen content was significantly higher. The existence of transplanted tomato plants in treatment 4 was only for three days, after which the plants succumbed to the cadmium toxicity. In view of this reality, the observed higher nitrogen content in shoots of Treatment 4 should be viewed as a natural phenomenon of detecting higher nitrogen content in younger tissue and vice versa in other lower doses which permitted plant growth. Hence all these variation in the nitrogen content should be construed as nitrogen content in accordance with the backdrop of growth and development of plants. Yet another possibility for the observed low content of nitrogen at lower levels of cadmium application might be due to decreased nitrogen reductase activity, in the presence of cadmium as observed by (Hernandez *et al.*, 1997). However, the reason cannot be fully appreciated in the present study as control plants showed similar but non-significant difference in the content of nitrogen in shoots.

5.8.3 Fruit

Apart from control, it is seen that the fruiting was observed only in those plants, which received addition of cadmium at lower levels (0.5 and 1.0 mg kg^{-1} soil). Higher levels of addition of the metal especially 1.5 mg Cd kg^{-1} soil did not permit any fruiting. Hence it is not possible to make any comparison on the effect of nitrogen content in fruits consequent to cadmium application. On a comparative evaluation of different plant parts of tomato, which held nitrogen, it is seen that in those successful fruits, the nitrogen content was assessed to be relatively twice as that of its content in roots. However, this sort of comparison cannot be made with shoots, which maintained more content of nitrogen than roots.

5.9 PHOSPHORUS CONTENT IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS

5.9.1 Roots

Table 9, which provides the phosphorus content in roots indicates that as levels of cadmium application increased, the phosphorus content in plants increased significantly. Ciecko *et al.* (2004a) have reported a similar effect of higher absorption of phosphorus in oats with enhancement in cadmium level in soil. Presence of metal contaminants, particularly cadmium might have modified the uptake and transport of phosphorus in plants to justify the current observation. The relatively low content of phosphorus in roots compared to other plant parts of tomato further substantiates this reasoning. Das *et al.* (1998) have also documented similar contention in soils contaminated with cadmium especially with respect to the uptake, transport and utilisation of different macro-elements such as phosphorus, potassium, magnesium or calcium in plants. Further, it is seen that under the influence of various cadmium doses, besides the plant species, plant organ is also equally important factor that determine the content of phosphorus in plants.

5.9.2 Shoot

In shoots it is observed that, the total phosphorus increased significantly as the level of application of cadmium in the soil increased maintaining the same trend as seen in roots with a range of 0.40-0.50 per cent (Table 9). The same contentions and reasons as described for the root portion hold good in this case also.

5.9.3 Fruit

Apart from control, it is seen that the fruiting occurred only in those plant, which received lower levels of addition of cadmium (0.5 and 1.0 mg kg^{-1} soil). Higher levels of addition of the metal especially 1.5 mg Cd kg^{-1} soil did not permit any fruiting. Hence it is not possible to make any comparison on the effect of phosphorus content in fruits consequent to cadmium application. On a comparative evaluation of different plant parts of tomato, which held phosphorus, it is seen that in those successful fruits, the phosphorus content was assessed to be relatively twice as that of its content in roots However, in the case of shoots, a similar comparison keeps the phosphorus content 1.5 times lesser than the fruits.

5.10 POTASSIUM CONTENT IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS TREATED WITH CADMIUM

5.10.1 Roots

The potassium content of roots increased significantly with increase in the concentration of cadmium in soil and the content ranged from 0.11 to 0.40 per cent (Table 10). Presence of metal contaminants, particularly cadmium might have modified the uptake and transport of potassium in plants to justify the current observation. Das *et al.* (1998) have also documented similar contention in soils contaminated with cadmium especially with respect to the uptake, transport and utilisation of different macro-elements such as phosphorus, potassium, magnesium or calcium in plants. Observance of the lowest content of potassium (0.11%) in the root portions of the control plants further strengthens the contention. Ciecko *et al.* (2004b) had observed similar effect in the roots of oats and maize under the influence of cadmium. The concentration of potassium was positively correlated with plant yield and the content of micro and macro elements in them (Ciecko *et al.*, 2004b).

5.10.2 Shoot

A similar significant trend was observed in potassium content of tomato shoot with higher levels of cadmium accumulating in treatments receiving highest dose of cadmium and the reverse trend noted with lower doses (Table 10). The same contentions and reasons as described for the root portion hold good in this case also.

5.10.3 Fruit

Apart from control, it is seen that the fruiting occurred only in those plant, which received lower levels of addition of cadmium (0.5 and 1.0 mg kg^{-1} soil). Higher levels of addition of the metal especially 1.5 mg Cd kg^{-1} soil did not permit any fruiting. Hence it is not possible to make any comparison on the effect of potassium content in fruits consequent to cadmium application. On a comparative evaluation of different plant parts of tomato, which held potassium, it is seen that in those successful fruits, the potassium content was assessed to be relatively four times as that of its content in roots and shoots.

