STATUS AND IMPACT OF HEAVY METALS IN SELECTED SOILS AND CROPS OF KERALA

By

USHA MATHEW

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN AGRICULTURE
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM

1999

DECLARATION

I hereby declare that this thesis entitled **"Status and impact of heavy metals in selected soils and crops of Kerala"** 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 of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

USHA MATHEW

College of Agriculture,
Vellayani
27-4-99.

CERTIFICATE

Certified that this thesis entitled **"Status and impact of *heavy metals in selected soils and crops of Kerala*"** is a record of research work done independently by **Smt. Usha Mathew** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship.

Alice Abraham

Vellayani,
27-4-99

Dr. ALICE ABRAHAM
(Major Advisor)
Professor (Retd.)
Department of Soil Science and
Agricultural Chemistry
College of Agriculture, Vellayani

Approved by

Major Advisor :

Dr. ALICE ABRAHAM

Members :

1. Dr. K. M. RAJAN

2. Dr. V. K. VENUGOPAL

3. Dr. P. SARASWATHI

4. Dr. S. K. NAIR

External Examiner :

Dr. L. SUSEELA DEVI

22/08/98

ACKNOWLEDGEMENTS

I wish to express my heartful gratitude and indebtedness to Dr. Alice Abraham, Professor (Retd.), Department of Soil Science and Agricultural Chemistry and Major Advisor, for formulating the research problem, her keen and sustained enthusiasm and support during the course of investigation and her expert guidance in preparation of the thesis.

My sincere thanks are due to Dr. Thomas Varghese, Professor and Head, Department of Soil Science and Agricultural Chemistry, Dr. V.K. Venugopal, Associate Professor, Department of Soil Science and Agricultural Chemistry, Dr. P. Saraswathy, Professor and Head, Department of Agricultural Statistics and Dr. S.K. Nair, Professor, Department of Plant Pathology, members of Advisory Committee for their critical scrutiny of manuscript, valuable suggestions, healthy criticism and constant encouragement extended through out the course of this research endeavour. I acknowledge the help rendered by Dr. K. M. Rajan, Dean and Professor and Head i/c., Department of Soil Science and Agricultural Chemistry in the conduct of the examination.

I gratefully acknowledge the expertise and help rendered to me by the late Dr. P. Padmaja and the late Sri. Abdul Hameed, former Professors and members of the Advisory Committee during the conduct of the programme.

I take this opportunity to acknowledge gratefully the help rendered by the staff members of various research stations and colleges of Kerala Agricultural University in sample collection and chemical analysis.

Sincere thanks are due to the staff members and post graduate students of the Department of Soil Science and Agricultural Chemistry for their constant encouragement and whole hearted assistance during the course of this investigation.

The inspiration and good will bestowed on me by my friends of other departments are also acknowledged with greatest gratitude.

I am unable to mention here by name many other persons who have rendered me help in the course of my study and I remember them gratefully.

The advice and assistance rendered by Sri. Ajithkumar, C.E., Computer Programmer, Department of Agricultural Statistics are gratefully acknowledged.

I sincerely thank the Kerala Agricultural University for granting me study leave and part time facility for completing this study.

Sincere thanks are due to M/s. Athira Computers, Kesavadasapuram, Thiruvananthapuram for the prompt computerised typesetting and documentation work of this thesis.

The prayers, love, patience, encouragement and help received from members of my family during the endeavour are remembered with humble gratitude.

USHA MATHEW

CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

INTRODUCTION

Air, water and soil are three basic necessities for life on earth and all three are closely associated in the terrestrial environment. Though the need to protect atmosphere and water from pollution has been understood for well over a century, it is only within the last decade that policies to safe guard soils and the crops they sustain have emerged. Polluted soils are those which contain alien substances that are likely to cause harm, directly or indirectly to man, to the environment and other targets. Agricultural activities are responsible for the addition of small but repeated amounts of contaminants to soil in large areas over long periods of time.

Heavy metals form an important group of contaminants in agricultural lands which may find an entry into human or animal food chain. The term 'heavy metal' is commonly adopted as a group name for the metals and metalloids which are associated with pollution and toxicity.

Some heavy metals like Cu, Fe, Mn, Zn, Co and under certain conditions Ni are essential plant nutrients, although they are phytotoxic at high concentrations. Others such as As, Cd, Cr, Hg and Pb are toxic even at very low concentrations. The accumulation of metals of the latter group in agricultural ecosystems from various sources has become the focus of interest from the point of view of soil pollution.

Historically soil has been used as an ideal waste disposal system, a biological incinerator digesting all the wastes deposited on or in it over periods of time. Surveys carried out since the 1960s have indicated that soils in many parts of the world especially in urban and industrial areas contain dangerously high concentrations of heavy metals. Reports from European Community and United States on the widespread use of Cd-Ni cells in rechargeable batteries of electronic and electrical commodities and their disposal in land fills have evoked great concern on the accumulation of heavy metals in soil system.

Various inputs in agriculture such as commercial fertilizers, manures of plant and animal origin and agricultural chemicals have also been identified as the major carriers of heavy metals like Pb, Ni, Cd, Cu, Zn, Hg and Cr. Concentrations of these heavy metals in soils high enough to negatively affect its quality have been identified as an important threat to the environment and soil ecosystem by Swedish Environmental Protection Agency.

Heavy metals in soils and plants have received increasing attention in recent years because of the growing scientific and public awareness of environmental issues and their direct bearing on human health and agricultural productivity. Although in most cases, the levels are not (yet) high enough to cause acute toxicity problems, increased concentrations in the food chain may cause significant health hazards in the long run. The metals viz., Cd and Pb which accumulate in human body are of particular cause for concern. The continuous intake of even minute quantities of these heavy metals result in their build up in human system leading to diseases like neuritis, proteinurea, osteomalacia and cancer. It must be remembered that heavy metal pollution represents a relatively new set of stresses to plants. Plant species thrive on soil rich in heavy metals by mechanisms of avoidance or tolerance. Studies on these aspects of the important crops of Kerala is scanty.

The world's increasing population needs an adequate supply of healthy food. Heavy metals can affect both crop yield and composition. Therefore periodical monitoring of the content of heavy metals in soils need to be done so that yield limiting deficiencies of micronutrients can be rectified, polluted soils identified and appropriate remedial actions taken against their entry into the crop and animal systems.

In countries like US, UK, GDR, The Netherlands and Japan standards and reference values have been proposed on the levels of heavy metals in soils and plants for phytotoxicity and food safety. Legislative regulations on maximum permissible level (MPL) of heavy metals in manures and fertilizers have also been imposed in many of these nations. However, no serious attempts have been made in India to stipulate such regulatory measures so far.

Although the fertility status and other physico-chemical aspects of the soil types of Kerala have been elaborately studied and documented, no detailed information is available with regard to the status of heavy metals or metallic pollutants in them. Further, information on the content of heavy metals in the crop plants and manures commonly used for crop production is also lacking though some data on the status of Cd, Pb and Ni in common fertilizers and few rice soils are available. High density micronutrients, Fe and Mn are not included in the study in view of the voluminous literature already available on their status, toxicity, deficiency and related aspects on important soils and crops in Kerala.

The retention pattern of heavy metals in the different soil types of Kerala and their impact on growth and yield of crops are also areas not so far investigated in detail. In the foregoing scenario, the present study has been planned with the following main objectives :

1. To determine the status of heavy metals like Cu, Zn, Ni, Pb and Cd in samples of soils, fertilizers, manures and crop plants from selected locations in Kerala.

2. To monitor the retention pattern of Cd and Ni in different soil types of Kerala.

3. To establish the effect of applied Cd and Ni on the growth, yield and nutrient content as well as their retention in plant parts of rice, sesame and cowpea.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The term heavy metal which is in common use refers to metals which are mostly of high density and belong largely to the group of transition elements in the periodic table (Taylor, 1964). The term is commonly adopted as a group name for the metals and metalloids which are associated with contamination, pollution and toxicity of the environment. Heavy metals include elements like Zn, Cu, Mn and Fe which are essential for living organisms at low concentrations. They are frequently referred to as micronutrients in agriculture. When concentrations of such elements exceed the upper critical levels they become toxic to plants (Scott, 1972 and Bolt and Bruggenwert, 1978). The term toxic / harmful heavy metal is applicable to some non-essential elements like Cd, Pb, Hg and Ni that are absorbed by plants without any physiological function at low concentrations, but having deleterious effects on crop growth at higher concentrations (Alloway, 1990).

The sources and status of heavy metals, especially in agricultural soils and their effect on crop growth, nutrient uptake, germination of seeds and the methods to combat heavy metal pollution are reviewed in this chapter.

2.1 Sources of heavy metals in soils

All soils are found to contain heavy metals from a trace to an appreciable level being derived from various sources. Some of the important sources which contribute to the status of heavy metals in soils with emphasis on Zn, Cu, Ni, Pb and Cd are reviewed here.

2.1.1 Geogenic origin

Metals contained natively in rocks and minerals from which the soils are formed are considered the primary source of heavy metals in soils (Taylor, 1964). According to him, the main factors that determine heavy metal content of soils are the composition of the parent rock and the process of soil formation. He found that soils formed from the same parent material contained different heavy metal concentration and that the surface soils in Tasmania formed from dolerite had 5 to 140 mg kg^{-1} Ni.

Rose *et al.* (1979) reported that the mean contents of Cd, Cu, Ni, Pb and Zn in earth's crust were 0.1, 50, 80, 14 and 75 mg kg^{-1}. According to them, the major rock types containing heavy metals as trace constituents are ultrabasic (dunite, peridotite and serpentinite), basic (basalt), granitic igneous rocks and sedimentary rocks (lime stone, sand stone and shales).

Lund *et al.* (1981) observed that residual soil material developed from shale parent material had the greatest Cd concentration with a mean value of 7.5 mg kg^{-1} whereas soil developed from sandstone and basalt had a Cd concentration with a mean of 0.84 mg kg^{-1}. Alluvial soils from parent materials of mixed sources had a mean Cd content of 1.5 mg kg^{-1}. Vegetables grown on these soils contained Cd sufficient to be of public health concern.

Alloway (1990) proposed the name "geochemical pollutants" to the toxic metals derived from parent materials. According to him, the rocks with highest concentrations of Cu, Pb and Ni are basic, ultra basic and granite and that of Zn and Cd are shales and clay. He further stated that the natural input of metals into the environment from volcanoes is high and it is a major source of natural atmospheric deposit of metals. He also reported that the concentration of Cd, Cu, Ni, Pb, and Zn in air from volcanoes in Hawaii were 8 - 92, 200 - 3000, 330, 28 - 1200 and 1000 ng m^{-3}

2.1.2 Anthropogenic origin

Heavy metals are introduced into soil by land application of sewage sludge, fertilizers and other waste materials (Adriano, 1986, Alloway, 1990). The extent of land contaminated with heavy metals has increased during the last century due to mining, smelting and other industrial activities (Brown *et al.*, 1995).

As stated by Bridges (1989) and Tiller (1989), deliberate addition of heavy metals to agricultural soils occur through the use of chemical fertilizers, organic manures, plant protection chemicals and irrigation water.

Swaine (1962), Williams and David (1973), Mulla *et al.* (1980) Sathyaprakasan (1989), Kongshaug *et al.* (1992), Mineev and Gomonova (1993) and Mortvedt (1996) have reported that several fertilizers mined from the earth or subsidiary fertilizers, derived from these always contain heavy metals as impurities and is a potential source of contamination. Continuous application of these fertilizers implies the build up of significant amount of heavy metals in the soil.

Chaney (1973), Tiller (1989), Sakal *et al.* (1992) Norwal *et al.* (1994) and Rao and Shantharam (1994) have reported that long term application of municipal, urban and farm wastes resulted in heavy metal accumulation in soils.

Emmerich *et al.* (1982), Logan (1985), Tiller (1989) and Mortvedt (1996) have reported appreciable amounts of heavy metals in sewage sludges produced world wide. *Disposal of sludges on land or its application to soil* as a nutrient and soil conditioner has led to heavy metal contamination and pollution of soils.

Very high amounts of toxic metals like Pb, Cd, Ni, and Cr were reported to be present in sewage from several cities in India by Singh and Kansal (1985), Gupta *et al.* (1986), Karunakaran Nair (1987), Jayabaskaran and Sreeramulu (1996).

Increased concentration of heavy metals has been observed by Anderson and Nielson (1976), Azad (1981), Sharma and Kansal (1986) and Kumar (1992) in industrial and domestic waste water, sewage water and fresh water which receive industrial, municipal and sewage effluents or wastes. According to them, their use for *irrigation* or *disposal on agricultural land* has resulted in heavy metal enrichment of soils and crops.

Azad (1981) compared the contents of Pb and Zn in a sewer irrigated soil and a normal soil. The content of Pb and Zn was observed to be 2.5 and 4.1 ppm in sewer irrigated soil, and 1.4 and 2.1 ppm in normal soil. Gupta *et al.* (1986) and Sharma and Kansal (1986) observed that the application of municipal waste water had substantially increased the accumulation of available Zn, Cu, Pb and Cd in Indian soils. The accumulation was reported to be higher in soils receiving waste water from industrial towns than non-industrial towns.

Increased concentration of heavy metals was also observed in soils and crops due to sewage irrigation by Karunakaran Nair (1987) and Rao and Shantharam (1994).

High levels of metal contamination was documented by Donald (1972) in orchards of horticultural crops due to the extensive use of pesticides containing Cu, Zn and Pb salts and metallo-organic compounds. He reported that metals added as impurities and as constituents of agricultural inputs become phytotoxic due to repeated annual applications. Tiller (1989) reported soil levels of Cu, Pb and As as 1000, 500 and 100mg per kg of soil in several countries due to the extensive use of Bordeaux mixture and lead arsenate sprays. Fergusson (1990) noted high DTPA extractable Cd in soils receiving Cu and Zn containing fungicides due to the presence of Cd as a contaminant of fungicides.

Kumar (1992) has reported that long term application of sewage water considerably increased the amount of available Fe, Cu, Zn and Ni in soils in Punjab. He analysed the DTPA extractable Fe, Mn, Zn, Cu and Ni and found that the content of these elements were 52,25,21,25 and 1 ppm respectively in sewage water while the soils receiving tube well irrigation recorded values of 26, 15, 5, 4 and 0.2 ppm respectively. He also found that disposal of domestic and industrial wastes into "Buddha Nullah", a fresh water tributary has elevated the level of heavy metals in its water. The content of Fe, Zn, Mn, Cu and Ni in the unpolluted water was 1.3, 0.3, 0.04, 0.09 and 0.04 mg l^{-1} and it was increased to 12.3, 2.8, 0.4, 0.3 and 0.9 Mg mg l^{-1} on merger of sewer containing wastes of industrial areas.

2.1.3 *Inadvertent transfer*

Buchauer (1973) and Lagerwerff *et al.* (1973) have reported that a large variety of industrial exhausts may be responsible for air pollution with heavy metals and consequently soil pollution when the elements reach soil surface through dew or rain.

As proposed by Bridges (1989), the industrial activities like manufacture of pesticides, paint and colouring materials, explosives and mining, smelting, refining and working of metals, gas works, chemical works, amunitions, oil and petroleum production and storage, pharmaceutical works, tanneries and wood preservation factories, docks and railways, asbestos factories, manufacture of integrated circuits and semi-conductors, scrapyards and land fills and waste disposal site etc. have found to result in extensive soil pollution.

Tiwana (1985), Bhatia *et al.* (1990), Saini and Kansal (1990) and Bhagat (1992) have reported that distilleries, sugar mills, pulp and paper mills, electroplating, dyeing, tanneries and dairying technologies produced large volume of effluents with variable chemical characters and metal content. According to them, the release of these effluents into adjacent agricultural land will significantly increase the concentration of Cu, Cr, Pb, Ni and Zn so as to affect the quality of crops making them unfit for consumption by animals and human beings.

Chrenekova *et al.* (1987) reported that power plants emit large quantities of metal containing particulates into the atmosphere. Fly ashes are reported by Bilski and Alva (1995) to contain a wide range of metals and other contaminants.

Tiller (1989) reported that incineration of plastics, wood products, fossil fuels and organic wastes by householders and municipal authorities result in the emission of heavy metals to the atmosphere.

2.2 Status of heavy metals in soils

It is worthwhile to review some of the reports on the status of heavy metals in agricultural soils to get an idea of the extent to which these soils are contaminated.

Yagamata and Shigematsu (1970) reported that Cd content of soils in non-polluted areas of Japan is below 1.0 ppm. They reported for contaminated rice soils, levels upto 50 ppm Cd. For top soil samples near a Zinc smelter, values as high as 1700 ppm Cd have been reported by Buchauer (1973). Iimura (1981) reported that the average content of Zn and Cd in paddy soils of Japan as 99 and 0.45 ppm.

Michael (1983) has reported that DTPA extractable Cu, Zn and Ni in the soils of Hebbal in Bangalore as 18.64, 0.92 and 0.08 ppm.

Okamoto *et al.* (1989) showed that the surface soils in Kanagawa prefecture of Japan had an average content of 0.58, 89.5, 8.5, 22.0 and 31.3 ppm Cd, Cu, Zn, Pb and Ni respectively. They also compared the content of

Cu and Zn in paddy soils with the orchard soils and found that the content of Cu and Zn were 178 and 164 ppm for paddy soils, while these values were 214 and 216 ppm for orchard soils, indicative of the increased use of agricultural chemicals in orchard soils.

As per the standards adopted in The Netherlands (Bridges, 1989), the reference values for Cu, Zn, Cd, Ni and Pb in soil were fixed as 50, 200, 1, 50 and 150 mg kg^{-1} dry weight.

Merry (1989) has reported that the virgin soils in the rural areas of Australia contained about 0.09 mg Cd per kg in the top soil while soils contaminated with sewage sludge in metropolitan areas had as high as 1-10 mg Cd kg^{-1} soil.

The range of values for DTPA extractable Cd, Pb and Ni in Kuttanadu soils of Kerala was reported by Sathyaprakasan (1989) as 0.014-0.026, 1.1-8.1 and 0.6-1.3 ppm respectively. He also found that the total content of Cd, Pb and Ni in these soils were between 1 - 2.3, 9 -18 and 30-53 ppm respectively.

Kabata-Pendias and Dudka (1991) reported that the average content of total Cd and Pb in the surface soils of Poland was 0.41 and 18.3 ppm. They proposed the reference values for evaluation of soil contamination as 0.1 to 0.6 and 7.6 to 22.5 ppm for Cd and Pb respectively.

Holmgren *et al.* (1993) analysed the surface soil samples in USA for Pb, Cd, Zn, Cu and Ni and reported the minimum - maximum values of Cd, Pb, Zn, Cu and Ni as 0.005 - 2, 0.5 - 135, 1.5 - 264, 0.3 -495 and 0.7 - 269 mg kg^{-1} dry soil.

Ogawa (1994) has reported that the average content of Cd, Cu, Zn and Pb in some of the polluted paddy fields in Japan was 2.1, 31.5, 34.4 and 22.3 ppm respectively.

Natural levels of heavy metals in red loamy soils of Hyderabad were determined by Rao and Shantharam (1994). No concentration of total and DTPA extractable Cr and Cd at all depths and Pb, Ni and Cr after 150 cm could be detected. The distribution of DTPA extractable heavy metals followed closely the pattern of organic carbon distribution in the soil profile.

Wallace and Wallace (1994) reported that DTPA extractable Pb in the soils of USA indicated levels beyond 20 mg kg^{-1} soil, which may be passed on to the food chain. Keller and Vedy (1994) measured the back ground concentration of Cu and Cd in a Typic Dystrochrept (acid brown soil) of Switzerland and reported the presence of 13.5 ppm Cu and 0.44 ppm Cd in the top soil.

Soil samples from fields in North Norway, on the Russian border were collected and analysed by Almas *et al.* (1995) for concentration of Cd, Cu, Cr, Ni, Pb and Zn to determine whether the atmospheric deposition from the Russian metal industry nearby has caused contamination. The mean concentration of HNO3 extractable Cd, Cu, Ni and Zn was 0.8, 44, 30.4 and 47.5 mg kg^{-1} soil respectively which indicated an accumulation of these elements. The mean soil concentration of Pb and Cr was 9.1 and 20.4 mg kg^{-1} soil respectively which are near to the normal levels of these metals in Norwegian soils. The concentration of DTPA extractable Cd in the soils was also high and ranged up to 0.58 mg kg^{-1}.

The tolerance limit set for heavy metal addition to the surface plow layer (20-30 cm) in German soils for Cd, Pb and Ni were 2.0, 50 and 100 mg kg^{-1} (Mortvedt, 1996).

2.3 Status of heavy metals in fertilizers

Agricultural soils regularly amended with fertilizers show a large build up of various heavy metals. Commercial fertilizers are reported to contain a great range of heavy metals like Cd, As, Cr, Pb, Hg, Ni and V. Contamination of soils by heavy metals, especially Cd from phosphatic fertilizers is getting increasing attention of the environmentalists.

World wide range in concentrations of Cd in rock phosphates as reported by Williams and David (1973) are 1- 90 mg kg^{-1}. Cd is the heavy metal receiving more attention because of its relative ease of transfer from soil to plant and the perceived health hazards. The content of Cd in some phosphatic fertilizers in Canada, Australia, United States, The Netherlands and Sweden as reported by Williams and David (1973) and Reuss *et al.* (1978) are 2.1-9.3, 18-91, 7.4-156, 9-60 and 2 - 30 mg kg^{-1} respectively.

The cadmium content of commercial fertilizers like urea, calcium ammonium nitrate muriate of potash, diammonium phosphate, super phosphate and rock phosphate was reported to be 1, 6, 14, 109,187 and 303 ppm respectively by Singh and Sekhon (1977).

Jaakola (1977) reported that application of P fertilizers containing 10, 150, 285 or 405 mg Cd/kg P did not affect Cd uptake by wheat. Mortvedt and Giordano (1977) reported that commercial diammonium phosphate fertilizers contained 100 to 260 mg Cd kg^{-1} while reagent grade DAP contained only 5 mg Cd kg^{-1} P. They have also reported greater Cd uptake by maize from commercial DAP.

Goodroad and Coldwell (1979) noticed that when concentrated superphosphate was applied continuously for 19 years, there was no addition of Pb, As or Cr in the soil. Their studies have revealed that P fertilizers at the rates presently applied would not add substantially to the natural levels of Pb, As or Cr in the soil.

According to Gunnarsson (1983) the current hazard due to heavy metals in phosphatic fertilizers appears minimal, but requires monitoring because the net transfer of these elements from phosphate rock deposits to agroecosystems is considerable and is disseminated widely.

Rothbaum *et al.* (1986) have reported that annual application rates of Cd through fertilizers in long term experiments were 5g ha^{-1} for 95 years in Rothamsted and 20 g ha^{-1} for 30 years in Newzealand.

Implemented Cd limits in mg kg^{-1} P for fertilizers in Australia, Germany, Japan, Sweden, Switzerland and The Netherlands were 350, 200 343, 100, 50 and 35 respectively (Anon, 1989).

The results of the study by Sathyaprakasan (1989) has revealed that phosphatic fertilizers contained the highest amount of heavy metals and among the phosphatic fertilizers, factamphos contained the maximum amount of Cd (7 ppm). Ni (45.2 ppm) and Pb (8 ppm). They were found to be highest in mussorie rock phosphate.

A tendency for accumulation of bulk forms of heavy metals like Cd, Ni and Pb in Sod-Podzolic soils had been observed due to the prolonged use of mineral and organic fertilizers, by Mineev and Gomonova (1993).

Srikanth *et al.* (1994) have reported that market samples of superphosphate sold in India had a concentration of cadmium in the range of 18-28.5 mg kg^{-1}. They have further shown that excess dose of such samples of superphosphate in the vineyards around Hyderabad has resulted in elevated concentrations of cadmium in the ground water. Recently Mortvedt (1996) has reported that 91 per cent of phosphate rock reserves of the world contain on an average 16, 16.5, 66 and 189 ppm of Cd, Pb and Ni respectively. He has also quantified the content of Cd, Pb and Ni added to soil every year with 20 kg P ha^{-1} as 3.3, 1 and 4 g ha^{-1} respectively.

2.4 Status of heavy metals in organic manures

The application of organic wastes on land has become increasingly popular as a means of waste disposal as well as a source of nutrients and a soil conditioner (Chaney, 1973). Bridges (1989) proposed that such materials like municipal wastes, sewage sludge, pig and poultry slurries etc. when spread on land as a convenient and economic means of disposal and for the benefit of soil productivity can cause appreciable contamination by heavy metals.

Chaney (1983) has reported the average content of Cd, Cu, Pb, Ni and Zn in dry digested biosolids in USA as 10, 800, 50, 80 and 1700 ppm respectively.

According to Webber *et al.* (1984) several countries have introduced control on heavy metal concentration in sewage biosolids because of the concern on heavy metal effects in the human food chain. They reported that the recommended and mandatory maximum annual loading for Cd in European community were 0.1 and 0.15 kg Cd ha^{-1} respectively while the recommended and mandatory cumulative limits were 2.4 and 8.4 kg Cd ha^{-1}.

Tiller (1989) reported that both composted and uncomposted municipal wastes add to soil in several countries as much as 2, 330, 215 and 800 mg kg^{-1} of Cd Cu, Pb and Zn. He also reported that pig and poultry waste slurries on a dry basis contained 600 to 900 mg Cu kg^{-1}.

The commission of European Community (Anon, 1989) has issued a directive specifying mandatory and recommended limits of 40 and 20 mg Cd kg^{-1} (dry weight basis) for biosolids applied to agricultural soils as a nutrient source.

Gupta *et al.* (1986) have shown that sewage from many towns in India contained very high amount of toxic elements like Pb, Cd, Ni and Cr. He has reported that the average total content of Cd, Ni and Pb in sewage sludge of many towns of India were 3.8, 58.1 and 39.9 ppm while the average available content of these elements were only 0.7, 3.4 and 4.8 ppm. In most towns in India, the sewage as such is used either directly to irrigate the agricultural land and as a supplement of essential plant nutrients or disposed into a fresh water tributary which again is used for agricultural purposes (Kansal, 1992 and Sakal *et al.* 1992).

Harada *et al.* (1993) showed that the content of Cu and Zn was very high in swine poultry waste compost. Such high content of heavy metals is believed to be caused by the addition of these elements to animal feed. Toharisman

(1994) analysed the compost made from sugar factory wastes for Zn, Cu, Pb and Cd and found that none of the samples contained Cd and that the content of other heavy metals except Zn was low in all composts. Apart from Zn in pressmud, all the heavy metal concentrations were well below the German and Swiss limits for soil amendments.

Rao and Shantharam (1994) have reported that long-term application of garbage in agricultural fields around Hyderabad has resulted in increased concentration of Zn, Cu and Mn. Soils to a depth of 30 cm were found contaminated with heavy metals due to the addition of such garbage.

Tam and Wong (1995) reported that spent pig litter had high content of Cu and Zn but did not interfere plant growth in any way. The amount of Zn and Cu accumulated in edible tissues was not in excess, indicating that heavy metal contamination was not a serious problem when the spent litter was recycled on to agricultural land. Tisdell and Breslin (1995) have reported that municipal solid waste composts in the US were enriched with Pb (314-671 mg kg^{-1}), Cd (2.6 - 10.8 mg kg^{-1}), Cu (121 - 762 mg kg^{-1}) and Zn (540- 2790 mg kg^{-1}).

Jayabaskaran and Sreeramulu (1996) observed that accumulation of Fe, Cu, Mn, Zn, Co, Cd, Cr, Pb and Ni in the surface soils of sewage farms of Tamil Nadu was due to continuous application of sewage.

Paino *et al.* (1996) detected no toxic concentration of heavy metals in soils amended with increasing quantities of municipal refuse compost. The concentrations of Cd and Pb were observed to be below 0.5 and 5 ppm respectively. However, concentrations of Cu and Zn in maize increased relative to the amount of urban compost added, but never reached toxic concentrations.

2.5 Heavy metal content in plants

The wide spread interest in the pattern of uptake and translocation of heavy metals by plants in recent years has arisen from the reported harmful health effects due to their dietary intake (Rivai *et al.* (1990) Wagner (1993) and Groten and Vanbladeren (1994)).

Allaway (1968), Haghiri (1976) and Gupta and Dixit (1992) observed depression in plant growth due to Cd toxicity when its concentration in plants was approximately 2 to 3 mg kg^{-1}.

Bingham *et al.* (1975) reported spinach, soybean and lettuce as Cd sensitive plants. Jarvis *et al.* (1976) suggested that high retention of heavy metals in roots was particularly desirable in forage, cereal and vegetable crops where the roots were not utilized, thus reducing the heavy metal burden to animals and men. They estimated that the retention of Cd in roots varied from 34-97 per cent of the total plant Cd.

Mc Lean (1976) showed that Cd was present in higher concentrations in roots than in other organs of oats, soybean, alfalfa, maize and tomato. However, in lettuce, carrot, tobacco and potato, Cd content was higher in the leaves compared to roots.

Davis *et al.* (1978) proposed the upper critical concentration of Cd in plants as 15 ppm. Bowen (1979) reported the normal range of Cd, Cu, Ni, Pb and Zn in plants as 0.1 - 2.4, 5-20, 0.02-5, 0.2- 20 and 1 - 400 ppm respectively.

Etherington (1982) reported that the normal content of Zn, Cu, Pb, Ni and Cd in agricultural crops was 15 to 100, 4 to 15, 0.1 to 10, above 1.0 and 0.05 to 0.5 ppm while the limits for phyto toxicity in shoot were more than 50, 5, 15, 5 and 1.0 ppm for Zn, Cu, Pb, Ni and Cd respectively.

Kabata-Pendias and Pendias (1984) and Nicol and Beckett(1985) reported that the concentrations or the levels above which toxicity effects were likely in plants for Cd, Cu, Ni, Pb and Zn were 5-30, 5-64, 8-220, 30-300 and 100-400 ppm respectively.

Alloway (1990) noticed the concentration of Ni in plants growing in a non-contaminated and non-serpentinic soil was generally in the range 0.1 - 5 mg kg^{-1}. Slightly higher values have been found in crops grown on organic soils. The concentration of Ni in plants from serpertine areas was commonly in the range 20 - 100 mg kg^{-1}. He has further reported that oats was especially susceptible to Ni uptake.

Guo and Marschner (1995) observed highest Cd concentrations in shoots of cereals and lowest in shoots of pulses. Contrary to Cd, the Ni concentration was highest in the shoots of pulses and lowest in cereals.

2.5.1 Cereals and Pulses

Giordani *et al.* (1975) found that the concentration of Ni in grain and forage ranged from 2.6 to 6.9 ppm with application of municipal waste.

Iwai *et al.* (1975) studied the Cd uptake in some plants and concluded that with increased Cd concentration in soil, the Cd content of plants increased and total dry matter and grain yield decreased. The relationship between dry weight and Cd content indicated that the critical Cd content above which plants suffer from Cd toxicity was about 20 ppm.

Ito and Iimura (1976) found that in rice plants grown in culture solutions containing zero to 3 ppm of Cd, tillering and root hair elongation were inhibited and grain yield decreased. They also showed that the Cd concentration decreased in the order root, stem, leaves and brown rice.

Mitchel *et al.* (1978) reported that Cd was most toxic to wheat followed by Ni, Cu and Zn. Yield reduction was noticed when the leaves contained 36 to 43 ppm Cd.

Chino (1981) indicated that the critical cadmium concentration which was injurious to rice plant was 5-10 mg kg^{-1} in top and 100-600 mg kg^{-1} in the root. The injurious concentration of Zn was 100-300 mg kg^{-1} in shoot and 500-1000 mg kg^{-1} in roots.

Threshold values of Cu in shoot portions of wheat and barley for sufficiency was 4 to 10 and 8 to 9 ppm and for toxicity 40 and 19 ppm respectively as reported by Bould *et al.* (1984). They have also reported that concentration of Zn in wheat and barley for sufficiency was 40 and 20 to35 ppm and for exhibiting toxicity 90 and 40 ppm respectively.

Sathyaprakasan (1989) reported the ranges of Cd, Ni and Pb in rice plants grown in different rice soils of Kerala as 0.9 - 2.4, 2 - 23 and 4.4 to 10.1 mg kg^{-1} respectively.

Boluda *et al.* (1993) reported that rice development was adversely affected when grown on soils contaminated with heavy metals. They have claimed that the contamination could be detected by remote sensing before it was actually detected in the field.

In a pot culture experiment with 15 varieties of rice conducted at CRRI, at two levels of Cd, no foliar symptoms of Cd toxicity was observed by Sarkunan *et al.* (1995) in many of the rice varieties. However, application of Cd caused significant decrease in both grain and straw yield and the magnitude of decrease varied among varieties.

Miller *et al.* (1995) studied the effect of different levels of sludge application to barley on the absorption of Cd, Cu, Ni and Zn. The content of metals was relatively low in the grains and high in straw. Metal content in plants increased with increasing sludge loading. Most plants grown on soil amended with the higher sludge rate were too high in Cd (0.5 mg kg^{-1}) to be suitable for feeding animals.

Singh (1995) reported that the toxic or upper critical level of Ni in cowpea leaf tissue which led to a reduction in the dry matter production was computed to be 30 mg kg^{-1}.

Guo and Marschner (1995) analysed plant parts of beans and rice grown in a nutrient solution with Cd and Ni concentrations of 0.5 mg each. They found that the content of Cd in shoots of beans and rice was 6.6 and 56.3 and that Ni was 14.2 and 9.3 mg kg^{-1} dry wt. They also found the content of Cd in roots of beans and rice as 293 and 336 and Ni as 48.8 and 44.5 mg per kg dry weight.

Mc Grath *et al.* (1995) reported that the symbiotic nitrogen fixation in legumes decreased by several orders of magnitude when concentrations of Zn, Cu, Ni and Cd were 130-200, 27-48, 11-15 and 0.8 - 1 mg kg^{-1} soil.

2.5.2 Other crops

Bingham *et al.* (1975) reported that spinach and lettuce accumulated 175 to 354 mg Cd kg^{-1} in their tissues. Michael (1983) noted the Ni content of coriander and amaranthus from Dharward in Karnataka as 1.32 and 1.21 ppm respectively.

Kohiyama *et al.* (1992) detected Ni in oil seeds and found that its average content was more than 3 ppm in soyabeans and walnut, more than 2 ppm in cotton seed and more than 1 ppm in sunflower, sesame, groundnut and copra. The content of Cu was highest in sesame (17 ppm) and lowest in maize (<2 ppm).

Kim *et al.* (1993) reported the natural content of Cd, Cu, Zn, Pb and Ni in orchard fruits in Korea as 0.07, 3.8, 20.7, 0.5 and 2.1 ppm respectively.

Guttormsen *et al.* (1995) reported that Cd removal by chineese cabbage and carrot was 0.7 and 1.3 g ha^{-1} and the Nordic food industries committee has proposed the maximum tolerable limit of Cd in vegetable crops as 0.1 mg Cd kg^{-1} fresh weight.

Lehoczky *et al.* (1996) reported that the content of Cd in leaves and bulbs of garlic was 0.6 and 1.6 mg kg^{-1} fresh weight and with Cd treatment at the rate of 10 mg kg^{-1} of soil, the content was raised to 1.6 and 4.6 mg kg^{-1} fresh weight.

Semu and Singh (1996) showed that the content of Cd, Zn and Cu in tobacco leaves was 0.08, 19.4 and 3.3 under low management where as it was 0.16, 31.9 and 3.7 mg kg^{-1} at high level management.

2.6 Factors controlling the availability of heavy metals in soils

Miller *et al.* (1977), Mc Bridge *et al.* (1981), Rana and Kansal (1983), Sposito *et al.* (1982), Mc Bride (1989) and several others have found that the availability of heavy metals in soils to be a function of various soil properties. According to them, sorption of heavy metals by soil is influenced by pH, organic matter, cation exchange capacity, clay content, presence of other ions and solution composition. The important literature available on these topics is reviewed.

