

**ASSESSMENT OF SOME PHOSPHATIC SOURCES
FOR POSSIBLE ACCUMULATION OF
HEAVY METALS IN CHILLI (*Capsicum annum* L.)**

**By
C. V. JIDESH**

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 654

KERALA, INDIA

1998

DECLARATION

I hereby declare that the thesis entitled '**Assessment of some phosphatic sources for possible accumulation of heavy metals in chilli (*Capsicum annuum* L.)**' 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.

Vellanikkara

- 1998


C.V. JIDESH

CERTIFICATE

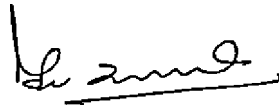
Certified that the thesis entitled '**Assessment of some phosphatic sources for possible accumulation of heavy metals in chilli (*Capsicum annuum* L.)**' is a record of research work done independently by **Sri.C.V. Jidesh**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.



SAM T. KURUMTHOTTICAL
Chairman, Advisory Committee

CERTIFICATE

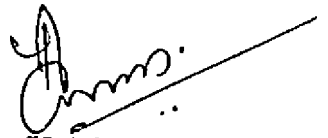
We, the undersigned members of the Advisory Committee of Sri.C.V. Jidesh, a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled '**Assessment of some phosphatic sources for possible accumulation of heavy metals in chilli (*Capsicum annuum* L.)**' may be submitted by Sri.C.V. Jidesh, in partial fulfilment of the requirement for the degree.



Sam T. Kurumthottal
Assistant Professor
Department of Soil Science and
Agricultural Chemistry
College of Horticulture, Vellanikkara
(Chairman)



A.I. Jose
Associate Dean
College of Horticulture
Vellanikkara
(Member)

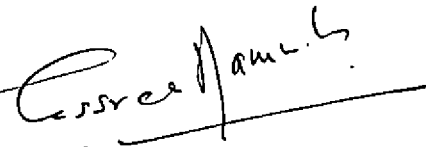


K.A. Mariam
Associate Professor
Regional Agricultural Research Station
Pattambi
(Member)



P. Indira
Associate Professor
Department of Olericulture
College of Horticulture
Vellanikkara
(Member)

Approved



EXTERNAL EXAMINER

ACKNOWLEDGEMENT

I express my deep sense of gratitude and indebtedness to Dr.Sam T. Kurumthottical, Assistant Professor, Department of Soil Science and Agricultural Chemistry and Chairman of the Advisory Committee for his valuable guidance, everwilling help, constant encouragement, inspiration and patience through out the course of study, research work and preparation of the thesis. It has been a great pleasure to work under his competent guidance and perpetual support.

I am very much indebted to Dr.A.I.Jose, Associate Dean, College of Horticulture for his valuable help and useful suggestions accorded to me during the course of study and in the preparation of manuscript.

Heartfelt thanks are due to Smt.K.Leela, Professor and Head, Department of Soil Science andAgricultural Chemistry for the help extented to me throughout this investigation.

I thankfully acknowledge Dr.K.A.Mariam, Associate Professor, Regional Agricultural Research Station, Pattambi and member of my advisory committee for her critical support and affectionate advice given throughout my course of study.

My profound sense of gratitude is due to Dr.Indira, Associate Professor, Department of Olericulture and member of my advisory committee for her whole hearted cooperation, candid suggestions and the keen interest she had shown in the completion of this work.

I extend my sincere thanks to Sri.S.Krishnan, Assistant Professor, Department of Agricultural Statistics for his valuable advice and help rendered in the statistical analysis of the data.

My sincere thanks are due to all the staff members of the Department of Soil Science and Agricultural Chemistry for extending all possible help in the proper conduct of this research work.

I can't forget the encouragement and help given by my friends Sudeesh, Ajay, Yogi, Prasad, Manoj, Ajith, Shyam, Satchith, Rajesh, Sakeer, Salvi Sir, Rao Sir and Nicy at the various stages of this programme.

I am thankful to Mr.Joy for the neat and prompt typing of the manuscript.

It is with deepfelt gratitude, I remember the warm blessings moral support and inspiring encouragement of my parents, sister (Jolsna) and relatives which helped me to undertake this endeavour successfully.

Above all, I submit this small venture before GOD ALMIGHTY for blessing me with health and confidence throughout the study.


C.N. JIDESH

Dedicated to my loving sister

Jolsna

CONTENTS

	Page No.
INTRODUCTION	1 - 2
REVIEW OF LITERATURE	3 - 24
MATERIALS AND METHODS	25-36
RESULTS AND DISCUSSION	37-74
SUMMARY	75-78
REFERENCES	1 - x
APPENDICES	79-82
ABSTRACT	83-84

LIST OF TABLES

Table No.	Title	Page No.
1	Concentrations of heavy metals in some phosphatic sources (mg kg^{-1})	38
2	Phosphate fractions in some phosphatic sources	38
3	General characteristics of the soil used for pot culture experiment	40
4	Drymatter yield of chilli root (g pot^{-1})	41
5	Drymatter yield of chilli shoot (g pot^{-1})	41
6	Drymatter yield of chilli fruit (g pot^{-1})	41
7	P uptake by chilli root (mg pot^{-1})	44
8	P uptake by chilli shoot (mg pot^{-1})	44
9	P uptake by chilli fruit (mg pot^{-1})	44
10	Cd uptake by chilli root ($\mu\text{g pot}^{-1}$)	46
11	Cd uptake by chilli shoot ($\mu\text{g pot}^{-1}$)	46
12	Cd uptake by chilli fruit ($\mu\text{g pot}^{-1}$)	46
13	Pb uptake by chilli root ($\mu\text{g pot}^{-1}$)	48
14	Pb uptake by chilli shoot ($\mu\text{g pot}^{-1}$)	48
15	Pb uptake by chilli fruit ($\mu\text{g pot}^{-1}$)	48
16	<u>Bray-I</u> extractable P from post-harvest soil samples (mg kg^{-1})	50
17	<u>DTPA</u> extractable Cd in post-harvest soil samples (mg kg^{-1})	50

18	<u>DTPA</u> extractable Pb in post-harvest soil samples (mg kg^{-1}).	50
19	Total Cd in post-harvest soil samples (mg kg^{-1})	53
20	Total Pb in post-harvest soil samples (mg kg^{-1})	53
21	Drymatter yield of chilli root (g pot^{-1}) from direct application of heavy metals in pots with and without organic matter	53
22	Drymatter yield of chilli shoot (g pot^{-1}) from direct application of heavy metals in pots with and without organic matter	55
23	Drymatter yield of chilli fruit (g pot^{-1}) from direct application of heavy metals in pots with and without organic matter	55
24	P uptake by chilli root (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	57
25	P uptake by chilli shoot (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	57
26	P uptake by chilli fruit (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	57
27	Cd uptake by chilli root (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	59
28	Cd uptake by chilli shoot (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	59
29	Cd uptake by chilli fruit (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	59
30	Pb uptake by chilli root (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	61
31	Pb uptake by chilli shoot (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	61

32	Pb uptake by chilli fruit (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter	61
33	Bray-I extractable P from post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter	63
34	DTPA extractable Cd post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter	63
35	DTPA extractable Pb post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter	63
36	Total cadmium in post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter	66
37	Total Pb in post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter	66
38	Drymatter yield of plant parts (g pot^{-1}) from partially acidulated phosphate rock applied pots	68
39	P uptake by chilli in root, shoot and fruit (mg pot^{-1}) from partially acidulated phosphate rock applied pots	68
40	Cd uptake by chilli in root, shoot and fruit ($\mu\text{g pot}^{-1}$) from partially acidulated phosphate rock applied pots	71
41	Pb uptake by chilli in root, shoot and fruit ($\mu\text{g pot}^{-1}$) from partially acidulated phosphate rock applied pots	71
42	DTPA extractable Cd and Pb in post-harvest soil samples (mg kg^{-1}) from partially acidulated phosphate rock applied pots	73
43	Total Cd and Pb in post-harvest soil samples (mg kg^{-1}) from partially acidulated phosphate rock applied pots	73

LIST OF FIGURES

Fig.No.	Title	Between Page no.
1	Concentrations of heavy metals in some phosphatic sources	38-39
2	Cadmium uptake by chilli root, shoot and fruit from different P sources at level 1	46-47
3	Cadmium uptake by chilli root, shoot and fruit from different P sources at level 2	46-47
4	Cadmium uptake by chilli root, shoot and fruit from different P sources at level 3	46-47
5	Lead uptake by chilli root, shoot and fruit from different P sources at level 1	48-49
6	Lead uptake by chilli root, shoot and fruit from different P sources at level 2	48-49
7	Lead uptake by chilli root, shoot and fruit from different P sources at level 3	48-49
8	Cadmium uptake by chilli root, shoot and fruit from direct application of heavy metals without organic matter	59-60
9	Cadmium uptake by chilli root, shoot and fruit from direct application of heavy metals with organic matter	59-60
10	Lead uptake by chilli root, shoot and fruit from direct application of heavy metals without organic matter	61-62
11	Lead uptake by chilli root, shoot and fruit from direct application of heavy metals with organic matter	61-62
12	Cadmium uptake by chilli root, shoot and fruit from partially acidulated phosphate rock	71-72
13	Lead uptake by chilli root, shoot and fruit from partially acidulated phosphate rock	71-72

LIST OF APPENDICES

Appendix No	Title	
1	Nitrogen uptake of chilli in root, shoot and fruit (mg pot ⁻¹)	79
2	Phosphorus uptake by chilli in root, shoot and fruit (mg pot ⁻¹)	80
3	Potassium uptake by chilli in root, shoot and fruit (mg pot ⁻¹)	81
4	Soil chemical parameters of post-harvest soil samples	82

Introduction

INTRODUCTION

The concern of increasing heavy metal concentration in the environment and its adverse effect on human health has created global awareness especially when inhalation and ingestion have been identified as the most important modes of entry. Though heavy metals are widely distributed in the environment the concentrations of individual metals in the living tissues are ordinarily very low and must be maintained within narrow limits to permit the optimum biological performance of most organisms.

Although metal concentration of the soil can occur through a variety of process its bioavailability is being regulated mostly through physical and chemical characteristics of soil. Once the conditions in the soil favour the uptake of heavy metals, it enters the food chain mainly through roots and will be selectively retained in the different plant parts. The exact portions of plant at which these selective retention occurs cannot be predicted as it varies with the variations in plant type. Such selective retention in the different plant parts open up the necessity to identify the exact plant part for each crop where such accumulation occurs and the concern attain global dimension especially when such accumulation confines to the economic plant parts.

In the present study with chilli (*Capsicum annuum* L.) as the index crop, emphasis is placed on the comparative evaluation of the uptake of heavy metals through fertilizers especially phosphate sources, acidulated rock sources and the uptake of heavy metals through soluble sources of heavy metals to re-define the following objectives set apart for this study.

1. To characterise the different P sources for possible level of contamination by the heavy metals especially Cd and Pb.
2. To assess the extent of selective retention of these metals in plant parts of the test crop chilli.
3. To ascertain whether the contaminants are present in the root, shoot or fruit portion of the crop.

Review of Literature

REVIEW OF LITERATURE

1 Soil factors controlling the heavy metal availability to plants

1.1 Organic matter

Andersson and Nilsson (1974) observed that the presence of high organic matter content in soil is found to decrease the heavy metal concentration in soil solution, possibly because of its high ability to form stable complexes with the metals, coupled with the high CEC permitting high adsorption of the metals.

Haghiri (1974) observed that the deleterious effects caused by Cd on plants could be reduced by an addition of organic matter, which significantly increased the adsorption of heavy metals especially Cd. He further noted that whenever the addition of organic matter was reduced in a contaminated soil, the availability of heavy metals remained high, which according to him was due to reduced CEC.

Andersson (1976) analysed a sample of farmyard manure for possible heavy metal content and reported that under normal application rates, an annual input of 1-4 g Cd ha⁻¹ can be expected in soils.

Alloway *et al.* (1984) reported that high organic matter content in soils or fresh addition of organic matter to soils decreased the solution concentration of cadmium.

Levi and Petruzzelli (1984) reported that addition of phosphatic fertilizers induced variations in the pH values of soil suspensions which in turn had influenced the solubility of the heavy metal in the two soils they studied. However, in the

organic matter rich soils they studied, effect of phosphate was less evident on account of the high buffering capacity of such soil.

Rothbaum *et al.* (1986) observed that whenever cadmium was incorporated into organic matter its mobility considerably decreased and under such conditions, the only factor which controlled the mobility of cadmium was the soil pH.

Erikson (1988) reported that organic components in soil played a significant role in absorbing Cd than clays by virtue of the specific sites for adsorption. According to him such adsorption resulted not only in the reduced availability of heavy metals to plants but also in the reduced uptake of such elements by plants. This report is in line with the finding of He and Singh (1993) where a decreased concentration of Cd was noted in rye grass consequent to heavy addition of organic matter.

Jones and Johnston (1989) noted that addition of FYM could supply extra organic matter, which could retain cadmium and other metals against leaching and crop uptake.

1.2 pH

Among the various factors that decide the availability of heavy metals from soil, pH plays a very significant role (Page and Bingham, 1973; Bingham, 1979).

Andersson (1976) reported that the exchange acidity caused by fertilizer addition, resulted in a drop in pH, favouring increased solubility of Cd in soils.

William and David (1976) observed that whenever radish (*Raphanus sativus*) was grown in limed soils, it had lower cadmium content in plant parts than those plants grown on unlimed control plots.

Cavallaro and McBride (1978) have shown that acidic soils demonstrated much less ability to retain heavy metals when compared to neutral soils. The probable mechanism that they had suggested is that, under low pH situations, the functional groups attached to soil organic matter retained either proton or Al^{3+} , thus reducing the chances of Cu^{++} or Cd^{++} from getting adsorbed to such sites.

Basta and Tabatabai (1992) observed that at high concentrations the metal adsorption by soils was strongly related to solution pH, and that enhanced metal adsorption by soils was related to an increased solution pH.

Wells *et al.* (1993) reported that yield of corn had no relation to the content of heavy metals in either the soil or in the grains produced. They also reported that there was no relationship between soil pH and heavy metal accumulation by grain.

1.3 CEC

Haghiri (1974) reported that continuous addition of heavy metal sources resulted in the gradual build up of metals, especially cadmium in soil. Wherever, the soil accounted for higher CEC, these metals were not immediately available to the crop and hence potential for crop damage is minimised in such cases.

He and Singh (1993) observed that plant cadmium was highly but negatively correlated with soil CEC.

1.4 Other factors

According to Bingham *et al.* (1983), in addition to the normal factors that are responsible for the availability of Cd in soil, the chemical species of the metal is an important factor influencing the availability of Cd to plants.

Basta and Tabatabai (1992) reported that the differences in the metal adsorption by soil were dependent on the initial heavy metal concentration and that at low concentrations all the added metals were adsorbed to soil regardless of solution pH.

2 Mobility of heavy metals in soil

John *et al.* (1972) observed that cadmium level decreased progressively with depth as downward movement of cadmium in the soil profile may occur only at a limited rate. A rapid decrease of cadmium level in the surface sample with increased lateral distance from the source of contamination was also noted by them.

The mobility of Cd^{2+} in soil is identified to be relatively more than that of Cu^{2+} , as the latter is more strongly adsorbed than the former in soils (Cavallaro and McBride, 1978).

According to Doner (1978), the relative concentration of chloride was observed to be higher in irrigated soils and in waste disposal sites. These chloride ions are known to form stable complexes with cadmium which increased the mobility of Cd in such soils. A similar view regarding the mobility of Cd had been reported by Bingham *et al.* (1984).

Mulla *et al.* (1980) reported that the mobility of cadmium was less than phosphorus in soil profile, as indicated by a high retention value of 71 per cent of the accumulated cadmium in the surface soil (0 to 15 cm), whereas the corresponding retention of residual phosphate was only 45 per cent.

According to Khan and Frankland (1983) there was only very little movement of Cd and Pb in soil and for this reason they are largely retained in the surface soil. However, a contradictory view on the mobility of Cd had been reported by Alloway and Morgan (1986), wherein the relative availability of Cd to plants was much greater than that of other potentially harmful heavy metals like lead in soil.

Bjerre and Schierup (1985) reported that cadmium was more mobile than lead and copper in all types of soil they studied.

According to Hargitai (1989), results obtained from a 10 year long-term experiment with sewage sludge application indicated that heavy metals (Pb, Ni, Cd) did not have much mobility. He further suggested that the possible reason for this could be due to the poly functionality and the chelating character of humic substances present in the soil. According to him the depression effect of humic materials was much greater for the heavy metals like, Pb and Ni when compared to cadmium.

According to Mench *et al.* (1994) the maximum decrease in mobility and plant uptake of Cd and Pb should mainly related to their solubility and sorption mechanism in soils especially to hydrous iron oxide.

Ramos *et al.* (1994) reported that lead and zinc were associated with the crystalline Fe-oxide fraction in soils and their mobility in soil was in the order of Cd > Zn > Pb > Cu.

3 Forms of cadmium and other heavy metals in soil

Williams and David (1973) indicated that Cd in the superphosphate was mostly water soluble and usually seen associated with the phosphate and sulphate components of the fertilizer.

Mortvedt and Osborn (1982) found that the chemical form of Cd contained in TSP and DAP is $\text{Cd}(\text{H}_2\text{PO}_4)_2$, CdHPO_4 , or a mixture of these salts.

According to Sposito *et al.* (1982) the concentrations of exchangeable and water soluble forms of Cd were very low in soils.

Eriksson (1988) reported that in organic matter rich soils, majority of the Cd adsorbed to soil remained in a non-exchangeable form, indicating thereby presence of strong organic complexing.

A sequential extraction technique for cadmium according to He and Singh (1993) will reveal the distribution of cadmium in various chemical forms, its solubility, mobility and bioavailability in soils.

4 Phosphatic sources - a potential source of heavy metal contamination

Phosphatic fertilizers are manufactured by using phosphate rock either directly or indirectly. Under certain situations phosphate rocks are used for direct

application to soil as ground mineral phosphate. Phosphate rocks, in general and superphosphates in particular, contain discrete amounts of various heavy metals as impurities, particularly Cd, leading to a possible enrichment of heavy metals in agricultural soils, especially when the recipient soils are acidic in nature or rich in organic matter.

Very little information is available on the heavy metal contents of Indian phosphate rocks and this becomes all the more conspicuous in the context of greater diversity that exists in the Indian phosphate rocks which are generally rated as low grade materials, consequently necessitating their application in greater quantities. A brief review of the heavy metal status of some important phosphate sources around the world is attempted.

It is clear from the various reports that no two phosphatic sources can be grouped for their relative heavy metal content. Schroeder and Balassa (1963) indicated a low analysis for Cd in superphosphate (7.25 ppm). However, when they had added extremely heavy doses of superphosphate fertilizer to soil, they confirmed that such high doses of superphosphate fertilizers were potential source for supply of Cd to plants. On the contrary, Huffman and Hodgson (1973) in a study observed that extensive use of superphosphate fertilizers in soils had not resulted in any notable increase in Cd levels in plants.

Williams and David (1973) reported a cadmium content of 38-48 ppm in another sample of superphosphate elsewhere and, for the phosphatic fertilizer manufactured in New South Wales their reported values on the Cd content were in the range 18-91 ppm. Further they suggested that more than 80 per cent of the Cd in the phosphate rock remained with the P component during the manufacturing process resulting in the enrichment of heavy metals in the final product.

After examining 21 commercial fertilizer samples, Lee and Keeney (1975) reported that Cd concentration ranged from 1.5 to 9.7 mg kg⁻¹, while Zn showed a much wider range of 21 to 3290 mg kg⁻¹. Further, they suggested that depending on the raw materials and manufacturing process employed the content of heavy metals in fertilizers differed. Reuss *et al.* (1978) also expressed a similar view emphasising that phosphate ores used for the manufacture of P fertilizers were highly variable especially with regard to heavy metals and more so with cadmium content.

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 deposition.

William and David (1977) reported that the Cd content of plants was affected by the amount of P fertilizer applied to soil.

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.

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 (Mortvedt and Osborn, 1982).

Morvedt and Hamphill (1984) noted relatively lower plant availability for Cd and Zn observed as contaminants in P fertilizers even at higher levels of P fertilization.

Muramoto and Aoyama (1990) reported that some phosphate fertilizers and phosphorite contained high concentration of Cd (4 to 77 $\mu\text{g g}^{-1}$) and were considered to be one of the main reasons for increasing Cd content in rice plants.

The water soluble fraction of Cd in soil had been reported to be enhanced with increased levels of P fertilization (Kaushik *et al.*, 1993).

Hlusek (1994) found that with heavy doses of superphosphate application no appreciable increase in cadmium content of soils was noted. According to him, the content of Pb decreased with increasing P levels.

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.

5 Interaction of heavy metals with other ions

John (1972) had shown that the total and exchangeable Al in soils were negatively correlated to Cd^{2+} adsorption, suggesting that reduced Cu^{2+} and Cd^{2+} adsorption maxima observed in acid soils might have resulted from the possible Al competition for exchange sites.

Mulla *et al.* (1980) observed that very high levels of P in soil, inactivated the Zn and Cd and this reduced their uptake in barley plants, while the control plots permitted relatively higher uptake of Zn in barley grains.

Bingham *et al.* (1984) reported that cadmium/zinc ratio of plant tops of Swiss chard was significantly influenced by both cadmium and zinc application to soils.

6 Bioavailability of heavy metals

Alloway and Morgan (1986) reported that relative availability of Cd to plants is much greater than that of other potentially harmful heavy metals like lead in soil.

Bingham *et al.* (1986) reported that plant cadmium correlated primarily with total concentration of Cd in solution than its Cd activity.

The bioavailability of cadmium was calculated by Mench *et al.* (1989), as the ratio of the cadmium level in the control plants to that in the soil or as the ratio of the added Cd taken up from Cd(NO₃) to the amount of Cd applied.

According to Pierzynski and Schwab (1993), addition of cattle manure had a positive influence in reducing the bioavailability of Zn, Cd and Pb grown in a metal contaminated alluvial soil.

Ramos *et al.* (1994) in a study found that the bioavailable fraction of Cd approximates to more than 50 per cent of the total Cd found in soils.

Uptake of heavy metals by plants

The influence of pH on the uptake of Cd and Zn by radish plants was examined by Lagerwerff (1971). He found that there was a fall in the uptake of Zn when soil pH was raised from 5.9 to 7.2. Mortvedt (1985) too had expressed a similar view. However, according to him the uptake of Cd was more than that of Zn, under the increase in pH.