5.11 NITROGEN CONTENT IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS TREATED WITH LEAD

5.11.1 Root

The total nitrogen content of tomato roots ranged between 1.31 and 2.43 per cent (Table 11). The reason for a negative relationship of nitrogen with the varying levels of lead application of lead in soil might be due to the possible formation of lead nitrate, which in all probability might have been formed proportionate to the levels of addition of the metal. Since the metal compound containing nitrogen readily got translocated to aerial parts of the plant necessarily indicating a low content of nitrogen in roots. The significantly high content of potassium in the root portion of control plants, where the possibility of lead concentration is relatively the lowest when compared to other treatments is a clear justification for the above contention.

5.11.2 Shoot

Quite contradictory to the trend observed between lead and nitrogen in roots, it has been observed that shoots content of nitrogen increased generally at lower doses of metal addition (Table 11). The reverse trend observed for nitrogen in shoots at the highest dose of application of lead might be due to its further effective utilization for growth and development of the tomato plant. Incidentally, Treatment 4 which received maximum dose of lead recorded the highest values in all biometric observations recorded against that treatment (Table 19) justifies the low content of nitrogen in shoots, possibly through a dilution effect.

5.11.3 Fruit

The reason for high content of nitrogen in fruits, particularly in control plants might in all possibility be due to the further translocation of nitrogen from shoots to fruits. While comparing the nitrogen values with the corresponding biometric observations as noted from Table 19, where relatively lesser biometric values have been noted in control than treated pots. Further, it is very clear that due to lesser growth observed in control, it is to be believed that lesser dilution effect of nitrogen must have occurred in such plants necessarily indicating higher nitrogen content in fruits, particularly when compared with other treatments which received different levels of lead.

5.12 PHOSPHORUS CONTENT IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS TREATED WITH LEAD

5.12.1 Root

The factual reason for the control plants recording the least amount of phosphorus (0.27 %) and Treatment 4 recording the highest content (0.40 %) with significant difference existing between them might be due to a higher absorption of phosphorus in tomato with enhancement in lead level in soil. Ciecko *et al.* (2004a) have reported a similar enhanced uptake of phosphorus in oats under the influence of cadmium. To further substantiate the observation, it could be possible that metallic contaminants might have modified the uptake and transport of phosphorus in plants. Das *et al.* (1998) have also indicated that in contaminated soils there is modified uptake, transport and utilisation of different macro-elements such as phosphorus, potassium, magnesium or calcium in plants.

5.12.2 Shoot

In shoots, the same significant trend as observed for the root portion of tomato has been identified with highest content of phosphorus (0.49 %) in Treatment 4 (Table 12) and the least content (0.39%) in control. The reasons and explanations already proposed for the root portions of the plant are equally valid here to justify the context.

5.12.3 Fruit

The maximum content of phosphorus among the different plant parts of tomato had been identified in the fruits, irrespective of any treatment difference. Highest content of phosphorus has been analysed in Treatment 4 and relatively least content in control indicating that more mobility of phosphorus is seen associated with metal ions. It may be recalled from Table 17, that the fruits maintained one of the highest levels of lead, compared to other plant parts. Since fruits are to be conceived as the final sink in tomato plants, the modified uptake and transport of phosphorus in plants under the influence of cadmium must have naturally culminated in the fruits to present a relatively higher concentration.

5.13 POTASSIUM CONTENT IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS TREATED WITH LEAD

5.13.1 Root

The potassium content analysed in the root portions of tomato plants differed significantly without showing any specific trend under the influence of varying levels of lead. Except for control, the presence of enhanced metallic level in soil promoted the uptake of potassium in roots. The present finding is in conformity with that of Das *et al.* (1998) where they had indicated that in contaminated soils there is modified uptake, transport and utilisation of potassium. The control values remained distinctly different from all treatments and the reason for such an occurrence cannot be explained.

5.13.2 Shoot

The potassium content in tomato shoots, arising from different treatments, which received varying levels of lead differed significantly and ranged between 0.14 and 0.16 per cent (Table 13). The reason for the least content of potassium in control and the highest content in Treatment 4 has already been explained in the discussion on potassium uptake under the influence of lead in the root portions of the plant.

5.13.3 Fruit

In fruits, the potassium content ranged between 0.48 and 0.55 per cent in different treatments with no significant difference existing between them (Table 13). While comparing the potassium content in tomato plants, particularly with respect to different parts, it could be seen that fruit maintained roughly 3.5 times higher content than rest of its plant parts. Nevertheless, the comparatively higher content of potassium in fruits is to be conceived in view of a source sink relationship where final culmination of photosynthates occur in fruits especially under the influence of a metal whose influence modifies the uptake and transport of potassium in plants.

5.14 DRY MATTER YIELD OF TOMATO PLANTS TREATED WITH CADMIUM

5.14.1 Root

In roots, there was a reduction in dry matter yield and that significant reduction in yield ranged between 0.131 g pot^{-1} and 4.152 g pot^{-1} (Table 14). The existence of a negative relationship between the level of cadmium application and the dry matter yield is very evident all through. The production of phenolic compounds under the influence of cadmium in tomato has been projected as one of the primary reasons for developing inhibitory effects on growth by Khan *et al.* (1999). Probably the same reason, which they projected, must have turned instrumental in retarding the growth in tomato in the current experiment leading to reduction in dry matter production. High and significant dry matter yield observed in control is fully justifying the observations of Khan *et al.* (1999). Further, the contentions on the inhibitory effects of cadmium observed in maize by Narwal and Singh (1993); in wheat and soybean by Haghiri (1972) and finally in sorghum by Mehla *et al.* (1989) are fully justifying the current observations.