2.6.1 pH and CEC

Chaney (1973) identified pH and CEC as soil factors controlling the bioavailability of heavy metal elements in soil. Iimura (1973) and Ito and Iimura (1975) have stated that among the soil conditions affecting Cd availability in rice fields, the pH and oxidation-reduction state are prominent. They have shown that at a higher pH range, both the stability of complex compounds with soil humus and the extent of their adsorption by the hydroxides of aluminum and iron increased. The availability of Cd to the plant was lowered under these conditions. Korte *et al.* (1976) and Christensen (1984) correlated soil pH and clay content with heavy metal adsorption.

Miller *et al.* (1977) noticed that Cd uptake decreased as soil pH and CEC increased. However, availability of Cd increased with increase in acidity. Harter (1979, 1983) correlated heavy metal adsorption with soil properties such as pH and CEC.

Sposito *et al.* (1982) stated that heavy metals in soil react with organic matter and clay exchange sites, carbonate and oxide surface and get precipitated as hydroxides, carbonates, sulphides, phosphates and silicates.

Rana and Kansal (1983) showed that pH through its indirect effect on organic matter, clay and CaCO3 content depressed the availability of Cu, Zn and Cd in the soil. But Pb availability was found to be controlled by almost all soil properties.

Zang *et al.* (1987) and Sakal *et al.* (1992) found a significant multiple correlation between soil pH and heavy metal content of soil.

Mc Bride (1989) reviewed the reaction controlling heavy metal solubility in soils and stated specific sorption and surface precipitation on oxides and carbonates as the chief process.

Mann and Ritche (1993) have reported that in a sandy soil, the proportion of Cd present in the exchangeable form increased as the soil solution pH increased. However an opposite trend was observed in a peaty sand. In soils where the main adsorption surface was dominated by hydrous oxides, 50-70 per cent of the Cd extracted was bound to oxides. At pH values greater than 5, 90 per cent of Cd was extracted in this way in soils containing clay (mainly Kaolinite) as the major adsorbent. These soils retained Cd mostly in the exchangeable form at all pH values.

Allen (1993) reported that the primary variable of soils contributing to metal mobility and availability to plants is pH. Sanchez and Sanchez (1993) confirmed that CEC of a soil is highly influential on Cd adsorption and mobility.

Guttormsen *et al.* (1995) reported that the Cd concentration consistently and significantly increased with decreased soil pH. They have reported that Cd uptake by cabbage and carrot was significantly higher at pH 5.5 than at pH 6.5 and Cd concentrations in these crops were 23 and 46 per cent higher at pH 5.5 than at pH 6.5.

Oborn *et al.* (1995) determined the content of heavy metals in crops grown in commercial fields in Sweden. They found that concentrations of Cd, Ni, Zn and Cu showed significant negative correlation with surface soil pH. They concluded that if the decrease in pH of arable soils due to various acidifying processes are not balanced by liming it will lead to increased levels of trace elements in crops.

Reddy *et al.* (1995) indicated that at near neutral pH dissolved metal concentration in soil water extracts was dominated by dissolved organic carbon (DOC) metal complexes. At low pH dissolved metal concentration in soil water extracts was dominated by free ionic forms followed by ion pairs. As soil pH decreased the availability and mobility of metal ions increased due to the nature of the chemical form in which these metal ions are present in soil solution.

Singh *et al.* (1995) found that the concentration of Cd in different plant species decreased with increasing soil pH. Significant difference between soil pH levels was seen more in wheat and carrot than in lettuce. The effect of pH was more pronounced in a loamy soil than in clay loam soils.

Lehoczky *et al.* (1996) recorded the availability of Cd in an acidic soil of pH 4.2 as 0.06 mg kg^{-1} soil whereas, it was 0.08 mg kg^{-1} in a neutral soil having a pH of 6.8.

2.6.2 Organic matter

Organic matter is reported to play an important role in the sorption / complexation of heavy metals and their availability in soils. Petruzzelli *et al.* (1978) have suggested that metals were adsorbed by organic matter through complexation. White and Chaney (1980) stated that a high content of organic matter was very effective in reducing metal availability and it limited the uptake of Cd by plants. The soil type also exerted a strong influence on Cd and Zn uptake of plants.

Khalid *et al.* (1981) reported that bioavailability of heavy metals tend to decrease in the presence of dissolved organic matter (DOM) and organic matter generally had a positive effect on decreasing availability of heavy metals in soil. However, Sharma and Kansal (1986) have reported a positive correlation between organic carbon and availability of heavy metals indicating that an increase in organic matter would increase the availability of these metals by forming organo-metallic complexes which could exist in soil solution for a longer period.

Piccolo (1989) showed that addition of humic substances efficiently immobilised the soluble and exchangeable forms of Cu, Pb, Cd, Zn and Ni. Retention capacity was directly related to the amount of added humic substance Metal forms extracted with DTPA showed that the amount of soil borne organic matter determined the availability of heavy metals. The interaction of native organic matter with added organic matter reduced the extractability of metals. In soils low in native organic matter, freshly added humic substances bound the metals in readily accessible complexes which could be displaced by DTPA thereby enhancing their availability.

Karapanagiotis *et al.* (1991) studied the role of organic matter in metal retention. They noted that the organic complexes of copper and cadmium were stronger than that of the other metals and the binding capacity of the organic matter for metals was greater for copper and nickel.

Basta *et al.* (1993) obtained a positive correlation between organic matter and metal adsorption indicating the capacity of organic matter for adsorption of heavy metals. Retention of heavy metals by organic matter reduced the availability of heavy metals to plants (He and Singh, 1993).

2.6.3 Flooding

Flooding of soils, leading to the elimination of O_2, creates a gradient of oxidised and reduced soil conditions bringing out changes in the availability of heavy metals.

Ito and Iimura (1976a) have shown that when the submerged water was drained in the middle and later growth stages of rice, the capacity of the soil for metal adsorption increased markedly. The authors have observed that when submerged condition was maintained throughout the growing period, the cadmium concentration in brown rice was only less than 1 ppm even in the case where the soil content was 100 ppm. Upon draining the soil after the tillering stage, the content of Cd in brown rice reached a peak level of 5 mg kg^{-1}.

Khalid *et al.* (1981) demonstrated that an increase in redox potential (Eh) from -150 to 500 mV led to a decrease in exchangeable Cd.

The influence of waterlogging on the availability and uptake of Cd, Pb, Zn, Cu, Mn and Fe was studied by Bjerre and Schierup (1985) in a pot experiment using different soils. Waterlogging resulted in the release of more Cd, Pb and Zn to the inorganic reservoir. Mn and Fe concentrations increased during waterlogging. The availability of Cu was not much affected. The total uptake of all heavy metals decreased during waterlogging. The uptake of all metals, except cadmium was lowest in plants grown in the organic soil under flooded conditions.

Ogawa (1994) has reported that continuous flooding of rice soils from panicle formation stage to 20 days after heading could reduce the content of heavy metals to a safe limit in brown rice in polluted soils.

2.7 Mobility of heavy metals in soils

Taylor and Griffin (1981) carried out pot culture experiments to determine the leaching potential of topically applied lead, cadmium and nickel in soil. They found that lead was confined to the upper few centimeters of soil whereas Cd moved down to a considerable depth. Ni was seen to be more uniformly distributed over the total soil depth. Cd and Ni were found to be more mobile.

Legret *et al.* (1988) have reported Cd as the most mobile heavy metal element in soil. They have found Cd in an exchangeable form up to 60-80 cm depth in the soil profile. Ni was seen to be associated with the oxidisable phase of the soil and migrated down to 40-60 cm. They found Pb to be associated with the acid soluble and reducible phases and moved as far as the 20-40 cm layer and Cr remained mostly in the surface horizon.

In a study conducted to assess the vertical movement of Cu, Zn, Ni and Cr added to clay loam and sandy loam soils through urban waste compost, Giusquiani *et al.* (1992) found that the increase in these metal concentrations was greater in the sandy loam soil and that 70 to 80 per cent of the water soluble fraction was retained in the upper 10 cm layer of soils.

Koch and Grupe (1993) studied the mobility of Cd, Pb, Zn and Ni in three German Soils. The results showed that heavy metals from anthropogenic sources showed significantly greater mobility than those from geogenic (parent material) sources. Variations in heavy metal mobility with the exception of Pb were relatively marked in the soil water system. Variations in pH, causing mobility variations were more marked in geogenic than anthropogenic source of heavy metals.

Swarup and Ulrich (1994) studied the movement of applied Zn, Pb and Cd under steady state unsaturated flow condition in soil. Most of the applied heavy metals were retained in the top 10 cm of soil and this resulted in low recovery of heavy metals in the leachate. They estimated the retention as 87 to 96 per cent of the total quantity applied. The recovery of Zn, Pb and Cd in the leachate was 12.6, 6.0 and 8.3 per cent respectively.

Berthelsen and Steinness (1995) studied the vertical distribution of Zn, Pb, Cu and Cd in soil profiles of forested and clear cut areas in Norway. Lower Zn and Cd content were observed in the top H horizon of clear cut areas than in forest areas. The total content of Pb was significantly lower in clear cut than in forested areas. Higher Pb content in the B-horizon on clear cut area soils than in forest soil areas showed that Pb lost from the H-horizon was readsorbed and repreceipitated in the B-horizon. Compared to Pb, retention of Zn, Cu and Cd was high in the humus layer.

Bezvodova (1995) reported that the extractable portion of Cr, Co, Ni, Cu, Pb and Zn was higher in topsoil than in subsoil.

Cong and Tu (1996) reported that transfer of added Ni in soil was greater than native Ni but declined with time. The mobility was greater for the soluble plus exchangeable fraction of soil Ni, but much smaller for residual and Fe / Mn oxide bound fractions. This showed that Ni was more mobile and more harmful in soils with a low pH and or low content of Fe / Mn oxides.

2.8 Absorption of heavy metals by plants

Fleming and Parle (1977), Singh (1981), King and Hajjar (1990), Singh and Jeng (1993) and He and Singh (1994 a, 1994b) reported that large quantities of Cd, Zn, Cu and Pb were absorbed by oats, rye grass, carrot, spinach, lettuce, tobacco, peanuts and by a variety of crop plants when grown on soils containing elevated levels of the metals.

Plant species and also genotypes within the same species differ greatly in their ability to take up and transport heavy metals within the plant as shown by Petterson (1977). Similar observations were made by Gabrielli *et al.* (1990) also.

Allison and Dzialo (1981) reported that presence of added Cd, Pb and Ni to the soil resulted in enhanced tissue concentration of these in rye grass and oats. This effect was particularly enhanced in a soil of pH 4.5.

Taylor and Allison (1981) observed that addition of Pb, Cd and Ni to the soil resulted in both increased metal uptake and concentration in alfalfa tissue particularly for Cd and Ni. The highest tissue concentration of Cd and Ni was associated with plant stunting and necrosis. However, at rates of 125 ppm or less, substantial increase in Cd and Ni concentration was obtained without any yield reduction or phytotoxic symptoms. The tissues however were unsuitable for consumption due to the high content of Cd and Ni.

Michael (1983) reported that with graded levels of Ni (10-100 ppm) its uptake by coriander and amaranthus ranged from 53 to 104 and 23 to 65 mg pot^{-1}. Cataldo *et al.* (1983) reported that in soybean, about 98 per cent of the absorbed Cd is strongly retained by roots and only 2 per cent is transported to the shoot system. Similar observations were made by Guo and Marschner (1995) in many other pulses and cereals.

Sharma and Kansal (1986) observed that spinach grown on sewage irrigated soils accumulated the maximum amount of Cd and other elements followed by berseem. Wheat had absorbed the least amount of these elements. These results indicate the need for selection of a crop which absorbs the lowest amount of metals to prevent the entry of these toxic elements from contaminated soils into the food chain.

Il'in (1991) reported that the uptake of heavy metals from soils into the top organs of plants especially storage organs was limited by some non-specific protective mechanisms in the plants. The uptake of heavy metals was less in cabbage and tomatoes than in beets and potatoes.

Lubben and Sauerbeck (1991) reported that accumulation of Cd, Zn Pb and Cr in grain was lower than those of straw in spring wheat. They proposed that Cd content in soil should be less than 0.5 mg kg^{-1} and pH more than 5.7 to produce grains with Cd content lower than the German guide value of 0.12 mg kg^{-1} dry weight.

Sauerbeck (1991) confirmed that most dicotyledonous plants absorb more heavy metals than monocotyledons. An exception was rye grass which absorbed Ni in unusually large amounts. The uptake of Cu, Pb and Cr was small compared with Cd, Zn and Ni. Cu and Ni were preferentially translocated into fruits and seeds. Cd, Zn and Ni content was influenced by soil acidity, but no significant change in uptake was found for Cu, Pb and Cr.

Plant species and even varieties differed in their susceptibility and tolerance to heavy metals. Leafy vegetables and root crops accumulated higher amounts than grain crops. Other factors like the nature of various agricultural inputs used, native soil content, soil reaction and interaction among metal ions (Davies, 1992 and Gorlagh and Gambus, 1992) also affected their uptake.

Singh and Nayyar (1994) have observed that under normal conditions plants take up small quantities of Cd from soil. But in areas of suspected Cd contamination, the plant levels may be higher and cause total reduction in growth as measured by reduced dry matter yield and root damage. Forage species belonging to Leguminosae family prove more sensitive to Cd than those belonging to Graminae.

2.9 Effect of heavy metals on plants

Foy *et al.* (1978) have emphasised that increasing use of heavy metals in various products and their continuous discharge from foundaries, smelting industries, from burning coal, diesel, fuel, heating oil and impurities of fertilizers have led to a build up of their toxic levels in the soil. As Hagemeyer *et al.* (1986) have stated, during recent years great interest has been generated to examine the toxic effects of heavy metals on plant growth and metabolism.

2.9.1 Germination

Heale and Ormrod (1983) studied the effect of Ni and Cu ranging in concentrations from 4 to 20 mg l^{-1} on seed germination and development of seedlings of some tree species. They found that germination was delayed at lower concentrations and prevented at higher concentrations. Increasing metal concentration resulted in the development of fewer lateral roots which were stunted and thicker.

Leblova *et al.* (1986) reported the inhibitory concentration of Cd, Cu, Pb and Zn as 10, 100 and 1 mM respectively for seed germination and seedling development of maize. 30 to 70 per cent of the metal ions present in the medium accumulated in the roots and 5 to 14 per cent in the shoots. They have noticed the metal induced production of low molecular weight proteins rich in SH groups called metallothionines more in roots than in shoots. Binding of metals to metallothionines probably reduced their toxicity and prevented the inhibition of enzymes containing SH groups.

Herstein and Jager(1986) observed that seedlings of grass species originated from metal contaminated habitats, possessed tolerance to Cd, Zn Cu, Pb and Ni. Tolerance was determined by comparing the root growth in metal free and metal enriched culture solutions.

Dubey and Dwivedi (1987) reported that soaking soybean seeds in solution containing various concentrations of Cd, Co, Ni and Zn for 6 to 24 hours decreased germination percentage and seedling growth. Cd showed the greatest inhibitory effects. The effect was found to increase with increase in concentrations of heavy metals as well as increase in soaking time.

Rani and Paliwal (1988) germinated seeds of forage crops in blotter papers wetted with distilled water and 10-5000 mM Cu^{2+} and Cd^{2+}. The percentage germination increased with concentrations of Cu and Cd upto 100 and 50 mM. A concentration of 25 mM Cu^{2+} or Cd^{2+} increased shoot elongation but this was inhibited with further increase in concentration. Inclusion of Cd and Ni in water (Bishnoi *et al.,* 1993) to moisten filter paper differentially induced dry matter mobilisation from cotyledons of germinating pigeon pea seeds. Cd depressed the activities of enzymes in germinating seeds. The activities of these enzymes were stimulated at lower concentrations of nickel and suppressed at higher ones. The dual response of hydrolytic enzymes to Cd and Ni was postulated to account for the promotary and inhibitory effect of these heavy metals on dry matter mobilisation.

Al-Helal (1995) reported that percentage germination of rice and alfalfa decreased with increasing concentration of Cd and Hg. There was little or no germination at 50 mM Cd Cl_2 and 10 mM Hg Cl_2 in rice. In alfalfa germination was completely inhibited at 5 mM Cd Cl_2 and 2 mM $HgCl_2$. Heavy metals adversely affected the growth of roots more than that of shoot in rice seedlings.

Subramani *et al.* (1997) investigated the influence of Cr, Cd and Hg on germination and seedling growth of black gram. Germination percentage and growth parameters of seedlings showed a gradual decline with increase in concentrations of heavy metals. Cr and Cd showed a growth promoting effect at the lowest concentration of 5 mg l^{-1}. No such promoting effect was noticed in germination index, vigor index, root / shoot ratio and dry weight of seedlings. The order of toxicity of the metals recorded was Cr < Cd < Hg.

Mathew and Abraham (1998) studied the effect of graded levels of Cd and Ni on germination of rice and cowpea. They found that low concentrations of Cd (5 ppm) stimulated germination while higher concentrations did not show any significant effect. Presence of Ni decreased the germination of rice seeds at a concentration of 15 ppm, but the effect was not significant. In the case of cowpea both Cd and Ni produced significant negative effect on germination at a concentration of 25 ppm only. The growth of hypocotyl and epicotyl of germinated seeds was severely affected by Cd and Ni.

2.9.2 Growth of plants

Khalid and Tinsley (1980) observed a depression in shoot yield when Ni level in the nutrient medium was above 30 ppm. Ni concentration of 50 ppm in plants did not reduce dry matter production in rye grass, although slight chlorosis appeared at this level. Allinson and Dzialo (1981) reported that addition of Cd to the soil lowered the dry matter yield in rye grass and oats.

Wong *et al.* (1988) reported that Cd damaged tissue growth by the narrowing of vascular pits and deposition of unknown debris which blocked water transport. Root was the most tolerant plant part and it prevent Cd from being transported to the upper plant parts which were more susceptible. Barcelo and Poschenreider (1990) and Godbold and Knetter (1991) reported that cell growth as well as whole plant growth was drastically inhibited due to Cd toxicity.

Singh *et al.* (1994) noted severe reduction of fresh weight of roots and leaves of sesame seedlings due to Cu and Cd while it was little affected by Pb. They reported that nitrate reductase activity was inhibited in the roots in the order Pb > Cu >. Cd.

Shah and Dubey (1995) indicated that Cd in the growth medium caused a decrease in length of roots and shoots, altered RNA level and inhibited ribonuclease activity. Chen and Kao (1995) observed that the reduction of root growth induced by Cd was closely associated with accumulation of proline in roots.

Guo and Marschner (1995) observed no adverse effect on dry matter production when rice, maize, beans and kale were grown in nutrient solutions with 0.5 mM Cd and 1.0 mM Ni.

Wetzel and Werner (1995) observed an adverse effect of heavy metals on the macro and or microsymbionts vitality and reduced nodulation in legume roots before any visible damage of the plant occurred. Therefore formation and extent of damage of nodules may serve as a criteria for the ecotoxicological evaluation of contaminated soils.

2.9.3 Metabolism of plants

Bingham *et al.* (1975 and 1976), Foy *et al.* (1978) and Taylor and Allinson (1981), Muthuchelian *et al.* (1988) and Kumar and Banerjee (1992) have reported that plants accumulate high concentrations of heavy metals such as Cd and Ni and produce several adverse effects on plant metabolism.

Fuhrer (1982) reported that Cd exerts its toxicity through membrane damage and inactivation of enzymes possibly through reaction with SH groups of proteins. A SH interaction was suggested to explain the small inhibitory effects of Cd on the activity of the cholroplast enzyme RUBP carboxylase and phosphoribulokinase in presence of millimolar metal concentration.

Stobart *et al.* (1985), Weigel (1985), Shrivastava and Singh (1986) and Satakopan and Rajendran (1989) have stated that high Cd levels interfere with the primary process of photosynthesis and inhibit the biosynthesis of cholorophylls and nucleic acids.

Krupa (1988) stated that heavy metal accumulation in the leaves of higher plants was associated with reduction in net photosynthesis.

Becerril *et al.* (1989) observed inhibition of electron flow in chloroplasts of maize plants exposed to 0.2 mM Cd. Krupa *et al.* (1993) noticed a decrease in total chlorophyll content and chlorophyll a / b ratio in higher plants and concluded that Cd primarily affected the photosynthetic pigments before photosynthetic function.

Moya *et al.* (1993) reported that treatment with 0.1 mM Cd and 0.5 mM Ni inhibited rice growth and stimulated carbohydrate accumulation especially in seeds. Immobilization of carbohydrate reserve in such seeds resulted in slow seedling emergence and crop stand.

Prasad (1995) reported that excess cadmium caused toxic symptoms in plants such as growth retardation, inhibition of photosysnthesis, induction and inhibition of enzymes, altered stomatal action, water relations, efflux of cations and generation of free radicals. He further stated that plants attempted to adapt to environments contaminated with excess Cd by tolerance mechanisms like accumulation, sequestration, synthesis of Cd binding complexes and their stabilization by sulphides.

Gangopadhyay and Santra (1996) observed marked reduction in chlorophyll content and nitrogen fixation activity when *Azolla pinnata* was grown in nutrient solution containing 5- 15 ppm of Cu and Cd. The reduction was directly correlated to concentration of toxicant and period of exposure. Cu was found to be less toxic than Cd.

2.9.4 Nutrient composition and crop quality

Knight and Crooke (1956) reported that high Ni concentration reduced the uptake and utilization of most nutrients. In cereals, Ni toxicity produced pale yellow strips running along the length of the leaves. Later, the entire leaf turned white and necrosis occurred at leaf margins.

The effect of supplying Pb, Cd, Cr and Cu to the roots of coconut palms on the concentration of P, K, Ca and Mg in the leaves was investigated by Biddappa *et al.* (1987). The results showed that compared to the control, the amount of leaf phosphorus was reduced by the presence of heavy metals. They also reported a reduction in concentration of K by Cd. Leaf Ca on the other hand, increased in the presence of Cd. The amount of Mg was not affected by Cd but increased by Pb.

Frossard *et al.* (1989) studied the effect of different heavy metals on fructan, sugar and starch content of rye grass. They noted that the fructan content of shoots increased by 25 per cent due to Cd and Ni added to soil at the rate of 0.4 and 100 ppm respectively. Addition of 100 mg Cu and 360 mg Zn kg^{-1} soil resulted in 42 and 118 per cent increase in fructan content. Sucrose concentration increased by 26 and 38 per cent at 0.4 and 5 ppm of Cd and Ni in soil but decreased by 38 per cent at 100 ppm Ni. Starch content decreased with increasing Ni in the soil, but decreased with high Cu supply. The results suggested that accumulation occurred without yield reduction and any visible symptoms of phytotoxicity in the case of Cd and Zn. They also reported that a high concentration of Cd, Ni and Cu in soils just below the toxic level altered carbohydrate content of fodder plants.

Chernykh (1991) observed that raising of soil Cd to 5 ppm, Zn to 250 ppm and Pb to 125 ppm did not alter the uptake of minerals but higher heavy metal concentration disrupted mineral uptake and translocation. Reduction in the uptake of P, Ca, Mg and Fe was more pronounced in pulses than in cereals. The effect of heavy metals was more pronounced in acid soils than in calcareous soils. Plant N concentration increased with increase in Zn, Pb and Cd.

Hlusek and Richter (1992) reported that increasing concentration of Zn, Pb and Cd in soil reduced leaf N and P content in potatoes and had variable effect on K content. Leaf Ca and Mg contents were increased at the higher levels of soil contamination. Tuber N content was reduced only at highest contamination level and P content was variable. K content was highest at highest contamination whereas Ca and Mg contents were usually reduced as contamination increased.

Significant nitrate accumulation in the above ground parts of many crops was revealed when they were grown in heavy metal polluted soils by Yevdokimova (1994). He observed a lower content of carotene due to heavy metal accumulation in plants. Higher concentration of various nitrogen forms in plants seems to be due to their accelerated sorption by roots from the polluted soils with a consequent detoxification of heavy metals ions by nitrogen compounds, proteins and free aminoacids.

Trivedi and Singh (1995) attempted to establish the relationship between air pollution and protein content in a few plants growing in the vicinity of a thermal power plant. The reduction in total protein content was more in herbs and shrubs as compared to trees. This reduction in total proteins may be used as a bio-indication of air pollution.

Brune and Dietz (1995) analysed the elemental composition of barely seedlings grown in the presence of toxic concentrations of Cd, Mo, Ni and Zn. They noted a decrease in root Mn and Mg at elevated levels of all heavy metals. They also concluded that heavy metal toxicity caused excessive accumulation or depletion of nutrient elements which may be deleterious to the plants in addition to other primary damages caused by the heavy metal ions.

2.10 Methods to combat heavy metal pollution

Crooke (1956) has found that Ni toxicity in soils can be alleviated by liming. When a serpentine soil was limed to increase the pH from 4.8 to 6.8, the concentration of Ni in leaf dry matter was reduced from 188 to 77 ppm. K application was also found to reduce Ni toxicity.

Takijima and Katsumi (1973) noticed that Cd uptake in rice after earforming stage was reduced remarkably by a basal application of soil amendments followed by top dressing. Combined use of calcium silicate and fused magnesium phosphate was most effective in producing rice with lowest Cd content. Chaney *et al.* (1977) have noticed that application of lime along with sewage sludge reduced the availability and uptake of Cd and Ni by maize plants.

Strickland *et al.* (1979) reported that inhibition of growth by Cd was reduced by the addition of organic matter. Tissue levels of Cd was markedly reduced in treatments with 2, 4 and 8 per cent organic matter.

The efficiency of barley in removing heavy metals was investigated by Larsen and Schierup (1981) who concluded that one gram of barley straw was able to absorb Zn, Cu, Pb, Ni and Cd ranging from 4.3 to 15.2 mg. The capacity to absorb these metals by straw was improved by 10 to 90 per cent when mixed with $CaCO_3$.

Yoshikawa *et al.* (1986) discovered that manganese sulphate and other soluble manganese salts had a suppressive effect on cadmium absorption by rice plants grown in a pot culture experiment under oxidised soil conditions. In polluted soils, application of 0.1 per cent by weight of manganese to the soil decreased cadmium uptake of rice plants by 83 per cent.

Obata and Umebayashi (1988) found that the flooding of soils between the booting and milk stage in rice considerably depressed the accumulation of cadmium in brown rice. They concluded that it was essential to keep paddy fields submerged during heading stage to lower cadmium concentration level in rice grains.

Truby and Raba (1991) studied the content of Cd, Zn and Pb in vegetables grown on fields contaminated and not contaminated by heavy metals in Germany. Cd content at both sites was often at the same high level. NPK fertilization along with liming stimulated plant growth and reduced the heavy metal concentration by two third. Higher Cd concentration in the vegetables from uncontaminated field was primarily due to sub-optimal growth conditions. They concluded that sufficient NPK fertilization and liming must be carried out to produce vegetables complying with the standards.

Leidmann *et al.* (1994) reported that grass silage effluents containing organic compounds were able to complex heavy metals and could be used for the removal of Cd, Cu and Ni from polluted soils. Utilisation of sorbents to produce ecologically pure farm products was evaluated in Russia by Kireicheva and Glazunova (1994). A new organo mineral sorbing ammendment SORBEKS (a dark grey dust, pH 6.5-7.5, water content 5-10 per cent, more than 30 per cent potassium content) was found useful.

A new technology to use plants to clean up soil and water contaminated with heavy metals known as phytoremediation was reported by Raskin *et al.* (1994). This is based on the observation that certain plants are able to concentrate heavy metals in their roots and shoots to levels far exceeding those present in soil.

Kumar *et al.* (1995) and Huang and Cunningham (1996) tested the ability of various plant species including crops to accumulate heavy metals in shoots and roots. The high metal accumulation by some cultivars of maize, *Brassica juniea*, rag weed, *Thlaspi* sp. etc. suggested that these plants may be used to clean up toxic metal contaminated sites by a process termed phytoextraction. They also found that the addition of synthetic chelates like HEDTA (2 g per kg soil) to Pb contaminated soil (total soil Pb more than 2500 mg/kg) resulted in a surge of Pb accumulation in phytoextraction. The content of Pb in shoot was increased from 40 ppm in the control to 600 ppm in HEDTA treated soil. It was suggested that in combination with soil ammendments, agronomic crops such as maize can be used for the clean up of heavy metal contaminated soil.

Genetic improvement of Cd-hyper sensitive genotypes of agricultural, horticultural and silvicultural plants could be achieved through genetic engineering through transfer of mettalothionein genes (Prasad, 1995). Gutierrez *et al.* (1995) reported that heavy metals in soils from anthropogenic sources accumulate in the upper layers. The high level of organic matter and high pH of soils are preventing the solubility of heavy metals and their absorption by crops.

Brallier *et al.* (1996), Oliver *et al.* (1996) and Hooda and Alloway (1996) studied the effect of liming on heavy metal uptake in wheat, barley, carrot, spinach and potato. They found that liming reduced uptake of Cd, Ni and Zn in most crops but generally did not change Cu and Pb. According to them, raising soil pH to 6.0 was not sufficient to decrease Cd concentration in the edible parts of crops below the maximum permissible concentration and raising the soil pH above this value would not be considered economically viable in many areas.

MATERIALS AND METHODS

MATERIALS AND METHODS

The study on the "Status and impact of heavy metals in selected soils and crops of Kerala" was conducted at the College of Agriculture, Vellayani during 1995-98 as detailed below.

The three experiments conducted to complete the investigation are

1. Determination of heavy metal status of selected soils, fertilizers, manures and plants.
2. A study on the pattern of retention of applied Cd and Ni in different soil types and
3. Studies on the influence of Cd and Ni on the growth, yield and nutrient content of plants.

The materials used and methods followed for these experiments are described.

3.1. Heavy metal status of selected soils, fertilizers, manures and plants

The total and available content of Zn, Cu, Pb, Ni and Cd in the samples of soils, fertilizers, manures and plants collected from different locations as indicated below were assessed by chemical analysis.

3.1.1. Collection of soil samples

1.1.1. Wetland soils

Ten surface samples (0-15 cm) of soils were collected from each of the following locations representing four major rice growing soil types.

Pattambi - Eight plots of PME in rice at RARS, Pattambi (35 years and 70 crops) and two farmer's rice fields

Moncompu - Nine plots of PME in rice at RRS, Moncompu (nine years and 18 crops) and one farmer's rice field

Kayamkulam - Eight plots of PME in rice at RRS, Kayamkulam (32 years and 64 crops) and two farmers rice fields

Purakadu *kari* - Ten farmer's rice fields in *kari* lands

The treatments applied in the PME plots at the three locations are given in Tables 1a to 1c.

1.1.2. Upland soils

Ten surface samples (0-15 cm) each were collected from plots cultivated to vegetables in the Instructional Farm attached to the College of Agriculture, Vellayani and farmer's fields cultivated to vegetables in Pathanamthitta and Alappuzha districts and plots cultivated to fodder in the sewage disposal site in Thiruvananthapuram.

Surface samples from the wetland rice fields were collected during March-May, 1996 and upland soils were collected after harvest of vegetables during the same period. The soil samples were air dried, powdered with a wooden mallet, passed through 2 mm plastic sieve and stored in air tight containers for further chemical analysis.

Table 1a. Details of collection sites of wetland soils - Pattambi

Sample number	Location - Pattambi
S1	PME plots treated with cattle manure @ 18 t ha^{-1}
S2	PME plots treated with green leaf @ 18 t ha^{-1}
S3	PME plots treated with cattle manure and green leaf each @ 9 t ha^{-1}
S4	PME plots treated with ammonium sulphate @ 45 kg ha^{-1}
S5	PME plots treated with cattle manure @ 9 t ha^{-1} + NPK @ 45-45-45 kg ha^{-1}
S6	PME plots treated with green leaf @ 9 t ha^{-1} + NPK @ 45-45-45 kg ha^{-1}
S7	PME plots treated with cattle manure and green leaf each @ 4.5 t ha^{-1}
S8	PME plots treated with NPK @ 90-45-45 kg ha^{-1}
S9	Farmer's rice field near RARS, Pattambi
S10	Farmer's rice field near RARS, Pattambi

(N, P and K applied as ammonium sulphate, super phosphate and muriate of potash respectively)

Table 1b. Details of collection sites of wetland soils - Moncompu

Sample number	Location - Moncompu
S1	PME plots treated without any inputs (absolute control)
S2	PME plots treated with rice straw only
S3	PME plots treated with rice straw + N @ 90 kg ha^{-1}
S4	PME plots treated with rice straw + N and P @ 90 and 45 kg ha^{-1}
S5	PME plots treated with rice straw + N and K @ 90 and 45 kg ha^{-1}
S6	PME plots treated with rice straw + P and K @ 45 and 45 kg ha^{-1}
S7	PME plots treated with N, P and K @ 90-45-45 kg ha^{-1}
S8	PME plots treated with N, P and K @ 90-45-45 kg ha^{-1} + lime @ 600 kg ha^{-1}
S9	PME plots treated with rice straw + soil test based recommendation of fertilizers and lime
S10	Farmer's rice field near RRS, Moncompu

(N, P and K applied as urea, Mussorie phosphate and muriate of potash respectievly respectively)

Table 1c. Details of collection sites of wetland soils - Kayamkulam

Sample number	Location - Kayamkulam
S1	PME plots treated with cattle manure to supply N @ 40 kg ha^{-1}
S2	PME plots treated with ammonium sulphate to supply N @ 40 kg ha^{-1}
S3	PME plots treated with N and P @ 40 and 30 kg ha^{-1}
S4	PME plots treated with N and K @ 40 and 30 kg ha^{-1}
S5	PME plots treated with P and K @ 30 and 30 kg ha^{-1}
S6	PME plots treated with N, P and K @ 40-30-30 kg ha^{-1}
S7	PME plots treated with N, P and K @ 40-30-30 kg ha^{-1} + cattle manure to supply N @ 10 kg ha^{-1}
S8	PME plots without any fertilizers and manures (absolute control)
S9	Farmer's rice field near RRS, Kayamkulam
S10	Farmer's rice field near RRS, Kayamkulam

(N, P and K applied as ammonium sulphate, superphosphate and muriate of potash respectively)

1.1.3. Collection of fertilizers

Random samples of single superphosphate, rock phosphate and complex fertiizers marketted in the districts of Thiruvananthapuram, Alappuzha and Pathanamthitta were collected during August - September, 1996 and January - February, 1997. The details of the locations are as follows.

Name of fertilizer	Number of samples	Location
Single superphosphate	10	Pathanamthitta and Thiruvananthapuram
Rock phosphates		
Mussooriephos	5	Thiruvananthapuram and Alappuzha
Rajphos	5	Thiruvananthapuram
Complex fertilizers		
Factamphos	10	Alappuzha and Thiruvananthapuram
Diammonium phosphate	5	Thiruvananthapuram
Suphala (15 : 15 : 15)	5	Thiruvananthapuram
Vijay complex (17 : 17 : 17)	5	Thiruvananthapuram

3.1.1.4. Collection of manures

Ten random samples each of the following manures were collected from locations as noted below.

1. Sewage sludge from sewage farm, Valiyathura, Thiruvananthapuram

2. Vermicompost from households in the Kalliyoor village of Thiruvananthapuram district under the vermicultre demonstration scheme of the Department of

Agricultural Extension and from the Instructional Farm of the College of Agriculture, Vellayani

3. Ordinary compost prepared from household wastes in homesteads in the villages of Kalliyoor and Venganoor in Thiruvananthapuram district

4. Dung from cows of the above homesteads fed on fodder grass from sewage farm and those not fed on fodder from sewage farm were seperately collected.

3.1.1.5. Collection of plant samples

Whole plant samples (10 each) of rice, amaranthus, cowpea, graminaceous fodder and leguminous fodder were collected from the locations mentioned under 3.1.1.1 and 3.1.1.2 above. The plants were first washed in running water and then in distilled water, pressed between folds of blotting paper, dried in shade, separated into roots, edible and non-edible parts and dried in an electric air oven at 65°C. The dried samples were finely ground in an agate mortar and stored in air tight containers.