Plant uptake of Cd from the Cd residue in soil according to Williams and David (1973) in subterranean clover was generally small and it was only 0.4 to 7 per cent of the available quantity in soils. They also indicated that uptake was influenced mostly by the type of soils and presence of calcium carbonate.

Johns and Laerhoven (1976) reported that the ability to accumulate Cd in lettuce varied considerably with the variation in the varieties.

Mortvedt and Giordano (1977) reported a higher uptake of Cd and Zn when treated with commercial DAP (30-50 $\mu\text{g Cd g}^{-1}$) than those treated with reagent grade DAP (1 $\mu\text{g Cd g}^{-1}$).

Mortvedt and Giordano (1977) in a study on the crop uptake of heavy metal contaminants from fertilizers concluded that uptake of contaminants other than zinc was not significant at the normal rates of phosphorus application in the field.

Reuss *et al.* (1978) found higher Cd uptake by radish (*Raphanus sativus* L.), lettuce (*Lactuca sativa* L.) and peas (*Pisum sativum* L.) from application of commercial TSP containing 174 ppm Cd than from reagent grade $\text{Ca}(\text{H}_2\text{PO}_4)_2$, the

main P component in TSP, clearly indicating that Cd was taken up along with the phosphate.

Street *et al.* (1978) observed that when the amount of Cd added to soil was enhanced, concentration of Cd in the corn seedlings registered higher levels and that the form of Cd applied in soil had no influence on the uptake.

Allen *et al.* (1980) observed that plant uptake of Cd and its accumulation, leading to phytotoxicity were very much dependent on the activity of Cd in soil solution.

Mulla *et al.* (1980) reported a non-significant increase in the Cd and P concentration in barley grains grown on heavily fertilized soil having substantial Cd and P content. Further, their experiments with Swiss chard on surface soils which permitted heavy additions of N (400 kg N ha^{-1} through calcium nitrate and 200 kg N ha^{-1} through organic matter) over 36 years, indicated a significant increase in the level of Cd in the plant tissue (average $1.6 \mu\text{g g}^{-1}$) over control ($0.26 \mu\text{g g}^{-1}$). However, under such heavy accumulations of Cd in plants, they failed to register any yield depression.

The results obtained by Mortvedt *et al.* (1981) from a field experiment with winter wheat indicated that when DAP fertilizers, were applied in conjunction with Cd at three levels, the rate of uptake of Cd by plant both in grain and straw increased proportionally with the amount of Cd in the DAP sources.

Report by Carlton and Davis (1983) clearly indicated that when Cd was introduced into the soil through anthropogenic sources, Cd concentrations in plant tissues also increased markedly.

According to Khan and Frankland (1983), addition of Cd or Pb to soils raised their concentration in plant tissues to phytotoxic levels leading to reduction in plant growth. They also indicated that phytotoxicity was usually seen associated with the reduction of Zn in the plant tissue. Further they reported that of these two metals, Cd was more in the plant shoot while Pb was more in plant root.

An increase in the uptake of Cd by lettuce consequent to the nitrogen application in soil was noted by Singh *et al.* (1988). They reported that when N and Cd were applied together, increased uptake of Cd was seen noticed only up to a level of 100 mg N kg⁻¹ and beyond which there was a sharp reduction in the cadmium uptake at all levels of Cd, especially when the nitrogen levels were maintained at 150 mg kg⁻¹ soil.

Eriksson (1988) reported that soil acidity, organic matter content, cation exchange capacity, redox status and temperature influenced the uptake of heavy metals. He further suggested that the antagonistic or synergistic effects between other metals and P must also be taken into account in deciding the uptake.

Mann and Ritchie (1993) concluded that uptake of cadmium by plants was generally influenced by the form in which it was present in the soil, and this determined the indirect potential toxicity to animals and human beings.

Chien and Menon (1994) reported that as drymatter yield of maize increased with enhanced P application, the relative phosphate and cadmium uptake also increased. According to them Cd uptake by maize was more related to the phosphate solubility and total Cd content of the fertilizer applied.

8 Translocation of heavy metals by plants

Haghiri (1973) reported that radioactive cadmium applied to a trifoliate leaf of a four-week old soya plant, readily got translocated and distributed within the plant. Although foliar applied Cd was readily translocated into various parts of the soya plant, the uptake of Cd via root system was significantly higher. Results indicated that Cd concentration in the radish top ranged from 1.6-2.9 ppm while that of Zn was in the range 69.8-152 ppm.

Jarvis *et al.* (1976) reported that although the roots of several species could take up large quantities of cadmium from solution there were distinct mechanisms which might have restricted the movement of cadmium through plants, and thus to animals. They further reported that the transport and mobility of Pb and Cd within the plant related to the solubility of their phosphate, which was often affected by the seasonal variation, resulting in the re-distribution of metals within the plant.

Pettersson (1976) assessed the heavy metal uptake by rape, cucumber, wheat, oats and tomato from nutrient solution supplemented with certain heavy metals viz., Cr^{3+} , Cu^{2+} , Co^{2+} , CrO_4^{2-} , Ni^{2+} , Cd^{2+} , Pb^{2+} , Mn^{2+} , Zn^{2+} and Ag^+ . He found that only a few metals like Mn, Ni and Pb exhibited greatest mobility in cucumber plant which resulted in the highest shoot/root concentration ratio. The concentration of Ni in general and Cd in particular in plant parts increased with the age of the plant.

The variation in the plant metal level could also result from a seasonal change or re-distribution of some of essential elements such as phosphorus within

the plant. Pb and Cd in most plants are found in a precipitated form associated with the cell walls (Jarvis *et al.*, 1977).

According to Mathews and Thornton (1982) increased metal burden in the aerial part of the plant corresponded to a decrease in the root metal content, thus establishing that it was the re-mobilisation of the metal within the plant part and not the increased uptake that was responsible for the observed seasonal variation in the plant shoot.

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 81 per cent of the total cadmium applied, and transported to leaves while the 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.

Cadmium and copper uptake in radish was seen more in the shoots, while that of lead was more in the roots (Salim *et al.*, 1993).

9 Accumulation of heavy metals in plants

Lagerwerff (1971) in a study found that high changes in the levels of Cd, Pb and Zn in soil caused only small changes in the content of these metals in radish.

Haghiri (1973) observed that the concentrations of heavy metals found in several crops were highly variable and cadmium concentration in vegetable crops was in the order of lettuce > radish top > celery stalk > celery leaves > green pepper > radish roots.

Addition of cadmium to soil either through a direct source like cadmium chloride or through an indirect source like superphosphate, always helped to increase the cadmium content of the grain in cereals or in the edible part of vegetables (Williams and David, 1973). According to them plant uptake of cadmium from soil was generally small and ranged from 0.4 to 7 per cent of what was available. They also reported that plants differed greatly in their ability to absorb Cd and vegetable crops generally recorded higher Cd content than cereals and grasses. Among the important cereals, Cd was found to accumulate more in the roots of rice plants than wheat or oats. However, according to them when water soluble Cd was added to soil, most of the Cd taken up by the rice plants were translocated to the plant shoots, where accumulation varied with the rice varieties.

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.

Jarvis *et al.* (1977) indicated that Pb and Cd in most plants are found to be in a precipitated form associated with the cell walls. Koppe and Miller (1970) identified this precipitate as Pb-phosphate complex in corn plant.

Jarvis *et al.* (1978) reported that the cadmium content of the roots of rye grass was much greater than that of the corresponding shoots. It is concluded that

the roots of rye grass restricted the transport of cadmium to the shoots, leading to a relative accumulation of Cd in roots.

Bingham (1979) reported that many vegetables may accumulate large amounts of Cd without showing any phytotoxic symptoms.

McBride *et al.* (1981) and King (1988) indicated that the ability of soils to sorb Cd was inversely related to the extent of Cd accumulation in plants.

Matthews and Thornton (1982) noted that the transport of heavy metals to the aerial part of the plant was greatly influenced by the amount of the metal present in the soil and higher metal content in the shoot was only a reflection of the distribution of metals previously bound within the root. According to them grasses accumulated least amount of Cd compared to the members of the family compositae, with the metal burden in grasses mostly confined to the roots.

Bingham *et al.* (1983) reported that increased solubility of Cd consequent to addition of chloride salt resulted in a greater accumulation of Cd in the test plants (Swiss chard), to the extent that the concentration of plant Cd inhibited its growth.

According to Mortvedt (1985) the extent of accumulation of Cd in cultivated soils was difficult to determine because of the difficulty in assessing the mechanism of addition and removal from soils.

According to Chang *et al.* (1987) the Cd and Zn concentrations in radish tubers were always lower than those of above ground parts of the plant. Seasonal variations also resulted in greater accumulation of these elements in plant tissues.

Cd and Zn in radish, grown during spring season recorded higher concentration of these metals in than those grown in the fall season.

Shrivastava and Singh (1989) noted that with the liquid sewage applications, cadmium accumulation was higher in roots than in shoots of bhindi (*Abelmoschus esculentus* (L) Moench.). They further observed that with the application of solid sewage sludge, cadmium was not seen to be adsorbed by bhindi (*A. esculentus* (L) Moench.).

According to Alloway *et al.* (1990) total cadmium in the soil was inversely related to plant cadmium accumulation. They had also reported that cadmium accumulation by plant grown on sewage sludge amended soils was much lower than that grown on inorganically contaminated soils.

Bosque (1990) observed the highest concentration of Pb and Cd in the soft tissues including bulbs and leaves of chard, parsley, spinach and lettuce in contrast to the relative low concentration of these metals in the fruits and vegetables like tomato, cucumber and green pepper.

Zawadzka *et al.* (1990) reported a wide range of variation in the content of Pb in plants like parsley, carrot and lettuce (0.055 to 0.380 mg kg⁻¹). The usual range of Cd levels seen in the common vegetables was relatively lower (0.004 to 0.070 mg kg⁻¹) with the observation that root vegetables were more contaminated with Pb than leafy vegetables.

High concentration of lead in the leaves of spinach reaching up to 23.58 mg kg⁻¹ was observed by Srikanth and Reddy (1991). They also noted that cabbage and spinach showed higher uptake of cadmium than amaranthus. They further

reported maximum Cd concentrations of 4.75 and 9.67 mg kg⁻¹ for cabbage and spinach respectively, suggesting that continuous intake of leafy vegetables grown on sludge was likely to create health hazards to consumers.

10 Effect of plant species on heavy metal accumulation

Williams and David (1973) found that plant species differed greatly in their ability to absorb Cd. According to them the vegetable crops generally contained higher amount of Cd than cereals and grasses.

Matthews and Thornton (1982) pointed out that the species variation existing among the pasture plants permitted variation in the metal content within the plant. A similar observation on this aspect was earlier reported by John and Laerhoven (1976).

Vlamiš *et al.* (1985) reported that barley straw accumulated more Zn and Cd compared to barley grain.

Kuboi *et al.* (1986) reported that the concentration of cadmium in plants varied among species and cultivars.

11 Effect of heavy metals on plant growth and yield

Haghiri (1973) reported that in soybean and wheat the cadmium concentration of plant tops increased while yield decreased with increasing level of applied cadmium.

Turner (1973) studied the effect of Cd treatment on several vegetable species using nutrient solution culture. Results indicated that yields of tops of beetroot, carrot, lettuce, radish and Swiss chard were essentially unaffected by Cd levels of 0.01 to 0.10 $\mu\text{g Cd ml}^{-1}$ in nutrient solution. Yield of tomato top, however, was severely reduced at 0.01 $\mu\text{ Cd ml}^{-1}$. For all species, there was no apparent specific visual symptom of Cd toxicity except for obvious yield differences at highest rate of Cd addition.

Haghiri (1974) reported that an excessive amount of Zn (5-50 ppm) resulted in a possible displacement of Cd from soil, which subsequently entered the plant and resulted in the accumulation leading to suppression of growth of plants. He also suggested that Cd in many respects resembled the element zinc in its behaviour.

Carlson and Bazzaz (1977) noted a reduction in both photosynthetic and transpiration rate in American sycamore (*Plantanus accidentalis* L.), when heavy metals like cadmium and lead were applied either alone or in combination.

While comparing the toxicity symptoms of Cd and Pb on radish, Khan and Frankland (1983) observed that in the case of Cd there was progressive chlorosis, particularly of the young leaves, followed by necrosis, whereas that of Pb was manifested by stunted growth. Further, they observed that in metal contaminated soils, root growth was more affected than shoot growth. On molarity basis, Cd turned out to be 20 times more inhibiting than lead on radish plants. However, they also suggested that, addition of Cd or Pb to soil raised the level of metals in plant tissue to phytotoxic concentration and reduced the growth considerably. Such phytotoxicity seemed to be associated with some reduction of Zn in the plant tissue to near the lower critical level of deficiency threshold values.

Logan and Chaney (1983) estimated that in plant foliage Zn concentrations of 500 to 1500 mg kg⁻¹ were phytotoxic. But according to Davis (1993), a zinc concentration of 300 mg kg⁻¹ in tissue is considered to be the toxic threshold value in radish (*Raphanus sativus* L.).

Mortvedt (1985) conducted two green house experiments to know if corn and Swiss chard adsorbed significant quantities of Cd, Ni and Pb from the zinc fertilizers prepared from industrial byproducts, under two pH situations in a silt loam soil. The results indicated that drymatter yields of several harvests of Swiss chard were not affected by Zn application at either soil pH.

Pezzarossa *et al.* (1993) indicated that in spite of repeated addition of superphosphate containing various amount of heavy metals, and consequent accumulation of heavy metals in plants, any reduction in the marketable yield of radish was not observed.

Mench *et al.* (1994) reported that plants need not necessarily show phytotoxicity symptoms or yield reduction at higher levels of heavy metal uptake.

Materials and Methods

MATERIALS AND METHODS

1 MATERIALS

1.1 Phosphatic sources

In order to generate maximum variability between and within phosphatic sources, a large number of phosphorus fertilizer samples were collected from different locations and were analysed for phosphorus and heavy metal content. After a preliminary screening, four sources of phosphorus which maintained relatively high content of phosphorus and heavy metals were retained for the major study. Among those sources selected for study, three were of indigenous origin and the fourth one of exogenous origin. For the purpose of meaningful comparison of different P sources both water soluble phosphatic source viz., single superphosphate and partially acidulated rock phosphates were also included in the study.

1.1.1 Phosphatic rocks of indigenous origin

1. Maton rock phosphate
2. Mussoorie rock phosphate
3. Rajasthan rock phosphate

1.1.2 Phosphate rock of exogenous origin

Gafsa rock phosphate

1.1.3 Water soluble phosphatic sources

Single superphosphate

1.1.4 Partially acidulated rock phosphates

1. Partially acidulated Maton rock phosphate
2. Partially acidulated Mussoorie rock phosphate
3. Partially acidulated Gafsa rock phosphate
4. Partially acidulated Rajasthan rock phosphate

1.2 Soil samples

In order to assess the bioavailability of the heavy metals from the selected phosphatic sources through a pot culture, bulk soil samples were collected from vegetable research farm, Department of Olericulture, College of Horticulture, Vellanikkara. These soils offered a favourable acidic pH (5.3) required for the study.

1.3 Preparation of pots

Earthen pots of uniform size with a capacity of 7 kg were filled with 5 kg sieved (< 5 mm) soil on oven dry weight basis after plugging the drain hole at the bottom.

1.4 Planting materials

Chilli (variety Ujwala) being resistant to bacterial wilt, tolerant to leaf curl virus and mosaic disease was selected as the test crop, since it is widely consumed by the people not only as a vegetable but also as a spice in relatively higher quantities. The crop was raised in the nursery attached to the Department of Olericulture and was transplanted to pots for study in the Kharif season of 1996.

The seeds for this purpose were procured from the Kerala Horticulture Development Programme, KAU, Vellanikkara.

2 METHODS

2.1 Preparation of acidulated rock phosphate

For the preparation of partially acidulated phosphatic fertilizers samples of phosphate rocks were ground to pass through a 100 mesh sieve. Fifty per cent acidulation of phosphate rock was carried out by adding pre-determined quantities of acids to phosphate rock. It may be mentioned here that for the manufacture of single superphosphate, the usual acid to rock ratio is about 60 kg sulphuric acid for every 100 kg of phosphate rock [with about 30% P_2O_5]. Using this as the basis, the quantities of sulphuric acid required for the partial acidulation were computed. Acid required for acidulation was diluted in such a way that the volume of diluted acid was just sufficient to wet the phosphate rock to the consistency of a paste. However, for the purpose of preparation of the material predetermined quantity of dilute acid was added rapidly with constant stirring to ensure contact with all the phosphate rock particles (Ashby *et al.*, 1966). This product was then cured at room temperature for seven days for the material to dry up to almost constant weight. The cured material was then ground to pass through a 100 mesh sieve and used for the study.

2.2 Analysis of fertilizer sources

2.2.1 Analysis of phosphate sources for heavy metals

All the fertilizer samples selected were subjected to total elemental analysis as per the procedures indicated by Page *et al.* (1982), and heavy metals Cd

and Pb were estimated in acid digest using an atomic absorption spectrophotometer (AAS).

Based on the total elemental analysis three indigenous rock phosphates, one exogenous rock phosphate and single superphosphate with maximum loading capacity for cadmium and lead were selected for further study.

2.2.2 Analysis of fertilizer materials for phosphate content

All the phosphatic fertilizers selected for the study were subjected to detailed analysis for different fractions of phosphate.

Total phosphate

For estimation of total phosphate, 1 g of fertilizer material was taken in a 250 ml conical flask to which 25 ml of concentrated HNO_3 was added and digested over a hot plate to initially oxidise the organic matter, if any. After cooling the contents, 20 ml of perchloric acid (60%) was added and further digested till the contents became clear. After cooling, 50 ml distilled water was added and the contents filtered through Whatman No.1 filter paper and made up to 100 ml. Phosphate in the aliquots after suitable dilution was determined colorimetrically as vanadomolybdo phosphoric yellow complex as described by Jackson (1958).

Water soluble phosphate

For the estimation of water soluble phosphate, 1 g of fertilizer material was placed in a filter cone (Whatman No.1 filter paper), leached with distilled

water several times (Fertilizer Control Order, 1957). Phosphate in aliquots was determined colorimetrically by the method as stated above.

Citrate soluble phosphate

For the estimation of citrate soluble phosphate, residue left on the filter paper after removing water-soluble part was transferred to a conical flask containing 100 ml of neutral ammonium citrate solution (sp. gr. 1.09) maintained at a temperature of 65°C, digested on a constant temperature water bath for 1 h with intermittent shaking and subsequently filtered through a Buchner funnel fitted with Whatman No.42 filter paper under suction. The citrate insoluble residue was washed 7-8 times with water at 65°C but whenever filtrate was turbid a 5% ammonium nitrate solution maintained at 65°C was used for washing the residue. Residue along with the filter paper was transferred to 250 ml conical flask and citrate insoluble phosphate was determined using the same procedure as adopted for total phosphate estimation. Citrate soluble phosphate was determined indirectly by subtracting the sum of watersoluble and citrate insoluble fractions from the total phosphate content in the materials. A wide range of methods were used for the analysis of the bulk soil sample collected for the pot culture experiment.

2.3 Soil analysis

Particle size analysis

Particle size analysis of the soil samples were carried out by the International Pipette Method as described by Piper (1942).

Soil reaction (pH)

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

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 .

Available nitrogen

Available nitrogen in all the soil samples was estimated by alkaline permanganate method (Subbaiah and Asija, 1956).

Available phosphorus

Available phosphorus in all the soil samples was extracted by Bray No.1 extracted (Bray and Kurtz, 1945), and P in the extract was determined colorimetrically by using ascorbic acid method of Watanabe and Olsen (1965).

Available potassium

Available potassium in the soil was extracted using 1N neutral ammonium acetate, and K in the extract was determined using EEL flame photometer.

Available cadmium and lead

The DTPA extraction was followed at a soil solution ratio of 1:2 and a reaction time of 2 hours (Lindsay and Norvell, 1978) and concentrations of Cd and Pb in solutions were determined by AAS as described by Page *et al.* (1982).

Total elemental analysis

Soil (0.5 g) was digested in platinum crucible with perchloric acid, sulphuric acid and hydrofluoric acid and digested material taken up in hydrochloric acid as described by Page *et al.* (1982). Cadmium and Pb in the aliquot after acid digestion were estimated using AAS.

2.4 Pot culture experiment

The design of experiment was completely randomised with three replications. The fertilizer recommendation envisaged for the variety Ujwala in this experiment was based on the package of practice recommendations of Kerala Agricultural University (KAU, 1993) for chilli (70.40-25 kg ha⁻¹). Since the experiment is essentially oriented towards the assessment of bioavailability of heavy metals from the different phosphatic fertilizers, a variety of P sources are tried. In all the pots, the required doses of N and K were maintained through urea and MOP at 70 and 25 kg ha⁻¹ respectively and P at three levels viz., 40, 80 and 120 kg ha⁻¹ through each source tried irrespective of their heavy metal loads. Separate treatments to provide the required NPK to the test crop through chemically pure salts have also been laid for proper comparison of nutrient sources for bioavailability of heavy metals from them.

To have more meaningful study of heavy metal uptake in this pot culture experiment, and to evaluate the influence of organic matter in regulating the heavy

metal availability, both Cd and Pb have been applied at two levels viz., 2.5 and 5.0 mg pot⁻¹ through the respective water soluble salts, with and without organic matter (quantity of organic matter is worked out based on the package of practice recommendation).

In order to see if acidulated rock phosphates have better capability to release the heavy metals in them, the same set of rock phosphate at the normal levels of application (L₁) has been partially acidulated to see their heavy metal release in soils and the subsequent uptake by the test crop.

A brief description of different treatment is given below:

Treatment No.	Details of treatment	Level of application (kg ha ⁻¹)		
		N	P	K
1	2	3	4	5

A. Indirect application of heavy metals through different phosphate sources applied at three levels

1	Maton rock phosphate	PL ₁	70	40	25
2	Mussoorie rock phosphate	PL ₁	70	40	25
3	Gafsa rock phosphate	PL ₁	70	40	25
4	Rajasthan rock phosphate	PL ₁	70	40	25
5	Single superphosphate	PL ₁	70	40	25
6	Maton rock phosphate	PL ₂	70	80	25
7	Mussoorie rock phosphate	PL ₂	70	80	25
8	Gafsa rock phosphate	PL ₂	70	80	25
9	Rajasthan rock phosphate	PL ₂	70	80	25
10	Single superphosphate	PL ₂	70	80	25
11	Maton rock phosphate	PL ₃	70	120	25
12	Mussoorie rock phosphate	PL ₃	70	120	25
13	Gafsa rock phosphate	PL ₃	70	120	25
14	Rajasthan rock phosphate	PL ₃	70	120	25
15	Single superphosphate	PL ₃	70	120	25

Contd.