5.14.2 Shoot

The shoot dry matter yield as evident from Table 14 also revealed the same trend, with the highest dry matter yield from control plants (15.18 g pot^{-1}) and the lowest from Treatment 4 (0.71 g pot^{-1}). The presence of cadmium had reportedly reduced the dry matter yield of maize (Florijn and Beusichem, 1993). In the current study, the same reasons and contentions upheld for the root portions of the plant are to be revalidated here for imbibing the reason behind the reduction in dry matter yield from different treatments. A similar reduction in dry matter yield in spinach under the influence of cadmium had been justified by Lehoczky *et al.* (1996) by stating that the plants remained sensitive to the metal and in such cases invariably the dry matter yield was compromised. Yet another reason stated for the reduction in dry mater yield in green gram by Krupa *et al.* (1993), is in favour of an alteration in fundamental physiological processes of plant metabolism, which might have initiated at the instance of cadmium. According to Greger *et al.* (1991), reduction in dry matter yield in sugar beet had occurred due to an enhanced cell respiration initiated at the expense of cadmium. The general contentions of Barcelo and Poschenrieder (1990) regarding the reduction in dry matter yield were more related to an induction of water stress in plants, once the plant senses the presence of the cadmium metal around it.

5.14.3 Fruit

The dry matter yield of economic plant part in tomato namely fruits also declined considerably with an increase in the concentration of cadmium. The application of treatments at higher levels, particularly at 1.5 and 2.0 mg Cd kg^{-1} soil has left the plant with no fruits in the former case and in the latter even the very establishment of the transplanted crop was at stake (Table 14). Nevertheless, in all treatments which permitted fruiting, an apparent reduction in fruit dry matter yield was noted. One or more of the several reasons, either independently or in combination must have acted in either retarding the fruit yield on one end and on the other extreme, these factors as stated, must have acted on the crop totally preventing them from fruiting. However, Poschenrieder *et al.* (1989) observed water stress, in relation to cadmium in bean plants necessitating reduction in fruiting.

5.15 DRY MATTER YIELD OF TOMATO PLANTS TREATED WITH LEAD

5.15.1 Root

The tomato plants treated with various levels of lead viz., 0.5, 1.0, 1.5 and 2.0 mg kg^{-1} soil did not bring about any significant reduction nor an increase in root dry matter production particularly when compared against the control with dry matter yield of roots ranging between 2.608 and 3.493 g pot^{-1}. It should be pursued from this result that the presence of lead even at 2.0 mg kg^{-1} soil hardly brought any remarkable influence on the dry matter production of roots.

5.15.2 Shoot

In case of shoots, though the dry matter yield exhibited a significant increase with enhancement in levels of addition of lead, the same never exceeded the dry matter production from control pots (Table 15). Compared to roots, the dry matter productions of shoots were generally higher. The significant difference particularly with an increase in dry matter production with enhancement in lead levels must be reckoned as a positive influence of the lead ions in altering the dry matter yield. The possible reason for such an occurrence in tomato could be explained in view of a justification already made in connection with the uptake of nitrogen in roots, where it is asserted that the nitrogen which is absorbed as lead nitrate, might have readily got translocated to aerial parts of the plant necessarily indicating a low content of nitrogen in roots. The same contention when viewed from another angle reinforces the fact that aerial parts contained fairly more nitrogen and lead. This enhanced level of nitrogen in shoot, particularly in the absence of any adverse effect of lead on growth and development must have kindled better growth of shoots and thereby promoting greater dry mater yield.

5.15.3 Fruit

In the absence of any inhibitory effect on fruiting, all levels of lead application permitted the tomato plants to produce fruits, though the fruits produced were seen to be positively influenced with enhancement in levels of addition. All levels of additions of lead, though helped to produce marginal difference in fruit dry matter yield, none was significant enough and all were comparable with control. In spite of this observed non-significant difference in dry matter yield for fruits, it is to be noted that fruits mainlined relatively highest dry matter yield when compared to its other parts.

5.16 CADMIUM UPTAKE IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS

In general, the tomato plants treated with different levels of cadmium accumulated cadmium in plants irrespective of any specific plant parts. Growing plant tissue acted more like a sink for both photosynthates and essential and non-essential mineral elements (Kabata-Pendias and Pendias, 1992).

5.16.1 Root

In tomato plants, higher accumulation of cadmium in roots is seen associated with higher levels of addition rather than its lower levels of addition. The failure of the transplanted plant to establish in Treatment 4 beyond three days is to seen as toxic effect of cadmium on the plant. As the dry matter yield of such plant at the time of death is very low, the computation of uptake, which is based both on concentration and dry matter yield, naturally justifies the highest uptake in Treatment 4. In the case of Treatment 3 where 1.5 mg Cd kg^{-1} soil had been added, the plant growth was normal but not as good as other treatment where lower doses had been applied. This observation implies that higher doses of cadmium particularly 1.5 mg Cd kg^{-1} soil was not capable of ensuring the death of tomato plants but such dose or even lesser doses were good enough to retard the growth to bring a noticeable and significant reduction in dry matter yield.