3.1.2. Chemical analysis

3.1.2.1. Soils

3.1.2.1.1. Total heavy metals

One gram soil sample was digested with 15 ml of a mixture of 10 ml concentrated H_2SO_4 and 5 ml $HClO_4$ in a 100ml conical flask, evaporated to incipient dryness, extracted with 50 ml boiling 1N HCl, filtered and made up to 100 ml. The heavy metal concentrations (Zn, Cu, Pb, Ni and Cd) in these extracts were measured in an atomic absorption spectrophotometer (AOAC, 1980).

3.1.2.1.2. DTPA extractable heavy metals

Ten gram of soil was mixed with 20 ml of DTPA - TEA solution (0.005 M) in polythene bottles and were shaken for two hours and filterd through Whatman No. 42 filter paper. Extractable heavy metals in the extract were measured in an atomic absorption spectrophotometer (Jackson, 1973).

Statistical analysis

The data generated from the soil analysis described above were subjected to suitable statistical analysis to estimate the degree of variability of the content of heavy metals in the soil samples collected from each location.

3.1.2.2. Fertilizers

One gram of the well ground fertilizer sample was dissolved in 10 ml of concentrated HCl in a 100 ml spouted beaker and evaporated almost to dryness. The residue was redissolved in 2 N HCl by gentle boiling. The solution was filtered through Whatman No.1 filter paper into a 100 ml volumetric flask, diluted to volume with double distilled water. This solution was used for the determination of Zn, Cu, Pb, Ni and Cd using the standard conditions for each element in an atomic absorption spectrophotometer (Everson, 1975).

3.1.2.3. Manures

One gram of the finely ground sample was digested with 10 ml of concentrated HNO_3 and 3 ml $HClO_4$ in a 100 ml conical flask and evaporated to dryness. The residue was dissolved in 5 ml of 6N HCl and made upto 50 ml with double distilled water and used for the determination of total Zn, Cu, Pb, Ni and Cd using the standard conditions for each element in an atomic absorption spectrophometer (AOAC, 1980).

The extractable content of these elements in manures were estimated as in 3.1.2.1.2.

3.1.2.4. Plants

The content of Zn, Cu, Pb, Ni and Cd was estimated in the extracts of plant samples prepared as under 3.1.2.3 above by direct reading in an atomic absorption spectrophotometer.

Statistical analysis

The degree of variability in the content of heavy metals in rice samples collected from different locations were estimated as suggested by Panse and Sukhatme (1967).

3.2. Pattern of retention of applied Cd and Ni in different soil types

The pattern of retention of Cd and Ni in six different soil types of Kerala was studied by taking their core samples in PVC columns and equilibrating with known amount of Cd and Ni for thirty days under specified moisture conditions. The influence of organic matter in modifying the pattern was also studied by including FYM in one set of soil column. The details of the experiment and the soil samples used for the study are described here.

The description of the soil types used for the column study is given below.

Location	Common name	Taxonomic name
Upland soils		
Kayamkulam	Sandy *Onattukara*	Oxyaquic Quartzipsament
Kottarakkara	Laterite soil	Typic Plinthustult
Thiruvallam	Red soil	Rhodic Haplustox
Wetland rice soils		
Vettikavala (Kottarakkara)	Lateritic alluvium	Typic Tropaquept
Karumadi (Kuttanadu)	*kari* soil	Typic Sulfaquent
Mangalam kayal (Kuttanadu)	*kayal* soil	Typic Hydraquent

2.1. Collection of core samples

Two core samples each were collected from the following six locations during May, 1997 before the onset of south west monsoon. PVC tubes of 10 cm diameter and 60 cm length were placed on the soil surface, covered with a wooden plank and driven into the soil with a wooden hammer to a depth of

50cm. The tubes were carefully withdrawn and both ends were closed with PVC caps, kept in an erect position and transported to the College of Agiculture, Vellayani. The soil columns were placed in an erect position with the help of metallic stands and clamps.

The wetland soils were flooded to maintain a layer of 5 cm water on the surface and the upland soils were maintained at field moisture capacity by pouring calculated quantity of distilled water. The base of flooded soil columns were covered with gauze cloth and closed with a PVC cap (5cm long), sealing the joint with m-seal.

The basic physico-chemical properties of soils relevant to the study were determined by standard analytical procedures as outlined by Jackson (1973) and are given in Table 2.

Samples were separately collected from each 10 cm segment to a depth of 50 cm for all the above soil types and analysed for total and extractable Cd and Ni as given under 3.1.2.1.

Experimental details

Uniformly dried and powdered FYM, to represent a level of 10 t ha^{-1} was mixed with surface 10 cm of soil in one set of each soil column. Solutions of $CdCl_2.2H_2O$ and $NiCl_2.6H_2O$ to supply 10 and 100 mg Cd and Ni per kg of soil were poured on the surface of soil in all columns, mixed with the upper 15 cm and maintained at the prescribed water levels for a period of 30 days. After 30 days, the standing water in submerged soil columns was completely drained and collected along with leachate in labelled containers. Each soil column was then cut into five segments of 10 cm length with a hack saw blade and soil from each segment was transferred to labelled plastic containers.

Table 2. Basic physico-chemical properties of soils used in column study

Soil type	pH	Organic matter (%)	Clay content (%)	CEC (cmol (P^+) kg^{-1})	Cadmium mg kg^{-1}		Nickel mg kg^{-1}	
					Total	Extractable	Total	Extractable
Sandy *Onattukara*	6.2	0.5	6.2	5.2	5.3	0.10	23.3	0.50
Laterite soil	5.7	1.7	30.4	6.9	6.8	0.18	43.6	1.30
Red soil	5.2	1.4	39.5	7.5	2.8	0.12	16.8	0.13
Lateritic alluvium	5.5	2.2	38.2	8.8	4.3	0.11	50.3	0.48
kari soil	3.9	8.5	52.5	31.6	2.2	0.06	26.9	0.53
kayal soil	4.6	8.1	53.1	37.5	3.5	0.15	45.3	0.90

These soils were then air dried, powdered with a wooden mallet, passed through 2 mm plastic sieve and analysed for total and extractable Cd and Ni as given under 3.1.2.1. The leachate collected from wetland soil columns was also analysed for Cd and Ni as above.

3. Influence of applied Cd and Ni on the growth and yield of plants

This experiment was conducted to study the effect of graded levels of Cd and Ni on the pattern of growth, yield, nutrient uptake and accumulation of Cd and Ni in different plant parts. Three important crops in Kerala viz., rice, sesame and cowpea were used for the study. Levels of Cd and Ni which permitted the establishment and growth were selected in each crop as the upper limit. Weather data recorded at College of Agriculture, Vellayani during the cropping period is given in Fig. 1. Chemical composition of manures and fertilizers used for the pot culture study is given below.

Analysis of manures, fertilizers and lime used in the pot culture studies

Materials	Nutrient composition	Content of	
		Cd ($mg\ kg^{-1}$)	Ni ($mg\ kg^{-1}$)
FYM	0.5% N, 0.32% P, 0.25% K	1.8	4.4
Urea	46% N	0.9	1.0
Super phosphate	16% P	20.4	29.8
Factamphos	20% N, 20% P	18.2	11.0
Muriate of potash	60% K	1.7	2.9
Burnt lime	71% Ca	Traces	0.5

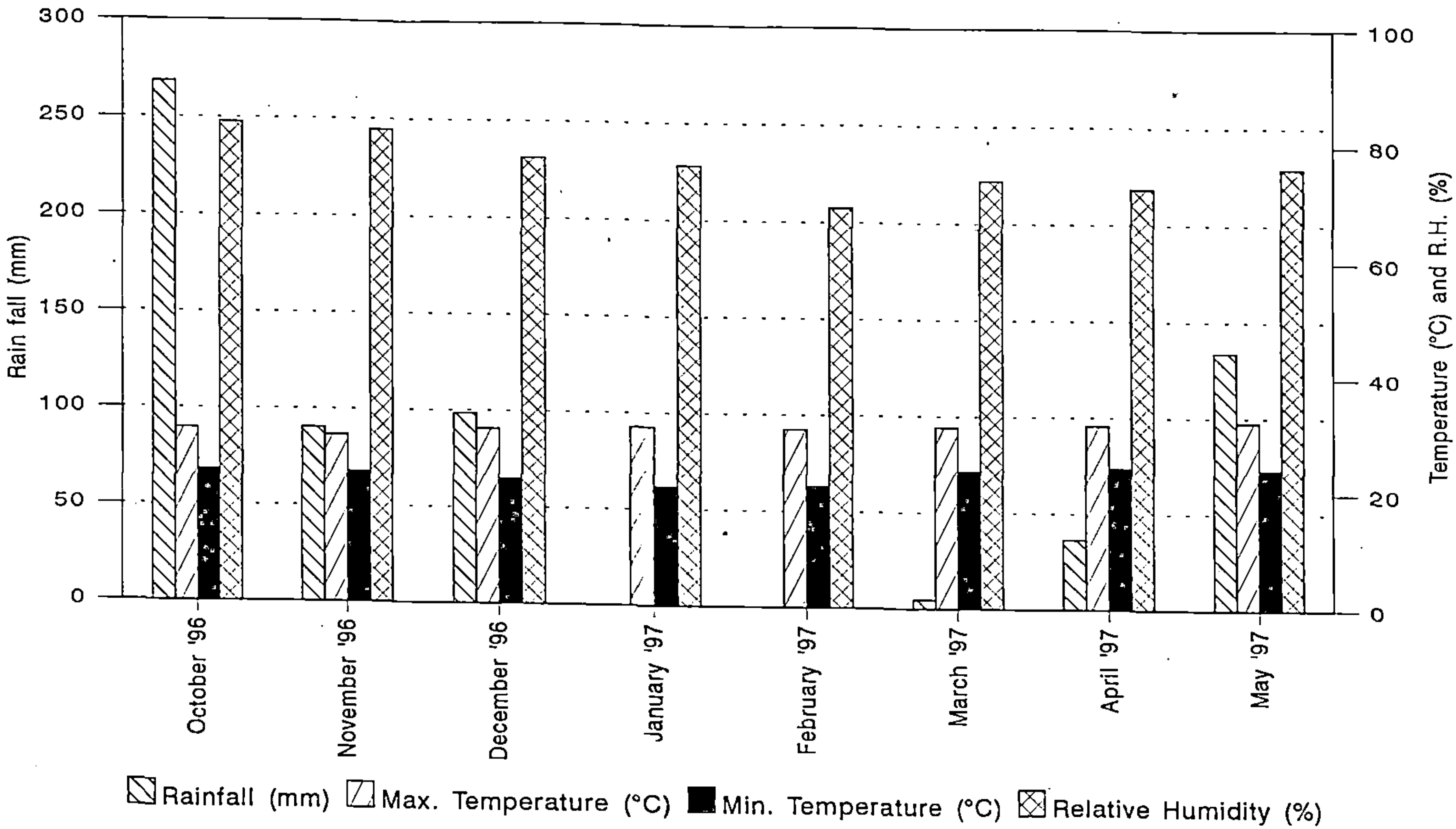

Fig. 1. Main meteorological parameters during the cropping period (October 1996 to May 1997)

3.3.1. Experiment with rice (*Oryza sativa* L.)

A pot culture experiment using rice var. Jyothi was conducted during October 1996 to March 1997 at the College of Agriculture, Vellayani, using a lateritic alluvial soil (Aquic Ustipsamment) collected from the rice fields in Nemom, a village adjacent to Vellayani.

The soil was air dried, powdered and 8.0 kg was placed in earthern pots of 30 cm diameter, puddled and maintained in a waterlogged condition. The physico-chemical properties of the soil are given in Table 3.

Table 3. Physico-chemical properties of the soils used in pot culture studies

Common name	Lateritic alluvium	Sandy *Onattukara*	Red soil
A. Mechanical composition			
Sand (per cent)	57.80	87.40	48.52
Silt (per cent)	19.70	6.00	27.50
Clay (per cent)	20.10	5.50	23.10
Texture	Sandy clay loam	Sandy loam	Sandy clay loam
pH	5.30	6.00	5.00
CEC (cmol $(p^+)kg^{-1}$	8.20	5.30	7.20
Organic carbon (per cent)	1.57	0.40	0.82
B. Chemical characteristics			
Total N (per cent)	0.070	0.045	0.051
Total P_2O_5 (per cent)	0.080	0.120	0.070
Total K_2O (per cent)	0.12	0.019	0.430
Total Cd (mg kg^{-1})	2.90	5.00	2.30
Total Ni (mg kg^{-1})	26.20	15.10	19.10
Available N (kg ha^{-1})	430.00	106.00	228.00
Available P_2O_5 (kg ha^{-1})	56.30	45.00	18.50
Available K_2O (kg ha^{-1})	286.00	74.00	126.00
Extractable Cd (mg kg^{-1})	0.08	0.10	0.06
Extractable Ni (mg kg^{-1})	0.23	0.12	0.10

3.3.1.1. Influence of Cd on rice

The treatments were given as follows in a completely randomised design in three replications

T_0	–	Absolute control (without any inputs)
T_1	–	Fertilizers + FYM + lime
T_2	–	Fertilizers + lime
T_3	–	T_1 + Cd 5 mg kg^{-1} soil
T_4	–	T_1 + Cd 15 mg kg^{-1} soil
T_5	–	T_1 + Cd 25 mg kg^{-1} soil
T_6	–	T_2 + Cd 5 mg kg^{-1} soil
T_7	–	T_2 + Cd 15 mg kg^{-1} soil
T_8	–	T_2 + Cd 25 mg kg^{-1} soil

Fertilizers, FYM and lime were given as per package of practices recommendation of the Kerala Agricultural University (KAU, 1993). NPK at the rate of 70-35-35 kg ha^{-1} as urea, factamphos and muriate of potash were applied on the transplanting day. Uniformly dried and powdered FYM at the rate of 5 t ha^{-1} was applied 10 days before transplanting. Fully burnt lime with a neutralising value of 99% was applied to each pot at the rate of 600 kg ha^{-1} one day before transplanting. A stock solution of $CdCl_2.2H_2O$ was prepared in water and the quantity required to provide the prescribed amount of Cd in each treatment was applied before transplanting rice seedlings. Three seedlings (18 days old) were transplanted in each pot and water level was maintained at 5 cm after two days. Pests and disease infected plant parts were removed by hand. No plant protection chemicals were used.

Observations

Biometric characters like height of plant, number of total and productive tillers and yield characters like length of panicle, number of spikelets per panicle, total number of grains and number of filled grains per panicle were recorded at the time of harvest. Number of days to flowering and harvest were also noted.

At the time of harvest the entire plants along wih roots in each pot were carefully removed, washed free of adhering soil particles, dried between folds of blotting paper and air dried. Plants were then separated into roots, straw and earheads, ovendried at 65°C and total dry matter produced per pot was estimated. The earheads were removed and grains separated into filled and unfilled grains. Weight of grain and hundred grain weight were noted and chaff percentage was calculated.

Plant analysis

The oven dried roots, straw and grains were powdered and stored in air tight containers and analysed for N, P, K, Ca, Mg and Cd following standard procedures outlined in AOAC (1980) and Piper (1944).

Post harvest studies on rice grains

Starch content

Starch content in rice grains was estimated by the method described in AOAC (1980).

Germination

Germination was tested by keeping 50 seeds on a filter paper kept in petridish moistened with distilled water. Germination percentage was recorded on the seventh day.

3.3.1.2. Influence of Ni on rice

This experiment was conducted as described in the study on the influence of Cd on rice. The treatments were the same except that the levels of Ni used were different as shown below

Treatments

T_0	–	Absolute control (without any inputs)
T_1	–	Fertilizers + FYM + lime
T_2	–	Fertilizers + lime
T_3	–	T_1 + Ni 50 mg kg^{-1} soil
T_4	–	T_1 + Ni 75 mg kg^{-1} soil
T_5	–	T_1 + Ni 100 mg kg^{-1} soil
T_6	–	T_2 + Ni 50 mg kg^{-1} soil
T_7	–	T_2 + Ni 75 mg kg^{-1} soil
T_8	–	T_2 + Ni 100 mg kg^{-1} soil

Each treatment was replicated thrice and Ni was supplied as a solution of $NiCl_2.6H_2O$ in water.

Observations

Biometric and yield characters, plant analysis and post harvest studies on rice grains were made as described under 3.3.1.1.

3.3.2. Experiment with sesame (*Sesamum indicium*)

Details of the pot culture experiment to study the effect of Cd and Ni on sesame (*Sesamum indicum*) an important oil seed crop of Kerala cultivated in the sandy soils of *Onattukara* region (Oxyaquic Quartzipsamment) are presented. Sandy soil of the *Onattukara* region was collected from the garden land of the Rice Research Station, Kayamkulam, brought to the College of Agriculture, Vellayani, air dried and filled in earthern pots of 30 cm diameter at the rate of 8 kg per pot. The experiment was conducted during January to April, 1997 corresponding to the third crop season of sesame in *Onattukara*. The details of physico-chemical properties of soil used in the study are given in Table 3.

One set of pots were used for studying the effect of Cd and another set for the effect of Ni as per the following treatments.

3.3.2.1. Influence of Cd on sesame

The following treatments were given in a CRD

T_0	–	Absolute control (without any inputs)
T_1	–	Fertilizers + FYM + lime
T_2	–	Fertilizers + lime
T_3	–	T_1 + Cd 5 mg kg^{-1} soil
T_4	–	T_1 + Cd 15 mg kg^{-1} soil
T_5	–	T_1 + Cd 25 mg kg^{-1} soil
T_6	–	T_2 + Cd 5 mg kg^{-1} soil
T_7	–	T_2 + Cd 15 mg kg^{-1} soil
T_8	–	T_2 + Cd 25 mg kg^{-1} soil

The treatments were replicated thrice in a CRD. The fertilizers were given as per the POP recommendations for sesame of the Kerala Agricultural

University (KAU, 1993) at the rate of 30-15-30 kg ha^{-1} N, P and K as urea, factamphos and MOP. FYM was used at the rate of 5 t ha^{-1} and cadmium was *provided as a solution of* $CdCl_2.2H_2O$ *in water.*

Ten seeds of sesame var. Thilak was sown in each pot and population thinned to two plants. The plants were given light irrigation. One dusting with 10 *per cent carbaryl and one spray with 0.2 per cent carbaryl* were given as plant protection measure against leaf and pod caterpillar and gall fly respectively.

Observations

Biometric characters like height of plant, number of branches, leaves, nodes and yield components like number and weight of capsules per plant and 100 seed weight were recorded at the time of harvest. Days to flowering and harvesting were also noted.

When the capsules were mature, the plants from each pot were carefully uprooted along with the roots, washed free of adhering soil particles and air dried by keeping in brown paper covers and oven dried at 65°C. After determining the total dry matter, the plants were separated into tops and roots and the capsules separated from the tops.

Plant anlysis

Roots, haulm and seeds were powdered and analysed for N, P, K, Ca, Mg and Cd following standard analytical procedures as described earlier.

Post harvest studies on sesame

Oil content

Content of oil was estimated by cold percolation method (Kartha and Seth, 1957).

Germination

50 seeds were placed in petridishes moistened with distilled water and germination percentage was recorded on seventh day.

3.3.2.2. Influence of Ni on sesame

This experiment was conducted as described above with the following treatments replicated three times in a CRD.

T_0	–	Absolute control (without any inputs)
T_1	–	Fertilizers + FYM + lime
T_2	–	Fertilizers + lime
T_3	–	T_1 + Ni 5 mg kg^{-1} soil
T_4	–	T_1 + Ni 15 mg kg^{-1} soil
T_5	–	T_1 + Ni 25 mg kg^{-1} soil
T_6	–	T_2 + Ni 5 mg kg^{-1} soil
T_7	–	T_2 + Ni 15 mg kg^{-1} soil
T_8	–	T_2 + Ni 25 mg kg^{-1} soil

Nickel was given as a solution of $NiCl_2.6H_2O$ in water.

Biometric observations, plant analysis and post harvest studies were made as under 3.3.2.1

3.3.3. Experiment with cowpea (*Vigna unguiculata*)

The pot culture studies with cowpea were conducted in the red soil (Rhodic Haplustox) of the Instructional Farm, College of Agriculture, Vellayani during March to May, 1997. Two plants of cowpea var. C152 were grown in earthen pots of 20 cm diameter filled with 5 kg soil treated as follows and replicated six times in a CRD. Three replications were used for destructive sampling of plants at maximum flowering stage. Table 3. presents the physico chemical properties of the soil used.

3.3.3.1. Influence of Cd on cowpea

The treatments used in the pot experiment were as follows

T_0	–	Absolute control (without any inputs)
T_1	–	Fertilizers + FYM + lime
T_2	–	Fertilizers + lime
T_3	–	T_1 + Cd 5 mg kg^{-1} soil
T_4	–	T_1 + Cd 15 mg kg^{-1} soil
T_5	–	T_1 + Cd 25 mg kg^{-1} soil
T_6	–	T_2 + Cd 5 mg kg^{-1} soil
T_7	–	T_2 + Cd 15 mg kg^{-1} soil
T_8	–	T_2 + Cd 25 mg kg^{-1} soil

Fertilizers, lime and FYM were applied as per package of practices recommendation of KAU (KAU, 1993). NPK were given at the rate of 20-30-10 kg ha^{-1} as urea, super phosphate and muriate of potash. Lime and FYM were added at the rate of 250 kg and 20 t ha^{-1} respectively. The plants were irrigated daily and two sprays of malathion (0.05%) for controlling pea aphids and one spray of carbaryl (0.2%) to protect the crop from pod borers were given as plant protection measure.

Observations

Maximum flowering stage

Observations on height of plant and number of leaves per plant as well as days to flowering were recorded. The plants were very carefully removed from the pot along with roots and nodules, after lavishly wetting the soil, washed free of soil and separated into tops and roots. The nodules were removed from the roots, counted separtely and weight of nodule per plant was recorded. Dry weight of roots and tops was also determined after drying in an oven at 65°C.

Plant analysis

Oven dried samples of tops and roots were powdered and analysed for N, P, K, Ca, Mg and Cd following standard analytical procedures as described earlier. N content in nodules was determined by Kjeldhal method.

Harvest stage

Observations on biometric characters like height, number of leaves, branches and peduncles per plant, number of seeds per pod, total seed and haulm yield including roots as well as number of days for harvesting were recorded. Total dry matter was estimated after drying the plant parts in an oven at 65°C.

Plant anlysis

Oven dried and powdered samples of seeds, haulm and roots were analysed for N, P, K, Ca, Mg and Cd. Protein content in grains was expressed by multiplying N conent with the factor 6.25.

Post harvest studies

Germination percentage was determined as described for sesame and rice.

3.3.3.2. Influence of Ni on cowpea

The treatments adopted for this experiment were as follows. Ni was supplied as an aqueous solution of $NiCl_2.6H_2O$.

T_0	–	Absolute control (without any inputs)
T_1	–	Fertilizers + FYM + lime
T_2	–	Fertilizers + lime
T_3	–	T_1 + Ni 5 mg kg^{-1} soil
T_4	–	T_1 + Ni 15 mg kg^{-1} soil
T_5	–	T_1 + Ni 25 mg kg^{-1} soil
T_6	–	T_2 + Ni 5 mg kg^{-1} soil
T_7	–	T_2 + Ni 15 mg kg^{-1} soil
T_8	–	T_2 + Ni 25 mg kg^{-1} soil

Observations on biometric and growth characters and plant analysis were made at maximum flowering stage and harvest as in the experiment with Cd.

Statistical analysis

The data generated from the pot culture experiments were subjected to analysis of variance technique (ANOVA) in CRD as suggested by Cochran and Cox (1962).

RESULTS

RESULTS

Data on the status of Zn, Cu, Pb, Ni and Cd in the soils, fertilizers and manures used as inputs in agriculture and plants collected from the locations described in chapter 3 are presented.

4.1.1. Heavy metal status in soils

The soils collected for the study represent soil samples from important wetland rice soils and upland soils cultivated to vegetables and fodder in different parts of the state. The data presented in tables 4 to 10 indicate the loading of Cu, Zn, Ni, Pb and Cd in each soil showing their total and extractable content. The status of each heavy metal is presented in the order of their abundance in soil. The results have shown that the content of extractable heavy metals in all the soils is very low compared to their total content.

Copper

As seen from tables 4-10, Cu is the most abundant heavy metal present both in wetland and upland soils. The content of Cu was highest in plots cultivated to vegetables in Pathanamthitta and Alapuzha districts where it ranged from 38.5 to 159.0, with an average value of 84.4 mg kg^{-1} (Table 9). In the other upland soils, as seen from Table 8, total Cu content ranged from 31.3 to 62.7 with a mean value of 46.0 mg kg^{-1} in the vegetable plots of Instructional farm, Vellayani and in the fodder plots of sewage farm, Valiyathura, total Cu content was in the range of 20.1 to 48.4 with a mean value of 29.3 mg kg^{-1} (Table 10).

The ranges of extractable Cu content in the above three locations were 1.5 to 5.8, 0.56 to 2.62 and 0.06 to 0.21 mg kg^{-1} with means of 3.60, 1.10 and 0.15 mg kg^{-1} (Tables 9, 8 and 10)

Among the wetland soils, total content of Cu was highest in the PME plots and farmer's field at Moncumpu and ranged from 63.5 to 87.8 mg kg^{-1} with an average value of 77.9 mg kg^{-1} as seen from Table 5. The highest content of 87.8 mg kg^{-1} was recorded in the plots receiving fertilizers and lime as per package of practices along with straw as treatment. The lowest content of 63.5 mg kg^{-1} was noted in the absolute control plots. The extractable content was very low and it ranged from 1.9 to 3.0 mg kg^{-1} with an average of 2.5 mg kg^{-1}.

In the PME plots and farmer's fields at Kayamkulam (Table 6), the total Cu content ranged from 60.0 to 79.0 with a mean of 65.3 mg kg^{-1}. The maximum and minimum values of 79.0 and 60.0 mg kg^{-1} were noted in samples S_1 and S_8 (Table 1c) collected from plots receiving FYM alone as treatment and absolute control plots respectively. Extractable content of Cu ranged from 1.8 to 3.0 with a mean of 2.5 mg kg^{-1}.

The total content of Cu in the PME plots and farmer's fields at Pattambi ranged from 39.2 to 68.4 mg kg^{-1} with a mean of 55.9 mg kg^{-1}, the maximum and minimum values being recorded in samples (Table 1a), collected from plots receiving cattle manure along with NPK fertilizers (S_5) and ammonium sulphate alone (S_4) as treatments. Range value for extractable Cu content was 1.2 to 4.3 mg kg^{-1} with a mean of 2.3 mg kg^{-1} (Table 4).

Table 4. Content of heavy metals (mg kg^{-1}) in the PME plots and farmer's fields (rice) - Pattambi

Sample No.	Copper		Zinc		Nickel		Lead		Cadmium	
	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
S1	62.7	2.8	40.1	6.0	50.6	0.40	28.0	2.6	2.5	0.04
S2	41.1	1.5	24.6	2.1	53.5	0.28	28.5	2.9	2.0	0.04
S3	60.8	2.9	30.8	3.4	58.9	0.50	29.4	2.7	2.2	0.04
S4	39.2	1.2	24.8	2.2	53.7	0.54	25.8	2.4	2.2	0.04
S5	68.4	2.3	29.1	2.6	53.1	0.44	30.4	2.6	2.1	0.02
S6	66.5	2.4	34.8	4.4	53.0	0.26	27.3	2.5	2.1	0.06
S7	58.4	2.3	22.8	1.8	46.4	0.50	25.7	2.1	2.2	0.04
S8	44.2	1.3	22.6	1.6	49.2	0.50	28.9	2.4	2.1	0.06
S9	61.6	4.3	26.1	2.8	52.4	0.50	29.2	2.4	2.2	0.06
S10	56.1	2.0	25.1	2.6	50.1	0.48	25.7	2.5	2.2	0.06
Mean	55.9	2.3	28.1	2.9	52.1	0.44	27.9	2.5	2.2	0.05
CV(%)	56.9	117.2	62.1	146.0	19.1	66.4	16.2	25.5	37.6	86.2

Table 5. Content of heavy metals (mg kg^{-1}) in the PME plots and farmer's field (rice) - Moncumpu

Sample No.	Copper		Zinc		Nickel		Lead		Cadmium	
	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
S1	63.5	2.2	68.1	1.4	34.7	1.5	10.6	2.1	1.7	0.04
S2	71.2	1.9	79.3	1.8	34.9	1.5	10.3	1.8	2.3	0.04
S3	74.9	2.4	74.1	1.3	40.1	2.2	11.5	1.8	1.9	0.02
S4	75.5	2.4	75.2	0.9	54.9	3.1	12.8	2.1	3.2	0.08
S5	84.6	2.8	80.4	1.6	46.2	2.6	10.5	2.0	2.0	0.04
S6	78.3	2.0	78.5	1.4	56.3	3.6	13.2	2.3	2.2	0.06
S7	81.2	2.8	88.6	1.7	58.5	3.8	12.6	2.4	3.6	0.08
S8	87.8	3.0	82.0	1.5	65.1	4.0	13.3	2.0	3.4	0.04
S9	87.0	3.0	82.7	1.4	63.8	3.8	11.7	2.1	3.4	0.02
S10	75.2	2.8	80.2	2.0	44.7	2.1	12.9	2.0	3.2	0.04
Mean	77.9	2.5	78.9	1.5	49.9	2.8	11.9	2.1	2.7	0.05
CV(%)	29.0	48.1	21.0	60.4	68.1	103.0	29.4	27.6	81.7	138.2

Table 6. Content of heavy metals (mg kg^{-1}) in the PME plots and farmer's fields (rice) - Kayamkulam

Sample No.	Copper		Zinc		Nickel		Lead		Cadmium	
	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
S1	79.0	3.0	35.6	2.5	19.8	0.17	8.8	1.9	5.9	0.10
S2	63.5	2.4	23.3	1.4	15.2	0.10	5.8	1.7	3.1	0.06
S3	61.4	2.6	24.1	0.9	25.2	0.20	4.6	1.3	7.0	0.12
S4	60.1	2.0	23.9	1.5	16.5	0.12	4.4	1.4	3.2	0.06
S5	60.2	2.4	25.4	0.9	18.9	0.12	7.5	1.8	6.4	0.08
S6	65.8	2.6	23.2	1.1	20.6	0.14	7.3	1.8	6.0	0.08
S7	75.6	3.0	34.6	2.6	27.4	0.22	8.4	2.1	7.2	0.10
S8	60.0	1.8	15.8	1.0	15.0	0.12	4.9	1.5	3.0	0.08
S9	65.0	2.5	18.2	1.1	21.1	0.15	5.8	2.0	3.2	0.06
S10	62.6	2.3	17.8	1.1	20.9	0.14	5.8	1.8	3.3	0.06
Mean	65.3	2.5	24.9	1.4	20.1	0.15	6.4	1.7	4.9	0.08
CV(%)	30.7	46.4	74.4	129.6	60.5	77.5	73.4	44.9	115.1	72.8

Table 7. Content of heavy metals (mg kg^{-1}) in the farmer's fields (rice) – *kari* land

Sample No.	Location	Copper		Zinc		Nickel		Lead		Cadmium	
		Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
1	Tharayakkari	18.9	0.3	15.5	0.9	32.4	0.6	17.6	3.1	2.3	0.06
2	Thakazhi	15.7	0.2	20.5	1.0	35.3	1.2	18.6	3.0	2.3	0.06
3	Munnorampadavu	15.9	0.6	19.5	1.0	30.5	0.6	20.4	4.2	1.5	0.04
4	Kalleppuram	18.7	0.9	28.8	1.6	30.8	1.1	21.1	4.6	2.4	0.06
5	Kavilthekkumpuram	18.3	0.8	40.2	2.5	29.0	0.8	24.3	4.8	2.0	0.06
6	Valiyathuruthu	16.9	0.8	41.5	2.6	32.6	0.9	20.8	4.2	2.9	0.08
7	Cheriyathuruthu	21.8	1.6	27.4	1.3	27.1	0.6	15.7	4.0	1.6	0.04
7	Ezhavankari	13.1	0.2	23.1	1.1	30.4	0.6	25.2	6.4	1.3	0.04
9	Karuvatta	14.4	0.2	30.8	1.6	30.9	0.7	20.1	6.0	1.9	0.06
10	Varikkattukari	18.7	1.0	31.4	1.5	35.3	0.7	22.9	5.8	2.2	0.08
Mean		17.2	0.7	27.9	1.5	31.4	0.8	20.7	4.6	2.0	0.06
CV(%)		44.3	206.9	92.2	120.1	24.5	84.7	42.6	75.7	70.8	76.3

Table 8. Content of heavy metals (mg kg^{-1}) in the vegetable plots of Instructional Farm, Vellayani

Sample No.	Copper		Zinc		Nickel		Lead		Cadmium	
	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
1	62.7	2.62	18.4	1.36	26.5	0.10	20.2	4.8	3.3	0.10
2	45.2	0.76	8.3	0.67	20.4	0.09	14.7	2.3	3.1	0.08
3	44.6	0.76	8.0	0.61	20.7	0.09	13.5	2.1	2.2	0.07
4	31.3	0.57	8.0	0.60	18.0	0.07	11.8	1.9	3.5	0.10
5	49.2	0.76	17.9	1.48	21.1	0.09	14.5	2.3	4.1	0.11
6	32.5	0.56	8.0	0.55	19.3	0.07	13.4	2.1	3.4	0.10
7	46.7	0.74	8.7	0.56	19.6	0.08	14.5	2.2	3.7	0.12
8	60.8	2.58	19.5	1.40	25.4	0.10	20.0	4.2	4.3	0.12
9	41.8	0.78	8.1	0.64	18.2	0.08	14.2	2.3	2.0	0.09
10	45.1	0.76	10.5	0.62	18.1	0.07	14.0	1.8	2.3	0.09
Mean	46.0	1.10	11.5	0.9	20.7	0.08	15.1	2.6	3.2	0.10
C.V (%)	66.2	220.5	128.5	138.5	43.0	41.9	55.2	118.3	74.4	49.6

Table 9. Content of heavy metals (mg kg^{-1}) in the vegetable plots of Alapuzha and Pathanamthitta districts

Sample No.	Location	Copper		Zinc		Nickel		Lead		Cadmium	
		Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
1	Kayamkulam	68.1	1.5	24.5	1.4	33.2	0.50	17.9	2.5	2.2	0.06
2	Krishnapuram	62.5	3.6	42.7	1.3	31.5	0.49	22.4	2.1	3.1	0.08
3	Venmony east	40.4	2.1	38.5	3.5	43.1	0.52	19.6	2.3	1.2	0.08
4	Venmony west	38.5	2.0	37.6	3.4	40.6	0.44	19.8	2.2	1.0	0.08
5	Kollakadavu	56.2	3.1	30.0	3.5	51.2	0.50	24.9	2.2	1.0	0.04
6	Kidanganoor east	159.0	5.8	62.4	4.2	46.3	0.51	21.7	2.8	4.1	0.10
7	Kidanganoor south	108.0	4.6	64.1	4.5	48.0	0.42	22.2	2.8	3.6	0.10
8	Mekkozhoor north	90.7	4.3	47.6	3.4	45.7	0.54	17.8	2.0	1.6	0.08
9	Mekkozhoor south	91.0	4.4	48.2	3.4	39.4	0.41	17.5	2.0	1.0	0.08
10	Elanthoor	129.2	4.1	39.8	3.6	50.9	0.48	25.1	2.6	1.0	0.06
Mean		84.4	3.6	43.5	3.2	43.0	0.48	20.9	2.4	2.0	0.08
C.V(%)		139.2	115.0	87.1	98.2	47.7	27.2	40.4	39.1	182.2	72.5

Table 10. Content of heavy metals (mg kg^{-1}) in the fodder plots of sewage farm, Valiyathura

Sample No.	Name of fodder	Zinc		Copper		Nickel		Lead		Cadmium	
		Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
1	Guinea grass	98.1	11.1	21.3	0.10	24.9	2.0	17.1	2.6	6.4	0.09
2		53.7	4.2	20.6	0.11	24.7	1.8	26.0	4.1	6.1	0.09
3		53.9	4.1	20.1	0.09	25.0	2.6	15.9	2.5	8.5	0.12
4	Para grass	69.2	5.5	31.4	0.21	30.5	3.4	19.8	2.9	12.0	0.10
5		78.2	5.4	27.0	0.20	24.6	1.7	29.5	6.5	5.1	0.10
6		103.4	17.6	20.3	0.14	24.2	1.6	25.7	3.2	4.3	0.10
7	Napier grass	59.8	4.2	43.2	0.24	24.9	1.8	27.9	5.3	11.2	0.12
8		81.8	10.3	30.8	0.27	28.1	3.0	18.3	2.9	10.4	0.10
9	Subabool	76.9	23.1	48.4	0.06	28.8	3.1	29.5	6.5	8.1	0.09
10		89.3	23.8	29.7	0.06	27.4	2.9	26.0	3.7	7.5	0.09
Mean		76.4	10.9	29.3	0.15	26.3	2.4	23.6	4.0	8.0	0.10
C.V(%)		68.6	215.7	101.1	154.9	25.8	85.2	66.8	115.5	97.9	34.6

Total Cu content in soil samples from farmer's fields of *kari* lands was the lowest and ranged from 13.1 to 21.8 mg kg^{-1} with a mean of 17.2 mg kg^{-1}. The extractable content of Cu ranged from 0.2 to 1.6 mg kg^{-1} (Table 7).