1	2		3	4	5
B. Direct application of NPK through chemically pure salts					
16	Urea, KH_2PO_4 , KCl		70	40	25
C. Direct application of heavy metals through water soluble salts					
17	Cadmium chloride @ 2.5 mg pot ⁻¹	HCL ₁	70	40	25
18	Lead nitrate @ 2.5 mg pot ⁻¹	HPL ₁	70	40	25
19	Cadmium chloride @ 5 mg pot ⁻¹	HCL ₂	70	40	25
20	Lead nitrate @ 5 mg pot ⁻¹	HPL ₂	70	40	25
21	Cadmium chloride @ 2.5 mg pot ⁻¹ with OM @ 25 g pot ⁻¹	HCL ₁	70	40	25
22	Lead nitrate @ 2.5 mg pot ⁻¹ with OM @ 25 g pot ⁻¹	HPL ₁	70	40	25
23	Cadmium chloride @ 5 mg pot ⁻¹ with OM @ 25 g pot ⁻¹	HCL ₂	70	40	25
24	Lead nitrate @ 5 mg pot ⁻¹ with OM @ 25 g pot ⁻¹	HPL ₂	70	40	25
D. Indirect application of heavy metals through partially acidulated rock phosphate					
25	P.A. Maton rock phosphate		70	40	25
26	P.A. Mussoorie rock phosphate		70	40	25
27	P.A. Gafsa rock phosphate		70	40	25
28	P.A. Rajasthan rock phosphate		70	40	25
29	Control (Absolute)				

Abbreviations used

MRP	- Maton Rock Phosphate
MUP	- Mussoorie Rock Phosphate
RJP	- Rajasthan Rock Phosphate
GAP	- Gafsa Rock Phosphate
SSP	- Single Super Phosphate
P.A. MRP	- Partially Acidulated Maton Rock Phosphate

- P.A. MUP - Partially Acidulated Mussoorie Rock Phosphate
P.A. RJP - Partially Acidulated Rajasthan Rock Phosphate
P.A. GAP - Partially Acidulated Gafsa Rock Phosphate
CPS - Chemically pure source

Levels of P application

PL₁ - 40 kg P ha⁻¹

PL₂ - 80 kg P ha⁻¹

PL₃ - 120 kg P ha⁻¹

Levels of Cd application

HCL₁ - 0.5 mg Cd kg⁻¹ soil

HCL₂ - 1.0 mg Cd kg⁻¹ soil

Levels of Pb application

HPL₁ - 0.5 mg Pb kg⁻¹ soil

HPL₂ - 1.0 mg Pb kg⁻¹ soil

2.4.1 Fertilizer application

A basal dose of nitrogen and potassium @ 70 and 25 kg ha⁻¹ each were given to all pots through urea and MOP. The different combination and levels of fertilizer materials envisaged in the experiment were accurately weighed out and thoroughly mixed with 5 kg soil in a polyethylene sheet and were filled into pots.

2.4.2 Sowing and after care

The seeds selected were of uniform size and shape. Seeds were sown in nursery during the month of June 1996. To prevent damping off the nursery soil was drenched with Indofil M-45. Forty days after sowing, the best looking healthy seedlings were identified from the nursery and transplanted to experimental pots at the rate of one seedling per pot. All through the period of growth only distilled water was provided to maintain soil moisture to field capacity. The duration of the crop was 153 days and the same was harvested at maturity.

2.4.3 Collection of plant samples and preparation for analysis

Immediately after harvest, the plants were repeatedly washed in distilled water to remove all the adhering soil particles and dried in shade for a few days and later in a oven at 70°C. The root, shoot and fruit portions were carefully separated with a pair of stainless steel scissors and dry weights recorded. Later, the dried samples were further chopped with a stainless steel cutter and powdered in a glass pestle and mortar.

Weighed quantity of ground plant materials were taken in 100 ml conical flasks and digested with di-acid mixture of $\text{HNO}_3\text{-HClO}_4$ 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 50 ml from which the heavy metals viz., Cd and Pb were determined directly using atomic absorption spectrophotometer.

The phosphorus content in the digested material was determined colorimetrically by developing the phospho- molybdo-vanadate yellow complex in

nitric acid system. Potassium content in the digested material was determined using EEL flame photometer.

Nitrogen content of the plant samples was determined by the microkjeldahl digestion and distillation method as described by Jackson (1958). Uptakes of all the required elements by chilli, especially by their root, shoot and fruit portions were separately computed using the drymatter yield and concentration of element in their respective plant parts.

2.4.4 Post harvest collection of soil samples and analysis

After the harvest of the crop the entire soil was emptied onto a polyethylene sheet, mixed well, a representative sample drawn and stored in polyethylene bags. The post-harvest soil samples were analysed for available nitrogen, phosphorus, potassium, cadmium and lead as well as for total cadmium and lead. The pH and EC of all the samples were also recorded.

2.5 Statistical analysis

The data generated from the pot culture experiment was analysed 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 and Discussion

RESULTS AND DISCUSSION

1 Characterisation of phosphate sources

1.1 Concentration of Heavy Metals

Chemical analysis of a large number of phosphorus fertilizer samples collected from different locations within Kerala have been done for the purpose of selecting a few phosphate sources which maintained relatively high content of both phosphorus and heavy metals. The analytical values for both Cd and Pb in the few selected phosphate sources are provided in Table 1 and Fig.1. Gafsa rock phosphate recorded the maximum content of Cd (55 mg kg^{-1}) followed by Maton rock with a relatively lesser Cd content of 25 mg kg^{-1} . Mussoorie rock and Rajasthan rock had more or less similar Cd content (20 mg kg^{-1}) in them. However, the least concentration of Cd (15 mg kg^{-1}) was recorded in the water soluble phosphate source viz., single superphosphate.

While assessing the concentration of Pb in fertilizer samples, the maximum content (230.5 mg kg^{-1}) of Pb was recorded in the Maton rock phosphate. The minimum analysis of Pb was noted in Mussoorie rock phosphate (38 mg kg^{-1}). The Pb content analysed in SSP was only 106 mg kg^{-1} followed by Rajasthan rock and Gafsa rock phosphate with 51 and 39.5 mg kg^{-1} respectively.

1.2 Phosphate fractions in Rock phosphate

The total P content of the finally selected phosphate sources (3 indigenous rock phosphates, 1 exogenous rock phosphate together with a conventional water soluble source of P, namely, single super phosphate) was

Table 1. Concentrations of heavy metals in some phosphatic sources (mg kg⁻¹)

Phosphatic sources	Cadmium	Lead
1. Maton rock phosphate	25	230.5
2. Mussoorie rock phosphate	20	38.0
3. Gafsa rock phosphate	55	39.5
4. Rajasthan rock phosphate	20	51.0
5. Single superphosphate	15	106.0

Table 2. Phosphate fractions in some phosphatic sources

Source	Water soluble		Citrate soluble		Total	
	P ₂ O ₅ (%)	P(%)	P ₂ O ₅ (%)	P(%)	P ₂ O ₅ (%)	P(%)
1. Maton rock phosphate	Tr	Tr	9.3	4.1	23.2	10.1
2. Mussoorie rock phosphate	Tr	Tr	4.7	2.1	18.4	8.0
3. Gafsa rock phosphate	Tr	Tr	19.4	8.5	30.7	13.4
4. Rajasthan rock phosphate	Tr	Tr	5.7	2.5	20.6	9.0
5. Single superphosphate	14.9	6.5	0.4	0.2	16.8	7.3

Tr - Trace

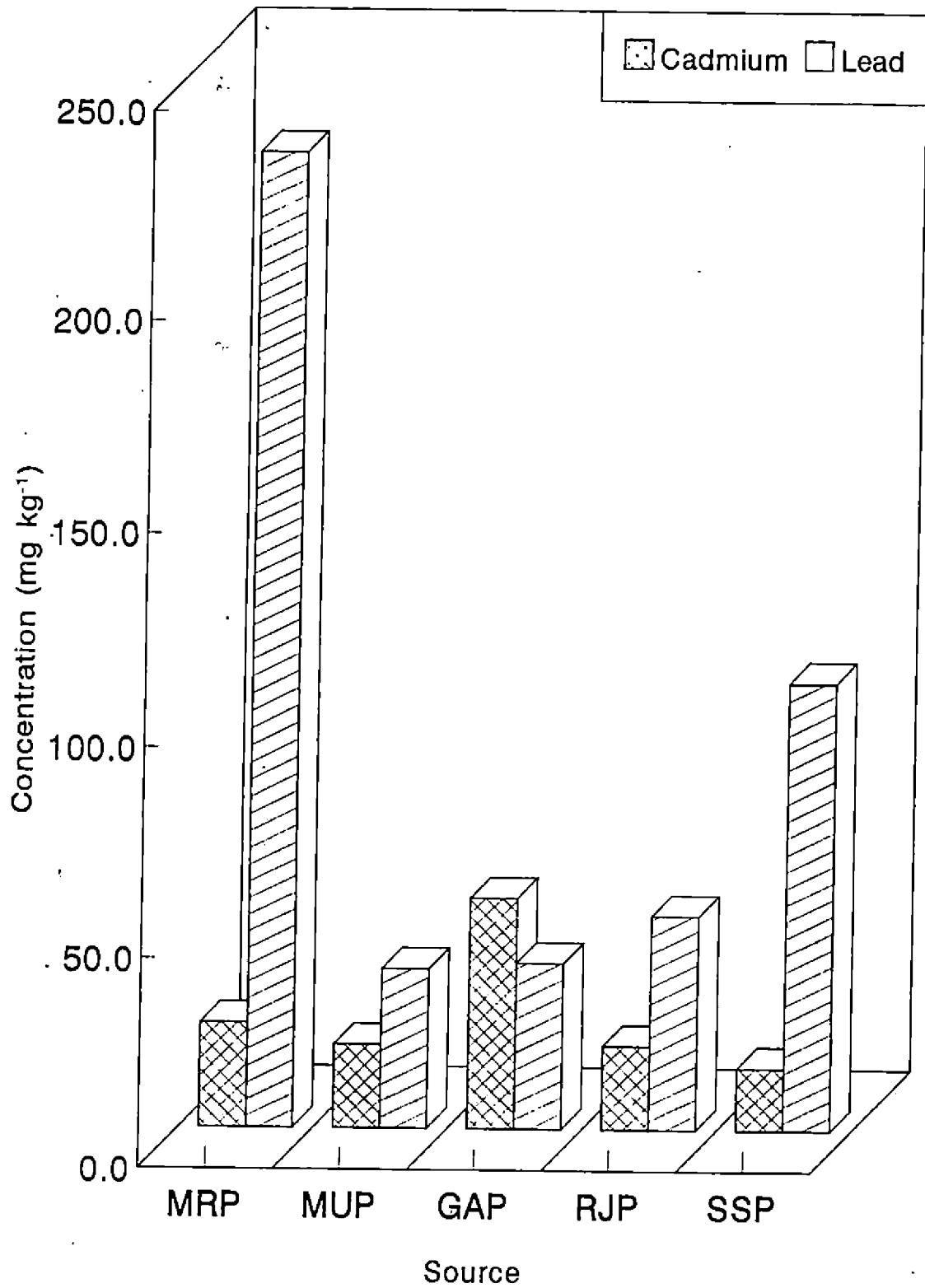


Fig 1. Concentrations of heavy metals in some phosphate sources

fractionated into water soluble, citrate soluble and citrate insoluble parts, details of which are furnished in Table 2. Water soluble P was below detectable limit in all rock phosphate sources. However majority of the P in SSP was found to be in the water soluble form.

Citrate soluble P was found to be relatively higher in Gafsa rock phosphate than in other rock phosphates. The least content of citrate soluble P was noted in Mussoorie rock. The total P content of the rock sources were observed to be quite variable (18.4 to 30.7 per cent P_2O_5). Among the selected rock sources, Gafsa rock phosphate recorded the highest total P_2O_5 (30.7 per cent) content, while SSP maintained the least content (16.8 per cent).

2 Pot culture experiment

Some of the important physico-chemical characteristics of the soil used for pot culture experiment are given in Table 3. The results of pot culture experiment have been outlined not only in terms of yield, but also in terms of both available nutrient and heavy metal especially in the post harvest soil samples. Attempts have been made to compute the uptake of major nutrients and heavy metals especially for Cd and Pb, for the root, shoot and fruit portions of the plant.

2.1 Assessment of different phosphate rock sources

2.1.1 Effect of different P sources on the dry matter yield of chilli crop

The results of the dry matter yield of chilli (root, shoot and fruit) are presented in Tables 4, 5 and 6 respectively. On application of five different sources of P having wide variation in the phosphate content, at three levels, it was observed that there was apparent difference in the dry matter yield especially for the root,

Table 3. General characteristics of the soil used for pot culture experiment

Particle size distribution (%)			
Coarse sand	Fine sand	Silt	Clay
8.90	50.10	34.60	6.40
Chemical characteristics			
	pH		EC (dS m ⁻¹)
	5.3		0.13
Available nutrient status (mg kg⁻¹)			
Nitrogen	Phosphorus		Potassium
110	19.7		120
Available heavy metal status (DTPA extractable (mg kg⁻¹))			
	Cadmium	Lead	
	0.04	0.13	
Total heavy metal status (mg g⁻¹)			
	Cadmium	Lead	
	0.79	1.2	

Table 4. Dry matter yield of chilli root (g pot⁻¹)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	1.47	1.67	1.83	1.66
2. MUP	1.20	1.40	1.70	1.43
3. GAP	2.17	2.57	2.70	2.48
4. RJP	1.33	1.67	1.73	1.58
5. SSP	1.53	1.57	1.63	1.58
Mean	1.54	1.78	1.92	
Control CD (0.05)	0.87 Source 0.20	Level 0.16		

Table 5. Dry matter yield of chilli shoot (g pot⁻¹)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	14.8	20.5	21.4	18.9
2. MUP	14.7	19.7	21.1	18.5
3. GAP	21.0	23.9	24.4	23.1
4. RJP	15.1	16.1	18.8	16.7
5. SSP	16.4	20.3	21.3	19.3
Mean	16.4	20.1	21.4	
Control CD (0.05)	4.73 Source 1.02	Level 0.79		

Table 6. Dry matter yield of chilli fruit (g pot⁻¹)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	4.10	4.20	4.77	4.36
2. MUP	3.20	3.97	4.57	3.91
3. GAP	4.73	5.43	5.80	5.32
4. RJP	3.53	4.13	4.20	3.96
5. SSP	3.37	3.73	3.83	3.64
Mean	3.79	4.29	4.63	
Control CD (0.05)	1.57 Source 0.19	Level 0.14		

shoot and fruit portions, clearly reflecting the effect of P variations noted among the sources. This difference in yield was visibly more pronounced between control (absolute) and the remaining five P sources taken as a group.

Between levels of application, any increase in level of application of P, had significant influence in increasing dry matter yield of root, shoot and fruit indicating the positive influence of higher doses of P on dry matter production. Among the five sources of P tried, Gafsa rock was found to be the best, in turning out maximum dry matter yield. This might be due to the relative high availability of citrate soluble P (19.4 per cent P_2O_5) from it. It was observed that, in general, the relative shoot yield of chilli was much higher than its corresponding root and fruit yields in all the pots. The comparatively lower dry matter yield recorded from other sources might be due to the slow dissolution rate of the rock matrix coupled with the relatively lower content of P in them.

The variations in the yield from different P sources could perhaps be better understood in view of the finding of Bolland *et al.* (1988), wherein they had indicated that yield of crops was more determined by the P content of the tissue, which again was an indirect influence of the effectiveness of the phosphate sources in soil.

Between levels of application of P, the root dry matter yield of chilli, though could maintain significant difference between level 1 and level 2, it failed to record significant difference between level 2 and level 3. However, in the case of dry matter yield for shoot and fruit, any level of application of P was significantly different from the other. While comparing the different sources and its effect on dry matter production, all sources remained significantly different from one another in

terms of root, shoot and fruit dry matter yield. This is more significant when any dry matter yield is compared against that of the control.

2.1.2 Phosphorus uptake by chilli root, shoot and fruit

The results of the P uptake by the root, shoot and fruit portions of chilli plant from the pots where different P sources have been used at three levels are depicted in Tables 7, 8 and 9, respectively.

While assessing the five different sources of P applied at three levels and the consequent uptake of P by root, shoot and fruit portion of the plant, it was observed that shoot portion of the plant maintained relatively more P content than fruit and root at all levels of application, irrespective of the sources. In general, Gafsa rock was found to be the best source in providing the maximum P uptake followed by SSP. Mussoorie and Maton rock were rated as the 3rd and 4th best source respectively in providing the P uptake.

However, Rajasthan rock was adjudged as the least effective source in providing the P uptake for the root and shoot portions. Rajasthan rock followed Gafsa rock in providing maximum P uptake by fruits. In this connection, both Mussoorie and Maton rock phosphates were rated on par while the water soluble SSP was adjudged to be the least effective source in providing P uptake to fruits, probably because of the inability of the source to provide P for the plant at the flowering and fruiting stage due to fixation especially when the soils in which they are applied are acidic.

At all levels of application, there had been significant increase in P uptake. The P uptake values from the control pots by the root, shoot and fruit

Table 7. P uptake by chilli root (mg pot⁻¹)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	1.0	1.0	1.1	1.1
2. MUP	1.0	1.1	1.1	1.1
3. GAP	1.2	1.6	2.1	1.6
4. RJP	1.0	1.0	1.1	1.0
5. SSP	1.0	1.1	1.2	1.1
Mean	1.1	1.2	1.3	
Control	0.2			
CD (0.05)	Source 0.13	Level 0.10		

Table 8. P uptake by chilli shoot (mg pot⁻¹)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	60.0	83.3	94.0	79.1
2. MUP	63.3	87.3	93.7	81.4
3. GAP	87.3	101.7	102.3	97.1
4. RJP	63.0	71.7	85.3	73.3
5. SSP	77.7	94.3	96.0	89.3
Mean	70.3	87.7	94.3	
Control	1.6			
CD (0.05)	Source 5.39	Level 4.17		

Table 9. P uptake by chilli fruit (mg pot⁻¹)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	24.3	25.3	28.3	26.0
2. MUP	22.0	26.0	30.0	26.0
3. GAP	29.0	32.0	36.7	32.6
4. RJP	24.3	30.3	33.0	29.2
5. SSP	20.7	25.0	27.0	24.2
Mean	24.1	27.7	30.9	
Control	3.3			
CD (0.05)	Source 1.93	Level 1.50		

portions of the plant were significantly inferior to the respective uptake from any source of P applied at any level.

2.1.3 Cadmium uptake by chilli root, shoot and fruit

The results on Cd uptake by chilli root, shoot and fruit from the different P sources applied in soil at three levels are presented in Tables 10, 11 and 12 and Fig. 2, 3 and 4, respectively.

In general, higher uptake of Cd was noted in the shoot portion of chilli plant than its root or fruit portion. The least uptake of cadmium was noted in the fruit portion. Presence of the least amount of Cd in the fruit portions of the plant at all levels of application could be perceived as a positive indication of the edible portion posing lesser health hazards, even when they are consumed in relatively larger amounts.

Lagerwerff (1971) and Khan and Frankland (1983) also reported relatively lesser content of cadmium in the edible portion of radish when compared to its other plant parts.