Further it has been observed that the root portions preferentially retained the metal than other plant parts of tomato and this retention was more in accordance with the concentration of the metal in the rhizosphere. This observation is justified by the findings of Grill *et al.* (1985), who proposed that binding of cadmium occurred in specific root cell proteins, which formed metabolically active complexes leading to cadmium accumulation in roots. Thus, the selective retention of cadmium in tomato roots might have prevented the roots from normal absorption of water and nutrients from soil, necessarily ensuring retardation of growth. The low content of nitrogen in the shoots and fruits together with the general chlorosis observed in cadmium treated plants provides another room for an argument that cadmium never supported the translocation nitrogen, leading to poor dry mater yield as against a reverse argument with lead in tomato plants. Cadmium accumulation in wheat roots had been reported by Florijn and Beusichem (1993), Koeppe (1997) and Mitchell *et al.* (1978).

5.16.2 Shoot

In the present study, a contradicting observation on the accumulation of cadmium in tomato had been noted with shoots preferring to accumulate less at higher doses of application of the metal vice versa at lower doses, remains hard to be explained. However, the genuineness for such an observance can perhaps be reasoned out through a contention where some cadmium might have migrated within the plant along with the transpirational pull of the water. This argument should be more valid in view of a report presented by Cieslinski *et al.* (1996) indicating their inability to identify the exact mechanism of internal cadmium translocation in wheat, although they observed that cadmium was mostly translocated from roots to top plant parts. At high concentration of the metal, particularly within the root portion, must not have favoured an internal diffusion of the metal on account of a possible binding of the metal to specific root cell proteins, forcing detection of higher concentration in such cases. On the contrary, at low concentrations, the metal must have diffused to other plant parts, more so to shoots forcing detection of lower concentration of these metals in roots. Further, Kabata-Pendias and Pendias (1992), without assigning any reason, observed that at lower levels of addition of cadmium, these metallic ions have been readily taken up by plants and retained in shoots even though they were not essential for plant growth. However, Florijn and Beusichem (1993) also failed to reason for a variation in the accumulation of cadmium in different plant parts on account of varying levels of the metal load in soil.

5.16.3 Fruit

In general, the fruits retained comparatively lower content of cadmium than other plant parts. On comparison of those treatments, which permitted the tomato plants to establish and then fruit, it is seen that the proportion of metal retained in the fruits had some direct bearing with the metal load in soil. Between the different treatments, which permitted fruiting, there was significantly difference in the retention of the metal, particularly when they are compared with control. The probable reason for the observed low level of cadmium and the variations in metal content in fruits, particularly on account of differences in treatment doses could in all probability due to the fact that re-translocation of cadmium from shoots to fruits perhaps might have taken place on a very slow rate. Similar observation of low content of cadmium in the grains of wheat and fruits of chillies, has been reported by Cieslinski *et al.* (1996) and Jidesh (1998) respectively reinforces the current observation in tomato.

The lowest content of cadmium in control plants, irrespective of the difference in plant parts might be due to the absence of sufficient quantity of the metal in the rhizosphere of the plant. The little cadmium content observed in such treatment might have been an indirect contribution mainly from some certain basic inputs like phosphatic fertilizer sources. Similar incidences of low content of cadmium in control treatments have been reported by Jaakkola *et al.* (1979), support the present argument in this study.

5.17 LEAD UPTAKE IN ROOTS, SHOOT AND FRUITS OF TOMATO PLANTS

Appreciable amounts of lead got accumulated in all the plant parts studied *viz*, roots, shoot and fruits with the highest accumulation in the fruits (edible part). A positive relationship had been noted between the level of lead application and the level of lead accumulation in plant parts in the current study. As the metal load in the soil increased, the corresponding uptake and subsequent accumulation in plant parts increased significantly. The accumulation of lead in tomato plant parts studied was observed to follow the order fruits > shoot > roots.

5.17.1 Roots

In roots, it had been noted that there was significant accumulation of lead (512.40 – 1745.0 μg pot^{-1}) in treatments and the extent of accumulation of lead had direct bearing on the metal load in soils. The relatively low uptake of the metal in roots compared to other plant parts might be due to its low retention in such parts. Metallic ions particularly lead which on entry into root region might have combined with nitrates to form lead nitrates which readily got translocated to aerial parts of the plant necessarily indicating a low content of lead in roots. The higher retention of lead observed at higher levels of metal application in soil, might be due to disparity in the availability of nitrate ions and lead ions, particularly when the later concentration is modified with enhancement in treatment levels. Yet another reason for this observation in view of the contentions of Jeana and Choudhuri (1982) in aquatic plants could be due to some membrane damage in root portions of the plant leading to higher permeability of tissues necessarily encouraging translocation of the metal to other parts in proportion to the metal load.