Zinc

As seen from Tables 4 to 10, Zn content was highest in the PME plots and farmer's fields at Moncompu, ranging from 68.1 to 88.6 mg kg^{-1} with a mean of 78.9 mg kg^{-1}. The maximum and minimum values were recorded by samples S_7 and S_1 (Table 1b) receiving NPK fertilizers along with straw and PME absolute control plots. The extractable content ranged from 0.9 to 2.0 mg kg^{-1} with a mean of 1.5 mg kg^{-1} (Table 5).

The total Zn content in the PME plots and farmer's field at Pattambi (Table 4) was lower and ranged from 22.6 to 40.1 mg kg^{-1} with a mean of 28.1 mg kg^{-1}. The maximum and minimum values of 40.1 and 22.6 mg kg^{-1} were recorded by S_1 and S_8 (Table 1a) receiving NPK fertilizers and cattle manure alone as treatments. The extractable content of Zn ranged from 1.6 to 6.0 mg kg^{-1} with a mean of 2.9 mg kg^{-1}.

The total content of Zn in rice soils of *kari* lands ranged from 15.5 to 41.5 mg kg^{-1} with a mean of 27.9 mg kg^{-1}. The extractable content ranged from 0.9 to 2.6 with a mean of 1.5 mg kg^{-1} (Table 7).

Among the wetlands, the total Zn content was lowest in the PME plots and farmer's fields at Kayamkulam, where it ranged from 15.8 to 35.6 mg kg^{-1} with a mean of 24.9 mg kg^{-1}. The maximum and minimum values of 35.6 and 15.8 mg kg^{-1} were noted in S_1 and S_8, (Table 1c) collected from PME plots receiving cattle manure alone as treatment and PME absolute control plots. The extractable content ranged from 0.9 to 2.6 mg kg^{-1} with a mean of 1.4 mg kg^{-1} (Table 6).

In the upland soils, total Zn content was highest and ranged from 53.7 to 103.4 mg kg^{-1} with a mean value of 76.4 mg kg^{-1} in the fodder plots of sewage farm. The extractable content ranged from 4.1 to 23.8 mg kg^{-1} with a mean of 10.9 mg kg^{-1} (Table 10). In the vegetable plots of Alapuzha and Pathanamthitta districts, the total Zn content ranged from 24.5 to 64.1 with a mean of 43.5 mg kg^{-1}. The extractable content ranged from 1.3 to 4.5 mg kg^{-1} with a mean of 3.2 mg kg^{-1} (Table 9). The total and extractable Zn content was lowest and ranged from 8.0 to 19.5 and 0.55 to 1.48 mg kg^{-1} with means of 11.5 and 0.9 mg kg^{-1} in the vegetable plots of Instuctional Farm, Vellayani (Table 8).

Nickel

Total and extractable nickel content was maximum and ranged in the wetland soils from 46.4 to 58.9 and 0.26 to 0.54 mg kg^{-1} with mean values of 52.1 and 0.44 mg kg^{-1} in the PME plots and farmer's fields at Pattambi (Table 4). The maximum and minimum values of 58.9 and 46.4 mg kg^{-1} were noted in S_3 and S_7 (Table 1a) collected from the PME plots receiving organic manures alone and organic manures along with NPK fertilizers as treatments.

In the PME plots and farmer's field at Moncompu, total Ni content was in the range of 34.7 to 65.1 mg kg^{-1} with a mean value of 49.9 mg kg^{-1} (Table 5). The maximum and minimum values were noted in S_8 and S_1 (Table 1b) from plots receiving NPK fertilizers with lime and absolute control plots. The extractable Ni content ranged from 1.5 to 4.0 mg kg^{-1} with a mean value of 2.8 mg kg^{-1}.

It may be seen from Table 7 that the total and extractable Ni content in the ten soil samples collected from *kari* lands ranged from 27.1 to 35.3 and 0.6 to 1.2 mg kg^{-1} with mean values of 31.4 and 0.8 mg kg^{-1}.

In the rice PME plots and farmer's fields at Kayamkulam, the total extractable Ni content was lowest and ranged from 15.0 to 27.4 and 0.10 to 0.22 mg kg^{-1} with mean values of 20.1 and 0.15 mg kg^{-1}. The maximum and minimum values of 27.4 and 15.0 mg kg^{-1} were recorded by S_7 and S_8 (Table 1c) collected from PME plots receiving NPK fertilizers with cattle manure as treatments and absolute control plots.

The total and extractable Ni content in the upland soils were in the range of 31.5 to 51.2 and 0.41 to 0.54 mg kg^{-1} with mean values of 43.0 and 0.48 mg kg^{-1} in the vegetable plots of Alapuzha and Pathanamthitta districts (Table 9).

The total and extractable Ni content in the fodder plots of sewage farm, Valiyathura were in the range of 24.2 to 30.5 and 1.6 to 3.4 mg kg^{-1} with mean values of 26.3 and 2.4 mg kg^{-1} (Table 10).

The vegetable plots of Instructional Farm, Vellayani, recorded values for total and extractable Ni contents in the range of 18.0 to 26.5 and 0.07 to 0.10 mg kg^{-1} with mean values of 20.7 and 0.08 mg kg^{-1} (Table 8).

Lead

Total content of Pb was highest and in the range of 25.7 to 30.4 mg kg^{-1} with a mean value of 25.7 mg kg^{-1} in the rice PME plots and farmer's fields at Pattambi, the maximum and minimum values being recorded by S_5 and S_7

(Table 1a). Extractable Pb content ranged from 2.1 to 2.9 mg kg^{-1} with a mean of 2.5 mg kg^{-1} (Table 4).

The total and extractable contents of Pb in soil samples collected from farmer's fields of *kari* lands ranged from 15.7 to 25.2 and 3.0 to 6.0 mg kg^{-1} with mean values of 20.7 and 4.6 mg kg^{-1} (Table 7).

It may be noted from Table 5 that the total Pb content in soil samples collected from rice PME plots and farmer's field at Moncompu was in the range of 10.3 to 13.3 mg kg^{-1} with a mean value of 11.9 mg kg^{-1}, the maximum and minimum values being recorded by S_8 and S_2 (Table 1b). Extractable Pb content ranged from 1.8 to 2.4 mg kg^{-1} with a mean of 2.1 mg kg^{-1}.

As revealed from Table 6, the total and extractable Pb content in the soil samples obtained from rice PME plots and farmer's fields at Kayamkulam were in the range of 4.4 to 8.8 and 1.3 to 2.1 mg kg^{-1} with mean values of 6.4 and 1.7 mg kg^{-1}. The maximum and minimum values of 8.8 and 4.4 mg kg^{-1} were recorded by S_1 and S_4 (Table 1c) collected from PME plots receiving cattle manure alone and NK fertilizers as treatments.

Among the upland soils, the total and extractable content of Pb was highest in the fodder plots of sewage farm, Valiyathura which ranged from 17.1 to 29.5 and 2.5 to 6.5 mg kg^{-1} with mean values of 23.6 and 4.0 mg kg^{-1} (Table 10).

The total and extractable Pb content in the vegetable plots of Alapuzha and Pathanamthitta districts followed next and were in the range of 17.5 to 25.1 and 2.0 to 2.8 mg kg^{-1} with mean values of 20.9 and 2.4 mg kg^{-1} (Table 9).

The vegetable plots of Instructional Farm, Vellayani recorded lowest value for the total and extractable Pb content existing in the range of 11.8 to 20.2 and 1.8 to 4.8 mg kg^{-1} with mean values of 15.1 and 2.6 mg kg^{-1} (Table 8).

Cadmium

Cadmium content was highest in the fodder plots of sewage farm, Valiyathura. The total and extractable content of Cd in these soils were in the range of 4.3 to 12.0 and 0.09 to 0.12 mg kg^{-1} with mean valus 8.0 and 0.10 mg kg^{-1} (Table 10). The vegetable plots of Instructional Farm, Vellayani followed with a total content of cadmium ranging from 2.0 to 4.3 mg kg^{-1} with a mean of 3.2 mg kg^{-1} (Table 8). The extractable content of Cd in these soils ranged from 0.07 to 0.12 mg kg^{-1} with a mean of 0.10 mg kg^{-1}. The total and extractable Cd content in the vegetable plots of Alapuzha and Pathanamthitta districts were lower and ranged in content from 1.0 to 4.1 and 0.06 to 0.10 mg kg^{-1} with mean values of 2.0 and 0.08 mg kg^{-1} (Table 9).

Tables 4 to 7 show that among the wetland soils, Cd content was highest in the rice PME plots and farmer's fields at Kayamkulam. The maximum and minimum values of total Cd content were recorded in S_7 and S_8 (Table 1c) collected from PME plots receiving NPK fertilizers and cattle manure as treatment and PME absolute control plots respectively.

The highest and lowest values of 3.6 and 1.7 mg kg^{-1} were recorded in PME plots of Moncompu receiving NPK fertilizers as treatment (S_7) and PME absolute control plots (S_1) (Table 1b).

The highest and lowest content of 2.5 and 2.0 mg kg^{-1} were recorded by S_1 and S_2 (Table 1a), collected from PME plots of Pattambi receiving cattle manure and green leaf as treatments.

It may be seen from Table 7 that the total and extractable content of Cd in soil samples collected from farmer's fields of *kari* lands was lowest and in the range of 1.3 to 2.9 and 0.04 to 0.08 mg kg^{-1} with mean values of 2.0 and 0.06 mg kg^{-1} only.

Generally, the extractable content of heavy metals showed a greater variation than their total content in the samples collected from the same location.

4.1.2. Heavy metal content in fertilizers

Status of heavy metals in selected phosphorus containing fertilizers collected from southern and central districts of Kerala are summarised in Table 11. The results indicated that Zn was the highest contaminant in all fertilizers followed by Pb, Ni, Cd and Cu.

The highest content of 1.4 to 2.9 per cent Zn was present in the samples of Rajphos and ranged from 0.05 to 0.36 per cent in the rest of the samples. Status of Pb and Ni was highest in Mussooriephos with an average value of 598.0 and 95.6 mg kg^{-1}, closely followed by Rajphos which was another type of phosphate rock with an average of 241.0 and 56.5 mg kg^{-1} of Pb and Ni.

All the other samples of water soluble phosphatic fertilizers contained only much lesser amount ranging from the highest value of 140.0 and 29.8 mg kg^{-1} Pb and Ni in single super phosphate (SSP) to the lowest of 7.4 and 6.6 mg kg^{-1} Pb and Ni in Vijay (17-17-17) complex. Next in abundance is Cd, recording 20.4 mg kg^{-1} in SSP closely followed by Factamphos (18.2 mg kg^{-1}), Suphala (15-15-15) complex (17.5 mg kg^{-1}), Mussooriephos (16.6 mg kg^{-1}) and Rajphos (12.8 mg kg^{-1}). The other fertilizer samples were much low in Cd content. Cu was the heavy metal element present in the least amount ranging in value from 1.6 in SSP to 13.9 mg kg^{-1} in Mussooriephos.

Table 11. Status of heavy metals in fertilizers (range and mean values)

Sample No.	Name of fertilizer	No. of samples	Zinc (per cent)	Lead ($mg\ kg^{-1}$)	Nickel ($mg\ kg^{-1}$)	Cadmium ($mg\ kg^{-1}$)	Copper ($mg\ kg^{-1}$)
1	Single super phosphate	10	0.15-0.24 (0.20)	112.0-232.0 (140)	25.2-35.1 (29.8)	16.2-23.9 (20.4)	1.0-2.5 (1.6)
2	Rock phosphates						
	a. Mussooriephos	5	0.05-0.12 (0.08)	189-922 (598)	58.4-154 (95.6)	13.1-20.2 (16.6)	10.2-22.3 (13.9)
	b. Rajphos	5	1.4-2.9 (2.0)	191-312 (241)	32.4-80.7 (56.5)	6.2-19.6 (12.8)	4.8-10.1 (7.0)
3	Complex fertilizers						
	a. Factamphos	10	0.11-0.36 (0.27)	48.1-95.4 (71.1)	9.7-14.5 (11.0)	9.2-25.1 (18.2)	6.4-15.6 (9.6)
	b. Diammonium phosphate	5	0.10-0.15 (0.13)	12.6-28.1 (19.3)	6.5-10.7 (9.0)	7.4-13.3 (9.9)	1.5-3.9 (2.5)
	c. 15-15-15 (Suphala)	5	0.18-0.31 (0.27)	11.7-38.2 (20.6)	4.9-9.9 (7.5)	12.8-25.3 (17.5)	9.1-12.4 (10.8)
	d. 17-17-17 (Vijay complex)	5	0.16-0.21 (0.19)	5.2-8.3 (7.4)	4.2-8.1 (6.6)	4.1-7.3 (5.8)	9.8-13.9 (11.1)

Table 12. Status of heavy metals (mg kg^{-1}) in manures (range and mean values)

Sample No.	Name of manure	No. of samples	Zinc		Copper		Lead		Nickel		Cadmium	
			Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable	Total	Extractable
1	Sewage sludge	5	327-412 (352)	75.3-93.2 (82.3)	108-147 (127)	9.4-15.8 (13.1)	44.4-61.6 (54.4)	1.6-3.4 (2.3)	14.9-20.7 (17.4)	1.7-2.4 (2.1)	6.1-8.8 (7.2)	0.16-0.28 (0.23)
2	Ordinary compost	10	90.2-148 (119)	7.8-10.9 (9.2)	10.8-18.1 (14.0)	0.20-0.30 (0.24)	2.3-4.5 (3.5)	0.4-0.8 (0.6)	7.1-13.4 (11.3)	0.20-0.40 (0.3)	1.8-2.8 (2.3)	0.06-0.09 (0.08)
3	Vermicompost											
	a. Homested waste	5	77.3-98.2 (83.8)	3.4-5.3 (4.2)	10.2-28.3 (14.0)	0.10-0.24 (0.16)	3.5-7.4 (5.3)	0.22-0.40 (0.31)	12.3-16.2 (14.2)	0.32-0.70 (0.49)	2.0-2.5 (2.3)	0.10-0.20 (0.12)
	b. Banana waste	5	144-293 (208)	11.2-18.1 (14.0)	19.3-36.1 (27.5)	1.3-3.0 (2.1)	2.3-3.2 (2.9)	0.13-0.21 (0.19)	6.1-9.2 (7.5)	0.11-0.22 (0.16)	1.1-2.9 (1.8)	0.04-0.08 (0.07)
4	Cowdung from cows fed with sewage fodder	10	79.5-111 (89.0)	1.8-3.0 (2.3)	21.2-43.1 (35.5)	0.40-1.0 (0.8)	2.9-3.4 (3.1)	0.10-0.40 (0.30)	4.6-6.7 (5.5)	0.10-0.30 (0.17)	1.8-3.0 (2.2)	0.04-0.08 (0.06)
5	Cowdung from cows not fed with sewage fodder	10	62.1-96.2 (80.2)	1.4-3.4 (2.2)	20.5-37.2 (26.8)	0.4-0.8 (0.5)	1.6-2.5 (2.1)	0.08-0.20 (0.13)	2.8-4.1 (3.4)	0.11-0.25 (0.15)	1.5-2.0 (1.8)	0.03-0.06 (0.04)

4.1.3. Heavy metal content in manures

The data given in Table 12 summarise the status of heavy metals in some of the common manures largely used in Kerala as organic supplements along with inorganic fertilizers for various crops. It may be seen that as in the case of fertilizers Zn was the most abundant element among the heavy metals studied followed by Cu. Cd was present in the least magnitude in all the organic manures.

It is clearly evident from the results that sewage sludge was loaded with the highest amount of all heavy metals compared to the rest. The mean values of total content of Zn, Cu, Pb, Ni and Cd in sewage sludge were 352.0, 127.0, 54.4, 17.4 and 7.2 mg kg^{-1} respectively.

Variation in the content of heavy metals was evident in vermicompost depending on the materials used for composting. Vermicompost made from house hold waste recorded higher values for all the elements except Zn and Cu compared to vermicompost made from banana crop residues. Appreciable difference between ordinary compost and vermicompost was however not apparent in the content of Pb, Ni and Cd.

The results also revealed that the dung from the cows fed with fodder grass from the sewage farm contained a higher amount of all heavy metals compared to dung from cows not fed on fodder grass from sewage farm.

4.1.4. Heavy metal contents in plants

The content of heavy metals in different plants collected from the same locations of soil sample collection are presented in Tables 13-19. Among the five elements studied Zn was the most abundant element in plants. In all cases, above ground plant parts registered much lower values of all heavy metals compared to roots.

Rice

In rice samples collected from the PME and farmer's fields at Pattambi (Table 13), Zn content was in the range of 16.0 to 22.0 mg kg^{-1} in grains, 33.0 to 45.8 mg kg^{-1} in straw and in root it was in the range of 58.8 to 75.0 mg kg^{-1}. Cu content in grains, straw and root was in the range of 10.0 to 20.5, 13.5 to 21.3 and 22.0 to 45.0 mg kg^{-1}. Content of Pb was in the range of 6.5 to 11.0 mg kg^{-1} in grain, 8.0 to 15.3 mg kg^{-1} in straw and 16.0 to 28.5 mg kg^{-1} in roots. Ni content in grain, straw and root was in the range 0.5 to 3.5, 1.0 to 6.8 and 2.0 to 9.5 mg kg^{-1}. Content of Cd ranged from 2.0 to 3.5 mg kg^{-1} in grain, 3.3 to 5.3 mg kg^{-1} in straw and 4.0 to 6.5 mg kg^{-1} in root.

As seen from Table 14, in rice samples collected from PME and farmer's field at Moncompu, Zn content was in the range of 9.5 to 16.5 mg kg^{-1} in grains, 8.8 to 22.5 mg kg^{-1} in straw and 15.0 to 25.8 mg kg^{-1} in roots. Cu content in grain, straw and root ranged from 6.0 to 13.8, 8.5 to 14.5 and 9.8 to 24.5 mg kg^{-1}. Content of Pb in grain straw and root was in the ranges of 2.5 to 7.5, 4.5 to 8.0 and 3.5 to 8.8 mg kg^{-1}. Ni content was in the range of 2.5 to 4.5 mg kg^{-1} in grains, 2.5 to 5.0 mg kg^{-1} in straw and 10.5 to 17.8 mg kg^{-1} in roots. Content of Cd in grain, straw and root was in the ranges of 1.0 to 1.5, 2.3 to 2.8 and 3.5 to 5.5 mg kg^{-1}.

In samples of grain, straw and root of rice collected from PME and farmer's fields at Kayamkulam, Zn content ranged from 8.0 to 14.3, 10.0 to

Table 13. Content of heavy metals (mg kg^{-1}) in different plant parts of rice - Pattambi

Sample No.	Zinc			Copper			Lead			Nickel			Cadmium		
	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root
1	16.5	39.5	75.0	17.5	21.3	23.5	7.0	8.3	16.5	0.5	1.0	2.0	3.0	4.0	5.8
2	17.0	38.5	67.3	13.0	18.5	22.0	8.5	10.5	20.3	1.5	3.0	7.3	2.0	3.3	4.0
3	16.5	38.5	66.0	10.0	18.0	30.5	11.0	15.3	28.5	3.0	5.3	8.5	3.3	4.5	6.3
4	16.0	33.0	70.0	11.3	14.5	34.0	8.3	9.0	19.5	1.3	1.8	3.0	2.8	4.0	6.0
5	16.0	42.5	63.8	20.5	16.5	38.8	8.0	9.0	19.0	2.0	3.5	7.8	2.0	3.3	4.5
6	16.5	45.8	58.8	16.0	13.5	45.0	7.5	8.5	16.8	3.0	5.0	8.3	3.5	5.0	6.5
7	17.0	42.5	61.5	14.3	19.3	28.5	6.5	8.0	16.0	3.5	6.8	9.5	3.0	4.5	6.0
8	22.0	34.3	70.5	11.5	18.0	35.3	10.8	15.0	25.8	2.3	3.3	7.5	3.5	5.3	6.5
9	20.3	43.0	64.8	12.3	19.3	29.8	7.8	9.0	18.8	2.5	4.0	8.0	2.5	4.3	5.3
10	19.8	40.8	66.5	19.0	20.8	30.5	7.5	8.8	20.5	2.3	4.5	8.0	2.0	3.8	5.0
Mean	17.8	39.8	66.4	14.5	18.0	31.8	8.3	10.1	20.2	2.2	3.8	7.0	2.8	4.2	5.6
C.V(%)	11.4	9.5	6.7	23.2	13.3	20.5	17.1	25.5	19.0	39.0	42.2	33.3	20.8	14.9	14.6

Table 14. Content of heavy metals (mg kg^{-1}) in different plant parts of rice - Moncompu

Sample No.	Zinc			Copper			Lead			Nickel			Cadmium		
	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root
1	9.5	10.3	15.8	6.0	8.5	9.8	2.5	4.5	3.5	2.5	2.5	10.5	1.0	2.3	3.5
2	11.0	10.5	20.0	6.5	9.5	12.0	3.0	4.5	4.8	3.5	3.5	12.3	1.5	2.5	3.8
3	9.8	17.5	19.3	6.0	8.5	10.3	4.5	4.5	6.5	3.5	3.3	14.5	1.3	2.3	3.5
4	9.5	8.8	15.0	9.5	12.0	21.3	5.8	5.5	7.5	4.0	3.8	14.0	1.5	2.8	5.5
5	14.0	21.0	24.3	6.5	8.5	10.5	6.5	7.5	8.0	3.8	4.3	17.8	1..2	2.5	4.5
6	12.8	17.5	20.8	9.0	10.8	13.0	7.5	7.5	8.0	3.5	4.0	15.8	1.5	2.8	5.0
7	13.5	20.8	21.0	12.0	14.0	22.8	7.3	8.0	8.8	4.0	4.5	16.5	1.5	2.8	5.0
8	16.5	22.5	25.8	13.8	14.5	24.0	3.5	5.0	7.8	4.0	5.0	17.8	1.0	2.3	3.8
9	15.5	22.3	24.5	12.5	14.0	24.5	3.3	4.8	5.5	4.5	4.8	16.8	1.2	2.3	3.8
10	12.8	16.5	18.3	6.8	9.0	11.3	5.0	5.5	7.8	3.8	4.0	16.5	1.3	2.8	5.0
Mean	12.2	16.8	20.5	8.9	10.9	16.0	4.9	5.7	6.8	3.7	4.0	15.3	1.3	2.5	4.3
C.V(%)	20.5	29.4	16.8	31.9	21.7	37.6	35.4	23.1	23.7	13.4	17.8	15.0	14.6	14.6	21.1

15.0 and 10.5 to 23.8 mg kg^{-1} respectively. Cu content was in the range of 5.3 to 17.8 mg kg^{-1} in grain, 5.8 to 19.0 mg kg^{-1} in straw and 10.3 to 32.5 mg kg^{-1} in roots. Content of Pb in grain, straw and root was in the range of 1.5 to 4.0, 2.0 to 7.8 and 4.5 to 11.8 mg kg^{-1}. Ni content ranged from 1.0 to 2.8 mg kg^{-1} in grain, 2.0 to 3.0 mg kg^{-1} in straw and 2.5 to 6.8 mg kg^{-1} in root. Content of Cd ranged from 1.8 to 3.0, 2.0 to 6.0 and 2.0 to 8.3 mg kg^{-1} in grain, straw and root respectively (Table 15).

The data presented in Table 16 indicate the content of heavy metals in rice samples collected from *kari* lands. Zn content in grain, straw and root was in the range of 10.0 to 14.0, 11.0 to 15.0 and 13.5 to 18.3 mg kg^{-1}. Cu content was in the range of 4.0 to 7.0 mg kg^{-1} in grain, 5.0 to 8.5 mg kg^{-1} in straw and 8.5 to 13.8 mg kg^{-1} in root. Content of Pb in grain, straw and root was in the ranges of 5.0 to 8.5, 6.0 to 10.5 and 9.0 to 12.0 mg kg^{-1}. Ni content ranged from 1.5 to 2.5 mg kg^{-1} in grain, 2.0 to 4.5 mg kg^{-1} in straw and 2.5 to 4.0 mg kg^{-1} in root. Content of Cd in grain, straw and root was in the range of 1.5 to 2.0, 2.5 to 3.5 and 3.0 to 4.0 mg kg^{-1}.

Variation in the content of heavy metals in rice plants was much less compared to their content in corresponding soils.

Amaranthus

Range and mean values of Zn, Cu, Ni, Pb and Cd content in the top and in the root of amaranthus collected from the districts of Alapuzha and Pathanamthitta and Instructional Farm, Vellayani are given in Table 17. Highest content of all heavy metals was noted in the samples collected from Pathanamthitta district. With the exception of Zn, content of all other heavy metals was more in the root than in the top of amaranthus.

Table 15. Content of heavy metals (mg kg^{-1}) in different plant parts of rice - Kayamkulam

Sample No.	Zinc			Copper			Lead			Nickel			Cadmium		
	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root
1	14.0	14.8	16.8	5.8	7.0	10.3	2.5	2.5	4.5	1.2	2.0	2.5	2.0	4.0	5.5
2	11.3	13.0	15.0	8.3	12.5	22.8	3.0	6.5	9.3	1.5	2.0	3.0	2.0	4.3	5.5
3	7.5	10.0	21.5	9.0	9.5	23.5	3.5	7.0	9.0	2.5	2.5	6.0	2.8	5.5	6.3
4	9.0	11.5	13.5	5.3	6.5	12.0	3.0	6.0	11.8	1.5	2.2	3.0	2.3	4.8	5.5
5	8.3	12.8	23.8	11.0	12.5	22.5	3.5	7.3	11.0	2.5	2.8	5.8	2.8	5.5	6.0
6	13.0	13.5	15.0	10.5	14.0	19.3	4.0	7.8	10.5	2.8	3.0	6.8	3.0	6.0	8.3
7	14.3	15.0	18.5	14.3	5.8	32.5	3.5	7.5	9.8	2.3	2.0	3.0	2.5	4.8	5.5
8	8.0	10.00	10.5	17.8	19.0	26.8	1.5	2.0	4.5	1.0	2.3	2.5	1.8	2.0	2.0
9	13.3	14.3	15.0	11.0	18.5	20.0	3.0	5.8	8.8	2.8	3.0	6.0	2.0	4.3	6.0
10	12.8	12.9	19.8	10.5	16.0	19.5	3.0	6.0	9.0	2.8	2.8	6.3	2.0	4.5	5.5
Mean	11.2	12.8	16.9	10.4	12.1	20.9	3.1	5.8	8.8	2.1	2.4	4.5	2.3	4.6	5.6
C.V(%)	22.8	13.3	22.3	34.1	37.9	29.4	21.3	32.7	26.6	32.3	16.8	38.2	17.4	22.9	25.9

Table 16. Content of heavy metals (mg kg^{-1}) in different plant parts of rice - *kari* land

Sample No.	Zinc			Copper			Lead			Nickel			Cadmium		
	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root	Grain	Straw	Root
1	10.5	11.5	13.5	4.5	5.0	8.5	5.5	6.0	9.3	1.5	2.0	3.0	1.5	3.0	4.0
2	12.3	11.0	15.8	4.3	5.0	10.5	5.0	5.8	9.0	1.5	2.0	2.5	1.5	3.0	4.0
3	12.5	12.0	15.0	5.0	7.3	12.0	5.8	7.5	9.5	1.5	2.5	2.5	1.5	3.0	3.0
4	13.0	13.5	16.5	5.5	8.0	13.5	5.8	7.5	9.8	2.0	3.0	4.0	1.8	2.5	4.0
5	13.0	14.5	18.0	5.3	7.5	12.8	6.0	7.0	10.0	2.0	3.5	4.0	2.0	2.5	3.5
6	13.0	15.0	18.0	5.5	8.0	13.5	7.0	7.5	10.8	2.5	3.5	3.5	2.0	3.0	3.0
7	14.0	15.0	18.3	7.0	8.5	13.0	5.0	6.8	9.0	2.0	4.0	3.0	1.5	2.8	4.0
8	10.0	11.5	13.5	4.5	5.8	11.0	8.5	10.3	11.5	2.5	4.5	3.5	1.5	2.8	4.0
9	13.5	11.3	14.8	4.0	5.0	10.5	8.5	10.3	12.0	2.5	4.5	3.5	1.8	3.5	3.5
10	13.3	13.0	16.0	5.8	7.5	13.8	8.0	10.5	11.8	2.3	4.5	4.0	2.0	3.5	3.5
Mean	12.5	12.8	15.9	5.1	6.8	11.9	7.3	7.1	10.3	2.0	3.4	3.4	1.7	2.9	2.7
C.V(%)	9.8	11.7	10.6	16.3	19.7	13.8	12.1	30.8	10.8	19.6	27.7	16.4	12.9	14.5	14.7

Table 17. Content of heavy metals (mg kg^{-1}) in different plant parts of amaranthus in different locations (range and mean values)

Location	No. of samples	Plant part	Zinc	Copper	Lead	Nickel	Cadmium
Alappuzha district	5	Top	31.0-56.0 (45.4)	1.5-2.5 (2.0)	1.0-1.8 (1.3)	2.0-5.0 (3.6)	0.5-1.5 (0.9)
	5	Root	18.0-30.0 (25.7)	2.5-6.0 (3.9)	1.5-3.3 (2.4)	2.3-5.5 (4.5)	2.0-2.5 (2.2)
Pathanamthitta district	5	Top	63.0-90.5 (71.3)	2.5-4.0 (3.2)	1.5-5.3 (3.4)	2.8-5.5 (3.4)	0.8-1.8 (1.1)
	5	Root	30.0-44.0 (37.6)	3.5-6.0 (4.6)	3.5-6.0 (5.0)	3.0-5.8 (4.7)	2.0-2.8 (2.4)
Vellayani Instructional Farm	5	Top	16.0-22.0 (19.4)	1.0-1.8 (1.4)	1.0-2.0 (1.2)	0.8-1.5 (1.2)	0.3-1.0 (0.6)
	5	Root	9.8-14.0 (10.9)	1.5-2.5 (1.8)	1.8-2.5 (2.1)	1.0-1.5 (1.3)	1.0-1.5 (1.4)

Zn content was in the range of 16.0 to 90.5 mg kg^{-1} in the top and 9.8 to 44.0 mg kg^{-1} in the root. Content of Cu in the top and in the root was in the range of 1.0 to 4.0 and 1.5 to 6.0 mg kg^{-1} respectively. Ni content ranged from 0.8 to 5.5 mg kg^{-1} in the top and 1.0 to 5.8 mg kg^{-1} in the root. Content of Pb in top and in root was in the range 1.0 to 5.3 and 1.8 to 6.0 mg kg^{-1}. Cd content varied from 0.3 to 1.8 mg kg^{-1} in the top and 1.0 to 2.8 mg kg^{-1} in root.

Cowpea

Range and mean values of Zn, Cu, Pb, Ni and Cd content in the pod, vine and root of cowpea collected from the vegetable plots of Alapuzha and Pathanamthitta districts and Instructional Farm, Vellayani are presented in Table 18. Among the three locations, samples collected from Pathanamthitta district recorded the highest content of Zn, Cu and Ni in all plant parts while for Pb and Cd highest values were noted in samples collected from Instructional Farm, Vellayani. In all cases, a higher accumulation of all heavy metals was noted in the root.

Zn content in pod, vine and root varied from 10.5 to 67.0, 14.5 to 325.0 and 25.0 to 351.0 mg kg^{-1}. Content of Cu was in the range of 2.0 to 15.5 mg kg^{-1} in pod, 4.0 to 15.5 mg kg^{-1} in vine and 5.0 to 17.5 mg kg^{-1} in root. Content of Pb in pod, vine and root ranged from 2.0 to 3.0, 3.5 to 6.5 and 3.0 to 10.5 mg kg^{-1}. Ni content was in the range of 1.0 to 2.5 mg kg^{-1} in pod, 0.5 to 2.5 mg kg^{-1} in vine and 2.0 to 3.5 mg kg^{-1} in root. Cd content in vine and root varied from 1.0 to 2.3 and 1.2 to 2.5 mg kg^{-1} which was more than that in the edible pods. The Cd content in pod ranged only from 0.3 to 1.8 mg kg^{-1}.

Table 18. Content of heavy metals (mg kg^{-1}) in different plant parts of cowpea in different locations (range and mean values)

Location	No. of samples	Plant part	Zinc	Copper	Lead	Nickel	Cadmium
Alappuzha district	5	Pods	43-62 (53)	2.3-5.5 (3.8)	2.0-2.5 (2.3)	1.0-2.0 (1.6)	0.7-1.2 (0.9)
	5	Vines	108-190 (152.8)	4.8-8.3 (6.4)	3.5-5.5 (4.2)	0.5-1.5 (0.9)	1.0-1.6 (1.3)
	5	Roots	143-230 (152.8)	5.8-14.3 (6.4)	3.0-7.0 (4.2)	2.0-3.0 (0.9)	1.5-2.0 (1.3)
Pathanamthitta district	5	Pods	50-67 (54.6)	9.6-15.5 (12.4)	2.0-3.0 (2.4)	1.5-2.5 (1.9)	0.3-0-0.8 (0.6)
	5	Vines	153-325 (251.6)	10.0-15.5 (13.0)	4.0-6.0 (5.4)	1.0-2.5 (1.8)	1.0-2.0 (1.4)
	5	Roots	280-351 (316.6)	8.0-17.5 (13.4)	5.0-6.5 (6.0)	2.5-3.5 (2.9)	1.2-2.0 (1.6)
Vellayani Instructional Farm	5	Pods	10.5-30.0 (18.3)	2.0-2.5 (2.3)	2.0-3.0 (2.6)	1.0-1.5 (1.3)	0.8-1.8 (1.0)
	5	Vines	14.5-34.0 (21.7)	4.0-8.0 (4.4)	5.0-6.5 (5.7)	0.8-1.5 (1.2)	1.0-2.3 (1.9)
	5	Roots	25-32 (28.0)	5.0-8.0 (6.8)	8.0-10.5 (9.2)	2.0-3.0 (2.6)	1.5-2.5 (2.0)

Table 19. Content of heavy metals in different plant parts of fodder in sewage farm, Valiyathura (range and mean values)

Fodder	No. of samples	Plant part	Zinc (per cent)	Copper ($mg\ kg^{-1}$)	Nickel ($mg\ kg^{-1}$)	Lead ($mg\ kg^{-1}$)	Cadmium ($mg\ kg^{-1}$)
Guniea grass	4	Top	0.034-0.046 (0.040)	13.2-17.6 (14.6)	1.0-3.0 (2.3)	0.5-2.5 (1.4)	0.4-1.5 (1.1)
	4	Root	0.048-0.081 (0.067)	5.5-9.5 (7.8)	4.0-7.5 (5.9)	2.5-3.3 (2.9)	2.2-3.5 (3.0)
Napier grass	4	Top	0.038-0.050 (0.043)	12.0-19.6 (16.9)	1.5-3.4 (2.8)	1.5-2.0 (1.8)	0.3-1.8 (1.1)
	4	Root	0.048-0.065 (0.058)	9.5-11.5 (10.4)	5.3-6.5 (6.1)	3.3-5.5 (4.5)	2.0-3.5 (2.6)
Para grass	4	Top	0.068-0.090 (0.080)	8.3-14.5 (11.9)	1.0-3.0 (2.3)	1.8-3.0 (2.5)	0.3-1.0 (0.7)
	4	Root	0.071-0.095 (0.086)	23.3-45.0 (34.4)	2.5-4.5 (3.9)	3.5-6.0 (4.9)	2.0-3.0 (2.3)
Subabool	4	Top	0.031-0.046 (0.035)	8.5-18.8 (13.3)	2.8-4.0 (3.5)	2.0-3.3 (2.8)	1.0-2.3 (1.5)
	4	Root	0.038-0.045 (0.042)	29.0-40.5 (32.5)	3.5-6.5 (5.5)	4.2-6.8 (5.9)	2.5-4.0 (3.1)

Fodder

Range and mean values of the heavy metal content in the top and root of four types of fodder cultivated in the sewage farm, Valiyathura in Thiruvananthapuram are presented in Table 19. A greater accumulation of all heavy metals was noted in the roots except in the case of copper in guniea and napier grasses.