Among the various sources of P applied, Gafsa rock appeared to be the most significant source causing maximum uptake of Cd by both the root and shoot portion of the plant, probably due to the higher Cd content in them. Among the P sources, least uptake of cadmium by plants was noted from single superphosphate, which again might have been due to the low cadmium load in them (15 mg of Cd kg^{-1}), especially with the remarks of Tyler and Mc Bridge (1982), who suggested that uptake of heavy metals from rock sources was reflection of the metal load in

Table 10. Cd uptake by chilli root ($\mu\text{g pot}^{-1}$)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	1.8	2.5	2.9	2.4
2. MUP	1.8	2.4	2.6	2.3
3. GAP	2.1	2.6	3.1	2.6
4. RJP	1.7	2.2	2.4	2.1
5. SSP	1.7	2.2	2.5	2.1
Mean	1.8	2.4	2.7	
Control	0.8			
CD (0.05)	Source	Level		
	0.20	0.15		

Table 11. Cd uptake by chilli shoot ($\mu\text{g pot}^{-1}$)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	2.6	3.0	3.8	3.1
2. MUP	2.8	2.9	3.3	3.0
3. GAP	2.9	3.3	3.9	3.4
4. RJP	2.6	3.1	3.4	3.0
5. SSP	2.5	3.1	3.3	3.0
Mean	2.7	3.1	3.5	
Control	0.5			
CD (0.05)	Source	Level		
	NS	0.24		

Table 12. Cd uptake by chilli fruit ($\mu\text{g pot}^{-1}$)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	1.2	1.3	1.5	1.3
2. MUP	1.1	1.8	2.0	1.6
3. GAP	1.7	2.2	2.6	2.2
4. RJP	1.1	1.4	1.5	1.3
5. SSP	1.1	1.3	1.4	1.3
Mean	1.2	1.6	1.8	
Control	0.2			
CD (0.05)	Source	Level		
	0.12	0.09		

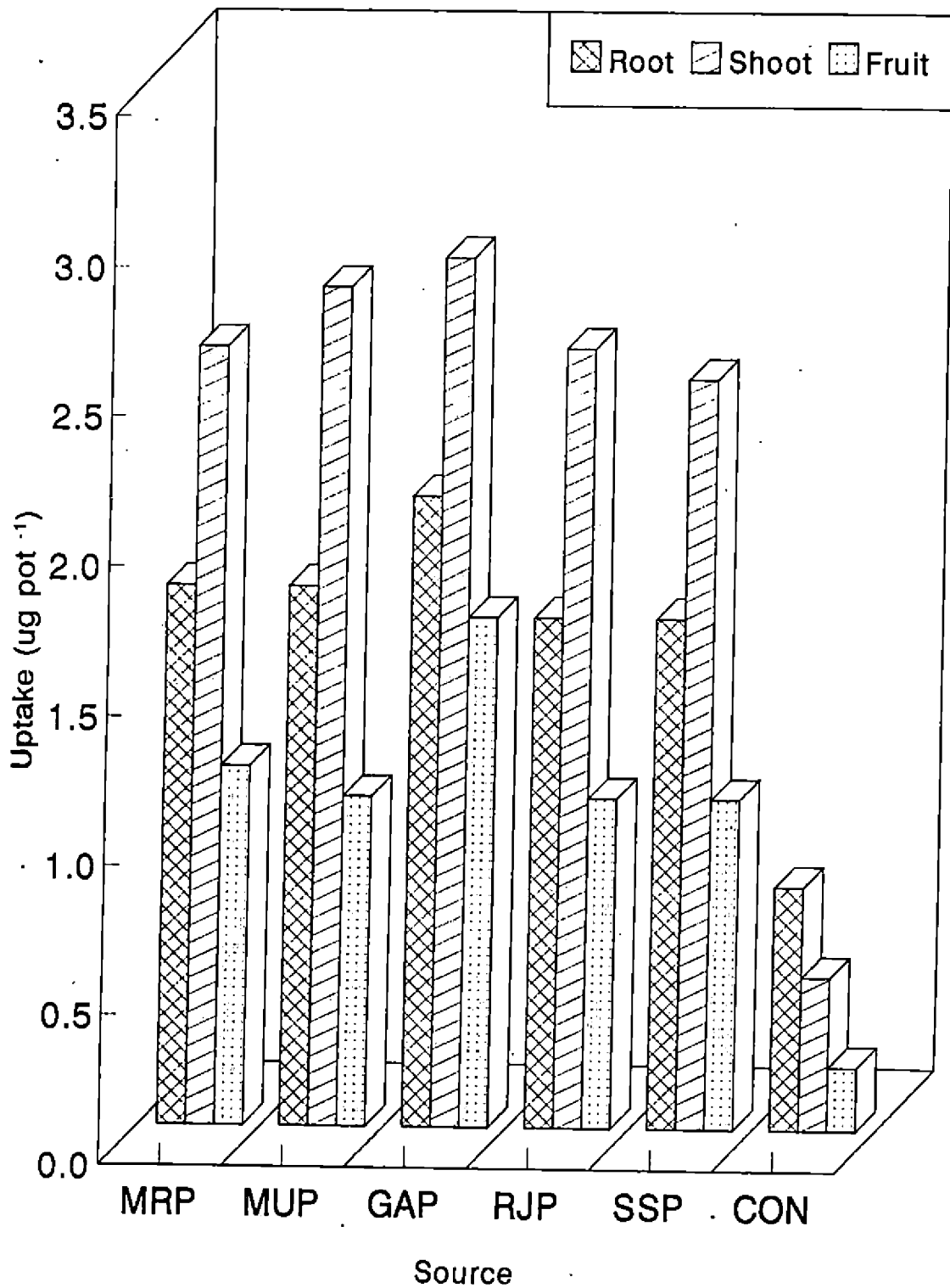


Fig 2. Cadmium uptake by chilli root, shoot and fruit from different P sources at level 1

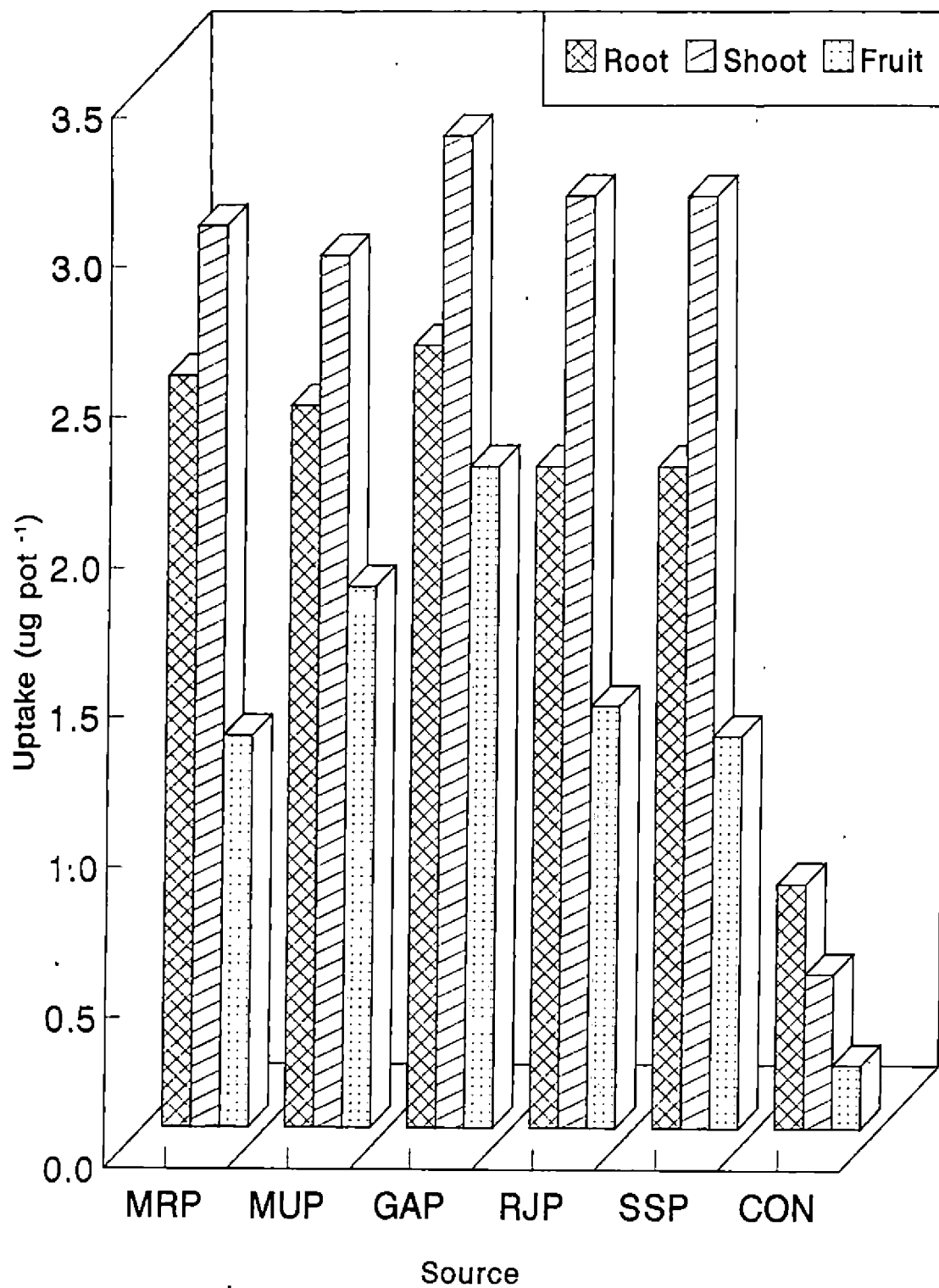


Fig 3. Cadmium uptake by chilli root, shoot and fruit from different P sources at level 2

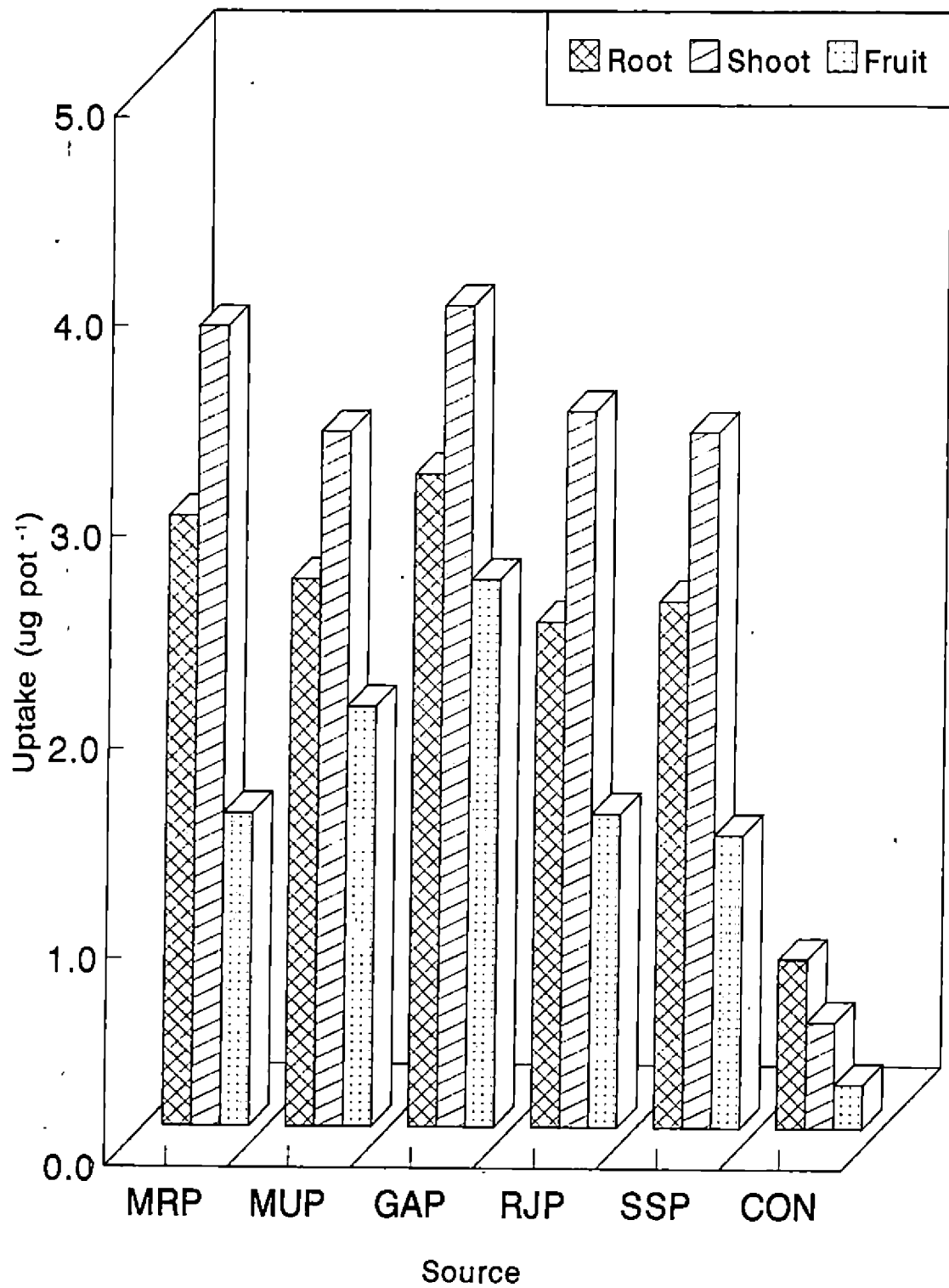


Fig 4. Cadmium uptake by chilli root, shoot and fruit from different P sources at level 3

them. Maton, Rajasthan and Mussoorie rock phosphate had also permitted varied cadmium uptake in chilli plants with significant difference between their uptake.

The least amount of cadmium uptake in plants was noted from control, suggesting that the uptake of cadmium in plants might have come only from the various P sources applied and that the variations in cadmium uptake noted in plants might have been a true reflection of the differential heavy metal load in them. Between the root and shoot portion of the plant the relative load of cadmium appeared to be much lesser in the root portions, irrespective of the sources tried. The higher uptake of cadmium in chilli shoot might have been due to the selective retention of this element in shoots.

Between levels of application, there had been considerable increase in the cadmium uptake especially at higher levels making levels of application quite significant necessarily due to the fact that more amount of rock phosphate applied to give higher level of P will automatically supply more Cd also.

2.1.4 Lead uptake by chilli Root, Shoot and Fruit

The uptake of Pb from the different sources of P by the root, shoot and fruit portions of the chilli plant is presented in Tables 13, 14 and 15 and Fig.5, 6 and 7, respectively. Among the five different sources of P tried at three levels, it was generally observed that the root portion of the plant maintained more Pb than the shoot or fruit portion at all levels of application. Similar observation had been made by Khan and Frankland (1983) and Salim *et al.* (1993) in their heavy metal uptake studies in radish. The reason for the low Pb content in shoot could perhaps be understood on account of the possible redistribution of the metal previously bound within the plant especially when the movement of Pb is associated with the changes in the phosphate status of the plant (Mathews and Thorton, 1982).

Table 13. Pb uptake by chilli root ($\mu\text{g pot}^{-1}$)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	14.4	16.2	20.8	17.1
2. MUP	12.4	12.9	13.4	12.9
3. GAP	11.8	12.1	12.9	12.3
4. RJP	12.5	13.2	13.7	13.2
5. SSSP	13.3	15.1	16.3	14.9
Mean	12.9	13.9	15.4	
Control	2.9			
CD (0.05)	Source	Level		
	0.34	0.26		

Table 14. Pb uptake by chilli shoot ($\mu\text{g pot}^{-1}$)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	8.4	10.1	12.9	10.5
2. MUP	6.4	6.9	7.4	6.9
3. GAP	6.3	6.5	6.9	6.6
4. RJP	6.5	7.2	7.7	7.1
5. SSP	7.3	9.1	10.2	8.9
Mean	7.0	8.0	9.0	
Control	1.5			
CD (0.05)	Source	Level		
	0.17	0.13		

Table 15. Pb uptake by chilli fruit ($\mu\text{g pot}^{-1}$)

Source	Level 1	Level 2	Level 3	Mean
1. MRP	3.1	3.8	4.5	3.8
2. MUP	2.3	2.5	2.8	2.5
3. GAP	2.2	2.4	2.5	2.4
4. RJP	2.3	2.6	2.9	2.6
5. SSP	2.7	3.4	3.9	3.3
Mean	2.5	2.9	3.3	
Control	0.5			
CD (0.05)	Source	Level		
	0.18	0.14		

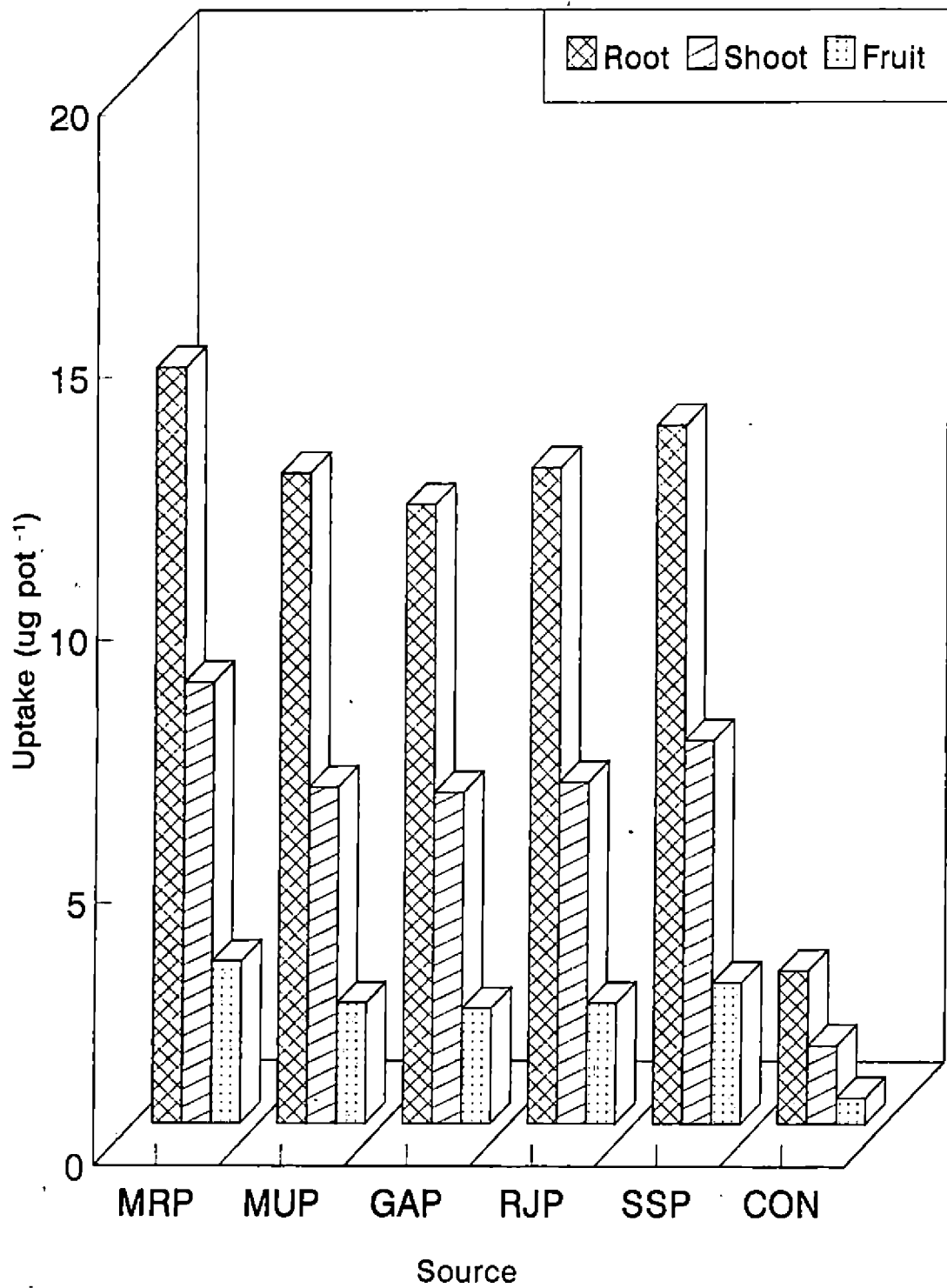


Fig 5. Lead uptake by chilli root, shoot and fruit from different P sources at level 1

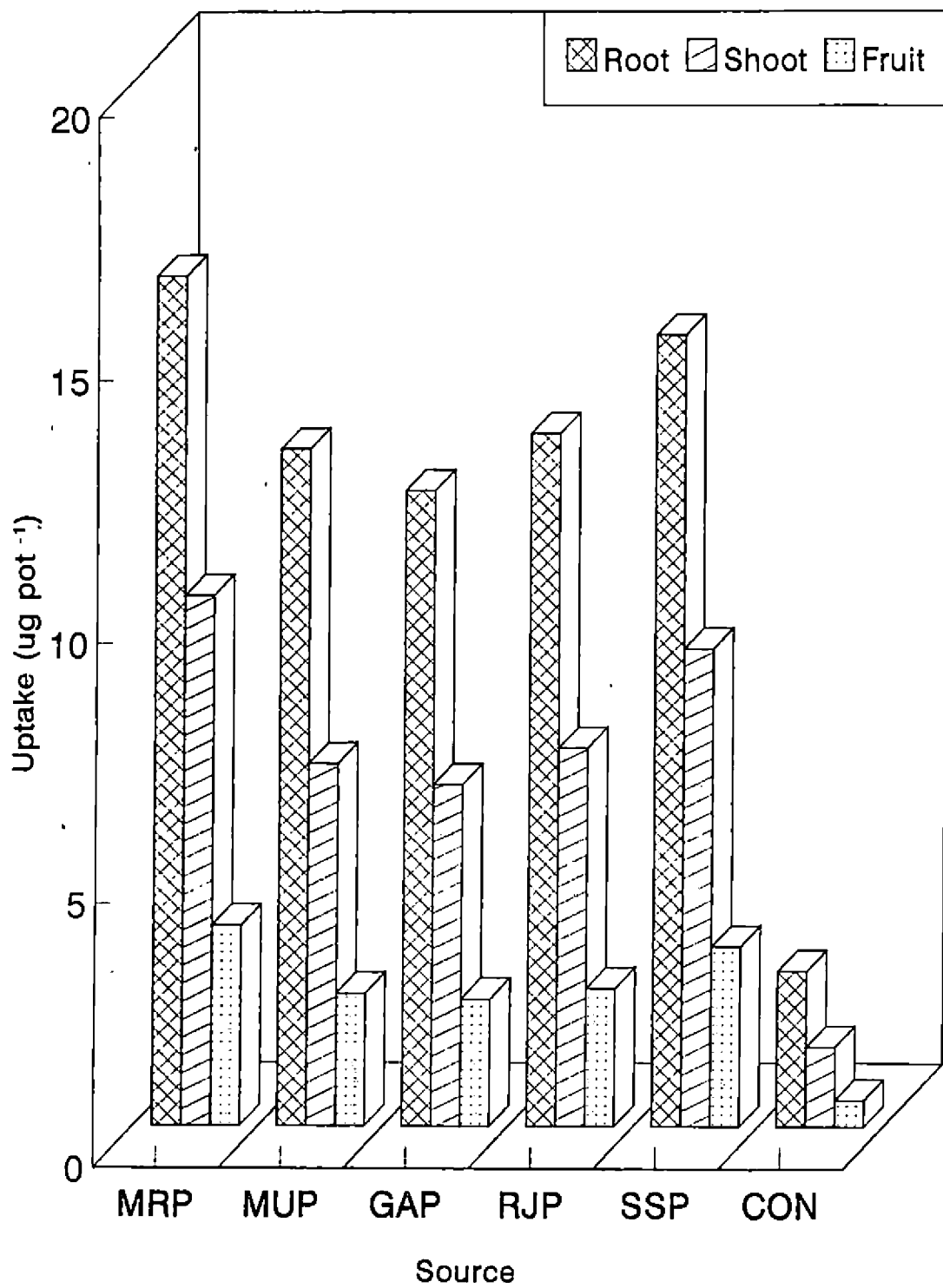


Fig 6. Lead uptake by chilli root, shoot and fruit from different P sources at level 2

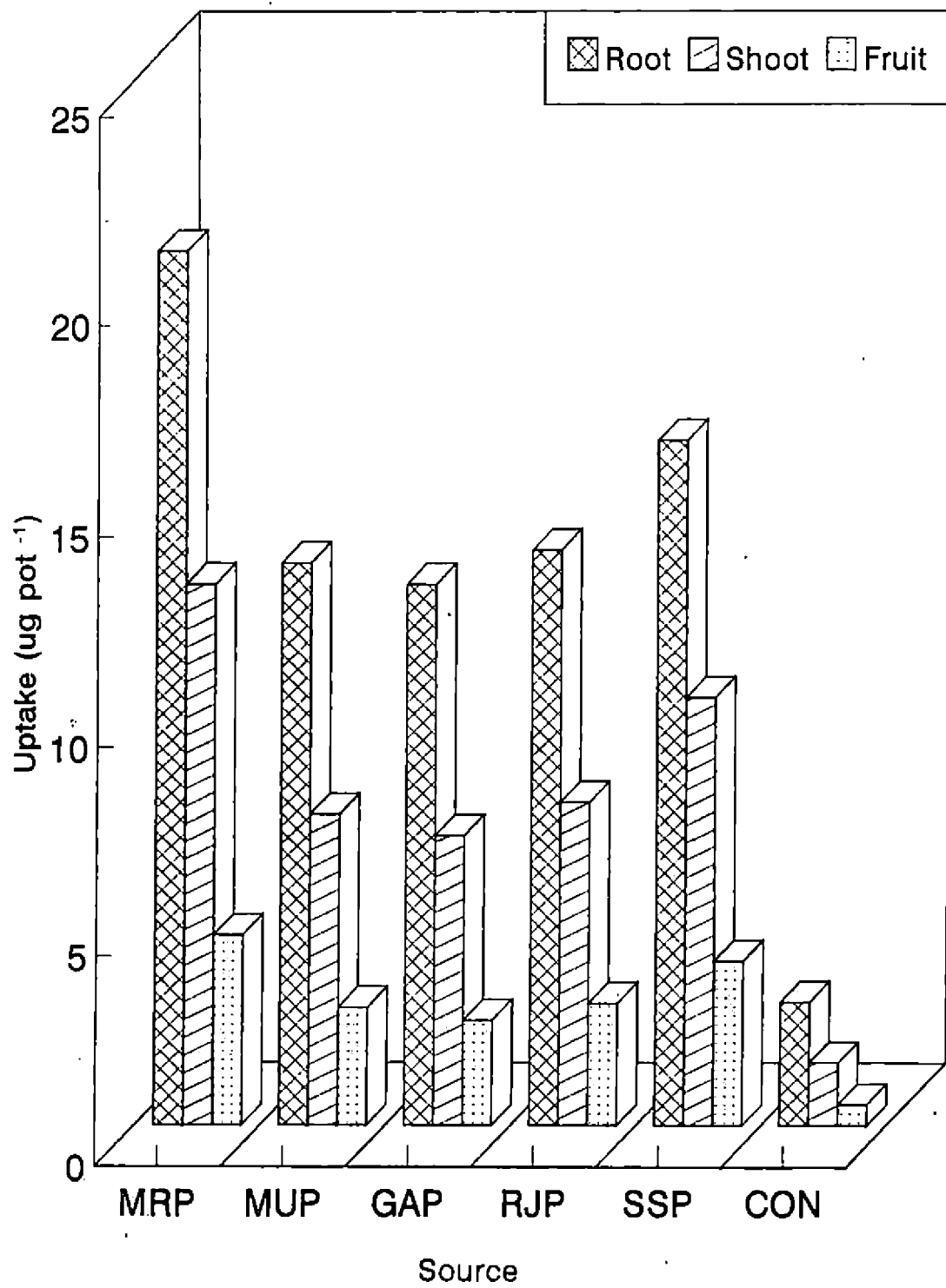


Fig 7. Lead uptake by chilli root, shoot and fruit from different P sources at level 3

However, Keefer *et al.* (1986) had contradicted such an observation where in maximum Pb uptake was noted in the shoot portion than the respective root portion. Application of Maton rock resulted in maximum uptake of Pb by chilli plants (17.1, 10.5 and 3.8 $\mu\text{g pot}^{-1}$ in root, shoot and fruit portion respectively). This was followed by SSP, Rajasthan rock and Mussoorie rock phosphate. Mussoorie and Rajasthan rocks were found to be on par and remained much lower to SSP in providing Pb uptake especially to chilli root.