5.17.2 Shoot

In shoots, the same trend as observed with respect to root portion was evidently noted in tomato from the current studies (Table 17). Either the contentions in the formation of lead nitrate or that pointed out by Jeana and Choudhuri (1982) in aquatic plants, might have been a reason for the observed variation in the content of lead in shoots of tomato. The relatively low content of 497.6 μg Pb pot^{-1} observed in control plants perhaps might have come as a possible contribution from some basic inputs employed in the study particularly from 433.42 mg pot^{-1} of rock phosphate and 55.8 g pot^{-1} of organic manures which silently contributed 39.43 μg and 1.66 mg of lead respectively.

5.17.3 Fruit

The highest content of lead in fruits, with metal level increasing with enhancement in treatment levels, must be conceded as a natural phenomenon in view of the possible reasons enlisted for translocation of lead from roots and shoots. Since fruits are formed towards the fag end of the vegetative period of the plant, maximum translocation under any one or all the mechanisms of translocations suggested must have certainly operated to highlight the maximum content of lead in fruits. Though the mechanism of accumulation of lead in fruits has not been mentioned by Ghafoor *et al.* (2004), they have asserted accumulation of higher levels of lead in fruits in okra.

Even though, the roots, shoot and fruits of tomato plants from control pots, did not receive any external addition of lead at different levels, there was accumulation of lead in all plant parts at a minimal level and the only possibility for such a source could be from some basic inputs, which analysed the presence of lead. Jaakkola *et al.* (1979) reported the possible entry of metals from basic inputs particularly from fertilizers while Shrivastav (2001) indicated the entry of heavy metals particularly lead through atmospheric deposition whose principal site of accumulation according to him is the cell wall and intracellular membrane.

5.18 MEAN BIOMETRIC OBSERVATIONS OF CADMIUM TREATED TOMATO PLANTS 68 DAYS AFTER SOWING

Quite a few variations in biometric characters were observed in tomato plants due to different levels of application, particularly when compared to control. The absence of any influence of cadmium on the leaf production in tomato plants was very much evident through a non-significant variation in the number of leaves observed between any treatment and control. The stress induced in the plant on account of physico-chemical changes brought about by the presence of cadmium, perhaps must have prompted such plants to initiate fresh leaf buds enhancing the leaf numbers. Such an effort of the plant to stabilise under adverse conditions must have naturally compromised on the leaf length. A significant reduction in leaf length, as observed in different treatments, particularly with increasing doses of cadmium further testifies the above apprehension (Table 18). The significant reduction in the number of branches produced might have been due to a direct influence of the metal on growth upholding the contentions of Adriano and Aiken (2001), where they related the impaired plant growth with relatively high internal cadmium concentrations. At higher concentrations of the metal, particularly at 2.0 mg Cd kg^{-1} soil, the very survival of the tomato plants, even for a few days was questioned in the study. The report of Cobb *et al.* (2000) conforms such an observation.

From the results it is clear that none of the treatments particularly when compared against control, was not that significantly effective in altering the production of trusses. It was clear from the results that, as doses of cadmium increased the tendency to produce fruiting branches decreased and with the highest dose of 2 mg Cd kg^{-1} soil, even the very establishment of the transplanted tomato was questioned, not even giving a chance for the production of any trusses (Table 18).

The plant height of the tomato plants was found to be significantly and negatively influenced by the presence of cadmium with the maximum height of 31.25 cm observed in control. The tendency to decrease the height of tomato plants was very much evident from the doses, which provided enhanced metal loads in soil (Table 18). The tendency of the tomato plants to exhibit a retarded growth in presence of cadmium, notably at various levels of cadmium had already been established by Cobb *et al.* (2000) and Singh and Tiwari (2003) and the current observation is only strengthening contention to their views.

5.19 MEAN BIOMETRIC OBSERVATIONS OF LEAD TREATED TOMATO PLANTS 68 DAYS AFTER SOWING

Total absence of any significant difference in tomato, particularly in many biometric observations like, number of leaves, number of branches, number of trusses, leaf length and plant height, consequent to the application of lead at different levels (Table 19) spells its ineffectiveness in altering any biometric observations in that plant. Further, 68 days of establishment of the plant with different level of metal load as assigned by treatments highlights the ineffectiveness of time factor or duration of treatment in imparting any change in biometric observations. Ramani *et al.* (2002) upheld the same contentions in *Seshania aculeate*. Luxuriant growth observed in all the treatments is yet another indication of the fact that lead concentration did not produce any variation, which led to ambiguity on the effect of different levels of lead.

5.20 YIELD OF TOMATO PLANTS TREATED WITH DIFFERENT LEVELS OF CADMIUM

A significant reduction in yield was observed in tomato plants (46.5 – 292.8 g pot^{-1}) where cadmium had been applied at increasingly higher levels (Table 20) establishing a negative correlation between yield and levels of cadmium application. The very establishment of tomato plants was questioned in the study beyond 1.5 mg Cd kg^{-1} soil. Transplanted plants from Treatment 4 could survive in treated pots not beyond three days clearly indicates the toxic effect in permitting the plants to establish. A similar result was observed in carrot by Nair (1999). The decline in tomato yield, even at lower levels particularly when compared to control, perhaps might be due to a gradual decline in chlorophyll content at the instance of cadmium. With the possible decline in chlorophyll content, an imminent reduction in photosynthesis must have occurred necessarily reducing the growth and yield. An apparent decline in productivity due to low content of chlorophyll was observed in *Hydrilla verticillata* Royle (Arunachalam *et al.*, 1996).