Zinc content was highest in paragrass with a mean value of 0.080 per cent in the top and 0.086 per cent in the root. Highest mean copper content of 16.9 mg kg^{-1} in the top was recorded by napier grass and in the root, highest copper content of 34.4 mg kg^{-1} was noted in para grass. Highest mean nickel content of 3.5 and 6.1 mg kg^{-1} was noted in subabool top and napier root respectively. Highest content of lead and cadmium in both top (2.8 and 1.5 mg kg^{-1}) and root (5.9 and 3.1 mg kg^{-1}) was observed in subabool.

4.2. Retention of applied Cd and Ni in soils

The pattern of retention and extractability of applied Cd and Ni with and without FYM in undistrubed soil columns of selected upland and wetland soil types of Kerala are presented in Tables 20 to 27. Basic physico-chemical soil properties influencing the retention and extractability of Cd and Ni in the soils used for the study are given in Table 2.

4.2.1. Cadmium

Retention of applied Cd in soil layers during downward movement in upland soils showed a regular gradation with depth, a greater proportion being retained in the upper layers and it was invariably higher in soils treated with FYM. It

Table 20. Depthwise distribution of total cadmium in upland soils as influenced by applied Cd and FYM (mg kg^{-1})

Depth of soil Column(cm)	Sandy *Onattukara*			Laterite soil			Red soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	5.3	18.4 (27.8)	13.9 (17.8)	6.8	36.4 (55.8)	27.2 (38.5)	2.8	27.6 (40.7)	16.7 (22.8)
20	5.0	19.2 (31.6)	14.5 (21.0)	6.5	22.5 (30.2)	17.3 (20.4)	2.2	17.9 (25.7)	17.4 (24.9)
30	4.5	11.7 (16.0)	17.5 (28.3)	6.1	9.6 (6.6)	13.4 (13.8)	1.9	8.9 (11.5)	17.0 (24.8)
40	3.0	9.5 (13.3)	12.4 (20.9)	3.5	4.3 (1.5)	10.5 (13.2)	1.8	8.2 (10.5)	12.9 (18.2)
50	3.0	5.8 (6.2)	6.3 (7.3)	3.4	6.1 (5.1)	9.2 (5.8)	1.9	7.0 (10.0)	6.7 (7.9)
Cadmium added (mg per column)	—	45.0	46.0	—	53.0	53.0	—	61.0	61.0

(Percentage retention of applied cadmium is given in brackets) may be seen from Table 20 that the retention of applied Cd in sandy Onattukara soils was 27.8 and 6.2 per cent in the top 10 cm and bottom 10 cm layers of the soil column mixed with FYM and 17.8 and 7.3 per cent Cd was retained in the top and bottom layers of soil column not mixed with FYM.

In laterite soil, retention of applied Cd in the top and bottom layers was 55.8 and 5.1 per cent in the soil column treated with FYM. It was 38.5 to 5.8 per cent in the soil column not treated with FYM. Percentage of applied Cd retained in the top and bottom layers of red soil varied from 40.7 to 10.0 in the column mixed with FYM and 22.8 to 7.9 in the column not mixed with FYM.

Data given in Table 21 revealed that the pattern of depthwise retention of applied Cd in the columns of wetland soils was also the same as that in upland soils. In all the wetland soils studied, a greater proportion of applied Cd was retained in the upper 30 cm soil layers and it was higher in soil columns mixed with FYM than without FYM. In lateritic alluvium, retention of applied Cd varied from 43.4 to 6.6. per cent in the top and bottom layers of soil column mixed with FYM and 35.7 to 8.8 per cent in the corresponding layers not mixed with FYM.

Retention of applied Cd in the top and bottom layers of columns of *kari* soil varied from 49.7 to 3.0 per cent in the presence of FYM and 36.5 to 4.4 per cent in its absence. In the columns of *kayal* soil mixed with and without FYM, retention of applied Cd in the top and bottom layers varied from 36.5 to 6.0 per cent and 24.7 to 6.7 per cent respectively.

Among the wetland soils, leaching loss of applied Cd was found to be lowest in lateritic alluvium. It was 14.7 per cent in the column treated with

Table 21. Depthwise distribution of total cadmium in wetland soils as influenced by applied Cd and FYM (mg kg^{-1})

Depth of soil Column(cm)	Lateritic alluvium			*kari* soil			*kayal* soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	4.3	27.3 (43.4)	22.5 (35.7)	2.2	33.5 (49.7)	24.8 (36.5)	3.5	28.3 (36.5)	18.3 (24.7)
20	2.0	10.5 (16.0)	9.6 (14.3)	2.0	7.6 (8.9)	4.8 (4.5)	3.2	17.6 (21.2)	13.9 (17.8)
30	1.6	7.2 (10.6)	7.5 (11.6)	1.5	3.8 (3.7)	6.3 (7.7)	1.5	7.5 (8.8)	6.7 (8.7)
40	1.8	5.3 (7.2)	6.8 (9.8)	1.5	5.0 (5.4)	6.9 (8.5)	1.2	6.3 (7.5)	4.6 (5.7)
50	1.5	5.0 (6.6)	6.0 (8.8)	0.6	2.5 (3.0)	3.3 (4.4)	1.0	5.1 (6.0)	5.0 (6.7)
Leachate	—	7.8 (14.7)	8.4 (16.5)	—	17.7 (28.1)	22.6 (36.5)	—	16.4 (24.1)	20.2 (33.7)
Cd added (mg per column)	—	53.0	51.0	—	63.0	62.0	—	68.0	60.0

(Percentage of applied cadmium retained and leached are given in brackets)

FYM and 16.5 per cent in the column without FYM. In the column of *kayal* and *kari* soils, leaching loss was 24.1 and 28.1 per cent in the presence of applied FYM and 33.7 and 36.5 per cent in the absence of applied FYM.

Extractable portions of applied Cd in different layers of the upland soil columns are presented in Table 22. Among the three upland soil types, highest concentration of DTPA extractable Cd was recorded by laterite soil. Extractable Cd content in the top layer of all the upland soils was found to be higher in the columns mixed with FYM than in the columns not mixed with FYM.

Extractable portions of applied Cd in the wetland soil columns are given in Table 23. It was more in the columns mixed with FYM than in the columns not mixed with FYM in all wetland soils. Highest concentration of extractable Cd in the presence of applied FYM was recorded by lateritic alluvial soil. In the absence of applied FYM, highest concentration of extractable Cd was recorded by *kayal* soil.

4.2.2. Nickel

The pattern of retention of Ni in upland soils (Table 24) unlike Cd showed only a slight gradation in content from the top to bottom layers of the soil column at the end of 30 days. Ni content in the top and bottom layers of soil columns of sandy Onattukara varied from 23.8 to 17.8 per cent in the presence of FYM and 21.0 to 17.8 per cent without FYM. In the laterite and red soils, the pattern of retention was more or less same both in the presence and absence of applied FYM.

Table 22. Depthwise distribution of DTPA extractable cadmium in upland soils as influenced by applied Cd and FYM (mg kg^{-1})

Depth of soil Column(cm)	Sandy *Onattukara*			Laterite soil			Red soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	0.10	0.57	0.29	0.15	13.87	10.04	0.12	11.04	0.24
20	0.00	0.48	0.34	0.06	4.74	12.83	0.05	5.35	0.14
30	0.04	0.14	0.22	0.06	0.98	6.42	0.02	1.29	3.17
40	0.02	0.24	1.86	0.04	0.15	2.23	0.00	1.48	3.05
50	0.03	0.55	1.40	0.00	3.17	1.27	0.01	2.97	4.24

Table 23. Depthwise distribution of DTPA extractable cadmium in wetland soils as influenced by applied Cd and FYM (mg kg^{-1})

Depth of soil Column (cm)	Lateritic alluvium			*kari* soil			*kayal* soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	0.11	6.04	0.16	0.06	4.9	3.60	0.15	4.20	3.11
20	0.04	1.58	0.60	0.02	0.24	0.22	0.06	0.62	0.38
30	0.02	1.72	0.58	0.00	0.00	0.08	0.04	0.60	0.40
40	0.00	0.90	0.12	0.00	0.02	0.20	0.00	0.07	0.52
50	0.00	0.34	0.08	0.00	0.14	0.30	0.00	0.62	0.64

Table 24. Depthwise distribution of total nickel in upland soils as influenced by applied Ni and FYM (mg kg^{-1})

Depth of soil Column(cm)	Sandy *Onattukara*			Laterite soil			Red soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	23.2	130.2 (23.8)	119.6 (21.0)	43.6	183.8 (26.5)	152.4 (20.5)	16.8	178.3 (26.5)	102.5 (14.0)
20	24.5	128.5 (23.1)	118.7 (20.5)	43.2	147.2 (19.6)	143.8 (19.0)	16.5	97.5 (13.3)	108.2 (15.0)
30	25.2	90.8 (15.6)	128.1 (22.4)	48.7	154.3 (19.9)	144.5 (18.1)	17.1	116.4 (16.3)	120.0 (16.9)
40	20.6	112.4 (19.4)	103.4 (18.0)	40.5	127.5 (16.4)	147.1 (20.1)	18.3	149.6 (21.5)	183.5 (27.1)
50	17.2	97.5 (17.8)	99.0 (17.8)	40.1	136.9 (18.3)	158.0 (22.2)	20.3	160.3 (23.0)	186.8 (27.3)
Nickel added (mg per column)	—	450	460	—	530	530	—	610	610

(percentage retention of applied nickel is given in brackets)

Data given in Table 25 reveal the amount of applied Ni retained at different depths of wetland soil columns and that lost through leaching. In the wetland soils gradation in retention of applied Ni with depth was more prominent in the soil columns treated with FYM than without FYM. Ni content varied from 24.1 to 6. 9 and 19.7 to 7.7 per cent of applied Ni in the top to bottom layers of the soil columns of lateritic alluvium with and without FYM. In *kari* soil, retention of applied Ni in the top and bottom layers of the soil column was 27.9 and 10.6 per cent in the presence of FYM and 20.9 and 12.4 per cent in the absence of FYM. Retention of Ni on the top and bottom layers of *kayal* soil columns varied from 27.6 to 11.2 per cent with FYM and 24.9 to 11.2 without FYM.

As seen from Table 25, among the wetland soils, leaching loss was highest in the soil columns of lateritic alluvium both in the presence and absence of FYM. Leaching loss of Ni did not show much variation between soil columns treated with and without FYM in the case of *kari* and *kayal* soils. However, in lateritic alluvium, leaching loss of applied Ni was markedly higher when the soil column was not mixed with FYM than when it was mixed with FYM. Loss of applied Ni through leaching was 20.6 and 23.7 per cent in soil columns of lateritic alluvium mixed with and without FYM. In *kari* soil, loss of applied Ni through leaching was 20.5 per cent in the column treated with FYM and 21.4 per cent in the column not mixed with FYM. Leaching loss accounted for 18.4 and 19.0 per cent of Ni in the columns of *kayal* soil with and without FYM.

Tables 26 and 27 reveal the extractable portions of applied Ni at different depths of upland and wetland soil columns mixed with and without FYM. As seen from Table 26, among the upland soils, highest concentration of extractable Ni

Table 25. Depthwise distribution of total nickel in wetland soils as influenced by applied Ni and FYM (mg kg^{-1})

Depth of soil Column(cm)	Lateritic alluvium			*kari* soil			*kayal* soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	50.3	178.0 (24.1)	150.6 (19.7)	26.9	202.4 (27.9)	156.5 (20.9)	38.0	225.8 (27.6)	187.6 (24.9)
20	51.7	169.4 (22.2)	152.5 (19.8)	27.1	135.6 (17.2)	129.0 (16.4)	35.3	161.2 (18.5)	142.3 (17.8)
30	51.2	130.8 (15.0)	145.3 (18.5)	22.3	108.5 (13.7)	112.8 (14.6)	40.1	130.6 (13.3)	130.5 (15.1)
40	48.6	95.3 (8.8)	96.6 (9.4)	18.5	76.0 (9.1)	99.3 (13.0)	39.6	112.4 (10.7)	115.6 (12.7)
50	45.5	82.3 (6.9)	85.0 (7.7)	20.8	87.3 (10.6)	97.6 (12.4)	40.5	116.8 (11.2)	108.1 (11.2)
Leachate	0.12	109.5 (20.6)	120.8 (23.7)	0.10	129.2 (20.5)	132.5 (21.4)	0.08	125.5 (18.4)	114.0 (19.0)
Nicke added (mg per column)	—	530	510	—	630	620	—	680	600

(Percentage of applied nickel retained and leached are given in brackets)

Table 26. Depthwise distribution of DTPA extractable nickel in upland soils as influenced by applied Ni and FYM (mg kg^{-1})

Depth of soil Column (cm)	Sandy *Onattukara*			Laterite soil			Red soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	0.45	25.8	15.8	1.3	36.4	30.5	0.10	14.2	7.2
20	0.45	18.6	8.1	1.3	31.5	33.1	0.10	9.4	7.6
30	0.50	19.8	10.5	1.3	10.9	22.3	0.11	10.1	13.9
40	0.38	10.1	23.0	0.9	6.3	17.8	0.12	12.8	20.0
50	0.26	11.8	24.2	1.1	10.4	16.0	0.11	10.6	23.1

Table 27. Depthwise distribution of DTPA extractable nickel in wetland soils as influenced by applied Ni and FYM (mg kg^{-1})

Depth of soil Column (cm)	Lateritic alluvium			*lari* soil			*kayal* soil		
	Control	With FYM	No FYM	Control	With FYM	No FYM	Control	With FYM	No FYM
10	0.48	25.5	14.3	0.59	19.5	13.2	0.75	13.3	12.4
20	0.50	20.8	13.5	0.56	6.0	5.8	0.74	10.1	9.5
30	0.41	12.0	10.4	0.25	5.4	2.5	0.92	10.5	9.8
40	0.38	10.6	11.6	0.14	3.9	8.1	0.81	11.0	10.8
50	0.25	4.2	3.9	0.25	4.8	9.3	0.79	12.8	11.6

was noted in laterite soil both in the presence and absence of FYM. Top layers of the column recorded higher values of extractable Ni than the bottom layers in laterite soil both in the presence and absence of applied FYM. In the columns of sandy *Onattukara* and red soils, top layers recorded higher concentrations of extractable Ni than the bottom layers in the presence of FYM and reverse was the case in the absence of FYM.

It may be seen from Table 27 that extractable Ni content in the wetland soil columns was more in the presence of FYM than without FYM. Among the wetland soils, extractable Ni was highest in the columns of lateritic alluvium both in the presence and absence of FYM. Gradation in extractable Ni with depth was also clearly evident in lateritic alluvium. No regular pattern was observed in the extractable nickel content in different segments of the columns of *kari* and *kayal* soils.

4.3. Influence of applied Cd and Ni on the growth and yield of plants

Results of the pot culture experiments conducted to study the effect of applied Cd and Ni on growth, yield, nutrient composition, quality and accumulation in different plant parts of rice, sesame and cowpea are presented in Tables 28 to 72. Influence of applied Cd and Ni at three levels with and without FYM are compared with POP treatments with and without FYM.

4.3.1.1. Influence of Cd on rice

Biometric and growth characters

Among the biometric characters (Table 28), plant height and total number of tillers per hill showed no significant reduction at any level of Cd.

Table 28. Biometric and growth characters of rice under varying levels of Cd

Treatments	Plant height (cm)	Total tillers $hill^{-1}$	Straw ($g\ pot^{-1}$)	Root ($g\ pot^{-1}$)	Days to flowering	Days to harvesting	Total dry matter ($g\ pot^{-1}$)
T_0	64.3	3.3	60.7	5.7	79.3	110	85.7
T_1	72.0	5.3	94.5	25.5	82.0	112	159.4
T_2	72.7	6.3	100.5	30.4	80.3	110	162.7
T_3	65.7	4.7	75.3	12.8	82.3	110	111.6
T_4	64.0	5.3	74.6	12.7	79.3	110	107.7
T_5	65.3	5.0	72.3	12.2	78.0	104	103.2
T_6	65.0	4.7	86.5	22.9	80.7	110	134.1
T_7	65.3	4.7	86.3	18.6	81.0	110	128.3
T_8	65.0	5.0	76.2	14.5	78.7	104	111.1
CD	—	—	17.22	5.33	2.29	0.66	24.8
SE	2.14	0.63	5.71	1.77	0.76	0.22	8.23

Significant reduction was noted in straw and root dry weight and total dry matter at all levels of Cd both in the presence and absence of FYM.

Days to flowering and harvesting were reduced significantly at the highest level of Cd in the presence of FYM. In the absence of FYM, days to flowering showed no significant variation, while days to harvesting was reduced significantly at the highest level of Cd.

An interesting observation was the profuse algal growth observed in the Cd treated pots.

Yield and yield attributes (Table 29)

Number of panicles per hill was highest (5.3) in the treatment as per POP (T_1) and it was reduced significantly when Cd was applied along with it at three levels (T_3, T_4 and T_5). In the POP treatment without FYM (T_2), number of panicles per hill was significantly lower than T_1 (4.0). However when Cd was applied along with T_2 at three levels (T_6, T_7 and T_8), further reduction was not significant.

Other yield components like panicle length, spikelets per panicle, total number of grains per panicle, filled grains per panicle and chaff percentage were not affected by Cd treatment. But hundred grain weight was reduced significantly at all levels of Cd in the presence and absence of FYM.

Grain yield was significantly affected due to the effects of various treatments. Absence of FYM significantly reduced grain yield. It was reduced from 39.4 in T_1 to 31.8 g pot^{-1} in T_2. Reduction was significant even at the

Table 29. Yield and yield attributes of rice

Treatments	Number of panicles hill^{-1}	Panicle length (cm)	Spikelets panicle^{-1}	Total grains panicle^{-1}	Filled grains panicle^{-1}	Grain yield (g pot^{-1})	Chaff (per cent)	100 grain weight (g)
T_0	2.7	19.8	9.3	111.7	79.0	19.3	28.8	3.01
T_1	5.3	19.8	9.1	134.8	85.0	39.4	22.4	3.02
T_2	4.0	18.8	8.7	101.7	69.7	31.8	31.5	2.95
T_3	3.3	19.4	9.1	109.3	71.7	23.5	35.1	2.91
T_4	3.7	18.1	8.9	98.3	66.0	20.4	33.6	2.91
T_5	3.7	18.6	8.3	91.3	58.3	18.7	36.6	2.89
T_6	3.7	19.4	8.6	113.3	77.0	24.7	32.3	2.92
T_7	3.3	18.7	8.2	115.3	79.0	23.4	31.3	2.91
T_8	3.3	18.7	8.3	91.7	69.3	20.4	32.6	2.89
CD	1.24	—	—	—	—	7.04	—	0.024
SE	0.41	0.71	0.44	10.10	8.86	2.34	3.41	0.008

lowest level of Cd both in the persence and absence ofFYM. Percentage reduction increased with increasing levels of Cd and it was more in the presence of FYM than without FYM.

Nutrient content and uptake

Compared to T_1 and T_2, the content of nitrogen in grain increased at all levels of Cd (Table 30) both in the presence and absence of FYM. Variations in P content was not significant, but K content slightly changed at varying levels of Cd. Ca content in grain increased significantly with increasing levels of Cd, but a significant reduction was noted at the highest level. Variations in Mg content were not significant.

No significant variation was noted in the content of N and P in straw (Table 31) at varying levels of Cd both in the presence and absence of FYM. K content was reduced significantly at higher levels of Cd with and without FYM whereas Ca content increased due to Cd treatment in the presence of FYM and it decreased in the absence of FYM. Content of Mg increased significantly at all levels of Cd in the presence of FYM and in its absence, the increase was not significant.

Compared to T_1, variations in the content of N, P, K, Ca and Mg in root (Table 32) was significant when Cd was applied along with T_1 at different levels. N content increased significantly with increasing levels of Cd without FYM. Variations in P and Mg content was not significant at any level of Cd without FYM. K and Ca decreased significantly with increasing levels of Cd without FYM. The uptake of nutrients also followed more or less similar pattern as seen from Tables 31, 31 and 32.

Table 30. Nutrient content and uptake in rice grains

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	1.05	0.21	0.27	0.08	0.04	20.2	4.1	5.2	1.5	0.8
T_1	0.92	0.21	0.31	0.16	0.06	36.4	8.3	12.2	6.3	2.4
T_2	0.94	0.21	0.34	0.18	0.09	29.9	6.7	10.8	5.7	2.9
T_3	1.18	0.23	0.35	0.20	0.08	27.7	5.4	8.2	4.7	1.9
T_4	1.05	0.21	0.31	0.22	0.06	21.5	4.3	6.3	4.5	1.2
T_5	0.95	0.16	0.32	0.22	0.08	17.9	3.0	6.0	4.1	1.5
T_6	1.09	0.25	0.34	0.18	0.09	26.9	6.2	8.4	4.4	2.2
T_7	0.96	0.23	0.34	0.16	0.08	22.4	5.4	8.0	3.7	1.9
T_8	1.11	0.24	0.38	0.13	0.07	22.6	5.0	7.8	2.7	1.4
CD	0.104	—	0.031	0.026	—	7.88	2.48	2.08	1.31	0.27
SE	0.035	0.018	0.011	0.009	0.008	2.61	0.82	0.69	0.43	0.090

Table 31. Nutrient content and uptake in rice straw

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.38	0.12	1.61	0.27	0.19	23.1	7.3	97.7	16.4	11.5
T_1	0.39	0.15	1.78	0.44	0.24	36.9	14.2	168.2	41.6	22.7
T_2	0.39	0.13	1.69	0.46	0.27	39.2	13.1	169.8	46.2	27.1
T_3	0.39	0.11	1.72	0.48	0.28	29.4	8.3	129.5	36.1	21.1
T_4	0.39	0.10	1.67	0.48	0.33	29.1	7.5	124.5	35.8	24.6
T_5	0.40	0.19	1.53	0.50	0.38	28.9	13.7	110.7	36.2	27.5
T_6	0.44	0.11	1.68	0.39	0.28	38.1	9.5	145.3	33.7	24.2
T_7	0.41	0.10	1.57	0.40	0.27	35.5	8.6	135.5	34.5	23.3
T_8	0.43	0.08	1.49	0.35	0.28	37.2	6.1	113.5	26.7	21.3
CD	0.099	0.047	0.098	0.043	0.032	8.69	3.78	30.21	8.10	4.31
SE	0.033	0.016	0.033	0.015	0.011	2.86	1.25	10.02	2.69	1.43

Table 32. Nutrient content and uptake in rice root

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.17	0.09	0.63	0.09	0.02	1.0	0.5	3.6	0.5	0.1
T_1	0.24	0.10	1.00	0.15	0.03	6.1	2.6	25.5	3.8	0.8
T_2	0.17	0.09	0.90	0.14	0.04	5.3	2.8	28.3	4.4	1.3
T_3	0.22	0.06	0.83	0.15	0.04	2.8	0.6	10.6	1.9	0.5
T_4	0.23	0.06	0.97	0.12	0.02	2.9	0.8	12.3	1.5	0.3
T_5	0.21	0.09	0.87	0.10	0.03	2.6	1.1	10.6	1.2	0.4
T_6	0.28	0.07	1.00	0.12	0.03	6.4	1.6	22.9	2.8	0.7
T_7	0.40	0.09	0.97	0.09	0.03	7.4	1.7	18.0	1.7	0.6
T_8	0.41	0.11	0.63	0.08	0.03	6.0	1.6	9.1	1.2	0.4
CD	0.043	0.035	0.249	0.026	0.012	1.93	1.08	8.00	0.90	0.14
SE	0.015	0.012	0.084	0.009	0.004	0.64	0.36	2.65	0.30	0.05

Starch content and germination of seeds

Compared to T_1 and T_2 starch content in grain (Table 33) was increased due to Cd treatment at lower levels. Seed germination was affected only by the highest level of Cd (25 mg kg^{-1}) in treatments T_5 and T_8. Lowest germination (46.7 per cent) was recorded by T_5 (25 mg Cd kg^{-1} soil with FYM).

Table 33. Starch content and germination of rice seeds

Treatments	Starch content (per cent)		Germination (per cent)	
	Cd	Ni	Cd	Ni
T_0	48.0	50.2	99.3	78.0
T_1	51.6	51.5	99.3	92.0
T_2	48.8	48.4	100.0	96.3
T_3	52.2	51.7	98.7	90.7
T_4	51.8	51.4	100.0	93.3
T_5	49.3	48.2	46.7	50.7
T_6	52.1	50.9	100.0	100.0
T_7	51.7	49.7	99.3	100.0
T_8	48.5	47.9	94.3	100.0
CD	0.89	0.91	4.48	4.91
SE	0.30	0.30	1.49	1.63

Cadmium content in rice

It may be seen from the Table 34 that the Cd content in grain was not significantly affected at 5 and 15 mg Cd kg^{-1} soil in the presence of FYM and a significant increase was noted only at 25 mg kg^{-1}. In the absence of FYM, a significant increase compared to T_2, was observed at higher levels of Cd. Even in absolute control pots (T_0) Cd content in grain was 1.0 mg kg^{-1} and in T_1 and T_2 it was 2.1 and 1.7 mg kg^{-1} respectively.

Table 34. Cd and Ni content in rice

Treatments	Cd (mg kg^{-1})			Ni (mg kg^{-1})		
	Grain	Straw	Root	Grain	Straw	Root
T_0	1.0	1.2	2.8	2.0	3.1	6.0
T_1	2.1	2.7	6.2	2.7	3.5	6.4
T_2	1.7	2.2	5.2	2.8	4.0	6.6
T_3	2.4	4.7	24.2	10.7	18.6	73.1
T_4	2.8	6.8	49.0	18.3	25.2	96.5
T_5	6.3	9.3	91.2	22.9	36.8	109.8
T_6	2.2	2.7	11.0	8.1	15.6	75.3
T_7	2.7	4.2	23.3	9.5	18.5	99.0
T_8	3.2	7.8	51.7	10.2	21.2	112.3
CD	0.71	0.93	1.29	0.76	1.98	3.26
SE	0.24	0.31	0.43	0.26	0.67	1.10

In straw and root Cd content in control pots ranged from 1.2 to 2.7 and 2.8 to 6.2 mg Cd kg^{-1} dry weight respectively. When the level of Cd in soil was increased, its content in straw and root increased significantly. A greater amount of Cd was retained in grain, straw and root in the presence of FYM than without FYM. Accumulation of Cd was highest in root and the amount of Cd translocated to the above ground plant parts was comparatively low.

4.3.1.2. Experiment on rice with Ni

Growth and yield characters

As seen from Table 35, plant height, weight of straw and root as well as total dry matter were significantly reduced with the highest level of Ni in the presence of FYM, whereas only plant height and root weight were affected at this level of Ni in the absence of FYM.

Data on yield and yield attributes given in Table 36 show a significant reduction in the number of filled grain and yield only in treatments T_5 and T_8 receiving the highest level of Ni.

Nutrient content and uptake

N content in grain (Table 37) increased significantly when Ni was applied along with T_1. But it decreased in the treatments where Ni was applied in the absence of FYM. Compared to T_1 and T_2 no significant variation in P content was observed with different Ni levels. Effect of Ni treatment on Mg content was not significant. K and Ca content increased with increasing levels of Ni. Uptake of nutrients also showed a similar trend.

Table 35. Biometric and growth characters of rice under varying levels of Ni

Treatments	Plant height (cm)	Total tillers hill^{-1}	Straw (g pot^{-1})	Root (g pot^{-1})	Days to flowering	Days to harvesting	Total dry matter (g pot^{-1})
T_0	62.3	3.0	12.6	8.8	79.7	110	31.9
T_1	70.3	6.0	34.6	22.2	82.3	104.3	88.7
T_2	67.0	4.3	26.3	21.1	83.0	106.3	72.8
T_3	71.7	6.0	34.2	25.4	81.0	101.0	88.2
T_4	67.3	5.0	29.9	17.6	81.3	101.3	75.0
T_5	67.3	5.0	25.4	17.4	81.0	101.0	65.3
T_6	66.7	4.7	26.1	21.5	81.0	100.7	73.5
T_7	65.7	4.3	24.9	17.8	80.3	99.3	66.8
T_8	63.7	4.3	22.9	16.3	81.3	103.7	57.3
CD	2.66	1.51	7.37	3.69	0.81	0.87	15.80
SE	0.88	0.50	2.44	1.22	0.27	0.29	5.24

Table 36. Yield and yield attributes of rice

Treatments	Number of panicles hill^{-1}	Panicle length (cm)	Spikelets panicle^{-1}	Total grains panicle^{-1}	Filled grains panicle^{-1}	Grain (g pot^{-1})	Chaff (per cent)	100 grain weight (g)
T_0	2.3	15.7	8.3	101.0	52.3	10.5	48.3	2.86
T_1	6.0	17.3	9.0	113.7	58.7	31.9	49.4	3.02
T_2	4.3	15.7	8.9	95.0	66.8	25.4	30.7	2.91
T_3	6.0	16.0	9.2	107.3	53.3	28.6	49.4	2.98
T_4	5:0	17.0	8.3	101.0	60.7	27.5	40.0	3.02
T_5	5.0	17.0	9.0	104.7	49.6	22.5	53.5	3.02
T_6	4.7	15.7	8.5	91.3	63.4	25.9	31.8	2.92
T_7	4.3	17.0	8.5	100.7	64.1	24.1	36.9	2.89
T_8	3.7	15.7	8.8	103.7	56.7	18.1	46.9	2.90
CD	1.51	—	—	—	8.73	6.83	11.13	0.218
SE	0.50	0.62	0.40	6.54	2.90	2.27	3.69	0.072

Table 37. Nutrient content and uptake in rice grain

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.93	0.21	0.25	0.08	0.05	9.8	2.2	2.6	0.8	0.5
T_1	0.89	0.22	0.32	0.08	0.08	28.4	5.5	10.2	2.6	2.6
T_2	1.07	0.20	0.32	0.11	0.06	27.2	5.8	8.1	2.8	1.5
T_3	1.07	0.22	0.34	0.09	0.05	30.6	6.3	9.7	2.6	1.4
T_4	1.09	0.22	0.35	0.11	0.07	30.0	6.1	9.6	3.0	1.9
T_5	1.03	0.20	0.37	0.13	0.06	23.2	4.5	8.3	2.9	1.4
T_6	1.01	0.22	0.31	0.11	0.05	26.2	5.7	8.0	2.9	1.3
T_7	1.01	0.20	0.35	0.12	0.06	24.3	4.8	8.4	2.9	1.5
T_8	0.97	0.19	0.35	0.13	0.06	17.6	3.4	6.3	2.4	1.1
CD	0.106	0.023	0.035	0.022	—	7.01	1.45	2.75	0.68	0.37
SE	0.035	0.008	0.012	0.007	0.008	2.33	0.48	0.91	0.23	0.12

Table 38. Nutrient content and uptake in rice straw

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.30	0.08	1.60	0.25	0.20	3.8	1.0	20.2	3.2	2.5
T_1	0.40	0.14	1.78	0.25	0.30	13.8	4.8	61.6	8.7	10.4
T_2	0.41	0.09	1.70	.024	0.27	10.8	2.4	44.7	6.3	7.1
T_3	0.49	0.12	1.78	0.30	0.26	16.8	4.1	60.9	10.3	8.9
T_4	0.40	0.12	1.76	0.32	0.26	12.0	3.6	52.6	9.6	7.8
T_5	0.38	0.11	1.78	0.34	0.23	9.7	2.8	45.2	8.6	5.8
T_6	0.46	0.09	1.70	0.24	0.23	12.0	2.4	44.4	6.3	6.0
T_7	0.44	0.09	1.69	0.23	0.25	11.0	2.2	42.1	5.7	6.2
T_8	0.35	0.07	1.70	0.21	0.25	8.0	1.6	38.9	4.8	5.7
CD	0.083	0.020	0.082	0.035	0.052	3.32	1.00	13.19	2.35	2.00
SE	0.028	0.007	0.027	0.012	0.017	1.10	0.33	4.38	0.78	0.66

Table 39. Nutrient content and uptake in rice root

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.25	0.09	0.77	0.06	0.03	2.2	0.8	6.8	0.5	0.3
T_1	0.44	0.09	0.90	0.10	0.04	9.8	2.0	19.9	2.2	0.9
T_2	0.24	0.09	0.90	0.08	0.04	5.1	1.9	19.0	1.7	0.8
T_3	0.32	0.06	0.93	0.13	0.04	8.1	1.5	23.6	3.3	1.0
T_4	0.33	0.06	0.93	0.12	0.03	5.8	1.1	16.4	2.1	0.5
T_5	0.31	0.04	0.97	0.11	0.03	5.4	1.1	24.4	2.8	0.5
T_6	0.24	0.07	0.97	0.12	0.04	5.2	1.6	21.5	2.7	0.9
T_7	0.24	0.07	1.07	0.12	0.02	4.2	1.3	19.0	2.1	0.7
T_8	0.24	0.08	1.10	0.13	0.03	5.2	1.8	23.6	2.8	0.6
CD	0.054	0.025	—	0.029	—	1.37	0.55	4.67	0.70	0.28
SE	0.018	0.008	0.063	0.010	0.005	0.45	0.18	1.55	0.23	0.09

Nitrogen content in straw (Table 38) decreased at the highest level of Ni with and without FYM and the reverse was the case at the lowest level compared to T_1 and T_2. P content decreased with increasing levels of Ni with FYM and no significant variation was noted with increasing levels of Ni without FYM. Variation in K content was not significant, due to treatments with Ni and Mg content in straw showed a decrease due to Ni treatment.

Compared to T_1 and T_2, content of N in roots (Table 39) decreased when Ni was applied at varying levels along with T_1 and remained the same at all levels of Ni along with T_2. Content of P has decreased while that of K and Ca increased at all levels of Ni with and without FYM. Mg content was not significantly affected by Ni treatment. Uptake of nutrients in straw and root also showed a similar pattern.

Starch content and germination (Table 33)

Compared to T_1 and T_2, starch content decreased significantly at the highest level of Ni with. However, a significant increase in starch content was noted at lower levels of Ni without FYM. Seed germination was significantly reduced only at the highest level of Ni with FYM.

Nickel content in rice

The Ni content in grain in T_0 was 2.0 mg kg^{-1} and in T_1 and T_2 it was 2.7 and 2.8 mg kg^{-1} respectively as revealed from Table 34. Ni content in grain increased significantly with increasing levels of Ni both with and without FYM. Ni content in grain was more when Ni was applied along with FYM than when Ni was applied without FYM. Content of Ni in straw and root also followed the same pattern. Content of Ni was highest in root and lowest in grain.

4.3.2.1. Experiment on sesame with cadmium

Biometric and growth characters (Table 40)

Vegetative characters of sesame, like plant height, number of leaves, nodes and branches per plant were reduced significantly in all the treatments of Cd with and without FYM compared to T_1 and T_2. The extent of reduction was more or less same in Cd treated plants in the presence and absence of FYM. The length of tap root was found to be significantly reduced at higher levels of Cd. It was 22.3 and 17.3 cm in T_1 and T_2 and was reduced to 17.0 and 14.0 cm in T_5 and T_8 receiving 25 mg kg^{-1} Cd.