The highest and lowest uptake of Pb from Maton and Gafsa rock by the chilli crop is a clear reflection of the relative metal load in them. Like cadmium the lead load in chilli fruit is comparatively much lesser than the corresponding shoot and root portion. However, while comparing the uptake of heavy metals especially Cd and Pb in the fruit portion, the relative uptake of Pb appeared to be slightly higher than Cd under comparable conditions. In this context, though Rajasthan and Mussoorie rock remained on par, was much lower to SSP in providing the Pb uptake, which might have been due to the relative higher metal load (106 mg kg^{-1}) in SSP. The least uptake of Pb was noted in control and this when compared to other sources and levels remained significantly inferior.

2.1.5 Bray-I extractable P from the post-harvest soil samples

The available P status of post-harvest soil samples which had received different sources of P at different levels are presented in Table 16.

Application of all the sources of P at three levels resulted in extracting significantly higher content of available P than the unfertilized control. The highest amount of available P (21.4 mg kg^{-1}) extracted from Gafsa rock applied pots might be due to the very high content of total phosphorus in them (30.7 per cent P_2O_5).

Table 16. Bray 1 extractable P from post-harvest soil samples (mg kg^{-1})

Source	Level 1	Level 2	Level 3	Mean
1. MRP	20.2	20.2	20.2	20.2
2. MUP	20.1	20.1	20.1	20.1
3. GAP	21.1	21.5	21.5	21.4
4. RJP	20.0	20.2	20.5	20.2
5. SSP	20.1	20.1	20.1	20.1
Mean	20.3	20.4	20.5	
Control	19.8			
CD (0.05)	Source	Level		
	0.20	0.16		

Table 17. DTPA extractable Cd in post-harvest soil samples (mg kg^{-1})

Source	Level 1	Level 2	Level 3	Mean
1. MRP	0.05	0.07	0.07	0.06
2. MUP	0.05	0.07	0.08	0.07
3. GAP	0.06	0.08	0.09	0.08
4. RJP	0.05	0.06	0.07	0.06
5. SSP	0.05	0.06	0.07	0.06
Mean	0.05	0.07	0.08	
Control	0.04			
CD (0.05)	Source	Level		
	0.01	0.004		

Table 18. DTPA extractable Pb in post-harvest soil samples (mg kg^{-1})

Source	Level 1	Level 2	Level 3	Mean
1. MRP	0.13	0.14	0.14	0.14
2. MUP	0.13	0.13	0.13	0.13
3. GAP	0.13	0.13	0.13	0.13
4. RJP	0.13	0.13	0.13	0.13
5. SSP	0.13	0.13	0.14	0.13
Mean	0.13	0.13	0.13	
Control	0.12			
CD (0.05)	Source	Level		
	0.002	0.002		

The available P values from all the other sources were on par and remained much inferior to Gafsa in the post-harvest soil samples.

Increasing levels of P application to soils had very little influence in enhancing the extractable P content, in the post-harvest soil samples. This must be due to the higher utilization of P sources from soil which indirectly supported the production of dry matter yield.

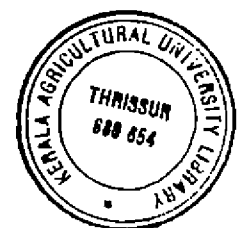
2.1.6 Available Cd in post-harvest soil samples

The content of DTPA extractable Cd in the post-harvest soil samples where five different sources of P have been applied at 3 levels, is depicted in Table 17.

The highest amount of extractable Cd (0.08 mg kg^{-1}) in the post-harvest soil samples was recorded from the pots where Gafsa rock had been applied. This must be due to the relatively higher content of Cd in Gafsa rock (55 mg kg^{-1}) and it might be due the higher residual effect of P fertilizer in soils. The available Cd status in soils, where in other P sources had been applied remained more or less same with no significant difference between them. The least amount of available Cd (0.04 mg kg^{-1}) was recorded in the control. However, when all the other treatments are taken as a unit and compared with control, there had been significant difference. Variation in the content of DTPA extractable Cd due to levels of P application was found to be significant.

2.1.7 Available Pb status in the post-harvest soil samples

Table 18 presents the details of the available Pb status (as extracted by DTPA) in the post-harvest soil samples which had received different P fertilizers at



three levels of application. The availability of Pb from control pot remained significantly lower to all other levels of Pb indirectly attained through the different levels of fertilizer P application. Application of Maton rock recorded higher availability of Pb in the post-harvest soil samples. All the other sources of P viz. Mussoorie, Gafsa, Rajasthan and SSP remained on par in providing the available Pb status in the post-harvest soil samples.

The normal variation of Pb content observed in the different P sources, had not reflected proportionately in building the available Pb status in the post-harvest soil samples, even at its higher levels of application.

2.1.8 Total Cd status in the post-harvest soil samples

The total Cd status in soil consequent to the addition of five different sources of P at 3 levels is depicted in Table 19.

The total Cd content of control pot remained significantly inferior to all other sources of P tried at three levels. The contents of total Cd in the post-harvest soil samples were more or less similar with no significant difference between any treatment though there had been marked differences in the Cd load in majority of the P fertilizers at the time of application.

Increasing level of P application could not influence the total Cd status of post-harvest soil sample, even between the lowest and the highest level of P application. This must have been probably due to the differential uptake of cadmium from the applied P sources at all levels, through out the growth period, leaving very low but stable levels of Cd in the soils especially towards the end of the crop.

Table 19. Total Cd in post-harvest soil samples (mg kg^{-1})

Source	Level 1	Level 2	Level 3	Mean
1. MRP	0.79	0.79	0.79	0.79
2. MUP	0.79	0.79	0.79	0.79
3. GAP	0.79	0.79	0.79	0.79
4. RJP	0.79	0.79	0.79	0.79
5. SSP	0.79	0.79	0.79	0.79
Mean	0.79	0.79	0.79	
Control	0.78			
CD (0.05)	Source 0.001	Level 0.0003		

Table 20. Total Pb in post-harvest soil samples (mg kg^{-1})

Source	Level 1	Level 2	Level 3	Mean
1. MRP	1.20	1.21	1.25	1.22
2. MUP	1.20	1.21	1.21	1.21
3. GAP	1.20	1.20	1.20	1.20
4. RJP	1.20	1.21	1.21	1.21
5. SSP	1.20	1.21	1.21	1.21
Mean	1.20	1.21	1.22	
Control	1.19			
CD (0.05)	Source NS	Level NS		

2.1.9 Total Pb status in the post-harvest soil samples

Total Pb status in soil consequent to the addition of five different sources of P at three levels is depicted in Table 20.

Application of Maton rock though recorded highest total Pb content in post-harvest soil samples was not significantly different from the other sources in providing total Pb content. There had been no significant difference in the total Pb status in post-harvest soil samples even when the lowest and highest level of application of any source is compared.

On comparison with the control values, all sources and levels maintained a significantly higher total Pb status in the post-harvest soils. The wide variation in the content of Pb observed in the different P sources at the time of application was not reflected properly in the total Pb status in the various post-harvest soil samples. The regular Pb uptake by chilli plants as evidenced by its sizable retention in different plant parts all through the active periods of growth might have been a possible reason for such an observation.

2.2 Assessment of direct sources of heavy metals

2.2.1 Effect of direct sources of heavy metals on the dry matter yield of chilli

The results of the dry matter yield of root, shoot and fruit portions of chilli plant from pots receiving application of two direct water soluble sources of heavy metals at two levels are depicted in Tables 21, 22 and 23, respectively.

Application of CdCl_2 and $\text{Pb}(\text{NO}_3)_2$ at two levels meeting the P requirements of the plant are met through chemically pure KH_2PO_4 , recorded significantly lower dry matter yield in chilli plants. The dry matter yields of root due to the application of other fertilizer P sources were significantly higher over this

Table 21. Drymatter yield of chilli root (g pot^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	1.23	1.43	1.33
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	1.17	1.27	1.22
3. CdCl_2	L ₂	1.03	1.53	1.28
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	1.30	1.50	1.40
Mean		1.18	1.43	
Control		0.87		
CD (0.05)		Source	Level	
		0.09	0.07	

Table 22. Drymatter yield of chilli shoot (g pot^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	14.0	17.4	15.7
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	14.1	17.2	15.7
3. CdCl_2	L ₂	14.8	15.3	15.1
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	15.1	15.9	15.5
Mean		14.5	16.5	
Control		4.7		
CD (0.05)		Source	Level	
		0.52	0.37	

Table 23. Drymatter yield of chilli fruit (g pot^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	3.43	3.43	3.43
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	3.37	3.53	3.45
3. CdCl_2	L ₂	3.47	3.60	3.53
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	3.20	3.53	3.37
Mean		3.37	3.53	
Control		1.57		
CD (0.05)		Source	Level	
		0.12	0.08	

chemically pure source of P applied in conjunction with heavy doses of heavy metals, indicating the negative influence of the direct dose of heavy metals in suppressing the dry matter yields especially for roots. However, when organic matter was applied to chilli plants in conjunction with the direct application of heavy metals, the relative dry matter yield of root, shoot and fruit portion of the plant were significantly higher indicating the positive influence of organic matter in retarding the ill effects of heavy metals like Pb and Cd in suppressing the dry matter yield. This might have been due to the possible chelating action of organic matter on the heavy metals which ultimately mitigated the ill effects of heavy metals on growth and uptake. Such a situation in soil also might have permitted improved absorption of nutrients leading to higher dry matter production. This observation is in conformity with the findings noted in soyabean and wheat by Haghiri (1973).

2.2.2 Phosphorus uptake by chilli root, shoot and fruit from chemically pure source of P applied along with direct source of heavy metals

The results of the P uptake from chemically pure source of P (KH_2PO_4) under the influence of the application of water soluble sources of heavy metals at two levels either alone or in combination with organic matter are presented in Tables 24, 25 and 26 respectively for the root, shoot and fruit portions of the chilli plant.

The results indicated that the presence of a direct source of heavy metals like Cd or Pb when applied with KH_2PO_4 retarded the uptake of P in all the parts of chilli plant. This uptake values were much lower, when compared to the uptake values of P from different rock sources, at comparable levels of P application (Table 7, 8 and 9). This might have been due to the negative influence of heavy metals especially cadmium and lead on the root growth, which ultimately should be made responsible for the uptake of any nutrient. Yet another reason for the reduced

Table 24. P uptake by chilli root (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	1.0	1.0	1.0
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	1.0	1.1	1.1
3. CdCl_2	L ₂	1.0	1.1	1.1
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	1.0	1.0	1.0
Mean		1.0	1.0	
Control		0.2		
CD (0.05)		Source NS	Level NS	

Table 25. P uptake by chilli shoot (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	58.3	78.3	68.3
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	56.0	77.0	66.5
3. CdCl_2	L ₂	63.7	68.0	65.8
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	64.0	73.7	68.8
Mean		60.5	74.3	
Control		1.6		
CD (0.05)		Source NS	Level 2.15	

Table 26. P uptake by chilli fruit (mg pot^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	21.0	20.3	20.7
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	19.3	21.3	20.3
3. CdCl_2	L ₂	20.0	20.3	20.2
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	16.7	21.7	19.2
Mean		19.3	20.8	
Control		3.3		
CD (0.05)		Source NS	Level 0.97	

uptake by P noted from KH_2PO_4 application under the influence of heavy metals especially in the absence of organic matter might have been due to the enhanced fixation of P, which normally should have occurred in the acidic soil used. The application of organic matter in conjunction with the heavy metals could not make much root uptake of P from KH_2PO_4 . However, the P uptake from this source by shoot and fruit portion was significantly higher than its root portions.

The uptake values of P from the different rock sources (Tables 7, 8 and 9) with their indirect supply of heavy metals to soils when compared with that of a fully water soluble P source like KH_2PO_4 , were relatively higher. The slow dissolution of rock matrix accompanied by the gradual release of a relatively low quantity of heavy metals compared to the amount of P release might have had only lesser negating effect on P on the root growth and thus favouring enhanced P uptake.

2.2.3 Cadmium uptake by chilli root, shoot and fruit from direct application of heavy metals

The results on the Cd uptake by the root, shoot and fruit portions of chilli plant from the application of CdCl_2 salt at two levels (2.5 and 5 mg pot^{-1}) are depicted in Tables 27, 28 and 29 and Fig.8 and 9, respectively.

Cadmium uptake by chilli root, shoot and fruit portion from the application of CdCl_2 was found to be significantly higher at higher levels of application. The organic matter application had also resulted in marginal but significant enhancement of the Cd uptake in all the plant parts. This must be due to the marginal contribution of heavy metals from organic matter under favourable condition. Anderson (1976) had reported that under normal application rates of organic matter an annual input of 1 to 4 g Cd ha^{-1} can be expected in soils. The

Table 27. Cd uptake by chilli root ($\mu\text{g pot}^{-1}$) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl ₂	L ₁	42.8	43.2	43.0
2. Pb(NO ₃) ₂	L ₁	1.1	1.3	1.2
3. CdCl ₂	L ₂	91.2	93.5	92.4
4. Pb(NO ₃) ₂	L ₂	1.1	1.2	1.2
Mean		34.1	34.8	
Control		0.8		
CD (0.05)		Source 0.94	Level 0.66	

Table 28. Cd uptake by chilli shoot ($\mu\text{g pot}^{-1}$) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl ₂	L ₁	77.2	79.4	78.3
2. Pb(NO ₃) ₂	L ₁	1.5	1.7	1.6
3. CdCl ₂	L ₂	137.1	140.4	138.8
4. Pb(NO ₃) ₂	L ₂	1.5	1.7	1.6
Mean		54.3	55.8	
Control		0.5		
CD (0.05)		Source 0.83	Level 0.63	

Table 29. Cd uptake by chilli fruit ($\mu\text{g pot}^{-1}$) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl ₂	L ₁	24.1	24.9	24.5
2. Pb(NO ₃) ₂	L ₁	0.5	0.5	0.5
3. CdCl ₂	L ₂	45.7	47.6	46.7
4. Pb(NO ₃) ₂	L ₂	0.6	0.6	0.6
Mean		17.7	18.4	
Control		0.2		
CD (0.05)		Source 0.36	Level 0.25	

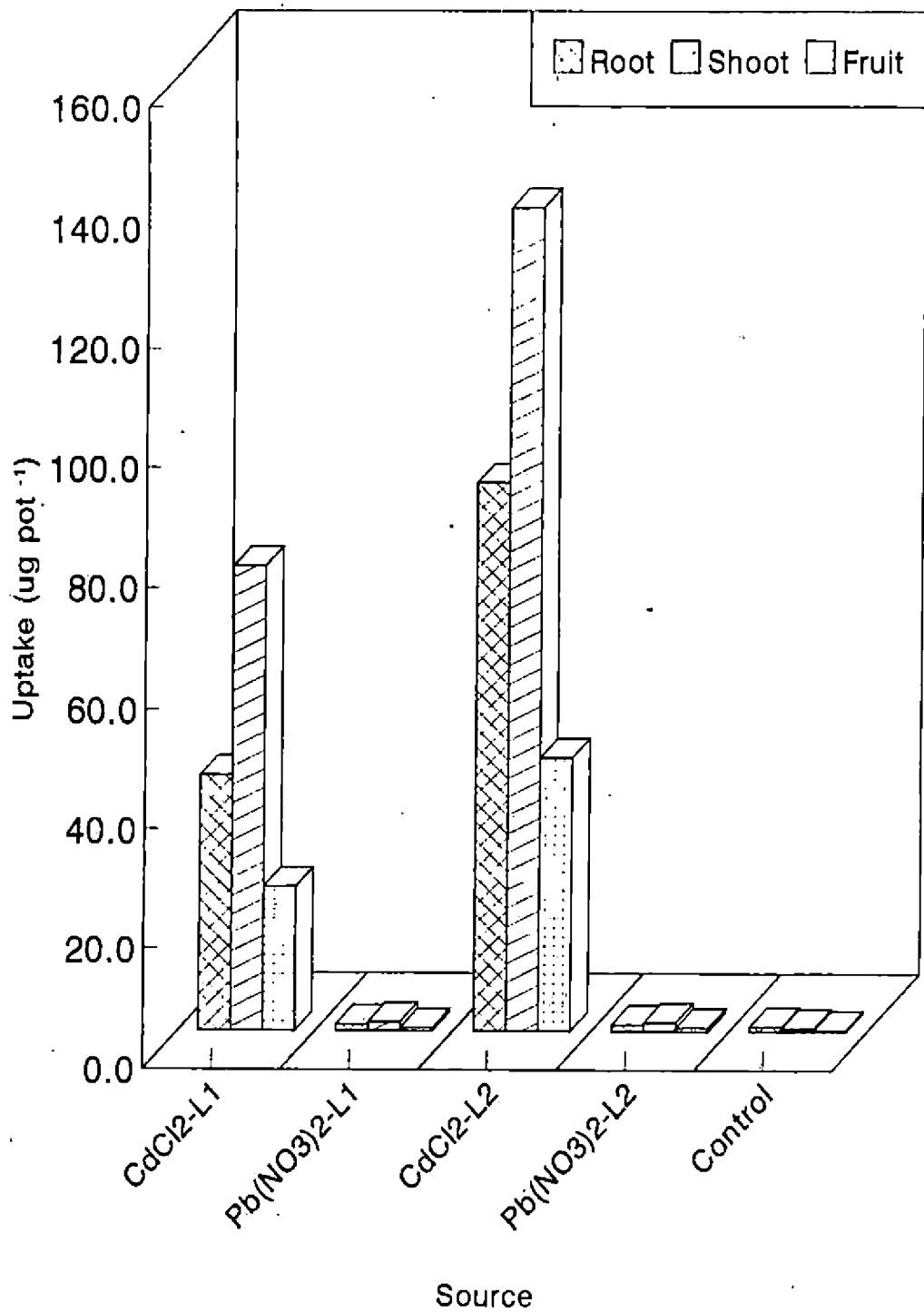


Fig 8. Cadmium uptake by chilli root, shoot and fruit from direct application of heavy metals without organic matter

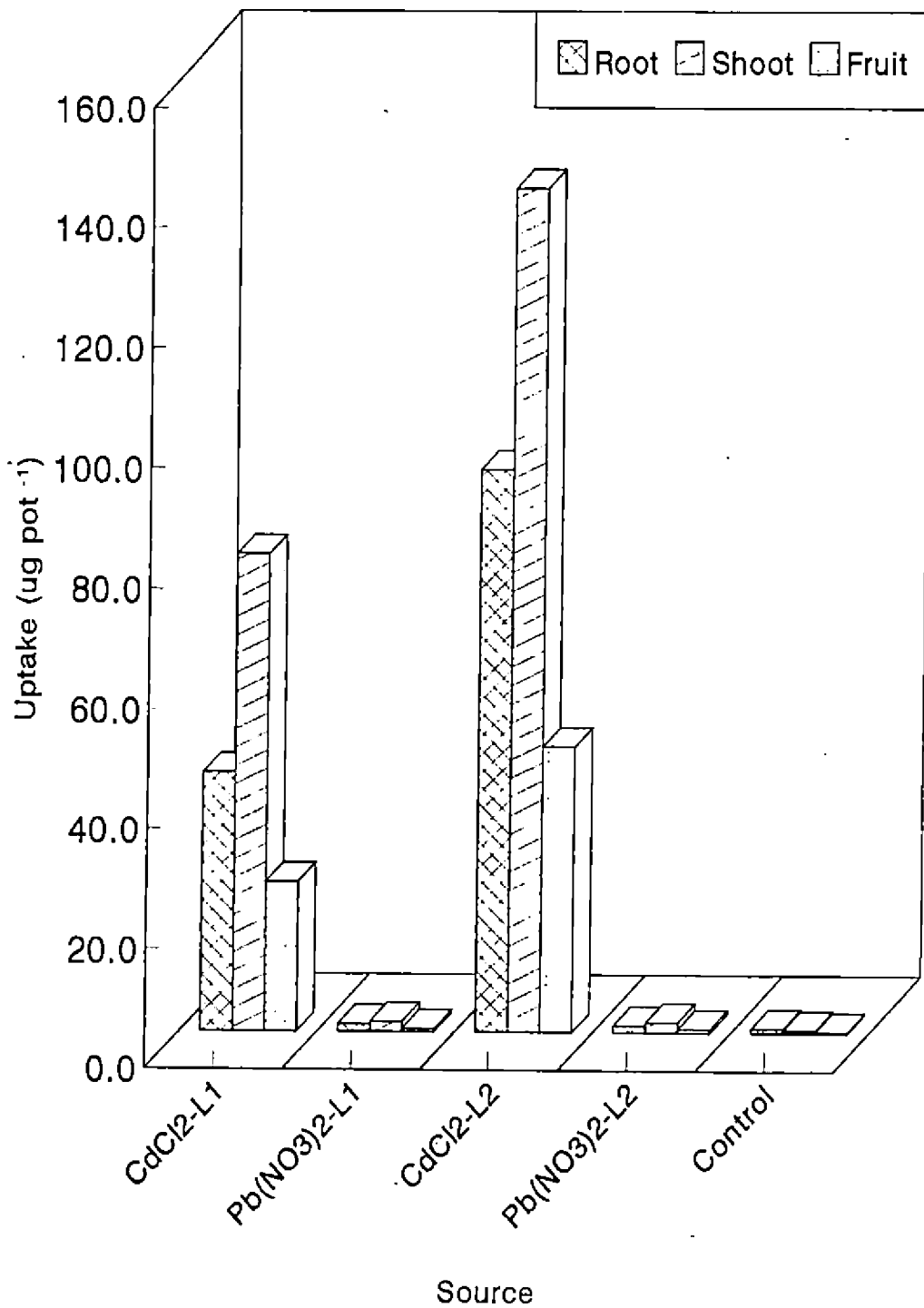


Fig 9. Cadmium uptake by chilli root, shoot and fruit from direct application of heavy metals with organic matter

relative retention of cadmium was found to be least in the fruit portion, followed by root and shoot portion even when the metal was applied as a readily available and water soluble sources, suggesting that the edible part of plant is relatively less loaded with the heavy metals, making them safe for human consumption. Further, the low metallic load in fruit portion could be viewed as either due to a redistribution of heavy metals within the plant or due to a possible failure to translocate the heavy metals to the fruit portion, which had been formed and developed towards the final stages of crop growth.