5.21 YIELD OF TOMATO PLANTS TREATED WITH DIFFERENT LEVELS OF LEAD

From the present study, it is very evident that all the different levels of lead application in soil were quite ineffective in bringing any significant reduction in yield of tomato plants (Table 21), though the yield ranged from 163.0 253.5 g pot $^{-1}$. This observed ineffectiveness of lead, particularly higher doses, in bringing about any reduction in yield is surprisingly a contradiction to what Nair (1999) had observed in carrot. However, according to Mench *et al.* (1994), yield reduction on account of a higher uptake of heavy metals, need not be mandatory.

5.22 GENERAL SYMPTOMS EXHIBITED BY TOMATO PLANTS TREATED WITH CADMIUM

Assche and Clijsters (1990) reported that plants supplied with heavy metals particularly cadmium exhibited many different phyto-toxic effects. However, this contention is absolutely true in wake of the observation noted against different doses of cadmium application in tomato plants. The classic symptoms that appeared on plants could be well identified on leaves, stem, flowers and fruits.

At lower levels of application of cadmium, the initial symptoms appeared on leaves with such leaves picking up yellowing and inter-veinal chlorosis. Perhaps, this might be due to the possible reduction in the activity of chlorophyll or its atrophy once the metal reaches these leaves. Navarro-Pedreno *et al.* (1997) have indicated the presence of other plant pigment such as xanthophylls and when the leaf colour was dominated by such pigments, particularly in the absence of chlorophyll, leaf damage together with leaf chlorosis is being manifested in tomato. The reduction in leaf size and area, curling-in and consequent drying up of the leaves exhibited at later stages might again be a possible outcome of water stress created subsequently in the plants due to the accumulation of metal ions.

As noted by Khan *et al.* (1999), phenolic compounds are produced by the plants consequent to the application of heavy metals, which result in shortening of internodal region, thus ensuring retardation in growth. It is to be understood that the retardation of growth is proportionate to the metal load in soil. When heavy metal, particularly accumulates mainly in the cell wall and intracellular membrane, impedes the cell growth at higher concentrations of cadmium (Shrivastav, 2001). The brown discolouration noted in the stem of such tomato plants might be at such a point where vulnerable concentration of the metal must have occurred. Kim *et al.* (2000) noted brown discoloration of certain cells in carrot consequent to metal application. Further, Ormrod (1978) noted some direct effect of induced toxicity in plants by cadmium through an exhibition of brown lesion, on stem and leaves.

In tomato plants, at high concentrations of the metal, splitting up of the stem at the collar region and thereafter the complete death of such plants occur. The decrease in water content in the plants might have further increased the concentration of the cell sap leading to plasmolysis of the cells. This in turn must have weakened the collar region necessarily permitting a split on the stem, particularly at the collar region.

5.23 GENERAL SYMPTOMS EXHIBITED BY TOMATO PLANTS TREATED WITH LEAD

Lead application in tomato, even at higher levels failed to impose any phyto-toxicity symptoms except for certain malformations observed on fruits. This indicates that the tomato plants are able to tolerate high concentrations of heavy metals inside them without any acceptable phyto-toxicity manifestations. A similar conclusion had been noted in *Sesbania* plants by Ramani *et al.* (2002). The isolated occurrence of twin fruits and common brown discolouration of all the tomato seeds, irrespective of the fact that fruits remained twin or independent, was the only indication of the lead toxicity in tomato. The death of such seeds, on account of lead toxicity might be a fair reason for the appearance of brown colour in seeds. The malformations observed in some fruits may be due to the increased rate of cell division and cell multiplication. Perhaps another possibility for such an observation could be due to hypertrophy and hyperplasic conditions that might have prevailed during the growth and development of tomato fruits, particularly under the influence of lead. The luxuriant growth that was noted in tomato plants treated at various levels of lead could only be reasoned for the enhanced availability of nitrogen in shoots mostly as lead nitrate.

Summary

SUMMARY

The effect of different levels of cadmium and lead ranging from 0.5 to 2.0 mg kg^{-1} soil was assessed in the present study using tomato (*Lycopersicon esculentum* Mill.) as an indicator crop. The metals were supplied to the soil in their respective pots through water-soluble sources of cadmium and lead with the finite objective of locating their retention sites in plants. In order to quantify the possible metal contribution from extraneous sources, all the inputs including the virgin soil used in pot culture were subjected to a preliminary chemical analysis. After providing pre-calculated quantities of chemicals in pots, 42 day old uniformly grown tomato plants of variety Sakthi were transplanted to pots. The plants were allowed to establish till majority of the plants (50 per cent) were at the turning stage. In between, many biometric observations on the plants due to the impact of the metals were recorded. Fruits as and when they turned ripe were harvested with proper acknowledgment to their identity in treatments for yield and its subsequent dry weight. At harvest, the plants were carefully uprooted, cleaned properly and separated into root and shoot portions. After recording the weight of each portions, these parts were taken for analysis besides their post-harvest soil samples. From the different analysis done on soils (pre-treatment and post treatment) and different plant parts, the following observations could be derived.