Root dry weight was reduced significantly in all treatments. Reduction in root dry weight was more severe in the Cd treatment without FYM. The stover yield in sesame was also affected by the addition of Cd. It decreased significantly at all levels of Cd with and without FYM.

As in the case of rice, the days to flowering and maturity showed significant variations between treatments. Flowering was significantly delayed at all levels of Cd in the absence of FYM. However, early flowering was observed when Cd was applied @ 25 mg kg^{-1} soil. Plants in T_5 flowered 36.3 days after sowing while it was 38.7 days for plants in T_1. Days to harvesting also was significantly reduced at the highest level of Cd both in the presence and absence of FYM. Total dry matter decreased significantly with increasing levels of Cd.

Table 40. Biometric and growth characters of sesame under varying levels of Cd

Treatments	Plant height (cm)	Leaves plant^{-1}	Branches plant^{-1}	Nodes plant^{-1}	Stover yield (g pot^{-1})	Tap root length (cm)	Root (g pot^{-1})	Days to flowering	Days to harvest	Total dry matter (g pot^{-1})
T_0	38.7	31.3	1.3	16.7	4.8	17.3	1.7	41.7	84.0	8.6
T_1	68.8	60.0	3.7	32.7	10.8	22.3	2.8	38.7	83.0	21.1
T_2	58.0	49.3	2.0	24.0	7.6	17.3	2.3	40.0	80.3	13.1
T_3	52.0	47.3	0.7	22.0	8.2	21.0	2.6	40.0	82.0	13.8
T_4	50.5	45.3	2.0	20.7	7.4	18.7	2.2	38.0	82.0	12.0
T_5	49.3	42.7	1.7	19.3	5.6	17.0	2.0	36.3	79.0	9.7
T_6	49.0	35.3	1.7	16.7	6.6	19.0	1.8	42.0	80.7	10.6
T_7	47.0	32.7	0.7	15.3	6.2	15.0	1.8	43.0	80.7	10.2
T_8	37.7	26.0	0.0	12.0	6.2	14.0	1.7	43.0	78.0	9.2
CD	6.82	4.76	1.14	1.98	1.40	1.65	0.09	0.57	1.04	1.50
SE	2.26	1.58	0.38	0.66	0.46	0.55	0.03	0.19	0.35	0.50

Yield and yield attributes

All characters contributing to yield depicted in Table 41 were significantly affected by Cd resulting in an appreciable decrease in yield of sesamum. The number of capsules per plant was decreased from 24.0 in T_1 to almost half or less than half in all the treatments of Cd with FYM. The lowest capsule number was recorded by plants in T_8 (6.7) which received Cd @ 25 mg kg^{-1} soil without FYM. The same trend was noticed in the weight of capsules also. The highest weight of seeds in T_1 was 7.5 g pot^{-1} which decreased to 3.2 g pot^{-1} in T_2 when no FYM was given. When Cd was applied at varying levels along with T_1 and T_2, it was reduced to the lowest extent of 2.1 and 1.3 g pot^{-1} in T_5 and T_8 indicating the drastic effect of Cd in decreasing yield. The weight of hundred seeds which indicates the extent of seed filling was 0.33 g in T_1 and in all other treatments it was significantly reduced revealing the harmful effect of Cd on seed setting.

Table 41. Yield and yield attributes of sesame

Treatments	No. of capsules plant^{-1}	Capsule weight (g plant^{-1})	Seed weight (g pot^{-1})	100 seed weight (g)
T_0	8.0	2.0	2.1	0.30
T_1	24.0	5.6	7.5	0.33
T_2	12.3	2.7	3.2	0.29
T_3	10.7	2.6	3.0	0.30
T_4	10.0	2.2	2.4	0.29
T_5	9.7	2.1	2.1	0.28
T_6	10.0	2.1	2.2	0.27
T_7	10.0	2.1	2.2	0.28
T_8	6.7	1.6	1.3	0.27
CD	2.64	0.25	0.31	0.009
SE	0.88	0.08	0.10	0.003

In general, the adverse effect of Cd on the growth and yielding pattern of sesame was significant even from the lowest level. The adverse effect of Cd on growth and yield of sesame was comparatively higher in the presence of FYM than without FYM.

Nutrient content and uptake

Nitrogen content in sesame seed was maximum (3.86 per cent) in T_1, but decreased significantly at all levels of Cd (Table 42). It was 2.91 per cent in T_2 and no significant decrease was noted when Cd was applied at three levels along with T_2. P content was 0.55 and 0.52 per cent in T_1 and T_2. When Cd was applied along with T_1 at varying levels, no significant variation was noted. On the other hand, a significant increase in P and K content was obtained when Cd was applied in the absence of FYM. Percentage of Ca decreased significantly when Cd was applied @ of 25 mg kg^{-1} soil with and without FYM. Mg content increased significantly with increasing levels of Cd with FYM, while no significant variation was noted with Cd in the absence of FYM. Nutrient uptake decreased significantly with increasing levels of Cd.

Compared to T_1, content of N, P, K and Ca decreased at varying levels of Cd in the presence of FYM (Table 43). Variations in content of these nutrients were not significant when Cd was applied without FYM. Mg content alone increased with increasing levels of Cd in the presence and absence of FYM. Compared to T_1 and T_2, nutrient uptake decreased due to Cd treatment.

Table 42. Nutrient content and uptake in sesame seeds

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.38	0.41	0.51	0.22	0.39	5.00	0.86	1.07	0.48	0.86
T_1	3.86	0.55	0.56	0.26	0.44	28.95	4.13	4.22	1.95	3.30
T_2	2.91	0.52	0.52	0.25	0.43	9.31	1.66	1.66	0.82	1.31
T_3	3.39	0.60	0.57	0.22	0.47	10.17	1.80	1.71	1.17	2.10
T_4	2.92	0.61	0.58	0.22	0.48	7.01	1.46	1.39	0.53	1.15
T_5	3.12	0.53	0.58	0.19	0.49	6.55	1.11	1.22	0.40	1.05
T_6	2.62	0.67	0.57	0.20	0.43	5.76	1.47	1.25	0.37	0.95
T_7	2.75	0.65	0.57	0.20	0.43	6.05	1.43	1.25	0.44	0.95
T_8	2.80	0.72	0.61	0.18	0.45	3.64	0.94	0.79	0.23	0.56
CD	0.382	0.122	0.036	0.051	0.028	0.954	0.322	0.120	0.080	0.106
SE	0.127	0.041	0.012	0.017	0.009	0.316	0.107	0.040	0.027	0.035

Table 43. Nutrient content and uptake in sesame stover

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.92	0.26	0.60	0.17	0.63	4.42	1.25	2.88	0.82	3.02
T_1	0.92	0.38	0.68	0.18	0.71	9.94	4.10	7.34	1.94	7.67
T_2	1.01	0.31	0.64	0.17	0.69	7.68	2.36	4.86	1.29	5.24
T_3	0.92	0.31	0.66	0.13	0.74	7.54	2.54	5.41	1.07	6.07
T_4	0.72	0.28	0.62	0.13	0.76	5.33	2.07	4.59	0.96	5.62
T_5	0.52	0.32	0.56	0.14	0.80	2.91	1.79	3.14	0.78	4.48
T_6	0.94	0.28	0.62	0.13	0.69	6.20	1.85	4.09	0.86	4.55
T_7	1.02	0.28	0.62	0.14	0.71	6.32	1.74	3.84	0.87	4.38
T_8	1.03	0.31	0.56	0.16	0.74	6.39	1.92	3.47	0.99	4.59
CD	0.081	0.022	0.032	0.033	0.033	0.263	0.148	0.221	0.218	0.287
SE	0.027	0.007	0.011	0.011	0.011	0.087	0.049	0.073	0.072	0.090

Table 44. Nutrient content and uptake in sesame root

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.57	0.23	0.28	0.04	0.12	0.97	0.39	0.48	0.07	0.21
T_1	0.64	0.22	0.32	0.04	0.17	1.79	0.62	0.90	0.11	0.48
T_2	0.71	0.22	0.30	0.05	0.20	1.63	0.51	0.69	0.12	0.46
T_3	0.64	0.23	0.30	0.07	0.17	1.66	0.60	0.78	0.18	0.44
T_4	0.67	0.18	0.26	0.08	0.19	1.47	0.40	0.57	0.18	0.41
T_5	0.83	0.19	0.22	0.15	0.19	1.66	0.38	0.44	0.30	0.38
T_6	0.31	0.09	0.32	0.05	0.21	0.56	0.16	0.58	0.09	0.38
T_7	0.44	0.09	0.29	0.09	0.22	0.79	0.14	0.52	0.16	0.40
T_8	0.65	0.16	0.24	0.11	0.21	1.11	0.27	0.41	0.19	0.36
CD	0.143	0.034	0.035	0.018	0.027	0.308	0.074	0.068	—	0.124
SE	0.047	0.011	0.012	0.006	0.009	0.102	0.025	0.023	0.189	0.041

Table 45. Oil content and germination of sesame seeds

Treatments	Oil content (per cent)		Germination (per cent)	
	Cd	Ni	Cd	Ni
T_0	49.7	50.0	96.7	98.0
T_1	57.7	56.7	98.7	99.3
T_2	51.7	48.7	98.7	99.3
T_3	58.7	55.3	93.3	100
T_4	57.7	51.7	93.3	100
T_5	47.3	51.7	96.7	97.3
T_6	51.7	48.3	99.3	98.3
T_7	51.7	46.7	98.7	100.0
T_8	49.3	46.0	98.0	100.0
CD	1.49	1.32	—	2.03
SE	0.49	0.44	1.27	0.67

Nutrient content in root showed a varying pattern (Table 44). N content was significantly raised (0.83%) due to the effect of 25 mg kg^{-1} soil Cd (T_5) in the presence of FYM. But in the absence of FYM, N content was reduced. However, an increasing trend with increasing Cd levels was evident. P content in root was significantly affected only in the treatments with Cd in the absence of FYM (T_6, T_7 and T_8). A decreasing tendency was noticed in the K content of roots with increase in Cd levels both with and without FYM. The reduction was most significant at the highest level of Cd. Ca and Mg content increased due to Cd treatment. Uptake of N, P, K and Mg decreased due to Cd treatment. Effect of Cd on Ca uptake was not significant.

Oil content and germination of seeds

As seen from Table 45, the oil content in sesame was 57.7 per cent in T_1 and 51.7 per cent in T_2. Lowest level of Cd (5 mg kg^{-1}) along with T_1 increased the oil content. But, it was significantly reduced at the highest level of Cd with and without FYM. Germination of seeds was not affected to any significant extent due to Cd treatment. Eventhough the Cd content in seeds was more than double and even thrice (13.7 mg kg^{-1} Cd in T_5) in the Cd treated plants, compared to the untreated one, it did not in any way affect the process of germination of seeds.

Cadmium content in sesame (Table 46)

In general, the content of Cd was highest in root and lowest in seed and it increased with increasing Cd levels. But the increase was more appreciable in the seed and stover in the presence of FYM and in roots in the absence of

FYM. The content of Cd accumulated in roots increased with increasing levels of Cd and ranged from 52.0 to 108.0 and 97.0 to 134.7 mg kg^{-1} in different Cd treatments in the presence and absence of FYM.

Table 46. Cd and Ni content in sesame

Treatments	Cd (mg kg^{-1})			Ni (mg kg^{-1})		
	Seed	Stover	Root	Seed	Stover	Root
T_0	3.2	4.0	7.0	1.0	4.7	6.0
T_1	4.7	5.3	7.8	1.2	5.5	6.9
T_2	3.5	5.0	8.0	1.3	4.3	6.5
T_3	8,8	19.2	52.0	1.5	12.6	24.7
T_4	12.5	31.5	101.3	2.0	22.5	56.6
T_5	13.7	31.8	108.0	4.0	28.4	67.5
T_6	8.3	20.0	97.0	1.5	8.6	17.9
T_7	9.8	22.3	126.7	2.5	20.5	47.7
T_8	10.7	22.8	134.7	4.8	25.3	63.7
CD	1.58	4.57	31.19	0.54	2.78	7.66
SE	0.53	1.54	10.50	0.18	0.92	2.54

4.3.2.2. Experiment on sesame with nickel

Biometric and growth characters

The data presented in Table 47 show that compared to T_1 and T_2, characters like plant height, number of leaves, branches and nodes per plant decreased significantly at all levels of Ni. Stover yield was 10.8 and 7.8 g pot^{-1} in T_1 and T_2 respectively. It decreased significantly when Ni was applied @ 15 *and 25 mg kg^{-1} along with T_1 and at the highest level only, with T_2. Significant* decrease was noted in the length and dry weight of roots with increasing levels of Ni in the presence and absence of FYM. Days to flowering was not seen affected due to Ni treatment in the presence of FYM. It was significantly reduced at the lowest level of Ni without FYM and increased significantly at higher levels. Days to harvesting was not influenced by Ni, when applied along with FYM at three levels, while it increased significantly at the higher level of Ni without FYM compared to T_2.

Yield and yield attributes

Yield characters of sesame, like number of capsules and capsule weight per plant, seeds per capsule and hundred seed weight (Table 48) were significantly influenced by Ni. Number of capsules per plant was 22.7 in T_1 and it was reduced significantly when Ni was applied. In T_2 also a significant reduction was observed at all the three levels of Ni. Weight of capsule was 5.6 and 2.4 g per plant in T_1 and T_2 respectively and it was reduced significantly at all the three levels of Ni. Weight of hundred seeds showed a significant decrease at the highest level of Ni with FYM (T_5). Yield of sesame was 9.6 and 3.8 g per pot in T_1 and T_2 which decreased significantly at all the three levels of Ni in the presence of FYM. In the absence of FYM significant reduction was noted only at the higher levels of Ni (in T_7 and T_8).

Table 47. Biometric and growth characters of sesame under varying levels of Ni

Treatments	Plant height (cm)	Leaves plant^{-1}	Branches plant^{-1}	Nodes plant^{-1}	Stover yield (g pot^{-1})	Tap root length (cm)	Root (g pot^{-1})	Days to flowering	Days to harvesting	Total dry matter (g pot^{-1})
T_0	38.7	39.3	1.7	21.7	5.0	17.3	1.4	41.7	84.0	10.4
T_1	71.7	47.3	3.3	29.3	10.8	22.3	2.4	35.3	82.7	22.8
T_2	58.0	38.0	0.7	20.0	7.8	17.3	1.2	37.7	80.3	12.8
T_3	67.3	39.3	2.0	22.0	10.0	20.3	2.0	35.3	82.0	17.0
T_4	66.0	39.3	1.3	21.3	9.6	15.3	1.4	35.3	82.0	15.2
T_5	62.3	32.3	1.3	16.3	9.2	12.3	1.0	34.7	82.3	13.8
T_6	53.3	26.0	1.7	13.3	8.0	14.3	1.2	35.7	81.0	13.0
T_7	49.3	20.7	0.0	11.3	6.8	11.0	1.0	41.3	82.7	10.0
T_8	40.0	16.7	0.0	9.0	5.6	9.0	0.8	42.0	85.7	8.4
CD	5.02	3.15	0.81	3.18	1.04	2.01	0.28	0.93	0.93	1.40
SE	1.67	1.04	0.27	1.06	0.35	0.67	0.09	0.31	0.31	0.46

Table 48. Yield and yield attributes of sesame

Treatments	No. of capsules plant^{-1}	Capsule weight (g plant^{-1})	Seed yield (g pot^{-1})	100 seed weight (g)
T_0	8.7	2.5	4.0	0.33
T_1	22.7	5.6	7.9	0.32
T_2	11.7	2.4	3.8	0.30
T_3	12.7	2.4	5.0	0.33
T_4	13.0	2.6	4.2	0.33
T_5	11.0	2.1	3.6	0.28
T_6	9.0	2.0	3.8	0.32
T_7	5.3	1.4	2.2	0.33
T_8	5.3	1.2	2.0	0.28
CD	2.22	0.21	0.23	0.007
SE	0.74	0.07	0.08	0.002

Nutrient content and uptake

N content decreased while P and Ca content (Table 49) increased significantly at varying levels of Ni with and without FYM. Effect of Ni on K content was not significant. Mg content was not seen influenced by Ni treatment. Uptake of nutrients also followed a similar pattern.

Table 49. Nutrient content and uptake of sesame seed

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.4	0.21	0.50	0.32	0.40	9.6	0.84	2.0	1.3	1.6
T_1	3.9	0.22	0.55	0.30	0.48	37.6	2.11	5.3	2.9	4.6
T_2	3.0	0.22	0.52	0.26	0.44	11.4	0.84	2.0	1.0	1.7
T_3	3.4	0.34	0.55	0.34	0.50	17.0	1.70	2.8	1.7	2.5
T_4	2.9	0.35	0.57	0.35	0.48	12.2	1.47	2.4	1.5	2.0
T_5	2.9	0.35	0.57	0.36	0.48	10.4	1.26	2.1	1.3	1.7
T_6	2.5	0.31	0.55	0.37	0.46	9.5	1.18	2.1	1.4	1.8
T_7	2.6	0.31	0.57	0.38	0.45	5.7	0.68	1.3	0.8	1.0
T_8	2.6	0.28	0.58	0.40	0.45	5.2	0.56	1.2	0.8	0.9
CD	0.28	0.031	—	0.037	0.054	1.25	0.122	0.39	0.19	0.16
SE	0.09	0.010	0.024	0.012	0.018	0.42	0.041	0.13	0.06	0.05

Table 50. Nutrient content and uptake of sesame stover

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.90	0.27	0.58	0.25	0.65	4.50	1.35	2.89	1.25	3.25
T_1	0.92	0.39	0.68	0.27	0.74	9.94	4.21	7.34	2.92	7.99
T_2	0.99	0.30	0.65	0.21	0.70	7.72	2.34	5.07	1.64	5.46
T_3	0.91	0.36	0.67	0.20	0.75	9.06	3.60	6.68	1.98	7.45
T_4	0.76	0.32	0.67	0.18	0.75	7.30	3.07	6.46	1.73	7.20
T_5	0.56	0.27	0.67	0.19	0.75	5.15	2.48	6.16	1.75	6.92
T_6	0.95	0.30	0.65	0.21	0.72	7.60	2.38	5.19	1.68	5.76
T_7	1.03	0.33	0.65	0.23	0.71	7.00	2.24	4.42	1.56	4.83
T_8	1.02	0.33	0.66	0.23	0.72	5.71	1.85	3.70	1.29	4.03
CD	0.116	0.041	—	0.039	0.068	1.332	0.459	0.885	0.422	0.674
SE	0.038	0.014	0.019	0.013	0.023	0.442	0.152	0.294	0.140	0.224

Table 51. Nutrient content and uptake of sesame root

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.53	0.20	0.28	0.03	0.12	0.74	0.28	0.39	0.04	0.17
T_1	0.63	0.23	0.35	0.04	0.18	1.49	0.55	0.84	0.10	0.43
T_2	0.70	0.20	0.30	0.05	0.15	0.85	0.24	0.36	0.06	0.18
T_3	0.71	0.18	0.35	0.06	0.18	1.42	0.36	0.72	0.12	0.36
T_4	0.69	0.18	0.36	0.06	0.15	0.97	0.25	0.51	0.08	0.21
T_5	0.68	0.14	0.35	0.09	0.15	0.68	0.14	0.35	0.09	0.15
T_6	0.45	0.20	0.30	0.10	0.15	0.54	0.24	0.36	0.12	0.18
T_7	0.55	0.18	0.30	0.10	0.15	0.55	0.18	0.30	0.10	0.15
T_8	0.55	0.14	0.30	0.13	0.14	0.44	0.11	0.24	0.10	0.11
CD	0.099	0.031	—	0.018	0.029	0.220	0.083	0.158	0.030	0.043
SE	0.033	0.010	0.020	0.006	0.010	0.073	0.028	0.052	0.010	0.014

Content of N, P and Ca decreased significantly at all levels of Ni in the presence of FYM while K and Mg content showed no significant variation in Stover (Table 50). In the absence of FYM, content of these nutrients remained the same or increased at varying levels of Ni, except in the case of N in T_6. The uptake of all nutrients decreased due to Ni treatment.

Due to Ni treatment, N content in root increased in the presence of FYM and decreased significantly in the absence of FYM as seen from Table 51. Decrease in P content was significant at all levels of Ni with FYM and without FYM it was significant only at the highest level (T_8). Effect of Ni on K content was not significant. Ca content increased significantly with increasing levels of Ni and Mg content remained the same at the lowest level and decreased at the higher level of Ni with and without FYM. Uptake of nutrients also followed more or less a similar trend.

Oil content and germination of seeds (Table 45)

Oil content in sesame was 56.7 and 48.7 per cent in T_1 and T_2 respectively. It decreased significantly at all levels of Ni in the presence of FYM. In the absence of FYM, oil content decreased when Ni was applied only 15 and 25 mg kg^{-1} soil.

Germination of seeds was significantly reduced when Ni was applied @ 25 mg kg^{-1} soil in the presence and absence of FYM.

Nickel content in sesame

As seen from Table 46, the content of Ni was relatively lower than Cd and was highest in root and lowest in seed. Ni content in seed was 1.0, 1.2 and 1.3 mg kg^{-1} in T_0, T_1 and T_2. Application of Ni @ 5 mg kg^{-1} soil along with T_1 and T_2 did not have any significant effect on Ni content in seeds. Increase in the Ni content of seeds was significant at higher levels of Ni and it was more in the absence of FYM than with FYM. Ni content in other plant parts increased significantly with increasing levels of Ni. It was more in the presence of FYM than in its absence.

4.3.3.1. Experiment on cowpea with Cd

1. Maximum flowering

Biometric and growth characters

Biometric characters of cowpea at maximum flowering stage of growth are presented in Table 52. Height was maximum (67.3 cm) in T_1 where the plants received treatments as per package of practices recommendations of KAU. It decreased significantly in T_3, T_4 and T_5 when Cd was applied at varying levels along with T_1. Between different levels of Cd the reduction was not significant. In T_2 where fertilizers alone were given without FYM, plant height was reduced and was only 53 cm. Plant height was minimum and significantly low in T_8 (32 cm) with the highest level of Cd (25 ppm) without FYM. Number of leaves per plant was also reduced significantly at the highest level of Cd both with and without FYM. It was highest in T_3 where Cd was applied along with FYM @ 5 mg kg^{-1} soil.

Table 52. Biometric and growth characters of cowpea at maximum flowering stage under varying levels of Cd

Treatments	Plant height (cm)	Number of leaves $plant^{-1}$	Number of branches $plant^{-1}$	Shoot (g pot^{-1})	Root (g pot^{-1})	Days to flowering
T_0	37.0	27.0	Nil	4.0	1.64	43.0
T_1	67.3	41.3	4.0	19.6	5.40	40.7
T_2	53.0	27.0	Nil	5.1	1.06	43.3
T_3	57.3	47.7	4.0	14.7	2.76	44.7
T_4	56.0	35.3	3.0	12.6	2.34	44.0
T_5	50.0	27.0	1.0	9.5	1.87	44.3
T_6	54.7	34.0	2.0	5.6	1.49	45.0
T_7	50.0	31.3	0.7	5.1	1.15	48.7
T_8	32.0	19.3	Nil	4.2	0.98	51.3
CD	8.17	8.18	1.19	2.80	0.461	0.99
SE	2.71	2.71	0.40	0.93	0.153	0.33

Plate I. Effect of control treatments (T_0, T_1 and T_2) on nodulation

Plate II. Effect of Cd at varying levels with FYM on nodulation

Plate III. Effect of Cd at varying levels without FYM on nodulation

Number of branches per plant was also severely affected due to Cd treatment in the presence of FYM. It was significantly reduced at the highest level of Cd with FYM. A significant increase was noted at the lowest level of Cd without FYM in T_6. Shoot dry weight decreased significantly with increasing levels of Cd with FYM compared to T_1. The results did not reveal any significant difference between treatments on its impact on shoot dry weight per pot in T_6, T_7 and T_8 compared to T_2. Root dry weight was found to be highest in T_1 (5.4 g pot^{-1}) which decreased significantly in all the other treatments. It may be noted that flowering was delayed in all treatments receiving Cd and it was more significant in the absence of FYM.

Nodulation (Table 53)

Number of nodules per plant was highest in the plants in T_1 (88.3), managed as per POP recommendations and it was very low in T_2 in the absence of FYM (Plate I). Significant reduction in the number of nodules was noted when Cd was applied along with T_1 (Plate II). In the absence of FYM, Cd @ 5 mg kg^{-1} soil enhanced nodulation (Plate III).

Weight of nodules was also highest in T_1, (0.24 g $plant^{-1}$) and lowest in T_8 (0.07 g $plant^{-1}$) grown with the highest level of Cd without any FYM. Nodule weight was reduced significantly at all levels of Cd in the presence of FYM. Compared to T_2, weight of nodules was significantly higher when Cd was applied @ 5 mg kg^{-1} soil without FYM.

Nitrogen content in nodules was highest in T_1 (6.0 per cent). It was reduced significantly at all levels of Cd with FYM. Compared to T_2, nitrogen content in T_6 increased significantly while in T_7 and T_8, a significant reduction was noted.

Table 53. Nodule characters of cowpea at flowering

Treatments	Nodule number plant^{-1}	Nodule weight g plant^{-1}	Nitrogen content in nodule (per cent)
T_0	30.3	0.15	4.2
T_1	88.3	0.24	6.0
T_2	24.7	0.12	4.1
T_3	75.7	0.20	5.2
T_4	53.3	0.15	5.2
T_5	37.3	0.15	5.5
T_6	31.7	0.15	4.1
T_7	23.3	0.09	3.8
T_8	22.3	0.07	3.5
CD	6.79	0.022	0.08
SE	2.25	0.007	0.027

Nutrient content and uptake

Shoot (Table 54)

Nitrogen content in the shoot of cowpea at flowering did not show any significant difference due to Cd treatment. However the highest N content of 3.26 per cent was recorded at the highest level of Cd in the absence of FYM. Variations in P content was also not significant among different treatments of Cd compared to T_1 and T_2. But K content was reduced significantly at the highest level of Cd (25 mg kg^{-1} soil) both in the presence and absence of FYM.

Ca content in T_1 was 0.58 per cent and it did not vary significantly in the corresponding treatments with Cd at different levels. However Ca content increased significantly at all levels of Cd in the absence of FYM compared to T_2. Significant increase in Mg content was also observed at all levels of Cd both with and without FYM.

Eventhough the content of various nutrients in the shoot depicted a remarkable difference between treatments, their pattern of uptake revealed a clearer picture. In the case of all nutrients, there was a significant decrease with increase in levels of Cd in the presence of FYM. However, higher uptake was noted for N at all levels, for Ca and Mg at lower levels and for P and K at lowest level of Cd in the absence of FYM compared to T_2.

Root (Table 55)

Highest N content of 2.34 per cent was recorded in T_1. Significant decrease was noted in all the treatments of Cd along with T_1. Compared to T_2, no significant variation in N content was observed in Cd treatments in the

Table 54. Nutrient content and uptake in cowpea shoot at maximum flowering

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.25	0.34	0.63	0.50	0.76	9.0	1.4	2.5	2.0	3.0
T_1	2.78	0.39	0.77	0.58	0.89	54.5	5.9	15.1	11.4	17.4
T_2	2.17	0.30	0.71	0.50	0.82	11.1	1.5	3.6	2.6	4.2
T_3	2.95	0.39	0.79	0.61	0.95	43.4	5.7	11.6	9.0	14.0
T_4	3.16	0.42	0.76	0.49	1.02	39.8	5.3	9.6	6.1	12.9
T_5	3.10	0.41	0.63	0.51	1.08	29.5	3.9	6.0	4.9	10.3
T_6	2.92	0.33	0.72	0.71	0.89	16.4	1.9	4.0	4.0	5.0
T_7	2.94	0.30	0.69	0.72	0.92	15.0	1.5	3.5	3.7	4.7
T_8	3.26	0.31	0.66	0.71	0.99	13.7	1.3	2.8	3.0	4.2
CD	0.202	0.063	0.029	0.086	0.110	2.65	0.41	0.67	0.21	0.90
SE	0.067	0.021	0.010	0.029	0.037	0.88	0.14	0.22	0.07	0.30

Table 55. Nutrient content and uptake in cowpea root at maximum flowering

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	0.97	0.10	0.39	0.03	0.10	1.59	0.16	0.65	0.05	0.16
T_1	2.34	0.17	0.44	0.03	0.18	12.64	0.38	2.38	0.18	0.98
T_2	1.67	0.17	0.36	0.03	0.12	1.77	0.18	0.38	0.03	0.13
T_3	2.07	0.28	0.46	0.04	0.15	5.71	0.77	1.27	0.12	0.41
T_4	2.09	0.35	0.31	0.05	0.18	4.89	0.82	0.73	0.11	0.42
T_5	1.74	0.41	0.22	0.04	0.19	3.25	0.77	0.41	0.07	0.39
T_6	1.69	0.37	0.36	0.04	0.12	2.52	0.55	0.54	0.06	0.18
T_7	1.56	0.29	0.26	0.04	0.16	1.79	0.35	0.30	0.05	0.18
T_8	1.53	0.27	0.19	0.10	0.16	1.50	0.26	0.19	0.10	0.16
CD	0.236	0.047	0.025	0.014	0.046	0.537	0.102	0.073	0.031	0.091
SE	0.078	0.016	0.008	0.005	0.015	0.178	0.034	0.024	0.010	0.030

absence of FYM. P and Ca content increased at all levels of Cd, in the presence and absence of FYM while K content decreased significantly with increasing levels of Cd with and without FYM. Mg content was not affected by Cd treatment at anyl level.

Uptake of N and K decreased and P increased significantly due to Cd treatment in the presence of FYM. Uptake pattern of Ca and Mg was similar.

Cadmium content in cowpea (Table 56)

The content of Cd in T_0, T_1 and T_2 (Treatments with no added Cd) in the shoot and root of cowpea at maximum flowering stage was in the range of 2.7 to 2.8 and 3.0 to 4.2 mg kg^{-1} respectively. Content of Cd in the top increased significantly in all treatments of Cd except T_3. Higher content of Cd was observed at higher levels of applied Cd in the shoot and root in the presence of FYM than without it. The highest content of 6.0 and 5.7 mg kg^{-1} Cd in above ground plant parts was noted at the highest level of applied Cd in the presence and absence of FYM, while the same values for the root were much higher being 60.5 and 40.0 mg kg^{-1} respectively.

2. At harvest

Biometric and growth characters

The biometric characters of cowpea under varying levels of Cd at the time of harvest presented in Table 57 show that they have followed a more or less similar pattern compared to the maximum flowering stage. Plant height was maximum (84 cm) in cowpea getting treatment as per POP. It was reduced

Table 56. Content of Cd (mg kg^{-1}) in cowpea at different stages

Treatments	Maximum flowering		Harvest		
	Shoot	Root	Grain	Haulm	Root
T_0	2.8	4.2	1.2	1.3	3.8
T_1	2.7	3.0	1.7	2.2	6.5
T_2	2.7	3.0	1.3	2.1	4.3
T_3	3.8	14.3	1.7	2.5	11.7
T_4	6.0	23.9	2.3	3.3	21.3
T_5	6.0	60.5	2.8	7.0	38.8
T_6	4.5	20.6	1.7	3.3	8.1
T_7	4.7	24.3	1.7	4.0	18.8
T_8	5.7	40.0	1.7	5.5	21.0
CD	1.19	13.24	0.50	1.12	3.99
SE	0.40	4.39	0.17	0.37	1.32

Table 57. Biometric and growth characters of cowpea at harvest under varying levels of Cd

Treatments	Plant height (cm)	Number of leaves $plant^{-1}$	Number of branches $plant^{-1}$	Haulm ($g\ pot^{-1}$)	Root ($g\ pot^{-1}$)	Days to harvesting	Total dry matter ($g.\ pot^{-1}$)
T_0	44.9	32.7	Nil	15.1	2.8	89.7	23.1
T_1	84.0	49.3	4.3	43.4	7.3	88.0	64.9
T_2	65.5	33.3	Nil	10.5	2.3	90.0	16.3
T_3	70.9	51.3	4.0	35.7	4.6	90.0	52.7
T_4	69.1	43.3	3.0	33.4	3.4	90.0	47.8
T_5	60.9	32.3	1.0	20.4	1.9	92.0	29.1
T_6	65.3	51.0	2.0	12.5	2.5	90.0	18.9
T_7	59.2	41.3	0.7	11.0	1.9	92.0	15.0
T_8	39.2	23.7	Nil	5.6	1.6	95.7	8.3
CD	10.04	8.57	1.10	3.25	0.53	0.74	4.11
SE	3.33	2.84	0.37	1.08	0.18	0.25	1.36

significantly in the presence of FYM at all levels of Cd (T_3, T_4 and T_5). With Cd at lower levels in the absence of FYM (T_6 and T_7), the extent of reduction was non-significant, while a significant reduction was noted at the highest level (T_8). The number of leaves per plant did not show any significant variation at lower levels of Cd with FYM. It was significantly higher at lower levels of Cd without FYM. However, at the highest level of Cd (T_5 and T_8), a significant reduction in leaf number was noted, compared to T_1 and T_2. Plates V and VI reveal the adverse effects of Cd on the growth of cowpea.

Maximum number of branches per plant was noted in T_1 (4.3). No significant reduction in the number of branches was observed for the treatment in which the level of Cd applied was 5 mg kg^{-1} soil along with pop recommendations, while significant reduction was noted at 15 and 25 mg Cd kg^{-1} soil. However, at a level of 5 mg kg^{-1} Cd, without FYM, significant increase in the number of branches was observed compared to the plants not treated with Cd. Haulm yield and root dry weight followed a similar trend. Maturity was delayed significantly in all the plants compared to those in the pop treatment. Days to harvesting was minimum (88) in POP treatment and maximum in T_8 (95.7) with 25 mg Cd kg^{-1} soil without FYM.

Yield and yield attributes (Table 58)

The yield components were also significantly affected resulting in a drastic decrease in yield in treatments T_7 and T_8 suggesting the deleterious effect of Cd in decreasing grain yield especially in the absence of FYM. The presence of FYM in treatments T_3, T_4 and T_5 along with Cd although significantly reduced grain yield from 14.2 to 12.4, 11.0 and 6.8 g pot^{-1}, the extent of reduction was less

Plate V. Effect of Cd at varying levels with FYM on growth of cowpea

Plate VI. Effect of Cd at varying levels without FYM on growth of cowpea

Table 58. Yield and yield attributes of cowpea

Treatments	Peduncles plant^{-1}	Pods peduncle^{-1}	Pods plant^{-1}	Seeds pod^{-1}	Grain yield (g pot^{-1})
T_0	3.3	1.8	6.0	8.5	5.2
T_1	5.0	1.8	9.2	14.0	14.2
T_2	4.0	1.5	6.0	6.9	3.5
T_3	5.0	1.6	7.8	13.1	12.4
T_4	4.7	1.6	7.5	12.6	11.0
T_5	4.3	1.5	6.5	9.1	6.8
T_6	4.7	1.3	5.8	8.1	3.9
T_7	4.3	1.2	5.2	5.2	2.1
T_8	3.0	1.3	4.0	4.2	1.1
CD	0.74	0.29	0.83	0.92	1.01
SE	0.25	0.10	0.28	0.31	0.34

when compared to the treatments without FYM. It may be observed that at the lowest level of Cd (5 mg kg^{-1} soil) in the absence of FYM, all yield components were slightly stimulated resulting in a better yield of cowpea.

Nutrient content and uptake

Grain (Table 59)

Content of N in grain decreased significantly at the highest level of Cd with and without FYM compared to T_1 and T_2. P content increased significantly due to Cd treatment. K content in grains did not show any significant variation at all levels of Cd in the presence of FYM, while it decreased significantly at higher levels of Cd in the absence of FYM. Compared to T_1 and T_2, Ca content decreased due to Cd treatment in the presence of FYM and increased at lower levels without FYM. Variation in Mg content was not significant among different treatments. In general, uptake of nutrients (except P) decreased due to Cd treatment in the presence of FYM and it showed a varying pattern due to Cd treatment without FYM.