2.2.4 Lead uptake by chilli root, shoot and fruit from direct application of heavy metals

The results on the Pb uptake by the root, shoot and fruit portions of chilli plant from the application of $\text{Pb}(\text{NO}_3)_2$, a water soluble metal source at two levels (2.5 and 5.0 mg pot⁻¹) are depicted in Tables 30, 31 and 32 and Fig.10 and 11, respectively.

The results indicate that maximum uptake of Pb was noted in the root portions of the plant as against the shoot portions and the uptake became more conspicuous when a direct water soluble source of Pb was applied. However, the trend observed here is almost the same as that noted from the uptake of Pb from an indirect source like rock phosphate. The least uptake of Pb was noted in the fruit portions indicating that the edible portions of the plant is relatively free from this metal too, especially when compared to other plant parts. The uptake of Pb and the subsequent retention by the different plant parts at higher levels of application were found to be significantly higher. Organic matter addition in combination with heavy metals had no negating effect on the metal uptake and instead permitted higher uptake of Pb in all the plant parts studied. From this, it is clear that a direct source of Pb readily permitted higher uptake of the metal to all the plant parts when

Table 30. Pb uptake by chilli root ($\mu\text{g pot}^{-1}$) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl ₂	L ₁	12.0	12.2	12.1
2. Pb(NO ₃) ₂	L ₁	107.1	108.4	107.6
3. CdCl ₂	L ₂	12.1	12.2	12.2
4. Pb(NO ₃) ₂	L ₂	172.6	174.1	173.4
Mean		75.9	76.7	
Control		2.9		
CD (0.05)		Source 0.21	Level 0.15	

Table 31. Pb uptake by chilli shoot ($\mu\text{g pot}^{-1}$) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl ₂	L ₁	6.0	6.2	6.1
2. Pb(NO ₃) ₂	L ₁	57.1	58.4	57.8
3. CdCl ₂	L ₂	6.1	6.2	6.2
4. Pb(NO ₃) ₂	L ₂	72.6	73.1	72.9
Mean		35.5	36.0	
Control		1.5		
CD (0.05)		Source 0.21	Level 0.15	

Table 32. Pb uptake by chilli fruit ($\mu\text{g pot}^{-1}$) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl ₂	L ₁	1.9	2.2	2.1
2. Pb(NO ₃) ₂	L ₁	22.4	23.6	23.0
3. CdCl ₂	L ₂	2.2	2.3	2.3
4. Pb(NO ₃) ₂	L ₂	34.1	35.3	34.7
Mean		15.1	15.9	
Control		0.5		
CD (0.05)		Source 0.26	Level 0.18	

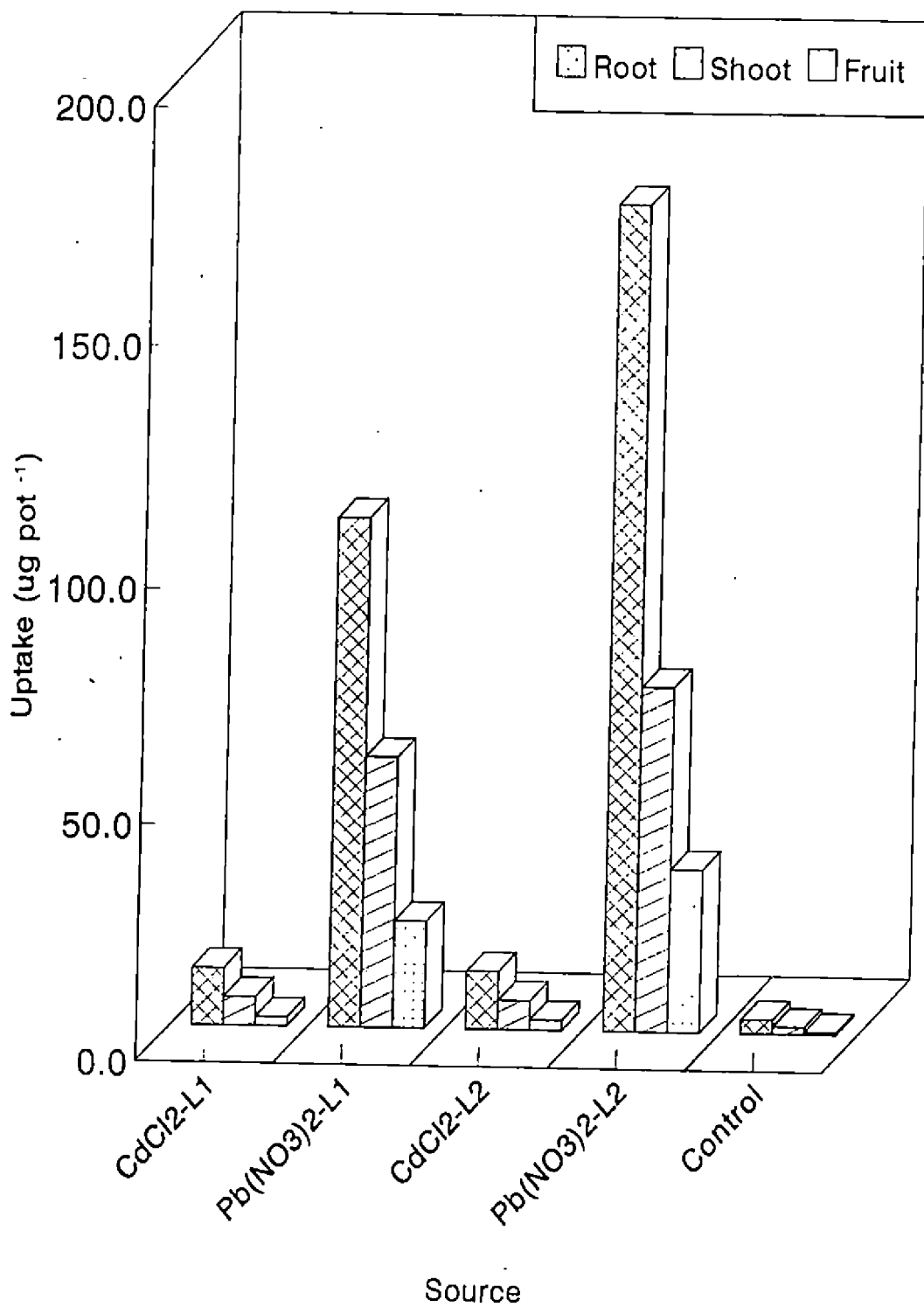


Fig 10. Lead uptake by chilli root, shoot and fruit from direct application of heavy metals without organic matter

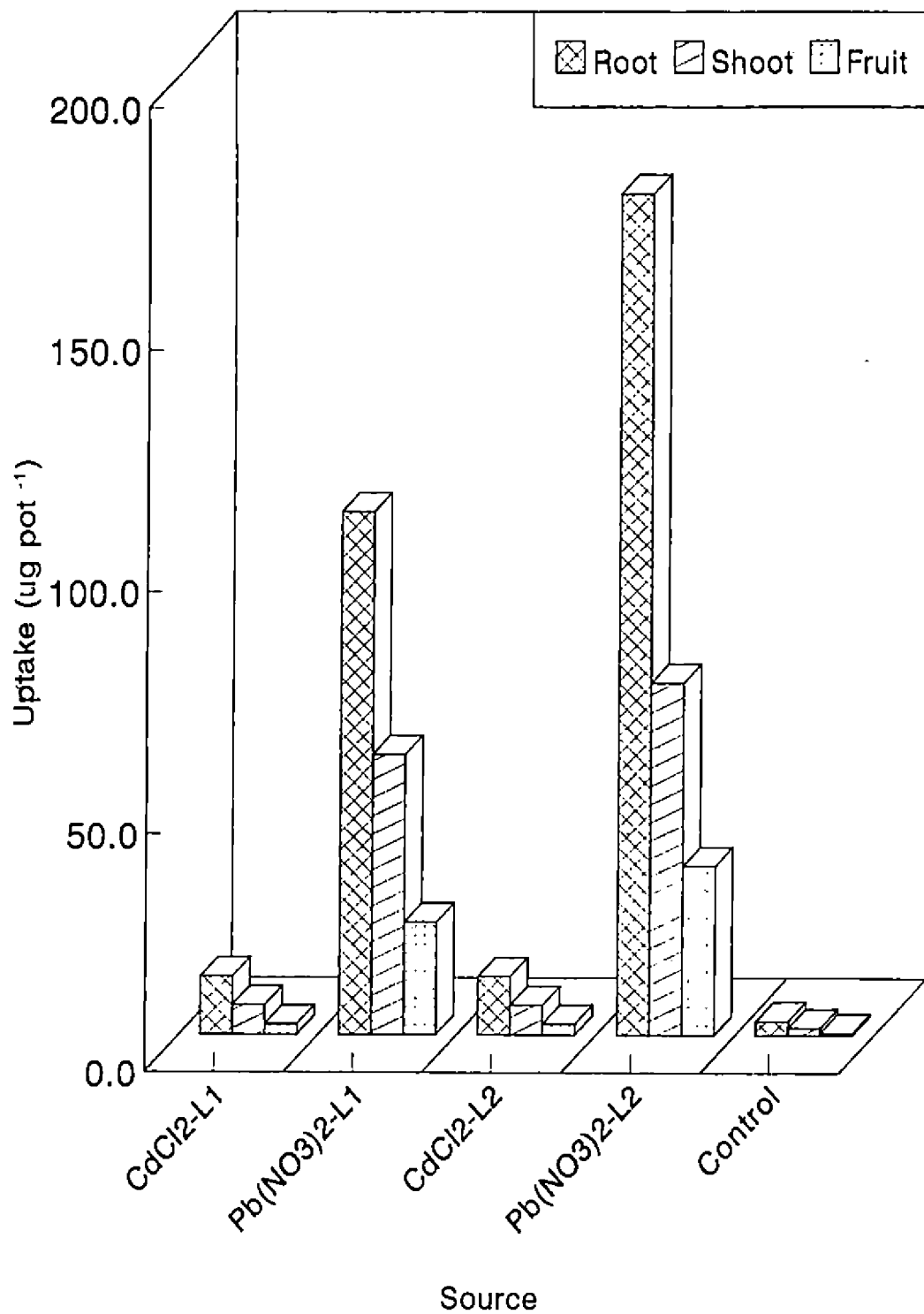


Fig 11. Lead uptake by chilli root, shoot and fruit from direct application of heavy metals with organic matter

compared to that from an indirect source like phosphate rocks (Tables 13, 14 and 15).

2.2.5 Bray-I extractable P from the post-harvest soil samples applied with chemically pure source of P along with direct source of heavy metals

The results of the available P status of post-harvest soil sample where chemically pure source of P (KH_2PO_4) (applied to meet the P requirement) had been combined with heavy metal sources and applied as such or in combination with organic matter are presented in Table 33.

Results indicated that the available P status in the post-harvest soil samples was neither influenced by any source of directly applied heavy metals nor its levels of application. The results presented in Table 16 (available P status of post-harvest soils from rock phosphate application) when compared with this indicated that the available P status in the post-harvest soil samples was hardly influenced by a direct soluble source like KH_2PO_4 or a water soluble source like any rock phosphate at comparable levels of P application. Application of organic matter was found to increase the available P status in the post-harvest soils significantly, especially when the organic is applied in conjunction with the heavy metals viz. CdCl_2 and $\text{Pb}(\text{NO}_3)_2$ at the both levels of application.

2.2.6 Available Cd status in post-harvest soil samples from direct application of heavy metals

The DTPA extractable Cd status in the post-harvest soil samples where direct application of heavy metals were effected at a two levels is given in Table 34.

It has been noted that with increasing levels of application of water soluble Cd salts, the extractable Cd status significantly increased in the post harvest

Table 33. Bray I extractable P from post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	20.1	21.1	20.6
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	20.1	21.2	20.6
3. CdCl_2	L ₂	19.9	21.0	20.5
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	20.0	21.0	20.3
Mean		19.9	21.1	
Control		19.8		
CD (0.05)	Source	Level		
		NS	0.22	

Table 34. DTPA extractable Cd in post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	0.37	0.37	0.37
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	0.04	0.04	0.04
3. CdCl_2	L ₂	0.53	0.58	0.55
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	0.04	0.04	0.04
Mean		0.24	0.26	
Control		0.04		
CD (0.05)		Source	Level	
		0.04	NS	

Table 35. DTPA extractable Pb in post-harvest soil samples (mg kg^{-1}) from direct application of heavy metals in pots with and without organic matter

Source	Level	Without OM	With OM	Mean
1. CdCl_2	L ₁	0.13	0.13	0.13
2. $\text{Pb}(\text{NO}_3)_2$	L ₁	0.49	0.50	0.49
3. CdCl_2	L ₂	0.13	0.13	0.13
4. $\text{Pb}(\text{NO}_3)_2$	L ₂	0.64	0.64	0.64
Mean		0.35	0.35	
Control		0.12		
CD (0.05)		Source	Level	
		0.003	0.003	

soil samples not because of its water solubility, but because of the metal load offered through them. Application of organic matter along with CdCl_2 did not have any additive effect in extracting an enhanced available Cd from post-harvest soil samples especially when the same is compared with the pots where organic matter addition had not been provided. Direct application of heavy metals in pots permitted higher Cd extraction over the indirect application of Cd through the application of various rock phosphates.

The available Cd status provided by the control pots was quite insignificant and was not much different from the available Cd status recorded from the soils where two levels of application of $\text{Pb}(\text{NO}_3)_2$ had been provided.

2.2.7 Available Pb status in post-harvest soil samples from direct application of heavy metals

Table 35 presents data on available Pb (as extracted by DTPA) of the post-harvest soil samples, which had received the application of CdCl_2 and $\text{Pb}(\text{NO}_3)_2$ at two levels.

It was observed that the available Pb of post-harvest soil samples increased significantly with increase in the levels of application of Pb salt. Compared to the extractable Pb content of soil which received application of rock phosphates, the direct application of Pb salts to soils readily permitted significantly higher levels DTPA extractable Pb. Control pots maintained significantly lower levels of extractable Pb when compared to other treatment. Addition of organic matter along with the Pb salts led to significant but marginal enhancement of the DTPA extractable Pb in the post-harvest soil samples. The marginal enhancement in the level of DTPA extractable Pb in organic matter treated pots could be due to the very low contribution of Pb from the organic matter

2.2.8 Total Cd content in post-harvest soil samples from direct application of heavy metals

The variations in the total Cd status of soil after the addition of heavy metal sources at two levels are presented in Table 36.

Increasing level of Cd application in soils through soluble CdCl_2 enhanced the total Cd status in the post-harvest soils. The contribution of P fertilizer, especially rock phosphates towards the total Cd of soil (Table 19) was relatively low when compared with that from the direct application of Cd salts (Table 36) were much lesser. The decreased level of total Cd observed in fertilizer treated pots at the end of the crop might have been due to the higher uptake of these metals from soils (Tables 27, 28 and 29). The higher level of total Cd observed in the post-harvest soil samples where Cd salts had been directly applied might be due to the very high concentration of Cd ions added. Addition of $\text{Pb}(\text{NO}_3)_2$ even at two levels did not influence the total Cd status in the post-harvest soils and these values were comparable with those obtained from the control pots.

2.2.9 Total Pb content in post-harvest soil samples from direct application of heavy metals

Data on total Pb in the post-harvest soil samples after the addition of CdCl_2 and $\text{Pb}(\text{NO}_3)_2$ at two levels are furnished in Table 37.

Increasing levels of Pb application in soils through soluble Pb salts resulted in significantly enhanced level of this element in the post-harvest soils. The contribution of total Pb through P fertilizers especially through phosphate rock

(Table 20) when compared with that from the direct application of Pb (Table 37) was much lower. The apparent variation in total Pb content observed here might be due to the higher contribution of Pb from the directly applied heavy metal sources where the levels of heavy metals are purposefully maintained at higher levels. The low content of Pb in rock phosphates together with a higher dry matter yield, might have certainly influenced in lowering the total Pb content in such treatments. High uptake of Pb by plants also would have caused a relatively low content of Pb in post-harvest soil.

It was observed that addition of organic matter could not impart any influence in enhancing the total lead status. The total lead status in control pots was significantly lower when compared to any other treatment.

2.3 Assessment of partially acidulated phosphate rock sources

2.3.1 Effect of partially acidulated P sources on the dry matter yield of chilli

The data on dry matter yield of root, shoot and fruit portions of chilli plant from the application of partially acidulated sources of P are presented in Table 38.

The dry matter yield of chilli roots was observed to be lower than its shoot and fruit portions on application of acidulated rock sources. But this yield when compared to that obtained by the application of different untreated rock sources, was higher. The relative increase in the dry matter yield noted for the shoot and fruit portions from partially acidulated sources might have been due to a more readily available P portions which might have permitted rapid growth. The significantly lower dry matter yield observed from the application of chemically pure P sources might have been due to a possible fixation of P in soils which must

Table 38. Drymatter yield of plant parts (g pot^{-1}) from partially acidulated phosphate rock applied pots

Source	Root	Shoot	Fruit
1. PA-MRP	1.27	15.20	4.33
2. PA-MUP	1.10	15.10	3.67
3. PA-GAP	2.67	24.30	5.80
4. PA-RJP	1.23	16.30	3.77
5. Chemically pure source of NPK	1.20	14.50	3.40
6. Control	0.87	4.70	1.57
CD (0.05)	0.26	1.36	0.26

Table 39. P uptake by chilli in root, shoot and fruit (mg pot^{-1}) from partially acidulated phosphate rock applied pots

Source	Root	Shoot	Fruit
1. PA-MRP	1.0	70.7	24.0
2. PA-MUP	1.0	70.0	23.7
3. PA-GAP	1.9	114.3	37.7
4. PA-RJP	1.0	75.3	23.7
5. Chemically pure source of NPK	1.0	61.3	19.3
6. Control	0.2	1.6	3.3
CD (0.05)	0.2	7.7	2.8

have negated the dry matter yield by permitting only slow growth. The dry matter yield in control pots was significantly lower than any other treatment.

2.3.2 P uptake by chilli root, shoot and fruit from the application of partially acidulated phosphate rock

The data on P uptake from partially acidulated sources by root, shoot and fruit portions of chilli plant are depicted in Table 39.

The values of P uptake in the root, shoot and fruit portions of the plant from the partially acidulated sources were much higher than that from the untreated rock phosphate treated pots (Tables 7, 8 and 9). The higher uptake noted from acidulated sources might be due to the readily available P portions in these sources. Application of the chemically pure source of P could support only a much significantly lower dry matter yield possibly due to the high P fixation that must have occurred in the acidic soils used thus permitting lower dry matter yield. The uptakes of P by root, shoot and fruit portions from the different partially acidulated rock sources were much higher when compared to that of the control pots.

2.3.3 Cd uptake by root, shoot and fruit portions of chilli from the application of partially acidulated phosphate rock

The data on Cd uptake by root, shoot and fruit portions of chilli plant from the application of partially acidulated P sources are presented in Table 40 and Fig.12.

The Cd uptake by chilli plant in the different portions from partially acidulated rock sources was much higher when compared to the corresponding uptake from the untreated rock source (Tables 10, 11 and 12). This must be possibly due to the fact that partial acidulation must have permitted the rapid dissolution of

heavy metals from the matrix of the rock phosphate which in turn must have permitted enhanced Cd uptake from them. It had been observed that fruit portions of the plant were relatively less loaded with the heavy metals when compared to its shoot and root portions. A similar trend was observed from the use of untreated rock source (Tables 10, 11 and 12).

Application of chemically pure source of NPK could not provide increased metal loads in plants, possibly indicating the absence of metal loads in them. Control values were significantly lower when compared to the corresponding uptake of Cd in the root, shoot and fruit portions of chilli from the treated sources.