1. The bulk soil selected for the study was found to be neither very rich in nutrients nor did they posses any abnormal problems like excessive acidity or electrolytic conductivity.

2. Invariably all the inputs utilized in the study, including the bulk soil, offered varying amounts of cadmium and lead.

3. The post-harvest soils, where cadmium and lead had been applied, registered a marginal increase in pH possibly due to the hydrolysis of the residual metal.

4. Transplanted tomato plants survived only at lower levels of addition of cadmium (0.5 and 1.0 mg Cd kg^{-1} soil). As concentration of the metal load increased (1.5 mg Cd kg^{-1} soil), the plants failed to fruit and at the highest concentration of the metal (2.0 mg Cd kg^{-1} soil), the very establishment of the transplanted tomato crop was failed.

5. Though significant variations in the available potassium status had been noted in the cadmium treated post harvest soil samples, the available phosphorus and nitrogen could not exercise their significant effect.

6. Invariably, the nitrogen content of roots of tomato plants was seen to increase with higher levels of cadmium application, and a reverse trend in the case of lower levels of application. It is seen that all levels of application of cadmium except Treatment 4, permitted significant increase in nitrogen content in shoots. The nitrogen content of fruits, particularly in those plants where fruiting was successful, was observed to be twice as that of its content in roots.

7. The phosphorus content of roots, shoot and fruits of tomato plants treated with varying levels of cadmium was found to increase significantly with an increase in metal load in soil. Among all the plant parts studied, fruits maintained the highest phosphorus content.

8. As levels of cadmium application of soil increased, there was a corresponding significant increase in the potassium content in tomato plants, irrespective of roots, shoot or fruits.

9. Much before an apparent growth or yield reduction was noted in tomato with cadmium application, the tomato plants readily exhibited certain characteristic symptoms, which could be associated with the metal toxicity on that plant. Preliminary indications appeared on leaves with such leaves picking up yellowing and inter-veinal chlorosis depending upon the metal load. At high

concentrations of the metal, invariable splitting up of the stem at the collar region leading to complete death of such plants has been noted.

10. On plants, which were permitted to survive under lower doses of addition of cadmium, the negative influence on growth and development was very much evident. Cadmium application resulted in significant reduction in number of branches, leaf length, leaf number, plant height, the production of trusses and subsequent reduction in yield.

11. Consequent to reduction in growth and yield of tomato plants from different levels of application of cadmium, necessarily brought significant reduction in dry matter yield, whose influence is clearly reflected in the roots, shoot and fruits portions underlining a negative influence of cadmium on the dry matter production.

12. Cadmium application in soil, irrespective of the levels permitted retention of the metal in all the plant parts, whether it is root, shoot or fruits. Roots of tomato are seen to preferentially retain more of cadmium than its other plant parts particularly at higher levels of addition. However, at lower levels of addition, shoots preferred to maintain more cadmium than its root portions.

13. The organic carbon content was found to be significantly low only in soils, which received the highest level of lead application, while with other treatments their status remained more or less same.

14. A general reduction observed for nitrogen and phosphorus status in the lead treated post-harvest soils could be due a better utilization of those nutrients by the crop.

15. Increasing levels of lead invariably decreased the root nitrogen content significantly while shoots content of nitrogen increased generally with lower

doses of metal addition. As observed in the case of cadmium, application of lead at all levels permitted the fruits to maintain a high content of nitrogen.

16. Lead application irrespective of its variation in levels permitted a significant increase in the phosphorus content in roots, shoot and fruits. As observed in the case of cadmium, lead application permitted the fruits to prefer the highest phosphorus content.

17. Though no specific trend was noted in the retention of potassium by roots under the influence of varying levels of application of lead, shoot portions indicated significant influence of the same by offering differential content of potassium in them.

18. Absence of any phyto-toxicity symptoms, particularly at higher levels of lead application in tomato, was a unique observation in the experiment. However, such higher doses rendered some fruits, if not all with certain malformations. This testifies that the tomato plants are able to tolerate high concentrations of lead inside them without any acceptable phyto-toxicity manifestations.

19. In the absence of any negative impact of lead on the growth of tomato, lead application is finally believed to have brought significant increase in dry matter production in tomato, particularly when higher levels of lead application promoting better growth than its corresponding lower levels. This is to be construed as an unusual influence of this heavy metal in enhancing dry matter production unlike cadmium.

20. Lead application in soil, irrespective of its levels, permitted maximum accumulation of the metal in fruits followed by shoots and roots. All accumulation noted in the plant were observed to be significant, projecting serious concern for the silent inclusion of lead in the economically important part of the plant.

21. It is to be presumed that entire quantity of the applied cadmium and lead were not seen completely absorbed by the plant especially in view of the detection of the residual metal in the post-harvest soil samples analysed. Further, it is to be noted that the absorption of cadmium and lead by the tomato plants is more or less in direct proportion to the metal load in the rhizosphere.

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* Originals not seen

ASSESSMENT OF SELECTIVE RETENTION SITES OF CADMIUM AND LEAD IN TOMATO
(*Lycopersicon esculentum* Mill.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

The bio-availability of the toxic heavy metals like cadmium and lead together with its selective retention sites in tomato (*Lycopersicon esculentum* Mill.) was one of the major concerns in the crop. For this, pre-calculated quantities of cadmium and lead were applied to the soil mainly as water-soluble sources (cadmium chloride and lead nitrate respectively) to assess the finite objectives envisaged in the study.