Haulm (Table 60)

Content of N was less at harvest than at maximum flowering. General nutrient content in haulm decreased due to Cd treatment except in T_3. P content was varying at different levels of Cd compared to T_1 and T_2. K content decreased significantly at all levels of Cd in the presence of FYM. Due to Cd treatment in the absence of FYM, decrease in K content was significant only at higher levels. Ca content showed significant decrease only at higher levels of Cd

Table 59. Nutrient content and uptake in cowpea grains

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.38	0.13	0.59	0.05	0.29	12.4	0.68	3.07	0.26	1.51
T_1	3.21	0.19	0.66	0.07	0.38	45.6	2.70	9.37	0.99	5.40
T_2	2.81	0.15	0.64	0.07	0.33	9.8	0.52	2.24	0.25	1.16
T_3	3.23	0.25	0.67	0.06	0.36	40.1	3.10	8.31	0.74	4.46
T_4	3.20	0.25	0.64	0.05	0.39	35.2	2.75	7.04	0.55	4.29
T_5	2.85	0.28	0.63	0.05	0.37	19.4	1.90	4.28	0.34	2.52
T_6	3.21	0.29	0.62	0.09	0.30	12.5	1.13	2.42	0.35	1.17
T_7	2.89	0.26	0.56	0.08	0.34	6.1	0.55	1.18	0.17	0.71
T_8	2.62	0.27	0.58	0.07	0.32	2.9	0.30	0.64	0.08	0.35
CD	0.125	0.027	0.033	0.012	0.028	4.22	0.188	0.221	0.121	1.129
SE	0.042	0.090	0.011	0.004	0.009	1.40	0.062	0.073	0.040	0.374

Table 60. Nutrient content and uptake in cowpea haulm at harvest

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.22	0.18	0.52	0.31	0.59	33.5	2.7	7.9	4.7	8.9
T_1	1.97	0.17	0.59	0.24	0.76	85.5	7.4	25.6	10.4	33.0
T_2	1.91	0.20	0.56	0.21	0.64	20.1	2.1	5.9	2.2	6.7
T_3	2.24	0.19	0.53	0.26	0.75	80.0	6.8	18.9	9.3	26.8
T_4	1.83	0.22	0.54	0.14	0.74	61.1	7.3	18.0	4.7	24.7
T_5	1.69	0.22	0.38	0.11	0.75	34.5	4.5	7.8	2.2	15.3
T_6	1.82	0.18	0.56	0.22	0.65	22.8	2.3	7.0	2.8	8.1
T_7	1.87	0.17	0.53	0.21	0.67	20.6	1.9	5.8	2.3	7.4
T_8	1.83	0.16	0.41	0.20	0.68	10.3	0.9	2.3	1.1	3.8
CD	0.244	0.036	0.042	0.047	0.099	2.62	0.33	1.75	1.47	1.59
SE	0.082	0.012	0.014	0.016	0.033	0.87	0.11	0.58	0.49	0.53

with FYM. In other treatments of Cd no significant variation in Ca content was noted. Mg content decreased due to Cd treatment in the presence of FYM and increased with increasing levels of Cd without FYM. Uptake pattern of nutrients was almost similar to that in grain.

Root (Table 61)

In root also N content was lower at harvest than at maximum flowering. Content of N, P and K in root decreased due to Cd treatment. Variations in Ca and Mg content due to Cd treatment were not significant except in T_5. Uptake of N, P, K, Ca and Mg decreased significantly due to Cd treatment in the presence of FYM. Effect of Cd treatment without FYM on nutrient uptake was varying.

Crude protein content and germination of seeds (Table 62)

Crude protein content of cowpea grain in T_1 and T_2 were 20.1 and 17.5 per cent respectively. It decreased significantly at the highest level of Cd both in the presence and absence of FYM. Compared to T_2, at the lowest level of Cd without FYM, a significant increase was obvious in crude protein content.

Germination per cent was 99.3 and 95.3 in T_1 and T_2. In the corresponding treatments of T_1 with Cd at three levels, no significant variation was noted, while a significant increase was recorded in T_6 and T_8 at the lowest level of Cd in the absence of FYM.

Table 61. Nutrient content and uptake in cowpea root at harvest

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	1.53	0.18	0.23	0.09	0.05	4.3	0.50	0.64	0.25	0.13
T_1	1.84	0.15	0.28	0.06	0.10	13.4	1.10	2.04	0.46	0.73
T_2	1.57	0.17	0.25	0.07	0.08	3.6	0.40	0.58	0.16	0.19
T_3	1.62	0.12	0.20	0.06	0.11	7.5	0.55	0.92	0.28	0.49
T_4	1.68	0.13	0.18	0.06	0.12	5.7	0.44	0.61	0.20	0.40
T_5	1.83	0.13	0.19	0.03	0.13	3.5	0.25	0.36	0.06	0.25
T_6	1.54	0.09	0.23	0.07	0.08	3.9	0.22	0.58	0.18	0.21
T_7	1.55	0.10	0.19	0.05	0.08	3.0	0.19	0.36	0.10	0.15
T_8	1.61	0.11	0.17	0.06	0.09	2.6	0.18	0.27	0.09	0.14
CD	0.098	0.018	0.027	0.017	0.027	0.34	0.052	0.105	0.071	0.106
SE	0.033	0.006	0.009	0.006	0.009	0.11	0.017	0.035	0.024	0.035

Table 62. Crude protein content and germination of cowpea seeds

Treatments	Crude protein (per cent)		Germination (per cent)	
	Cd	Ni	Cd	Ni
T_0	15.0	16.0	95.3	93.3
T_1	20.1	20.5	99.3	100.0
T_2	17.5	12.6	95.3	91.3
T_3	20.2	20.5	100.0	98.7
T_4	20.0	20.5	100.0	96.7
T_5	17.8	20.4	100.0	97.0
T_6	20.1	16.4	99.3	91.3
T_7	18.1	12.8	96.7	92.3
T_8	16.4	12.2	98.7	92.7
CD	0.68	0.95	3.10	3.78
SE	0.23	0.32	1.03	1.25

Cadmium content in cowpea (Table 54)

Grain content of Cd was 1.2 mg kg^{-1} in T_0 (absolute control) and it was 0.7 and 1.3 mg kg^{-1} in T_1 (fertilizers + FYM) and T_2 (fertilizers alone) respectively. With increasing levels of Cd, content in grain increased and was in the range of 1.7 to 2.8 mg kg^{-1} in T_3, T_4 and T_5. However, the Cd content in grain was not affected and was 1.7 mg kg^{-1} in the corresponding treatments of T_2 with increasing levels of Cd.

In control treatments (T_0, T_1 and T_2) Cd content in the above ground portion other than grain (haulm) was 1.3, 2.2 and 2.1 mg kg^{-1} respectively. In the presence and absence of FYM, increasing levels of Cd applied resulted in an increase from 2.5 to 7.0 and 3.3 to 5.5 mg Cd kg^{-1} dry weight respectively. At all levels of applied Cd, its content in haulm significantly increased in the absence of FYM, while no significant increase was noted at lower levels of applied Cd in the presence of FYM.

Among the various plant parts highest content was noted in root. Cd content in root increased with increasing levels of applied Cd both in the presence and absence of FYM and it ranged from 11.7 to 38.8 and 8.1 to 21.0 mg kg^{-1} respectively.

4.3.3.2. Experiment on cowpea with Ni

1. Maximum flowering

Biometric and growth characters (Table 63)

At maximum flowering stage of growth, height of plant in T_1 and T_2 were 65.0 and 53.0 respectively. Significant reduction in plant height was noted

Table 63. Biometric and growth characters of cowpea at maximum flowering under varying levels of Ni

Treatments	Plant height (cm)	Number of leaves plant^{-1}	Number of branches plant^{-1}	Shoot (g pot^{-1})	Root (g pot^{-1})	Days to flowering
T_0	40.3	27.0	2.2	5.4	2.0	45.7
T_1	65.0	41.3	5.5	19.8	4.9	44.7
T_2	53.0	28.7	3.3	8.1	2.1	46.3
T_3	63.0	37.7	5.8	18.9	3.0	46.3
T_4	58.7	31.3	6.0	12.4	2.4	47.0
T_5	44.3	27.3	7.3	11.0	2.0	42.7
T_6	66.7	32.0	5.8	9.5	2.4	46.0
T_7	52.7	18.7	3.3	9.1	2.0	46.7
T_8	41.7	16.3	3.7	8.4	1.7	47.7
CD	8.69	7.40	1.00	2.15	0.20	2.51
SE	2.88	2.45	0.33	0.71	0.07	0.83

only at the highest level of Ni (25 mg kg^{-1} soil) both in the presence and absence of FYM. Number of leaves per plant was reduced significantly at higher levels of Ni with and without FYM. An enhancing effect of Ni on branching was evident from the results. Haulm yield decreased significantly only at the higher levels of Ni in the presence of FYM compared to T_1. Increase in haulm yield was noted due to Ni treatment without FYM in T_6, T_7 and T_8 compared to T_2. Decrease in root dry weight was significant even at the lowest level of Ni in the presence of FYM and in the absence of FYM, it was significant only at the highest level of Ni (T_8). Days to flowering was not affected due Ni treatment.

Nodulation

Harmful effect of Ni on nodulation as clear from Table 64 was less compared to that of Cd. Though the number of nodules per plant decreased significantly due to Ni treatment in the presence of FYM, weight of nodules per plant showed no significant variation in T_3 and T_4 compared to T_1. However, application of Ni @ 5 and 15 mg kg^{-1} soil in the absence of FYM resulted in a significant increase of nodule number and weight. The decrease in the number and weight of nodules per plant at the highest level of Ni without FYM was not significant.

Nitrogen content in nodules was highest (5.8 per cent) in T_1. When Ni was applied along with T_1 at three levels in T_3, T_4 and T_5, N content in nodules showed no significant reduction. However Ni treatment in the absence of FYM increased the N content in nodules significantly at lower levels and at the highest level it was significantly reduced.

Table 64. Nodule characters of cowpea at flowering

Treatments	Nodule number plant^{-1}	Nodule weight g plant^{-1}	Nitrogen content in nodule (per cent)
T_0	31.0	0.15	4.2
T_1	52.7	0.25	5.8
T_2	25.3	0.14	4.6
T_3	42.0	0.25	5.6
T_4	34.0	0.23	5.6
T_5	30.7	0.17	5.6
T_6	28.3	0.22	5.1
T_7	29.0	0.18	4.9
T_8	23.7	0.12	4.0
CD	3.86	0.026	0.18
SE	1.28	0.009	0.06

Nutrient content and uptake

Shoot (Table 65)

In the above ground plant parts of cowpea at maximum flowering stage, N content was highest (3.43 per cent) in T_1. Application of Ni along with T_1 at three levels decreased the N content significantly. Ni application @ 5 and 15 mg kg^{-1} soil along with T_2 also decreased N content significantly, but at the highest level (T_8) a significant increase was noted. The trend was reverse in the case of P content. Effect of Ni treatment on K content was not significant. Ca content increased significantly in all the treatments of Ni except in T_5. Variations in Mg content due to Ni treatment was not significant. Uptake of N, P, K and Mg decreased and that of Ca increased due to Ni treatment.

Root (Table 66)

At maximum flowering stage, N content in root showed no significant variation at different levels of Ni. However, at the lowest level in the presence of FYM (T_3), a significant reduction was observed. P content increased significantly at all levels of Ni with FYM and without FYM, it decreased at the lower level and increased at the highest level. Effect of Ni treatment on K content was not significant in root also. Ca content increased significantly at all levels of Ni with and without FYM. No significant variation was noted in Mg content due to Ni treatment. The pattern of nutrient uptake was more or less similar to that in shoot.

Nickel content (Table 67)

Content of Ni in the above ground plant parts and root of cowpea in T_1 was 3.0 and 3.5 and that in T_2 was 3.5 and 4.0 mg kg^{-1}. Application of Ni along

Table 65. Nutrient content and uptake in cowpea shoot at maximum flowering

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.33	0.16	0.70	0.36	0.60	12.58	2.52	3.78	1.94	3.24
T_1	3.43	0.20	0.78	0.42	0.77	67.91	14.53	15.18	8.38	15.18
T_2	2.80	0.12	0.74	0.35	0.65	22.68	4.57	5.99	2.84	5.27
T_3	3.13	0.23	0.78	0.56	0.77	59.16	5.03	14.68	10.52	14.55
T_4	2.83	0.22	0.78	0.55	0.79	35.09	3.57	9.70	6.86	9.80
T_5	2.90	0.23	0.75	0.41	0.79	31.90	3.20	8.23	4.51	8.70
T_6	2.53	0.13	0.75	0.48	0.64	24.04	2.93	7.10	4.53	6.07
T_7	2.53	0.12	0.75	0.49	0.63	23.02	3.07	6.80	4.49	5.77
T_8	2.93	0.09	0.74	0.51	0.64	24.61	1.90	6.23	4.49	5.40
CD	0.119	0.024	—	0.076	0.087	2.335	0.478	0.710	0.692	1.118
SE	0.040	0.008	0.020	0.025	0.029	0.775	0.159	0.236	0.230	0.371

Table 66. Nutrient content and uptake in cowpea root at maximum flowering

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	1.0	0.08	0.40	0.03	0.05	1.9	0.15	0.79	0.05	0.10
T_1	2.1	0.08	0.45	0.03	0.14	10.2	0.39	2.19	0.16	0.68
T_2	1.7	0.17	0.40	0.03	0.08	3.5	0.35	0.83	0.06	0.16
T_3	1.5	0.14	0.45	0.06	0.14	4.4	0.41	1.35	0.17	0.42
T_4	2.0	0.14	0.44	0.07	0.13	4.7	0.33	1.04	0.17	0.31
T_5	2.0	0.12	0.44	0.10	0.13	4.0	0.24	0.87	0.20	0.26
T_6	1.9	0.10	0.40	0.05	0.08	4.5	0.24	0.98	0.13	0.20
T_7	1.7	0.11	0.40	0.07	0.08	3.5	0.23	0.82	0.14	0.16
T_8	1.7	0.19	0.41	0.10	0.10	2.9	0.32	0.68	0.16	0.16
CD	0.30	0.031	—	0.014	0.028	0.72	0.079	0.219	0.034	0.105
SE	0.10	0.010	0.020	0.005	0.009	0.24	0.026	0.073	0.011	0.035

with T_1 and T_2 at three levels raised the Ni content in top to a maximum of only 6.0 and 6.2 mg kg^{-1}. Compared to the top content of Ni in root was very high ranging from 8.6 to 18.8 and 10.9 to 21.2 mg kg^{-1} with increasing levels of Ni with and without FYM. Ni content in the top and in the root were slightly higher in the absence of FYM than in the presence of FYM.

Table 67. Content of Ni (mg kg^{-1}) in cowpea at different stages

Treatments	Maximum flowering		Harvest		
	Shoot	Root	Grain	Haulm	Root
T_0	3.0	3.5	1.8	2.0	4.0
T_1	3.3	4.0	2.0	2.2	5.0
T_2	3.5	4.0	2.1	2.4	5.0
T_3	4.0	8.6	2.5	3.0	6.8
T_4	6.0	15.6	3.0	6.1	11.3
T_5	6.0	18.8	3.4	6.5	15.2
T_6	4.5	10.9	3.1	3.0	8.5
T_7	6.0	18.2	3.3	6.5	14.2
T_8	6.2	21.2	3.4	6.9	16.5
CD	0.68	2.71	0.40	0.56	1.65
SE	0.23	0.90	0.13	0.19	0.55

2. At harvest

Biometric characters

Effect of Ni on biometric characters of cowpea at the time of harvest was almost similar to that at maximum flowering stage as seen from Table 68. Compared to T_1 and T_2, plant height was reduced significantly when Ni was applied @ 25 mg kg^{-1} soil both in the presence and absence of FYM. A significant increase in plant height was noted at the lowest level of Ni without FYM. Number of leaves per plant decreased significantly at higher levels of Ni with and without FYM compared to T_1 and T_2. Increase in the number of branches per plant was significant at the highest level of Ni with FYM and at lower levels of Ni without FYM.

Root dry weight also decreased significantly with increasing levels of Ni in the presence of FYM. Without FYM, decrease in root dry weight was significant only at the highest level of Ni (T_8). Haulm yield was decreased significantly at higher levels of Ni only with applied with FYM. It was not affected due to Ni treatment in the absence of FYM.

Yield and yield attributes (Table 69)

In general, the yield and yield attributes were significantly affected only when Ni was applied @ 25 mg kg^{-1} soil both in the presence and absence of FYM. Harmful effects of Ni on yield and yield components of cowpea were very much less than that of Cd. Grain yield was highest (11.1 g pot-1) in the POP treatment (T_1) and application of Ni along with T_1 significantly reduced the yield only in T_5. In the POP treatment without FYM (T_2) yield was only 7.5 g pot-1. Here also significant reduction was noticed only with the highest level of Ni in T_8.

Table 68. Biometric and growth characters of cowpea at harvest under varying levels of Ni

Treatments	Plant height (cm)	Number of leaves plant^{-1}	Number of branches plant^{-1}	Haulm (g pot^{-1})	Root (g pot^{-1})	Days to harvesting	Total dry matter (g pot^{-1})
T_0	46.7	29.0	2.2	13.7	3.0	90.0	22.1
T_1	74.0	43.3	6.0	34.3	7.4	90.0	52.8
T_2	62.3	32.0	3.2	18.0	3.1	92.0	28.6
T_3	71.7	39.3	6.0	31.8	5.0	90.0	47.6
T_4	68.3	31.7	6.0	27.3	3.9	90.0	41.2
T_5	53.7	28.7	7.8	21.8	3.0	90.0	33.1
T_6	74.0	32.7	6.3	23.1	3.5	90.0	33.9
T_7	61.3	19.3	4.7	19.6	3.0	92.3	29.0
T_8	49.7	17.0	3.7	17.5	2.5	92.7	25.1
CD	6.58	5.05	1.03	6.41	0.39	0.47	7.10
SE	2.18	1.68	0.34	2.13	0.13	0.16	2.36

Table 69. Yield and yield attributes of cowpea

Treatments	Peduncles $plant^{-1}$	Pods $peduncle^{-1}$	Pods $plant^{-1}$	Seeds pod^{-1}	Grain yield (g pot^{-1})
T_0	4.2	1.7	6.8	9.6	5.4
T_1	7.5	1.5	11.7	12.6	11.1
T_2	4.8	1.9	8.7	9.9	7.5
T_3	6.8	1.6	11.2	12.3	10.8
T_4	6.0	1.7	10.2	11.3	10.0
T_5	5.8	1.5	8.8	10.4	8.3
T_6	4.8	1.8	8.5	9.6	7.3
T_7	4.7	1.8	8.2	8.8	6.4
T_8	4.3	1.7	7.3	7.9	5.1
CD	0.52	0.18	0.47	0.89	1.41
SE	0.17	0.06	0.16	0.30	0.47

Nutrient content and uptake

In general, variations in nutrient content in the grain, haulm and root of cowpea due to Ni treatment was not significant as seen from Tables 70, 71 and 72. Effect of Ni treatment in reducing nutrient uptake was significant only at higher levels. Significant increase in the uptake of some of the nutrients was observed at the lowest level of Ni.

Table 70. Nutrient content and uptake by cowpea grains

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.56	0.11	0.52	0.03	0.30	13.8	0.59	2.8	0.16	1.62
T_1	3.28	0.22	0.65	0.06	0.35	36.4	2.44	7.2	0.67	3.89
T_2	2.02	0.18	0.60	0.04	0.32	15.2	1.35	4.5	0.30	2.38
T_3	3.28	0.24	0.65	0.05	0.36	35.4	2.59	7.0	0.54	3.89
T_4	3.28	0.24	0.67	0.06	0.38	32.8	2.43	6.7	0.59	3.79
T_5	3.27	0.24	0.67	0.04	0.39	27.1	2.06	5.6	0.33	3.24
T_6	2.62	0.21	0.60	0.07	0.32	19.1	1.53	4.4	0.51	2.34
T_7	2.04	0.19	0.61	0.06	0.33	13.1	1.22	3.9	0.38	2.11
T_8	1.95	0.18	0.63	0.06	0.33	9.9	0.92	3.2	0.31	1.68
CD	0.138	0.025	0.074	0.015	0.041	2.20	0.302	0.60	0.143	0.337
SE	0.046	0.008	0.025	0.005	0.014	0.73	0.100	0.200	0.047	0.112

Table 71. Nutrient content and uptake by cowpea haulm at harvest

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	2.24	0.13	0.50	0.31	0.16	30.7	1.78	6.9	4.2	2.2
T_1	1.93	0.11	0.60	0.36	0.20	67.2	3.83	20.9	12.5	7.0
T_2	1.91	0.15	0.53	0.32	0.12	34.4	2.70	9.5	5.8	2.2
T_3	1.98	0.18	0.62	0.36	0.23	63.0	5.72	19.7	11.4	7.3
T_4	1.94	0.18	0.64	0.36	0.22	53.0	4.91	17.5	9.8	6.0
T_5	1.93	0.20	0.64	0.36	0.23	42.1	4.36	14.0	7.9	5.0
T_6	1.79	0.14	0.53	0.33	0.13	41.4	3.23	12.2	7.6	3.0
T_7	1.81	0.14	0.55	0.33	0.12	35.5	2.74	10.8	6.5	2.4
T_8	1.81	0.17	0.55	0.32	0.09	31.7	2.98	9.6	5.6	1.6
CD	0.126	0.023	0.066	0.037	0.021	6.87	0.710	1.98	1.62	0.78
SE	0.042	0.008	0.022	0.012	0.007	2.28	0.236	0.66	0.54	0.26

Table 72. Nutrient content and uptake by cowpea root at harvest

Treatments	Content (per cent)					Uptake (g pot^{-1})				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
T_0	1.46	0.08	0.20	0.07	0.04	4.4	0.23	0.60	0.20	0.12
T_1	1.83	0.10	0.30	0.07	0.08	13.5	0.77	2.21	0.49	0.58
T_2	1.55	0.15	0.25	0.06	0.06	4.8	0.47	0.78	0.18	0.19
T_3	1.62	0.11	0.29	0.07	0.09	8.0	0.55	1.44	0.35	0.45
T_4	1.62	0.12	0.28	0.05	0.07	6.3	0.47	1.10	0.21	0.28
T_5	1.65	0.13	0.28	0.04	0.07	5.0	0.39	0.84	0.13	0.21
T_6	1.60	0.11	0.22	0.06	0.05	5.5	0.37	0.76	0.21	0.18
T_7	1.60	0.14	0.24	0.07	0.05	4.9	0.43	0.73	0.21	0.15
T_8	1.61	0.17	0.24	0.07	0.04	4.0	0.41	0.60	0.16	0.10
CD	0.049	0.021	0.049	0.016	0.019	0.65	0.117	0.186	0.054	0.076
SE	0.016	0.007	0.016	0.005	0.006	0.22	0.039	0.062	0.018	0.025

Crude protein content and germination of seeds (Table 62)

Crude protein content in cowpea grain was not affected due to Ni treatment. However a significant increase was noted at the lowest level of Ni applied without FYM (T_6). Germination of seeds from Ni treated plants also showed no significant variation at any level of Ni both in the presence and absence of FYM compared to T_1 and T_2.

Nickel content in cowpea (Table 67)

Content of Ni in grain was in the range of 1.8 to 2.1 mg kg^{-1} in the control treatments (T_0, T_1 and T_2). With increasing levels of Ni applied, content in grain significantly increased and was in the range of 2.5 to 3.4 mg kg^{-1} and 3.1 to 3.4 mg kg^{-1} in the presence and absence of FYM respectively.

In the above ground plant parts of cowpea other than seed (haulm), Ni content in T_1 and T_2 were 2.2 and 2.4 mg kg^{-1} respectively. Application of Ni at three levels along with T_1 and T_2 significantly increased the Ni content from 3.0 to 6.5 and 3.0 to 6.9 mg kg^{-1} respectively.

Among the various plant parts, Ni content was highest in root. It was in the range of 4.0 to 5.0 mg kg^{-1} in the control treatments. Increase in Ni content of root due to Ni treatment was highly significant. It ranged from 6.8 to 15.2 and 8.5 to 16.5 mg kg^{-1} in the presence and absence of FYM.

DISCUSSION

DISCUSSION

The important results of the experiments carried out to investigate the status and impact of heavy metals in soils and crops of Kerala presented in the preceding chapter are discussed in the light of fundamental principles and evidences from published literature, keeping in view the objectives proposed in the study.

5.1. Status of heavy metals in soils, fertilizers, manures and plants

5.1.1. Soils

Soils cultivated to agricultural crops are repeatedly contaminated with beneficial heavy metals like Cu, Zn and non-essential heavy metals like Pb, Hg Ni, Cd etc. due to the use of different types of fertilizers, manures, pesticides and a variety of other waste materials arising from domestic, urban and industrial activities. This process gradually transforms a healthy soil initially to a contaminated soil and then to a polluted soil at a stage when the heavy metal pollutants accumulate in quantities above a normal background level.

Even contaminated soils can be hazardous and periodical monitoring is essential to assess the soil quality and take appropriate remedial action against their entry into the crop and animal systems.

The status of Cu, Zn, Pb, Ni and Cd in the selected soils of Kerala State presented in Chapter 4 provide valuable information on these aspects, besides serving as a database for future reference.

Generally, it may be seen from the data presented in Tables 4 to 10 that only one or two of these metals are present in a few soils at levels prescribed to cause elemental toxicity (Alloway, 1990) to plants growing in them. It also shows that the proportion of DTPA extractable form is only a minor part of their total content and is highly variable between samples. Brummer *et al.* (1983) have stated that as the boundary between adsorption and solubility is sometimes very thin and sensitive to small changes in soil properties, a low status of availability need not necessarily be considered as always safe in view of their higher total content.

In the light of the increasing concern about the hazardous effect of heavy metals on human health by possible entry through food chain and their direct and indirect effect on soil fertility, the status of each heavy metal is discussed in the order of their abundance in soil, based on critical levels prescribed for plant growth and soil health.

Copper

Copper content was highest in the vegetable plots of Pathanamthitta and Alapuzha districts with an average value of 84.4 mg kg^{-1} soil. The PME plots of rice receiving combination of different inorganic fertilizers and organic manures in Moncompu, Kayamkulam and Pattambi had an average of 77.9, 65.3 and 55.9 mg Cu kg^{-1} soil respectively. Cu content was much less in other soils. Extractable Cu also followed the same order as their total content.

Alloway (1990) has proposed a critical level of soil Cu as 60 mg kg^{-1} whereas Bridges (1989) has fixed 50 mg kg^{-1} as critical for The Netherlands, above which periodic monitoring is insisted.

Based on these standards, the status of Cu appears to be above critical level in the vegetable plots of Pathanamthitta and Alapuzha and rice soils of Moncompu, Kayamkulam and Pattambi (Fig. 2). The high status of Cu in the vegetable plots which are actually located at a lower physiographic position of the land may possibly be due to the washouts from Bordeaux mixture applied to the rubber plantations in the surrounding hilly areas in addition to the residual effects from fertilizers and manures as proposed by Mortvedt (1996). This view is supported by the report of the collaborative project of the KAU and RRII that the soils of some of the rubber plantations in Kerala have a Cu content ranging from 44 to 175 mg kg^{-1} (KAU, 1998). The fact that Cu content was lowest in the soils of the absolute control treatment of the rice PME plots suggest that fertilizers and manures are responsible for leaving much Cu as residue in the rice fields.

The low values of available Cu observed in the soils (3.6 to 0.15 mg kg^{-1} soil), inspite of the comparatively higher total content may be attributed to the strong binding action of Cu with organic matter and clay present in them as proposed by Chatterjee and Rathore (1974) and Harter (1979).

Eventhough the supply of Cu as a micronutrient is quite assured under these circumstances, an adverse influence on plant growth, when the soil solution exceed the critical value of 0.1 mg kg^{-1} soil, as suggested by Bolt and Bruggenwert (1978), is a matter of concern in these soils. Presence of excessive Cu in soils has been evaluated by Komulainen and Mikola (1995) and Baath *et al.* (1998) as disadvantageous based on the reduction and alteration of soil fauna and flora and lowered rate of soil processes like respiration, nitrification and nitrogen fixation. Increased mortality, reduced reproduction and retarded growth of earthworms as a result of enhanced Cu concentration has also been reported by Ma (1982 and 1984) and Bengtsson *et al.* (1986).

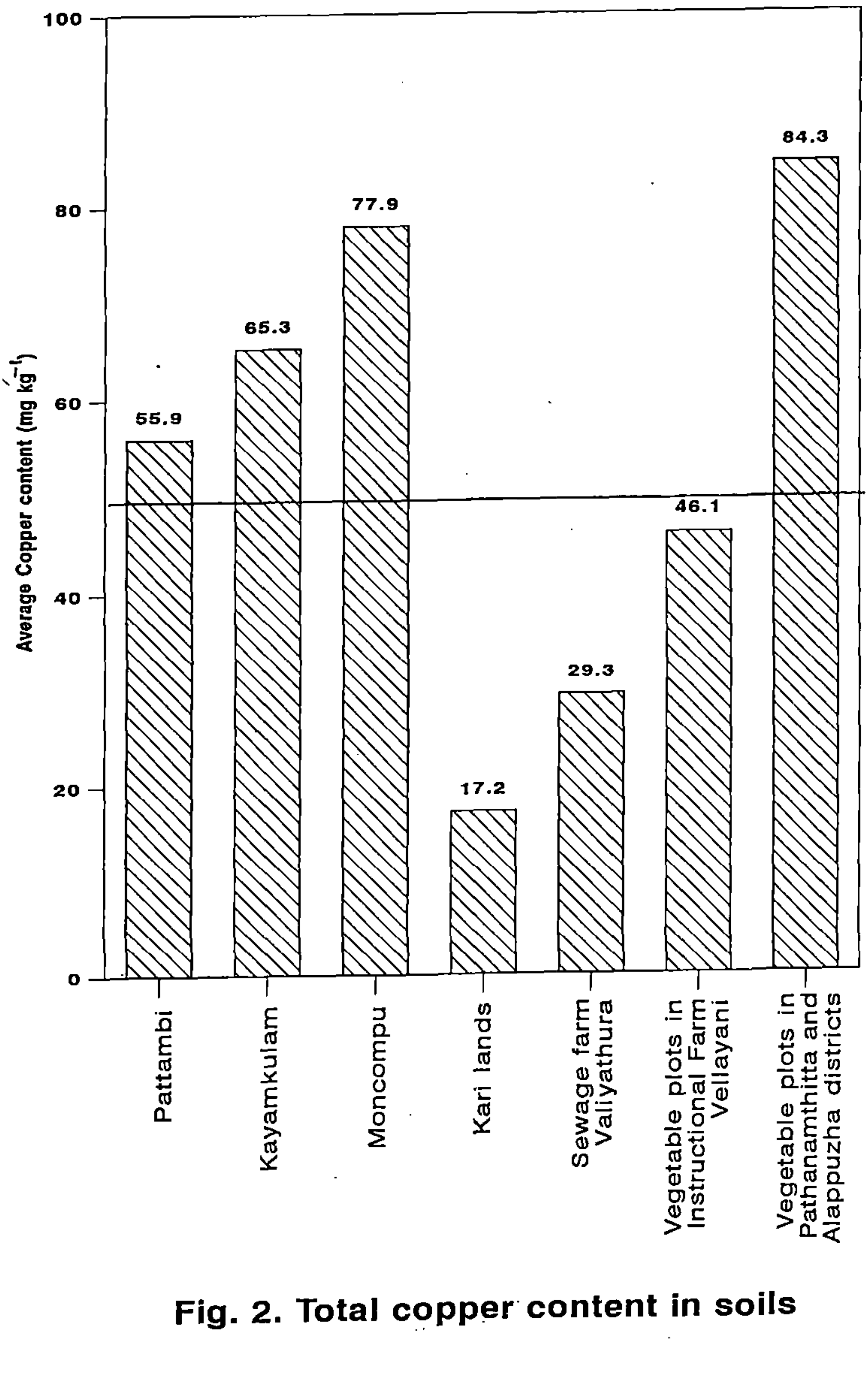

Fig. 2. Total copper content in soils

Zinc

Zinc content in the various soil samples as seen from tables 4-10 ranged between 11.5 to 78.9 mg kg^{-1} soil. It was invariably higher in the PME rice plots and vegetable plots treated with NPK fertilizers and organic manure compared to the absolute control plots which received neither fertilizers nor manures. The average Zn status also follow a similar pattern.

The data on the analysis of fertilizers and manures given in Tables 11 and 12 indicate that zinc is abundantly present in all of them, revealing clearly the source of zinc in these soils. However, the status is within the range of 2-285 mg kg^{-1} reported for Indian soils by Kanwar and Randhawa (1974) and 17-125 mg kg^{-1} reported for the surface soils of different countries as cited by Alloway (1990).

The tentative limits of Zn proposed by Kanwar and Randhawa (1974) for deficiency and toxicity in soils are 1.0 and more than 100 mg kg^{-1} soil respectively. Critical value of Zn as per the standards adopted in The Netherlands is 200 mg kg^{-1} (Bridges, 1989), above which periodical monitoring is advised. It is thus clearly evident from the studies that the status of Zn in these soils is within the levels of deficiency and toxicity proposed by these scientists.

Nickel

The status of Ni in various soils was very low and appear to be not dependent on the nature of inputs, as maximum and minimum values were exhibited by PME plots receiving organic manures alone or organic manures along with NPK fertilizers. Extractable Ni content was also very low (0.08 to 2.4 mg kg^{-1} soil) and ruled out any possible toxic effect on plants in view of the very high concentration of 200 mg kg^{-1} soil prescribed by Willaert and Verloo (1988) and the upper critical limit of 100 mg Ni kg^{-1} soil cited by Alloway (1990). However, they have indicated a level of 20 mg kg^{-1} soil as sufficient for exerting toxic effects in a sandy soil, which makes the sandy soils of the sewage farm, Valiyathura (24-30.5 mg Ni kg^{-1} soil) as likely to induce phytotoxicity to the fodder plants cultivated there.

Lead

Next in abundance to Ni is Pb showing the highest content of 30.4 mg kg^{-1} in the PME plots at Pattambi receiving NPK fertilizers and organic manures as treatment. Pb content was much lower in other samples and did not reveal any specific reason or input as responsible for its contamination.

Ure and Berrow (1982) have shown the normal Pb content of uncontaminated soils to be 29 mg kg^{-1} soil and Alloway (1990) proposed a much higher critical level of 100-400 mg kg^{-1} soil. On the other hand, Bridges (1989) have suggested a level of 50-150 mg kg^{-1} for soils to be in the safe limit.

The status of Pb in the soils studied is below the above standards prescribed and poses no problem of soil pollution and consequences at present.

Cadmium

In view of the danger of the chronic accumulation of Cd in human body entering through diet, a strict monitoring of its status in the soil is most important. Cadmium pollution of the soil has been rapidly increasing in recent decades as a result of the higher input of commercial fertilizers and manures contaminated by this element. A perusal of the average content of Cd in the selected soils reveal its greater accumulation in the upland soils (4.4 mg kg^{-}) compared to 2.5 mg kg^{-1} in the wetland soils. Highest Cd level is noticed in the sewage disposal sites, where it averaged to 8.0 mg kg^{-1}. All the other soils have recorded values ranging from 1.0 to 7.2 mg Cd kg^{-1} soil.

Page *et al.* (1972) have suggested that in general most soils can be expected to contain less than 1.0 mg Cd kg^{-1} except when contaminated from discrete sources or developed on parent materials with enormously high Cd content. They showed that Cd concentration in the soils uncontaminated from industrial pollution revealed a range of 0.005 - 2.4 mg kg^{-1}. A similar survey of 2276 soil samples from England and Wales gave a mean content of 1.2 mg Cd kg^{-1}. Therefore, any value above this may be attributed to some sort of contamination. Critical concentration of Cd is proposed (Alloway, 1990) to be 3-8 mg kg^{-1} in soils with a normal range of 0.01 - 2.0 mg kg^{-1}. Bridges (1989) has suggested a normal level of soil Cd as 1.0 mg kg^{-1} and insists on further investigation when it exceeds 5 mg kg^{-1}. .