2.3.4 Pb uptake by root, shoot and fruit portions of chilli from the application of partially acidulated phosphate rock

Data on Pb uptake from the partially acidulated P sources by the root, shoot and fruit portions of the chilli plant are presented in Table 41 and Fig. 13.

The values of Pb uptake by chilli plant in the different portions from partially acidulated rock sources were much higher when compared to the corresponding uptake from the untreated rock sources (Tables 13, 14 and 15). This must be again possibly due to the fact that partial acidulation must have permitted the rapid dissolution of heavy metals from the matrix of the rock phosphate which in turn might have permitted rapid uptake of Pb from them. It had been observed that fruit portions of the plant were relatively lesser loaded with the heavy metals when compared to its shoot and root portions. A similar trend was observed from the use of untreated rock sources (Tables 13, 14 and 15).

Application of chemically pure source failed to support increased metal uptake in plants. Control values were significantly lower when compared to the

Table 40. Cd uptake by chilli in root, shoot and fruit ($\mu\text{g pot}^{-1}$) from partially acidulated phosphate rock applied pots

Source	Root	Shoot	Fruit
1. PA-MRP	1.9	2.7	1.4
2. PA-MUP	1.9	2.7	1.1
3. PA-GAP	2.2	3.0	1.7
4. PA-RJP	1.8	2.8	1.2
5. Chemically pure source of NPK	1.1	1.6	0.6
6. Control	0.8	0.5	0.2
CD (0.05)	0.72	0.75	0.32

Table 41. Pb uptake by chilli in root, shoot and fruit ($\mu\text{g pot}^{-1}$) from partially acidulated phosphate rock applied pots

Source	Root	Shoot	Fruit
1. PA-MRP	16.3	10.0	3.9
2. PA-MUP	13.9	7.9	3.0
3. PA-GAP	13.5	7.5	2.9
4. PA-RJP	14.3	8.3	3.1
5. Chemically pure source of NPK	12.1	6.1	2.0
6. Control	2.9	1.5	0.5
CD (0.05)	0.46	0.29	0.32

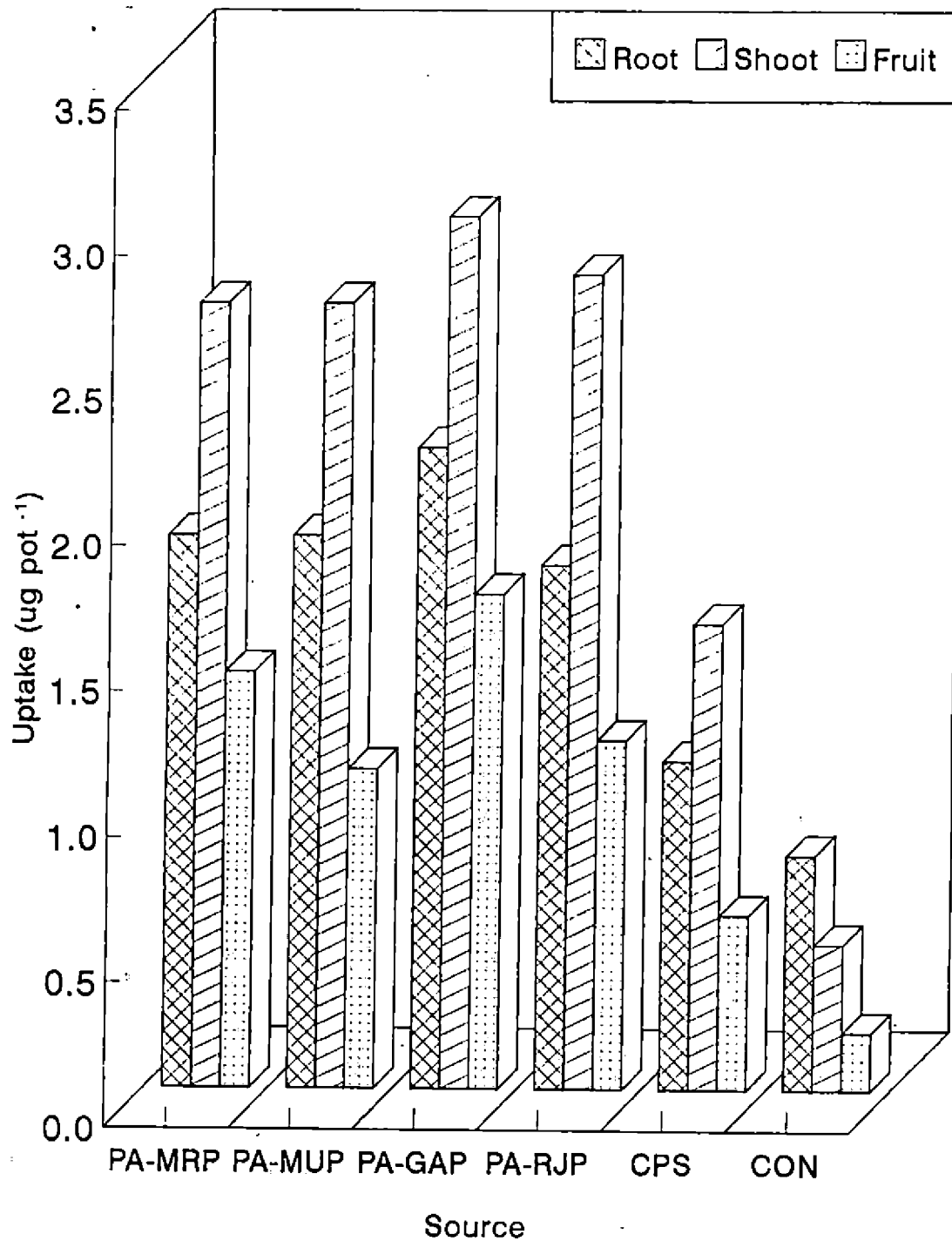


Fig 12. Cadmium uptake by chilli root, shoot and fruit from partially acidulated phosphate rock

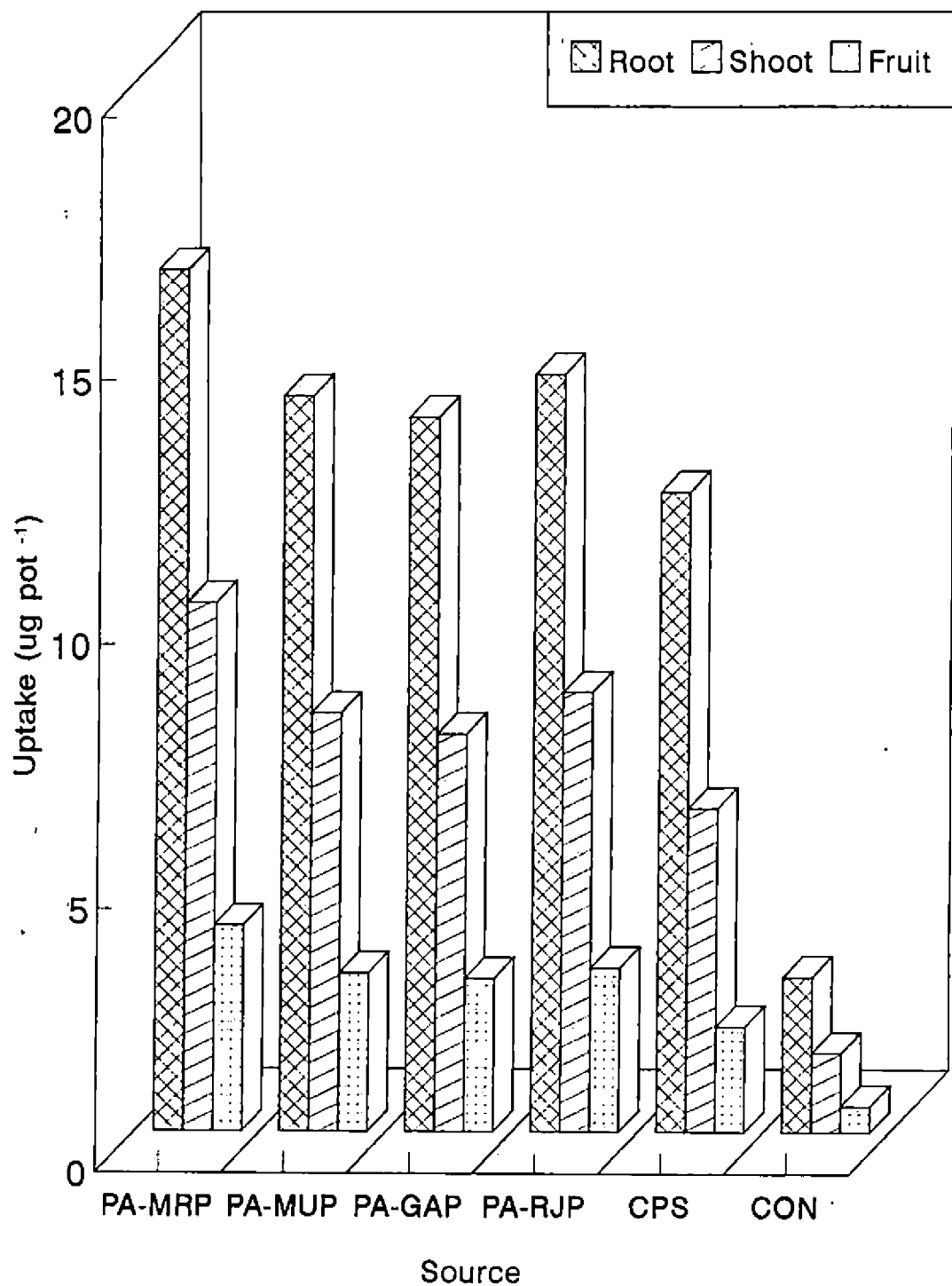


Fig 13. Lead uptake by chilli root, shoot and fruit from partially acidulated phosphate rock

corresponding uptake of Pb in the root, shoot and fruit portions of chilli from the treated sources.

2.3.5 Available Cd and Pb status in post-harvest soil samples from the application of partially acidulated P sources

The results of the available Cd and Pb status in the post-harvest soil samples after the application of partially acidulated P sources are depicted in Table 42.

No significant difference in the DTPA extractable Cd and Pb status was observed between the different post-harvest soil samples where different partially acidulated P sources had been tried. These values very much compared with the corresponding DTPA extractable metals (Tables 17 and 18) where non-acidulated rock sources were applied.

Though the acidulated rock sources permitted higher uptake of metals by plants than non-acidulated sources, the DTPA extractable Cd and Pb status remained more or less same in the post-harvest soil samples. This must be possibly due to the rapid dissolution of partially acidulated sources which must have permitted rapid uptake of metal from them. The gradual dissolution of heavy metal ions from the untreated rock sources and subsequent uptake by plants must have resulted in the comparable, available metal status in soils. The DTPA extractable Cd and Pb in the control pots were only marginally less when compared to the values furnished by the acidulated sources in the post-harvest soil samples.

2.3.6 Total Cd and Pb status in the post-harvest soil samples applied with partially acidulated P sources

The total Cd and Pb status in the post-harvest soil samples after the addition of partially acidulated P sources are presented in Table 43.

Table 42. DTPA extractable Cd and Pb in post-harvest soil samples (mg kg^{-1}) from partially acidulated phosphate rock applied pots

Source	Av. Cd	Av. Pb
1. PA-MRP	0.05	0.13
2. PA-MUP	0.05	0.13
3. PA-GAP	0.06	0.13
4. PA-RJP	0.05	0.13
5. Chemically pure source of NPK	0.05	0.13
6. Control	0.04	0.12
CD (0.05)	0.03	0.003

Table 43. Total Cd and Pb in post-harvest soil samples (mg kg^{-1}) from partially acidulated phosphate rock applied pots

Source	Total Cd	Total Pb
1. PA-MRP	0.79	1.21
2. PA-MUP	0.79	1.20
3. PA-GAP	0.79	1.20
4. PA-RJP	0.79	1.20
5. Chemically pure source of NPK	0.79	1.20
6. Control	0.78	1.19
CD (0.05)	0.03	0.26

The contents of total Cd and Pb in the post-harvest soil samples consequent to application of the partially acidulated sources were comparatively lesser when compared to the corresponding heavy metal status observed in the post-harvest soils from the application of untreated rock sources. The total Cd status of post-harvest soil samples of different partially acidulated sources remained more or less similar with no significant difference between them even when control pots are also compared. A similar trend could be observed for the total Pb status in the post-harvest soil samples when partially acidulated sources were applied. However, the lower total Cd and Pb status in the post-harvest soil samples where acidulated rock sources were tried could be due to the higher uptake of heavy metals from these sources by the plants due to the rapid dissolution of rock matrix consequent to the acidulation treatment.

Summary

SUMMARY

Different phosphate sources collected from different locations were subjected to analysis to quantify the extent of heavy metals in them with special reference to cadmium and lead. After a preliminary analysis of all those sources, a few sources which maintained relatively higher concentrations of cadmium and lead [Maton rock phosphate, Mussoorie rock phosphate, Gafsa rock phosphate, Rajasthan rock phosphate and single superphosphate] were selected for further studies employing a pot culture experiment. The test crop chosen was chilli (*Capsicum annuum* L.). To derive meaningful observations regarding the uptake of heavy metals from phosphate source, five sources of P including a water soluble source were selected, besides their partially acidulated form for application in pots at three levels, with the lowest level conforming to the P requirement envisaged in the package of practice for the chilli crop ($40 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$).

Direct sources of water soluble cadmium and lead were also included (as cadmium chloride and lead nitrate respectively) to assess their bioavailability to plants besides getting their comparison. In all the experimental pots N and K were supplemented at the required doses as per the package of practices recommendation of the Kerala Agricultural University (70 kg N and 25 kg K per hectare). The influence of organic matter in regulating the availability of heavy metals was also assessed in the present study by applying water soluble sources of heavy metals either alone or in combination with organic matter at the recommended doses.

The experiment was conducted in the Vegetable Research Farm, Department of Olericulture, Vellanikkara during the kharif season of 1996. Acidic soils were purposefully used for the pot culture experiment to maintain an

enhanced availability of heavy metals from all the applied sources to the test crop. From the ensuing analysis of both plant and soil samples the following observations were made.

1. All the phosphatic sources studied namely (1) Maton rock phosphate, (2) Mussoorie rock phosphate, (3) Gafsa rock phosphate, (4) Rajasthan rock phosphate and (5) Single superphosphate contained varying amounts of cadmium and lead.
2. Gafsa rock analysed the maximum content of cadmium (55 mg kg^{-1}) followed by 25 mg Cd kg^{-1} for the Maton rock. Single superphosphate which is a water soluble source of P analysed the least concentration of cadmium among the five P sources tried.
3. Maton rock recorded the maximum lead content (230.5 mg kg^{-1}), while the minimum analysis of lead (38 mg kg^{-1}) was noted in the Mussoorie rock with all the other sources registering their lead content between these values.
4. It was observed from the pot culture experiment that in general, the relative shoot dry matter yield was much higher than its root and fruit dry matter yields, irrespective of the treatments given. It was observed that the dry matter yield and P uptake by chilli plant were related to the P content in the phosphate sources tried.
5. Irrespective of the P sources the shoot portion of the plant maintained relatively more P uptake than its fruit or root portions at all levels of application. In general Gafsa rock provided the maximum P uptake to the chilli crop followed by SSP, a water soluble source of P. The P uptake in the

root, shoot and fruit portions of the plant from partially acidulated treatments was relatively higher than that from its corresponding untreated rock sources. The P uptake values resulted from the addition of chemically pure KH_2PO_4 (to meet the P requirements) when combined with the direct application of heavy metals like CdCl_2 and $\text{Pb}(\text{NO}_3)_2$, were much lower when compared to P uptake from different untreated rock sources or from their acidulated forms in soils.

6. In general a higher uptake of cadmium was noted in the shoot portion of chilli plant than its root portion. The least uptake of heavy metals was noted in the fruit portion of the plant from all treatments and at all levels of application. However, in the case of Pb, the roots maintained higher uptake than the shoot portion. Fruit portion of the plant maintained the least amount of Pb making the edible portion relatively more safe than its other plant parts.
7. Application of direct source of heavy metals (through water soluble salts) resulted in a considerable increase in the uptake of cadmium and lead in all its plant parts, with relatively lesser load of heavy metals in the edible part of the plant (fruit).
8. Cadmium and lead uptake by root, shoot and fruit portions of chilli from the application of partially acidulated sources registered a similar trend with slightly higher uptake.
9. The organic matter when applied along with the direct source of heavy metals viz., CdCl_2 and $\text{Pb}(\text{NO}_3)_2$ at two levels of application resulted in significantly increased uptake of cadmium and lead in all the plant parts. However, it maintained the same trend as seen earlier.

10. An assessment of the available cadmium and lead status in the post-harvest soil samples indicated that there was not much build-up of these metals in soils.
11. Direct application of higher levels of heavy metals in soils permitted higher cadmium and lead extraction in the post-harvest soils and the quantum of extracted heavy metals was much higher when compared to that extracted from soils where different rock sources had been applied.
12. Application of partially acidulated rock sources though could provide enhanced uptake of heavy metals by plants, could not cause higher residual effect of Cd and Pb in post-harvest soil samples, as assessed by the DTPA extraction.

References

REFERENCES

- Allen, H.E., Hall, R.H. and Brisbin, T.D. 1980. Metal speciation: Effects on aquatic toxicity. *Environ.Sci. Technol.* **14**:441-443
- Alloway, B.J., Jackson, A.P. and Morgan, H. 1990. The accumulation of cadmium by vegetables grown on soils contaminated from a variety of sources. *Sci. Total Environ.* **91**:232-236
- Alloway, B.J. and Morgan, H. 1986. The behaviour and availability of Cd, Ni and Pb in polluted soils. *Contaminated Soils* (Assink, J.W. and Brink, W.J.V. eds.) Kluwer Academic Press, Dordrecht, p.101-113
- Alloway, B.J., Tills, A.R. and Morgan, H. 1984. *Trace substances and human health* (Hemphill, D.D. ed.) *Proceedings XVIII. Annual Conference*, Columbia, Missouri, U.S.A. University of Missouri.
- Anderson, A. 1976. On the influence of manure and fertilizers on the distribution and amounts of plant available Cd in soil. *Swedish J. agric. Res.* **6**:27-36
- Anderson, A. and Nilsson, K.O. 1974. Influence of lime and soil pH on Cd availability to plants. *Ambio* **3**:198-200
- Ashby, D.L., Fenster, W.E. and Attoe, O.J. 1966. Effect of partial acidulation and elemental sulphur on availability of phosphorus in rockphosphate. *Agron. J.* **58**:621
- Basta, N.T. and Tabatabai, M.A. 1992. Effect of cropping systems on the adsorption of metals by soils. II. Effect of pH. *Soil Sci.* **153**:195-204
- Bingham, F.T. 1979. Bioavailability of Cd to food crops in relation to heavy metal contents of sludge amended soils. *Environ. Health Perspect* **28**:39-43

- Bingham, F.T., Strong, J.E. and Sposito, G. 1983. Influence of chloride salinity on cadmium uptake by Swiss chard. *Soil Sci.* **135**:160-165
- Bingham, F.T., Sposito, G. and Strong, J.E. 1984. The effect of chloride on the availability of cadmium. *J. Environ. Qual.* **13**:71-74
- Bingham, F.T., Sposito, G. and Strong, J.E. 1986. The effect of sulphate on the availability of cadmium. *Soil Sci.* **141**:172-177
- Bjerre, G.K. and Schiervp, H. 1985. Uptake of six heavy metals by Oat as influenced by soil type and additions of cadmium, lead, zinc and copper. *Pl. Soil.* **88**:57-69
- Bolland, M.D.A., Weatherley, A.J. and Gilkes, R.J. 1988. Residual effectiveness of super phosphate is greater than that of rock phosphate fertilizers for lateritic soils in South-Western Australia. *Aust. J. exptl. Agric.* **28**:83-90
- Bosque, M.A., Schuhmacher, M., Domingo, J.L. and Leobet, J.M. 1990. Concentration of Lead and cadmium in edible vegetables from Tarragona Province, Spain. *Sci. Total Environ.* **95**:61-67
- Bray, R.H. and Kurtz, L.T. 1945. Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* **59**:39-45
- Carlson, R.W. and Bazzaz, F.A. 1977. Growth reduction in American sycamore (*Plantanus occidentalis* L.) caused by Pb-Cd interaction. *Environ Pollut.* **12**:243-253
- Carlton, C.H.S. and Davis, R.D. 1983. Comparative uptake of heavy metals by forage crop grown on sludge treated soils. *Proc. Int. Conf. Heavy Metal Env.* Vol.I, Heidelberg, Germany, CEP Consultants Ltd. Edinburgh, U.K. p.393-396

- Cavallaro, N. and McBride, M.B. 1978. Copper and cadmium adsorption characteristics of selected acid and calcareous soils. *Soil Sci.Soc. Am. J.* **42**:550-556
- Chang, A.C., Page, A.L. and Warneke, J.E. 1987. Long term sludge application on cadmium and zinc accumulation in Swiss chard and radish. *J. environ. Qual.* **16**:217-221
- Chien, S.H. and Menon, R.G. 1994. Uptake of phosphorus and cadmium by maize from an acid soil treated with high rates of phosphate fertilizers varying in cadmium content. *Environ. Geochem. Health*, 205-214
- Doner, H.E. 1978. Chloride as a factor in mobilities of Ni (I), Cu(II) and Cd(II) in soil. *Soil Sci. Soc. Am. J.* **42**:882-885
- Eriksson, J.E. 1988. The effect of clay, organic matter and time on adsorption and plant uptake of cadmium added to the soil. *Water, Air Soil Pollut.* **40**:359-373
- Fertilizer (Control) Order. 1957. 9th ed., Nov. 1972. Issued by the Fertilizer Association of India, New Delhi, pp.58
- Haghiri, F. 1973. Cadmium uptake by plants. *J. environ. Qual.* **2**:93-95
- Haghiri, F. 1974. Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc and soil temperature. *J. environ. Qual.* **3**:180-183
- Hargitai, L. 1989. The role of humus status of soils in binding toxic elements and compounds. *Sci. Total Environ.* **81**:643-651
- He, Q.B. and Singh, B.R. 1993. Effect of organic matter on the distribution, extractability and uptake of cadmium in soils. *J. Soil Sci.* **44**:641-650