In order to meet the objectives, a pot culture experiment was conducted in the Vegetable Research Farm attached to the Department of Olericulture, College of Horticulture, Vellanikkara during the *rabi* season of 2003 with five treatments and four replications.

Pre-treatment analyses of all basic inputs and soil were carried out to quantify the possible inclusion of heavy metals from them. After providing pre-calculated quantities of metals in pots, 42 day old and uniformly grown tomato plants of variety Sakthi were transplanted to pots. The plants were allowed to establish till majority of the plants (50 per cent) were at the turning stage. Biometric observations on the plants due to the impact of the metals were recorded. Fruits as and when they turned ripe were harvested with proper acknowledgment to their identity in treatments for yield and its subsequent dry weight. At harvest, the plants were carefully uprooted, cleaned properly and separated into root and shoot portions. After recording the weight of each portions, these parts were taken for analysis. Post-harvest soil samples were also collected and analysed to see the extent of availability of major nutrients and heavy metals, particularly cadmium and lead. All the inputs including soil maintained variable amounts of cadmium and lead, with maximum metal load contributed from phosphatic sources.

It is seen that growth of tomato plants in pots, particularly under the influence of different levels of cadmium and lead, manifested differential growth and development. Internally also, the plants exhibited differential metal load and retention patterns apart from recording variation in the uptake of major nutrients. A brief resume of the major influence of different levels of cadmium and lead in soil and on the tomato plants is presented hereunder.

Variation in cadmium levels in soil could influence significant variations in the available nutrient status in post-harvest soil samples. Accordingly, an increase in metal load permitted enhanced potassium availability in soil while the same status had an opposite effect particularly with respect to the available phosphorus and nitrogen.

The nitrogen content of root and shoot of tomato plants was seen to be positively influenced with higher levels of cadmium application. However, a reverse trend in nitrogen content was observed with lower levels of application except for the shoot portions observed from Treatment 4. Among the various plant parts analysed, the fruits maintained the maximum nitrogen content and this content was roughly observed to be twice as that of its content in roots. Enhancement in cadmium level in soil resulted in a corresponding increase in the phosphorus content of roots, shoot and fruits. As observed for nitrogen, fruit portion maintained the maximum phosphorus content. A very similar trend was noted for the potassium content in tomato, consequent to the application of different levels of cadmium.

Much before an apparent growth or yield reduction was noted in tomato with cadmium application, the tomato plants readily exhibited certain characteristic symptoms, which could be associated with the metal toxicity on that plant. Preliminary indications appeared on leaves with such leaves picking up yellowing and inter-veinal chlorosis depending upon the metal load. At high concentrations of the metal, invariable splitting up of the stem at the collar region leading to complete death of such plants has been noted.

As concentration of the cadmium load increased beyond 1.5 mg kg^{-1} soil, the tomato plants failed to fruit and at the highest concentration of the metal envisaged in the study (2.0 mg Cd kg^{-1} soil), the very establishment of the transplanted tomato crop was questioned. However, the successful survival and fruiting of the transplanted tomato plants was noted only at lower levels of cadmium addition (0.5 and 1.0 mg Cd kg^{-1} soil). Lower doses of addition of cadmium had exhibited negative influence on growth and development in tomato with the manifestation of significant reduction in number of branches, leaf length, leaf number, plant height, the production of trusses and subsequent reduction in yield.

Reduction in growth and yield of tomato plants from different levels of application of cadmium, necessarily brought significant reduction in dry matter yield, whose influence is clearly reflected in the roots, shoot and fruits portions underlining a negative influence of cadmium on the dry matter production.

At all levels of cadmium application, there was sufficient retention of the metal in plant whether it is root, shoot or fruits. Roots of tomato are seen to preferentially harbour more of cadmium than its other plant parts particularly at higher levels of addition. However, at lower levels of addition, shoots preferred to maintain more cadmium than its root portions.

Increasing levels of lead invariably decreased the root nitrogen content significantly while shoots content of nitrogen increased generally with lower doses of metal addition. Variation in lead levels permitted a significant increase in the phosphorus content in roots, shoot and fruits. No specific trend was noted in the retention of potassium by roots while shoot portions indicated significant influence of the same by offering differential content of potassium in them. Among all the plant parts, fruits maintained the maximum nitrogen, phosphorus and potassium content.

Higher doses of lead rendered some fruits, if not all with certain malformations. This together with the total absence of any phyto-toxicity testifies that the tomato plants are able to tolerate high concentrations of lead inside them. Quite contrary to the expectations, an unusual increase in dry matter production was observed from lead treated tomato plants.

Lead application in soil, irrespective of its levels, permitted maximum accumulation of the metal in fruits followed by shoots and roots. All accumulations noted in the plant were observed to be significant, projecting serious concern for the silent inclusion of lead in the economically important part of the plant.

Variable amounts of cadmium and lead have been detected in the post-harvest soils indicating that the entire quantity of the applied cadmium and lead could not be completely absorbed by the plant.