- He, Q.B. and Singh, B.R. 1995. Cadmium availability to plants as affected by repeated applications of phosphorus fertilizer. *Soil Pl. Sci.* **45**(1):22-31
- * Hlusek, J. 1994. Contamination of soil with foreign elements using superphosphate as fertilizer. *Acta-Universitatis-Agriculturae-Facultatis-Agronomica* **42**:83-90
- Huffman, E.W.D.Jr. and Hodgson, J.F. 1973. Distribution of cadmium and zinc/cadmium ratios in crops from 19 states east of the rocky mountains. *J. environ. Qual.* **2**(2):289
- Jaakkola, A., Korkman, J. and Koshi, T.J. 1979. The effect of cadmium contained in fertilizers on the cadmium content of vegetables. *J. Sci. Agric. Soc. Finl.* **51**:158
- Jackson, M.L. 1958. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., NewDelhi, p.38-183
- Jarvis, S.C. and Jones, L.H.P. 1978. Uptake and transport of cadmium by perennial rye grass from flowing solution culture with a constant concentration of cadmium. *Pl. Soil.* **49**:333-342
- Jarvis, S.C., Jones, L.H.P. and Clement, C.R. 1977. Uptake and transport of Pb by perennial rye grass from flowing solution culture with a controlled concentration of Pb. *Pl. Soil.* **46**:371-377
- Jarvis, S.C., Jones, L.H.P. and Hopper, M.T. 1976. Cadmium uptake from solution by plants and its transport from root to shoots. *Pl. Soil.* **44**:179-191
- John, M.K. 1972. Cadmium absorption maxima of soils as measured by the Langmuir isotherm. *Can. J. Soil Sci.* **52**:343-350
- John, M.K., Chuab, H.H. and Van Laerhoven, C.J. 1972. Cadmium contamination of soil and its uptake by oats. *Environ. Sci. Technol.* **6**:555-557

- John, M.K. and Laerhoven, C.J. 1976. Differential effects of cadmium on lettuce varieties. *Environ. Pollut.* **10**:163-173
- Jones, K.C. and Johnston, A.E. 1989. Cadmium in cereal grain and herbage from long-term experimental plots at Rothamsted, U.K. *Environ. Pollut.* **57**:199-216
- KAU. 1993. Package of Practices Recommendations. Directorate of Extension, Kerala Agric. Univ., Thrissur, p.
- Kaushik, R.D., Gupta, V.K. and Singh, J.P. 1993. Distribution of zinc, cadmium and copper forms in soils as influenced by phosphorus application. *Arid Soil Res. Rehabilitation.* **7**:163-171
- Kefer, R.F., Singh, R.N. and Horvath, D.J. 1986. Chemical composition of vegetables grown on an agricultural soil amended with sewage sludges. *J. Environ. Qual.* **15**:146-152
- Khan, D.H. and Frankland, B. 1983. Effect of cadmium and lead on radish plants with particular reference to movement of metals through soil profile and plant. *Pl. Soil.* **70**:335-345
- King, L.D. 1988. Effect of selected soil properties on cadmium content of tobacco. *J. environ. Qual.* **17**:251-255
- Kuboi, T., Noguchi, A. and Yazaki, J. 1986. Family dependent cadmium accumulation characteristics in higher plants. *Pl. Soil.* **92**:405-415
- Lagerwerff, J.V. 1971. Uptake of cadmium, lead and zinc by radish from soil and air. *Soil Sci.* **111**:129-133

- Lee, K.W. and Keeney, D.R. 1975. Cadmium and zinc addition to Wisconsin soils by commercial fertilizers and waste water sludge application. *Water Air Soil Pollut.* **5**:109-112
- Levi, M.R. and Petruzzelli, G. 1984. The influence of phosphate fertilizers on Cd solubility in soil. *Water Air Soil Pollut.* **23**:423-429
- Lindsay, W.L. and Norvell, W.A. 1978. Development of a DTPA soil test zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* **42**:421-428
- * Logan, T.J. and Chaney, R. 1983. Metals. *Utilization of Municipal Waste Land and Sludge on Land.* (Page, A.L., Miller, R.H. and Keeney, D.R. eds.) Univ. of California, Riverside, USA. p.235-329
- Malone, C., Koeppel, D.E. and Miller, R.J. 1974. Localization of lead accumulated by corn plants. *Plant Physiol.* **53**:388-394
- Mann, S.S. and Ritchie, G.S.P. 1993. The influence of pH on the forms of cadmium in four Western Australian soils. *Aust. J. Soil Res.* **31**:255-270
- Matthews, H. and Thornton, I. 1982. Seasonal and species variation in the content of cadmium and associated metals in pasture plants at Shipham. *Pl. Soil*, **66**:181-193
- McBride, M.B., Tyler, L.D. and Hovde, D.A. 1981. Cadmium adsorption by soils and uptake by plants as affected by soil chemical properties. *Soil Sci. Soc. Am. J.* **45**:739-744
- Mench, M.J., Didier, V.L., Loffler, M., Gomez, A. and Mosson, P. 1994. A mimicked in-situ remediation study of metal contaminated soils with emphasis on cadmium and lead. *J. environ. Qual.* **23**:58-63

- Mench, M., Tancogne, J., Gomez, A. and Juste, C. 1989. Cadmium bioavailability to *Nicotiana tabacum* L., *Nicotiana rustica* L. and *Zea mays* L. grown in soil amended or not amended with cadmium nitrate. *Biol. Fertil. Soils* 8:48-53
- Mortvedt, J.J. 1985. Plant uptake of heavy metals in zinc fertilizers made from industrial by-products. *J. environ. Qual.* 14:424-427
- * Mortvedt, J.J. and Giordano, P.M. 1977. Crop uptake of heavy metal contaminants in fertilizers. *Biological Implications of Heavy Metals in the Environment.* (Wildung, R.A. and Drucker, H. eds.). ERDA, Rep. Conf. 750929, Oak Ridge. p.402-406
- * Mortvedt, J.J. and Hemphill, D.D. 1984. Cadmium and zinc uptake by vegetable tissue after nine annual applications of phosphate fertilizers to soil. *Trace Substances in Environmental Health.* (Hemphill, D.D. ed.) Proceedings XVIII Annual Conference Tennessee Valley Authority, U.S.A.
- Mortvedt, J.J., Mays, D.A. and Osborn, G. 1981. Uptake by wheat of cadmium and other heavy metal contaminants in phosphate fertilizers. *J. environ. Qual.* 10:193-197
- Mortvedt, J.J. and Osborn, G. 1982. Studies on the chemical form of cadmium contaminants in phosphate fertilizers. *Soil Sci.* 134:185
- Mulla, D.J., Page, A.L. and Ganie, T.J. 1980. Cadmium accumulation and bioavailability in soils from long-term phosphorus fertilization. *J. environ. Qual.* 9:408-412
- Muramoto, S. and Aoyama, I. 1990. Effect of fertilizers on the vicissitude of cadmium in rice plant. *J. Environ. Sci. Health A.* 25:629-635
- Page, A.L. and Bingham, F.T. 1973. Cadmium residues in the environment. *Residue Rev.* 48:1-44

- Page, A.L., Miller, R.H. and Keeney, D.R. 1982. *Methods of Soil Analysis*. Part II. Am. Soc. Agron, Madison, U.S.A. p.
- Panse, V.G. and Sukhatme, P.V. 1978. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi, p.339
- Pettersson, O. 1976. Heavy metal ion uptake by plants from nutrient solutions with metal ion, plant species and growth period variations. *Pl. Soil* **45**:445-459
- * Pezzarossa, B. Petruzelli, G., Malorgio, F. and Togneni, F. 1993. Effect of repeated phosphate fertilization on the heavy metal accumulation in soil and plants under protected cultivation. *Commun. Soil Sci. Pl. Anal.* **24**(17 & 18):2307-2319
- * Pierzynski, G.M. and Schwab, A.P. 1993. Bioavailability of zinc, cadmium and lead in a metal contaminated alluvial soil. *J. environ. Qual.* **22**:247-254
- Piper, C.S. 1942. *Soil and Plant Analysis*. Asian Reprint, 1966. Hans Publishers, Bombay. p.368
- Ramos, L., Hernandez, L.M. and Gonzalez, M.J. 1994. Sequential fractionation of copper, lead, cadmium and zinc in soils from or near Donaron National Park. *J. environ. Qual.* **23**:50-57
- Reuss, J.O., Dooley, H.L. and Griffis, W. 1978. Uptake of cadmium from phosphate fertilizers by peas, radish and lettuce. *J. environ. Qual.* **7**:128-133
- Rothbaum, H.P., Goguel, R.L., Johnston, A.E. and Mattingly, G.E.G. 1986. Cadmium accumulation in soils from long continued application of superphosphate. *J. Soil Sci.* **37**:99-107

- Salim, R., Al-Subu, M.M. and Atallah, A. 1993. Effect of root and foliar treatments with lead, cadmium and copper on the uptake distribution and growth of radish plants. *Environ. Int.* **19**:393-404
- Shrivastava, G.K. and Singh, V.P. 1989. Uptake, accumulation and translocation of cadmium and zinc in *Abelmoschus esculentus* (L.) Moench. *Pl. Physiol. Biochem., New Delhi.* **16**(1):17-22
- Shroeder, H.A. and Balassa, J.J. 1963. Cadmium uptake by vegetables from superphosphate and soil. *Sci.* **140**:819
- Singh, J.P., Singh, B. and Karwasra, S.S.P. 1988. Yield and uptake response of lettuce to cadmium as influenced by nitrogen application. *Fert. Res.* **18**:49-56
- Sposito, G., Lund, L.J. and Chang, A.C. 1982. Trace metal chemistry in arid zone field soil amended with sludge. I. Fractionation of Ni, Cu, Zn, Cd, Pb in solid phases. *Soil Sci. Soc. Am. J.* **46**:2600-2604
- Srikanth, R. and Reddy, S.R.P. 1991. Lead, cadmium and chromium levels in vegetables grown in urban sewage sludge Hyderabad, India. *Fd. Chem.* **40**(2):229-234
- Street, J.J., Sabey, B.R. and Lindsay, W.L. 1978. Influence of pH, phosphorus, cadmium, sewage sludge and incubation time on the solubility and plant uptake of cadmium. *J. environ. Qual.* **7**:286-290
- Subbaiah, B.V. and Asija, C.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* **25**:259-260
- Turner, M.A. 1973. Effect of cadmium treatment on cadmium and zinc uptake by selected vegetable species. *J. Environ. Qual.* **2**:118-119

- Tyler, L.D. and McBride, M.B. 1982. Influence of calcium, pH and humic acid on Cd uptake. *Pl. Soil.* **64**:259-262
- Vlams, J., William, D.E., Corey, J.E., Page, A.L. and Ganie, T.J. 1985. Zinc and cadmium uptake by barley in field plots fertilised seven years with urban and suburban sludge. *Soil Sci.* **139**:81
- Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic and method for determining phosphorus in water and NaHCO₃ extracts from soil. *Soil Sci. Soc. Am. Proc.* **29**:677-678
- Wells, K.L., Henson, G. and Kelley, G. 1993. Content of some heavy metals in soil and corn grain. *Commun. Soil Sci. Pl. Anal.* **24**:2617-2628
- Williams, C.H. and David, D.J. 1973. The effect of superphosphate on the cadmium content of soils and plants. *Aust. J. Soil Res.* **11**:43-56
- Williams, C.H. and David, D.J. 1976. The accumulation in soil of cadmium residues from phosphate fertilizers and their effect on the cadmium content of plants. *Soil Sci.* **121**:86-93
- Williams, C.H. and David, D.J. 1977. Some effects of the distribution of cadmium and phosphate in the root zone on the cadmium content of plants. *Aust. J. Soil Res.* **15**:59-68
- * Zawadzka, T., Mazur, H., Wejciechowska, M.M., Starska, K., Brulinska, O.E., Cwiek, K., Uminska, R. and Bichmewicz, A. 1990. Contents of metals in vegetables from different regions of Poland in the years 1986-1988. *Roczniki-Panstwowego-Zakladu-Higieny* **41**:111-131

* Originals not seen

Appendices

APPENDIX-1
 Nitrogen uptake by chilli in root, shoot and fruit (mg pot⁻¹)

Treatment	Root	Shoot	Fruit
1 MRP-L ₁	1.30	360	180
2 MUP-L ₁	1.03	350	140
3 GAP-L ₁	1.73	500	200
4 RJP-L ₁	1.27	370	150
5 SSP-L ₁	1.23	410	140
6 MRP-L ₂	1.03	490	160
7 MUP-L ₂	1.03	480	160
8 GAP-L ₂	1.47	570	210
9 RJP-L ₂	1.07	380	160
10 SSP-L ₂	1.10	480	140
11 MRP-L ₃	1.17	500	180
12 MUP-L ₃	1.07	490	170
13 GAP-L ₃	1.47	580	220
14 RJP-L ₃	1.10	440	160
15 SSP-L ₃	1.10	490	140
16 Chem. pure source of NPK	1.00	340	130
17 CdCl ₂ -L ₁	1.03	320	130
18 Pb(NO ₃) ₂ -L ₁	1.03	330	130
19 CdCl ₂ -L ₂	1.03	340	130
20 Pb(NO ₃) ₂ -L ₂	1.07	340	120
21 CdCl ₂ -L ₁ +OM	1.10	420	140
22 Pb(NO ₃) ₂ -L ₁ +OM	1.03	410	150
23 CdCl ₂ -L ₂ +OM	1.27	380	150
24 Pb(NO ₃) ₂ -L ₂ +OM	1.27	390	150
25 PA-MRP	1.07	340	170
26 PA-MUP	1.03	340	140
27 PA-GAP	1.80	550	220
28 PA-RJP	1.03	370	140
29 Control	1.03	90	50
CD (0.05)	0.17	29	3

APPENDIX-2
Phosphorus uptake by chilli in root, shoot and fruit (mg pot⁻¹)

Treatment	Root	Shoot	Fruit
1 MRP-L ₁	1.00	60.0	24.3
2 MUP-L ₁	1.10	63.3	22.0
3 GAP-L ₁	1.23	87.3	29.0
4 RJP-L ₁	1.00	63.0	26.3
5 SSP-L ₁	1.23	77.7	20.7
6 MRP-L ₂	1.00	83.3	25.3
7 MUP-L ₂	1.00	87.3	28.0
8 GAP-L ₂	1.63	101.7	36.7
9 RJP-L ₂	1.00	71.7	30.3
10 SSP-L ₂	1.03	94.3	25.0
11 MRP-L ₃	1.17	94.0	28.3
12 MUP-L ₃	1.07	93.7	28.0
13 GAP-L ₃	2.07	102.3	32.0
14 RJP-L ₃	1.13	85.3	31.0
15 SSP-L ₃	1.07	96.0	27.0
16 Chem. pure source of NPK	1.00	61.3	19.3
17 CdCl ₂ -L ₁	1.03	58.3	21.0
18 Pb(NO ₃) ₂ -L ₁	1.03	56.0	19.3
19 CdCl ₂ -L ₂	1.03	63.7	20.3
20 Pb(NO ₃) ₂ -L ₂	1.03	64.0	16.7
21 CdCl ₂ -L ₁ +OM	1.00	78.3	20.3
22 Pb(NO ₃) ₂ -L ₁ +OM	1.07	77.0	21.3
23 CdCl ₂ -L ₂ +OM	1.07	68.0	20.0
24 Pb(NO ₃) ₂ -L ₂ +OM	1.00	73.7	21.7
25 PA-MRP	1.03	70.7	24.0
26 PA-MUP	1.03	70.0	23.7
27 PA-GAP	1.87	114.3	37.7
28 PA-RJP	1.00	75.3	23.7
29 Control	0.20	1.6	3.3
CD (0.05)	0.20	7.7	2.8

APPENDIX-3
Potassium uptake by chilli in root, shoot and fruit (mg pot⁻¹)

Treatment	Root	Shoot	Fruit
1 MRP-L ₁	7.63	470	100.7
2 MUP-L ₁	5.50	480	75.7
3 GAP-L ₁	10.00	690	113.0
4 RJP-L ₁	8.07	510	82.3
5 SSP-L ₁	7.77	530	81.7
6 MRP-L ₂	6.67	630	96.0
7 MUP-L ₂	5.47	600	92.0
8 GAP-L ₂	11.30	710	126.3
9 RJP-L ₂	5.93	510	96.3
10 SSP-L ₂	6.77	640	87.3
11 MRP-L ₃	8.37	660	112.0
12 MUP-L ₃	6.97	660	106.0
13 GAP-L ₃	8.90	760	135.0
14 RJP-L ₃	7.23	590	98.7
15 SSP-L ₃	4.54	690	88.7
16 Chem. pure source of NPK	5.27	470	79.3
17 CdCl ₂ -L ₁	5.50	470	80.3
18 Pb(NO ₃) ₂ -L ₁	5.33	450	79.3
19 CdCl ₂ -L ₂	4.63	480	80.7
20 Pb(NO ₃) ₂ -L ₂	5.67	480	75.3
21 CdCl ₂ -L ₁ +OM	6.63	550	82.7
22 Pb(NO ₃) ₂ -L ₁ +OM	5.97	550	85.3
23 CdCl ₂ -L ₂ +OM	7.03	480	86.3
24 Pb(NO ₃) ₂ -L ₂ +OM	7.07	530	85.0
25 PA-MRP	5.70	590	101.0
26 PA-MUP	4.80	480	86.7
27 PA-GAP	11.67	760	133.3
28 PA-RJP	5.30	520	87.3
29 Control	2.90	130	20.7
CD (0.5)	2.32	58	7.0

APPENDIX-4
Soil chemical parameters of post harvest soil samples

Treatments	pH	EC	Available N mg kg ⁻¹	Available P mg kg ⁻¹	Available K mg kg ⁻¹
1 MRP-L ₁	5.1	0.16	111.8	20.2	119.0
2 MUP-L ₁	5.3	0.16	112.6	20.1	119.0
3 GAP-L ₁	5.3	0.18	111.4	21.5	118.2
4 RJP-L ₁	5.1	0.17	111.7	20.2	118.5
5 SSP-L ₁	5.3	0.16	110.9	20.1	119.4
6 MRP-L ₂	5.1	0.11	110.5	20.2	118.5
7 MUP-L ₂	5.0	0.14	110.6	20.1	118.7
8 GAP-L ₂	5.2	0.14	110.9	22.5	118.2
9 RJP-L ₂	5.3	0.11	112.2	20.0	119.0
10 SSP-L ₂	5.4	0.12	111.6	20.1	118.1
11 MRP-L ₃	5.1	0.15	110.9	20.2	118.1
12 MUP-L ₃	5.1	0.12	110.8	20.1	118.2
13 GAP-L ₃	5.0	0.11	111.7	21.1	118.7
14 RJP-L ₃	5.3	0.16	111.4	20.5	118.1
15 SSP-L ₃	5.4	0.13	111.4	20.1	118.0
16 Chem. pure source of NPK	5.1	0.11	111.4	20.4	118.0
17 CdCl ₂ -L ₁	5.3	0.11	111.8	20.1	118.3
18 Pb(NO ₃) ₂ -L ₁	5.2	0.10	111.7	20.0	118.0
19 CdCl ₂ -L ₂	5.3	0.10	111.7	19.9	118.2
20 Pb(NO ₃) ₂ -L ₂	5.3	0.10	112.1	20.0	118.2
21 CdCl ₂ -L ₁ +OM	5.1	0.16	112.3	21.1	119.0
22 Pb(NO ₃) ₂ -L ₁ +OM	5.2	0.15	112.1	21.2	119.0
23 CdCl ₂ -L ₂ +OM	5.3	0.16	111.9	21.0	119.2
24 Pb(NO ₃) ₂ -L ₂ +OM	5.3	0.17	113.1	21.0	119.8
25 PA-MRP	5.4	0.13	111.1	20.8	119.5
26 PA-MUP	5.4	0.16	110.9	20.8	118.9
27 PA-GAP	5.2	0.13	110.6	21.7	119.3
28 PA-RJP	5.4	0.12	110.7	20.5	119.5
29 Control	5.1	0.10	110.3	19.8	116.3
CD (0.05)	0.2	0.003	1.2	0.4	0.3

**ASSESSMENT OF SOME PHOSPHATIC SOURCES
FOR POSSIBLE ACCUMULATION OF
HEAVY METALS IN CHILLI (*Capsicum annum* L.)**

**By
C. V. JIDESH**

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Soil Science and Agricultural Chemistry

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680 654

KERALA, INDIA

1998

ABSTRACT

Rock phosphate sources collected from different locations were analysed for both phosphorus content and heavy metals namely cadmium and lead. Those sources which analysed relatively higher content of heavy metals were included for conducting a pot culture experiment using chilli (*Capsicum annum* L.) as test crop. To derive meaningful comparison in the study, partially acidulated rock phosphates as well as direct water soluble source of cadmium and lead were also applied to assess their bioavailability to plants. The influence of organic matter when applied alone or in conjunction with heavy doses of heavy metals was also assessed in the study.

The pot culture experiment was conducted in the Vegetable Research Farm, Department of Olericulture, Vellanikkara during the kharif season of 1996, with chilli as the test crop. The entire fertilizer management was based on package of practice (N, P and K at 70, 40 and 25 kg ha⁻¹) recommendation. Five different sources of P selected for the pot culture experiment were (1) Maton rock phosphate, (2) Mussorie rock phosphate, (3) Gafsa rock phosphate, (4) Rajasthan rock phosphate and (5) Single superphosphate.

The maximum content of cadmium (55 mg kg⁻¹) was recorded in Gafsa rock followed by 25 mg Cd kg⁻¹ for the Maton rock and single superphosphate analysed the least concentration of cadmium (15 mg kg⁻¹). Highest lead content of 230.5 mg Pb kg⁻¹ was analysed in Maton rock while lowest (38. mg kg⁻¹) in Musoorie rock. All the other sources maintained their heavy metal concentration in between these extremes.

In general, the shoot portion of test crop chilli recorded highest cadmium uptake while root portion noted the maximum lead uptake. The least uptake of heavy metals was noted in the chilli fruit, which is the edible part of the plant. This indicates that the heavy metal load in the fruit portion is much less when compared to other plant parts, irrespective of the sources used. The same trend was evident when either partially acidulated P sources or direct source of heavy metals (through water soluble salts) were applied. However, the uptake of cadmium and lead from those sources remained higher in plant parts.

Application of organic matter in conjunction with a heavy dose of heavy metals to soil resulted in a significantly higher uptake of cadmium and lead in all plant parts.

Analysis of the available cadmium and lead in the post-harvest soil samples indicated negligible build-up of these metals in soils. However, direct application of higher levels of heavy metals permitted higher cadmium and lead extraction in the post-harvest soil samples. Application of partially acidulated rock sources to soils, though could cause enhanced uptake of heavy metals, could not show higher residual effects of heavy metals in post-harvest soil samples.

171328