A perusal of the status of Cd in the different soils reveal that Cd content (Fig. 3) is in the critical range (3 to 8 mg kg^{-1}) in the soils of the PME plots at Kayamkulam (3.1 - 7.2 mg kg^{-1}) and in the soils of the sewage farm (4.3 to 12.0 mg kg^{-1}) growing fodder grass. The vegetable plots in Vellayani also have a Cd content of 2.0 - 4.3 mg kg^{-1} which is critical (Fig. 3). The use of municipal waste compost as manure in the recent years may be regarded as a reason for this higher build up of Cd in these soils.

The fact that the absolute control plots in PME at various locations invariably recorded the lowest status of Cd, identifies fertilizers and manures as a probable source of Cd contamination. The Cd contamination noticed in the absolute control plots may be attributed to seepage from adjacent plots during soil flooding.

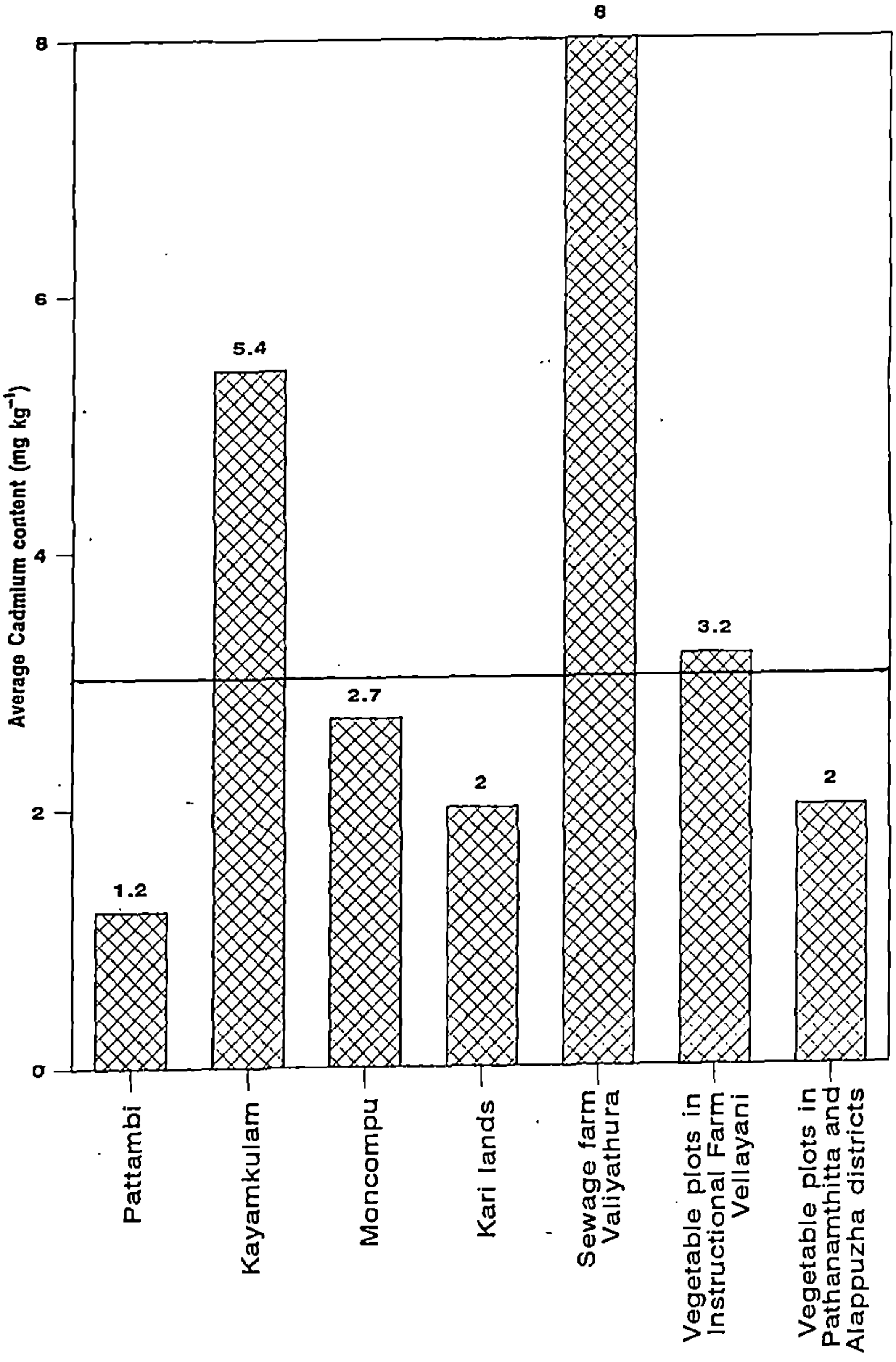

Fig. 3. Total cadmium content in soils

A dynamic equilibrium is reported to exist (Alloway, 1990) between Cd in the soil solution and that absorbed on the soil colloidal complex depending upon its physico-chemical properties. Usually, it may not reach a phytotoxic level, but it is a cause of serious concern, in view of the long term risk of entry into the food chain.

A critical analysis of the status of Cu, Zn, Ni, Pb and Cd in the wetlands and uplands soils studied here give room for concern only with regard to two metals existing beyond critical level. One is copper which is a beneficial heavy metal and the other is Cd, a harmful heavy metal.

The status of Cu in soils above critical limits can obviously affect soil biological and biochemical processes related to soil fertility rather than directly affecting the chemistry and nutrition of plants growing in them.

Cadmium existing in critical levels, although are not phytotoxic, pose a much serious problem by its possible entry through food into the human beings, causing dangerous clinical conditions. The vulnerable targets of heavy metal pollution thus not only include soil flora and fauna, but animals and human beings also.

Heavy metals in fertilizers

In the intensive and high input farming, commercial fertilizers constitute a major chunk to provide additional plant nutrients to ensure high productivity. Several problems related to excessive fertilizer use have been identified, the most important among them being the damage caused to the environment through pollution. Pollution of soils by heavy metals especially Cd in fertilizers is receiving increased attention from environmentalists (Kosital, 1986) in view of its possible entry to animals through diet. Pollution effects associated with fertilizers can be regulated , if proper monitoring is done periodically and tangible steps taken to redress it.

Among the commercial fertilizers, rock phosphate and other soluble phosphatic fertilizers derived from them are the chief sources delivering heavy metals to cultivated soils.

The results of the study presented in the previous chapter (Table 11) have indicated that Zn is the highest contaminant in all fertilizers followed by Pb, Ni, Cd and Cu.

The values of each metal is known to change depending on the location of the primary P source and the method of chemical processing. A highly variable status of heavy metals in fertilisers has been reported by Arora *et al.* (1975), Singh and Sekhon (1977) and Mortvedt (1996). The heavy metal load of the commonly used fertilizers in Kerala is thus found to be highly variable, but shows a common pattern with regard to the abundance of each metal, Zn being the highest contaminant and Cu the least.

There exists several reports from all over the world that heavy metals applied to the soil through different fertilizers accumulate almost completely in the surface soil in forms easily available to plants (Williams and David, 1973). Mortvedt and Osborn (1982) and Rana and Kansal (1983) have shown that heavy metals in fertilizers are conspicuously more available to plants in soils with coarser texture and acidic reaction suggesting a possibility for greater plant uptake in the soils of Kerala.

It may be noted in this context that in order to monitor and restrict the entry of heavy metals to soils, Germany, US, The Netherlands, UK and Australia have set upper limits for heavy metal addition to the surface plough layer of soil on the basis of the heavy metal content especially of Cd in fertilizers (Anon, 1989).

More than contaminating the soil and bringing it to a critical level due to continuous usage, the uptake of Cd in fertilizers by crop plants is the problem of immediate concern. Eventhough plant species differ considerably in this respect, some of them are reported (Semu and Singh, 1996) to accumulate appreciable amounts of various non essential heavy metals including Cd. Because of the potentially adverse effects of Cd on human health, several studies have been focused on the uptake of Cd from fertilizers.

Williams and David (1973) have shown that top dressing cereals and pastures with triple super phosphate has resulted in their increased Cd content.

A higher level of extractable Cd in the soils receiving high levels of fertilizer is reported (Semu and Singh, 1996) to be a reflective of the long term use of phosphatic fertilizers. Mulla (1978), Mortvedt (1987), Jones and Johnsten (1989) and He and Singh (1993) have also reported elevated levels of Cd where P fertilizers were used for a long term, confirming the role of P fertilizers in the contamination of soils by Cd. As discussed before, the higher status of Cd in the continuously fertilized PME plots on rice also confirms this observation.

Heavy metals in manures

Results on the analysis of some of the manures commonly used in Kerala (Table 12) have revealed that Zn, Cu and Ni are the most abundant elements and Pb and Cd are present only in lesser amounts. Sewage sludge was found to be loaded with the highest amount of all heavy metals compared to the rest.

Vermicompost made from domestic wastes was found to contain a higher amount of heavy metals compared to that made from banana waste alone. This probably indicates a higher status of these elements in the assorted domestic wastes used for composting. Similarly, the dung from cows fed on fodder grass supplied from the sewage farm also had a higher content of these metals compared to the dung from animals not fed on fodder grass from sewage farm.

A higher status of these elements in the soils of the sewage farm as revealed from the present study has naturally resulted in this observation. The fact that a part of the heavy metals are excreted through dung, indicate a possibility of their chronic accumulation in the meat and milk of these animals also. Use of cowdung and other manures contaminated with heavy metals, in turn contaminate the soil and the crops and ensure a slow but steady cycling until finally it may accumulate in the human beings.

Eventhough the content of the most harmful element Cd appears to be low in most of the organic manures, compared to inorganic fertilizers, they may be treated as a major soil contaminant in view of their large scale use @ 5-25 t ha^{-1} against the use of only 30-100 kg ha^{-1} of the inorganic fertilizers. As long as larger inputs of organic manures are used as a waste management programme as well as in organic farming, the likelihood of heavy metal contamination of agricultural soils and food crops is also higher.

Heavy metal content in plants

Of the five elements studied, all the plant samples had the highest amount of Zn and lowest amount of Cd in them. More heavy metals were retained in the roots compared to the above ground portions. This pattern may be the

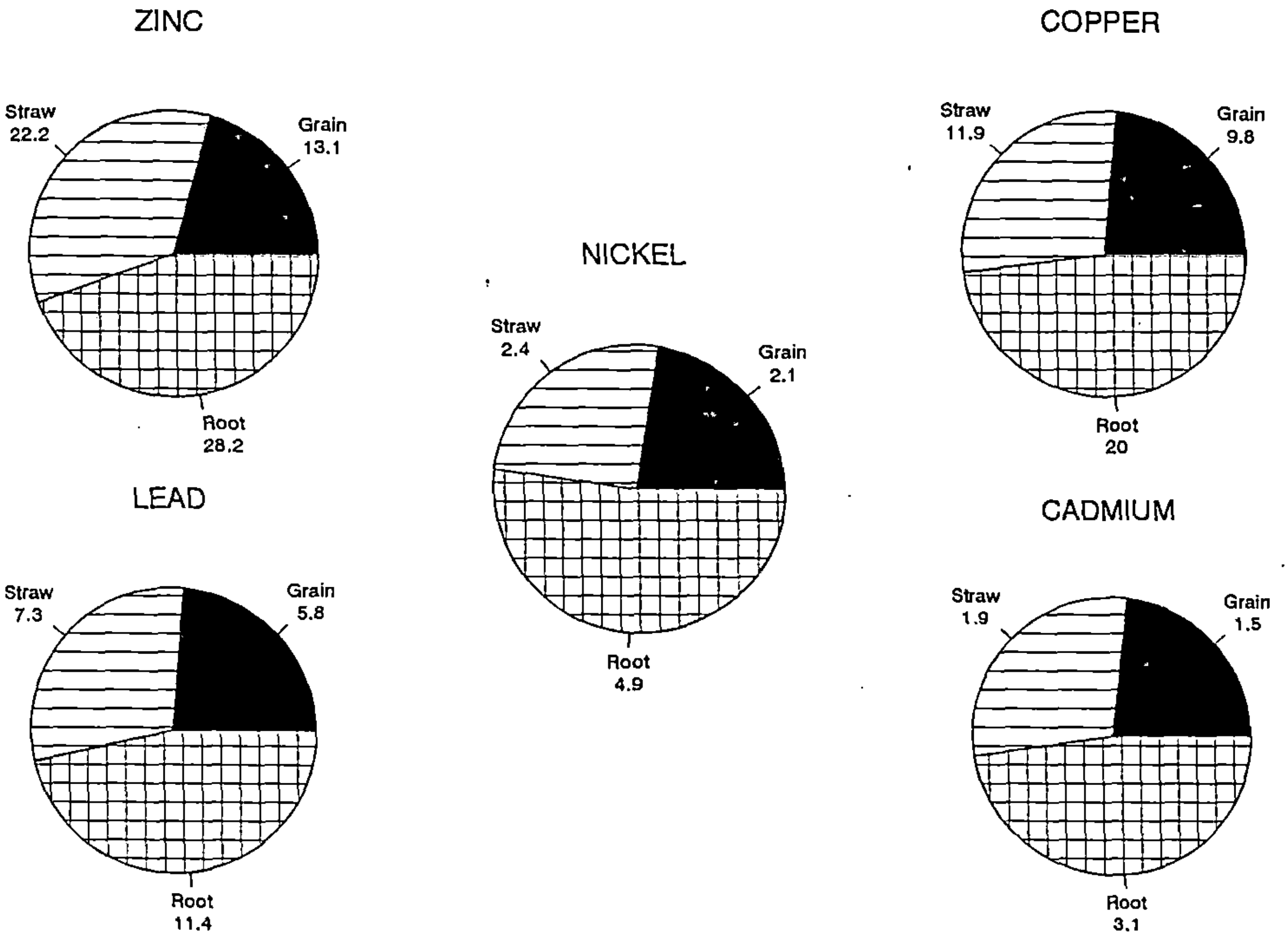

Fig. 4. Content of heavy metals in different parts of rice (mg kg^{-1})

consequence of a natural defensive mechanism where plant roots often function as detoxicating agents by immobilising and holding back elements that will be toxic to the rest of the plant. The concentration of such elements in root, according to Nicol and Beckett (1985), Guo and Marschner (1995) and Mortvedt (1996), may be considered as a more sensitive indicator of soil toxicity.

The status of heavy metals in different plants, especially in the edible parts will be discussed based on standards prescribed for food safety and phytotoxicity by different scientists in UK, Japan, GDR, US etc.

Allaway (1968) had reported the content of Zn, Cu, Pb, Ni and Cd in normal agricultural plants in the range 15.0-100.0, 4.0-15.0, 0.1-10.0 and 0.2-0.8 mg kg^{-1} respectively. According to Nicol and Beckett (1985) when the content of Cd, Cu, Ni and Zn in plants is less than 5, 10, 10 and 100 mg kg^{-1} respectively, then it is not phytotoxic.

According to food safety standard in Japan (Ito and Iimura, 1976a) Cd concentration in brown rice should not exceed 1 ppm. In GDR legislation, maximum permissible level (MPL) of Zn, Cu, Pb and Cd in vegetables (Bergmann, 1992) is fixed as 15, 5, 0.5 and 0.1 mg kg^{-1} respectively. Such food safety standards are not available in our country.

It may be seen from tables 13 to 16 that the status of heavy metals in the rice plants generally do not show much variation compared to the normal ranges suggested above and in none of samples Cd content exceed the critical level of 5 mg kg^{-1} for phytotoxicity as proposed by Nicol and Beckett (1985). In all cases, rice grains registered the lowest values compared to roots and straw, the roots showing the highest content of all heavy metals (Fig. 4). A perusal of the tables also reveal a strikingly higher content of all heavy metals in the grain, straw and

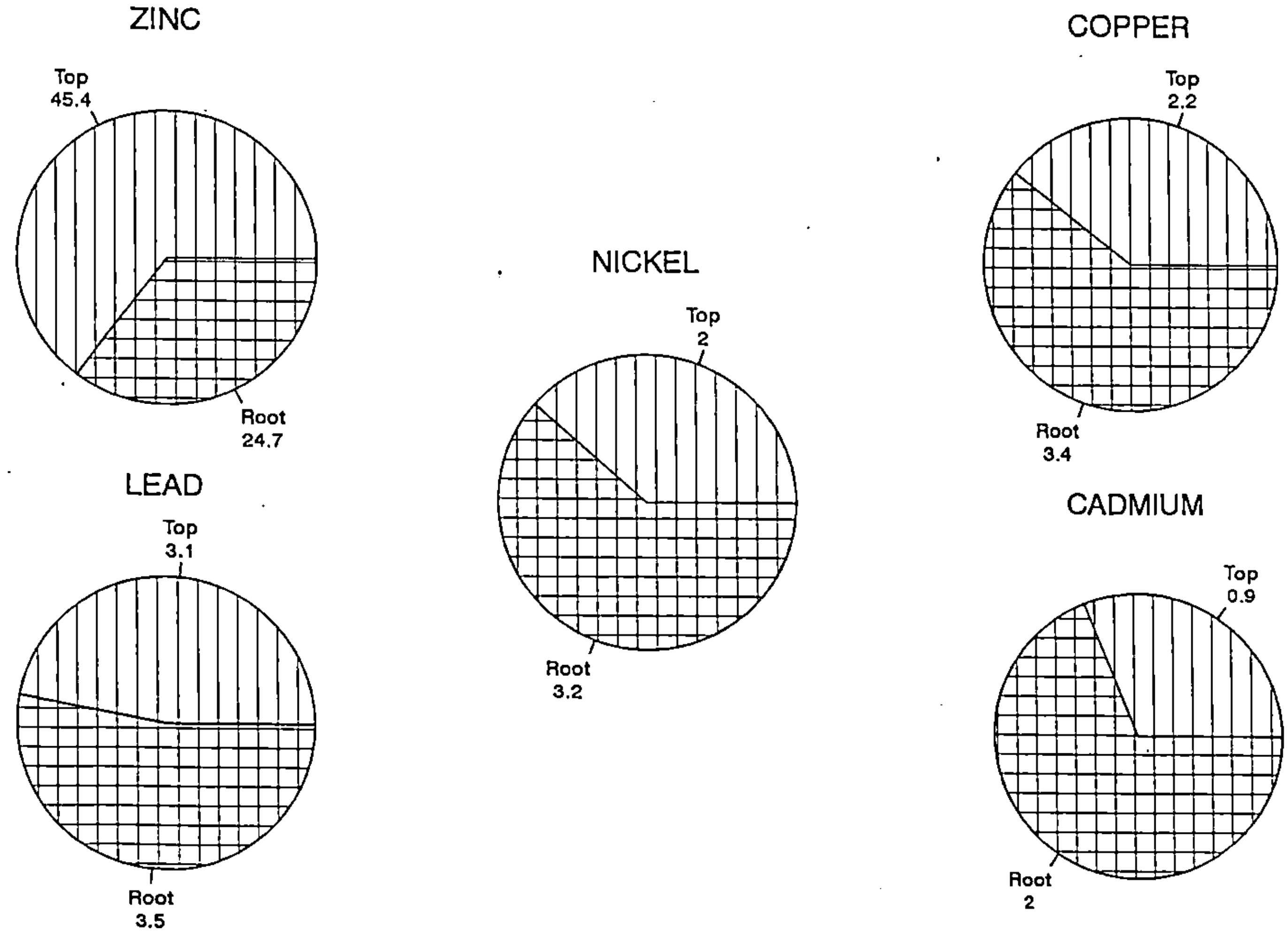

Fig. 5. Content of heavy metals in different parts of amaranthus (mg kg^{-1})

roots of rice plants collected from PME plots which were receiving a uniform level of organic manures and inorganic fertilizers continuously for the past several years.

Almost all the samples of rice grains from the different locations had 1.0 to 3.5 mg Cd kg^{-1} and exceeded the food safety standard of 1 mg Cd kg^{-1} suggested by Ito and Iimura (1976a) indicating that rice, the staple food of the people of Kerala is contaminated by Cd to a much higher level than is considered as safe. The copper content in rice grain and straw also is high and lies between 5.1 and 14.5 mg kg^{-1} and 6.8 to 18.0 mg kg^{-1} respectively and exceeds the critical level of 5 ppm proposed by Etherington (1982) to express phytoxicity.

Amaranthus

It is a leafy vegetable cultivated all over Kerala. Representative samples have a content of Cd (Table 17) ranging from 0.3 to 1.8 mg kg^{-1} in the leaf and 1.0 to 2.8 mg kg^{-1} in the roots indicating values coming much below 5 mg kg^{-1}, the phytotoxic level proposed by Nicol and Beckett (1985). However it is much above the MPL of 0.1 mg kg^{-1} proposed by Bergmann (1992) in GDR as food safety standard. Zinc content in amaranthus top (19.4 to 71.3 mg kg^{-1}) is almost double the content in root but is within the range proposed by Allaway (1968) in normal agricultural plants (Fig. 5). The levels of Cu, Ni and Pb are within the normal range cited as 5 to 20, 0.2 to 5 and 0.2 to 20 mg kg^{-1} respectively by Alloway (1990) in plants. Zn and Pb content exceeded the MPL of 15.0 and 0.5 mg kg^{-1} in vegetables according to GDR legislation (Bergmann, 1992). Cu content in within the permissible level proposed by him.

Cowpea

Cowpea is cultivated as a vegetable on a large scale by the farmers all

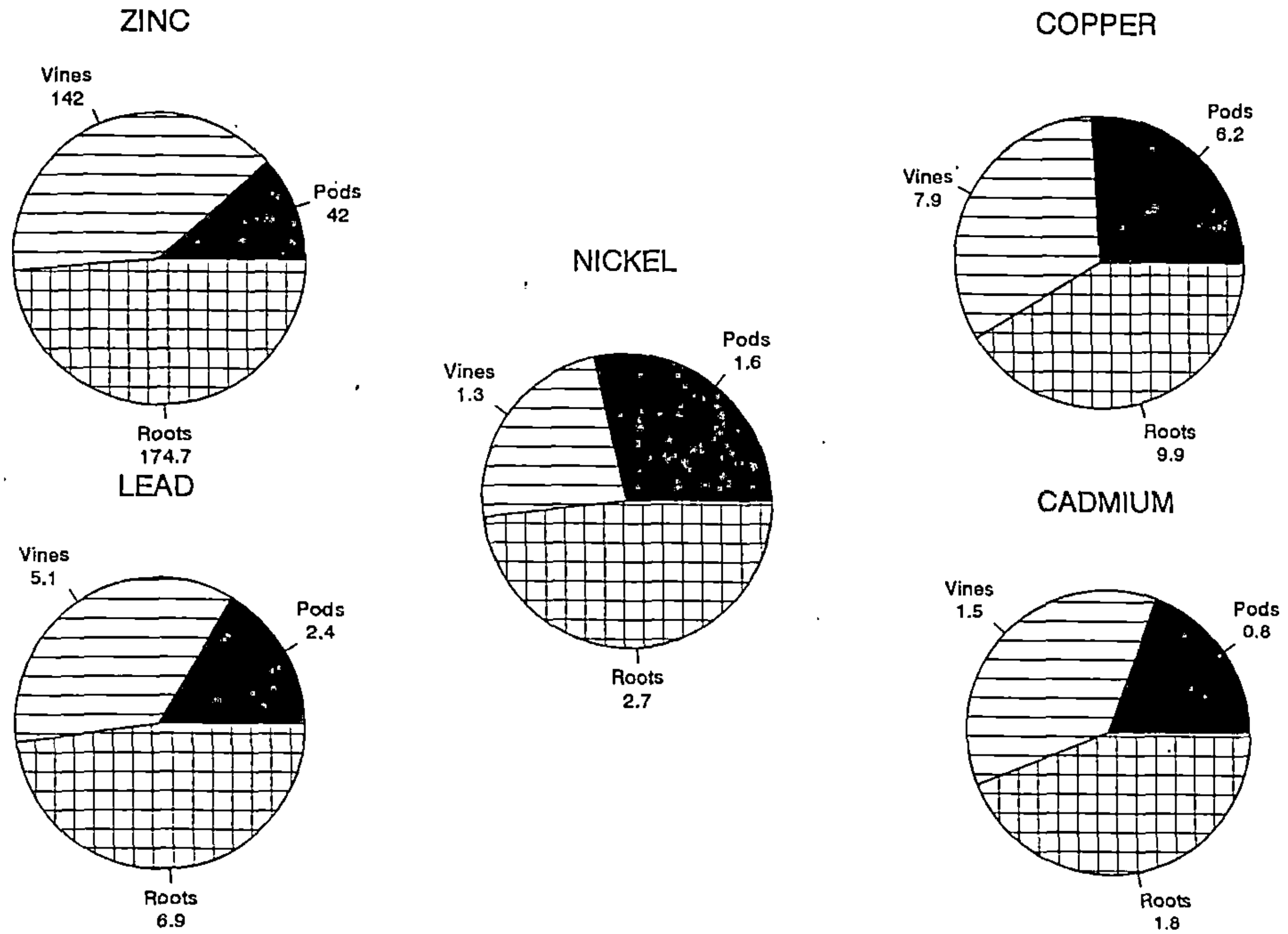

Fig. 6. Content of heavy metals in different parts of cowpea (mg kg^{-1})

over Kerala and yields about 700 kg ha^{-1} in response to the application of high levels of manures and fertilizers. Their pods, vines and roots contain a variable amount of heavy metals, the roots having the highest and pods the lowest content of Zn, Cu, Pb, Ni and Cd (Fig. 6). The content of all the five metals are within the normal range cited by Alloway (1990). As in the case of amaranthus, Zn, Pb and Cd content exceeded the GDR food safety standards for vegetables mentioned above.

Fodder Crops

Fodder crops extensively cultivated in the sewage farm, Valiyathura in Trivandrum are periodically cut and supplied to the farmers to feed their cattle. As seen from Table 10, Zn is the element present in highest quantity in them followed by Cu, Pb, Ni and Cd. Zn content varies from 0.035 per cent in subabool to 0.080 per cent in para grass, which is very much above the normal range of 1-400 mg kg^{-1} prescribed for plants by Bowen (1979) and 100 mg kg^{-1} suggested by Nicol and Beckett (1985). Copper content is also very high and varies from 11.9 to 16.9 mg kg^{-1}, coming above the critical level of 10 mg kg^{-1} suggested by them. Ni and Pb content in fodder is within the normal range of 0.02 to 5.0 and 0.2 to 20 mg kg^{-1} indicated by Bowen (1979). The most harmful element Cd is present in the range of 0.3 to 2.3 mg kg^{-1} which is below the upper limit of normal range (0.1 to 2.4 mg kg^{-1}) prescribed by Bowen (1979) for plants in general. Although the heavy metal concentration may not affect their growth in general, its use as a fodder for cattle will naturally result in a gradual accumulation of these elements in their body and may pose serious clinical problem, besides making the milk, meat and dung contaminated. The higher content of heavy metals in the dung of animals fed on fodder from the sewage farm obtained in the present study render support to this presumption.

A careful examination of the status of heavy metals in the soils, fertilizers, manures and plants selected for the study indicate that among the elements studies, Zn is the most abundant one present in fertilizers, manures and plants whereas, it is Cu that is present in the highest amount in soils. The status of an element in a soil is known to be the resultant equilibrium between addition through inputs, apart from its native content and removal through plant uptake and leaching. Fertilizers and manures contribute a substantial amount of Zn to the soil which is taken up by plants leading to a high content of Zn in them. Unlike fertilizers, organic manures are found to have a higher content of Cu and when applied at a rate of 2-25 t ha^{-1} for various agricultural crops, normally incorporates large amount of Cu in the soil. Due to the strong complexing action of Cu with organic colloids of the soil (Mc Bride, 1989) it may be retained at a higher level in the soil than Zn, which might suffer a greater loss through plant uptake as well as leaching.

Retention of applied Cd and Ni in soils

As the residence time of many heavy metals in soils is known to range from 75 to 900 years (Bowen, 1979) and a long term factor, it is important to understand their transport behaviour in soil so as to get a complete picture of their potential status in soil and availability to cultivated crops.

The retention of heavy metals in soils has been reported to be determined by the properties of the metal, the quantity and type of soil adsorption sites as well as competing and complexing cations in the soil (Alloway, 1990). Soil properties often correlated with metal adsorption include pH (Harter, 1983 and Christensen, 1984), soil CEC (Soldatini *et al.*, 1976; Harter, 1979), soil organic matter (Tyler and Mc Bride, 1982) and clay content (Korte *et al.*, 1976). The transport of reactive solutes in soil is driven by simultaneous physical and chemical process as well (Buchter *et al.*, 1996).

As a result of all these factors, the pattern of metal retention in soil is expected to be different in different soil types which show high variability with respect to the characters stated above. To understand the phenomenon of metal transport in soils, researchers have carried out laboratory experiments with large undisturbed soil cores or monoliths (Singh and Kanwar, 1991 and Buchter *et al.*, 1996); by monitoring the extent of heavy metal retention by shaking and centrifugation of small quantities of soils with solutions of different input concentration (Hinz and Selim, 1994); using ion exchange methods (Gaston and Selim, 1990) and by treating soil column with heavy metals and then eluting with different extractants (Tyler and Mc Bride, 1982). Undisturbed soil columns under steady state unsaturated flow conditions as used by Swarup and Ulrich (1994) is also a useful method.

All these studies have helped in eliciting upon some aspects of heavy metal - soil interaction and binding capacities in different soil types. Such studies also provide a basis for the prediction of likely or possible influx of heavy metals through inputs in agriculture like fertilizers and manures. However, although the extent of adsorption can be measured and isotherms calculated, it is difficult to be precise about which particular process is responsible for their retention in any soil. The behaviour of heavy metals in the different soil types of Kerala is an aspect not so far investigated in detail. The results of the studies on the pattern of retention of applied Cd and Ni in undisturbed soil columns of important soil types of Kerala, revealed from Tables 20-27 gives more insight into these aspects.

Results given in Tables 20 and 21 show that more Cd is retained in the top than in the bottom layer in all soil types. It is invariably higher when the soils were treated with FYM and decreased in the order laterite > red > sandy *Onattukara*. Basic analysis of the soils have revealed that their organic matter

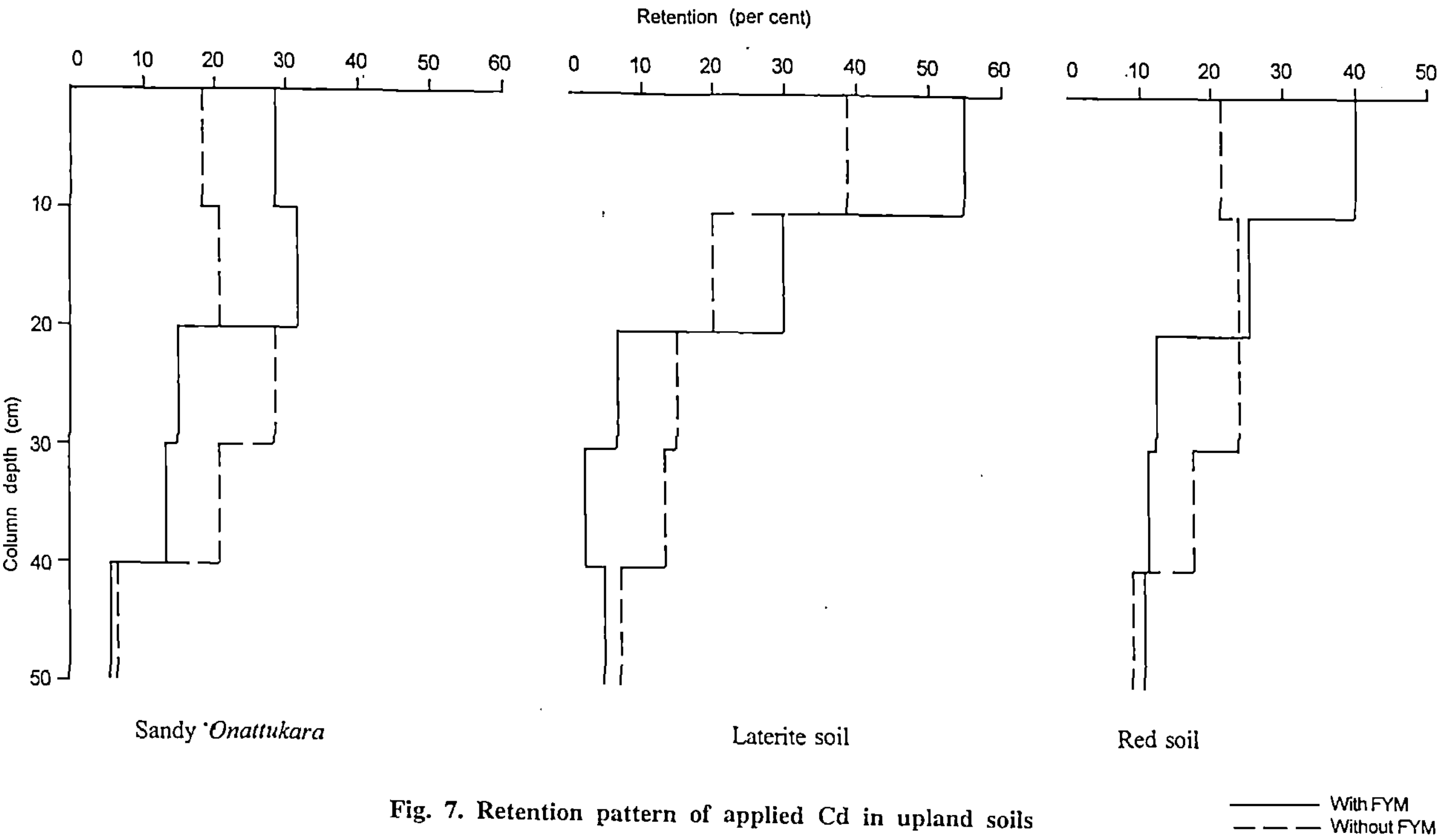

Fig. 7. Retention pattern of applied Cd in upland soils

content also decrease in the same order suggesting a possible relationship between retention of Cd and organic matter status in them. The addition of fresh organic matter in the form of FYM has further decreased their downward mobility resulting in greater retention in the top layers. It may be computed from the data in Table 20 that the upper 30 cm soil layer of laterite soil held more than 90 per cent of added Cd and it was 78 and 75 per cent in the case of red soil and sandy *Onattukara* soil with added FYM (Fig. 7).

Higher retention of Cd in the surface soils has been reported earlier by Piccolo (1989), Karapanagiotis *et al.* (1991), Basta *et al.* (1993) and Swarup and Ulrich (1994). Piccolo (1989) has attributed the increased retention capacity of added humic substances and Karapanagiotis *et al.* (1991) have specifically identified complexation reaction as responsible for greater retention of Cd.

In the completely flooded wet land soils also, a similar pattern was noticed, the leaching loss in percolating water being less in the presence of added FYM. A comparison of the extent of loss suffered in different wet land soils indicate this to be lesser in lateritic alluvial soil which has a higher pH of 5.5 compared to the kayal (pH 4.6) and kari soils (pH 3.9). Alloway (1990) has observed an increased retention of Cd in soils with increasing pH value upto 8. The high pH, combined with a moderate amount of organic matter (2.2%) clay content (38.2) and CEC (8.8 cmol(+)kg^{-1}) of the lateritic alluvial soils might have also contributed to a greater retention of Cd. These results suggest the possibility of a comparatively higher consequential adverse effect of Cd to rice in lateritic alluvial soils compared to the kayal and kari soils. This view is supported by a higher content of Cd in the grain, straw and roots of rice plants collected from the lateritic alluvial soils of the PME plots in Pattambi as presented in the preceeding sections.

It may be seen from Table 21 that leaching loss was further reduced in

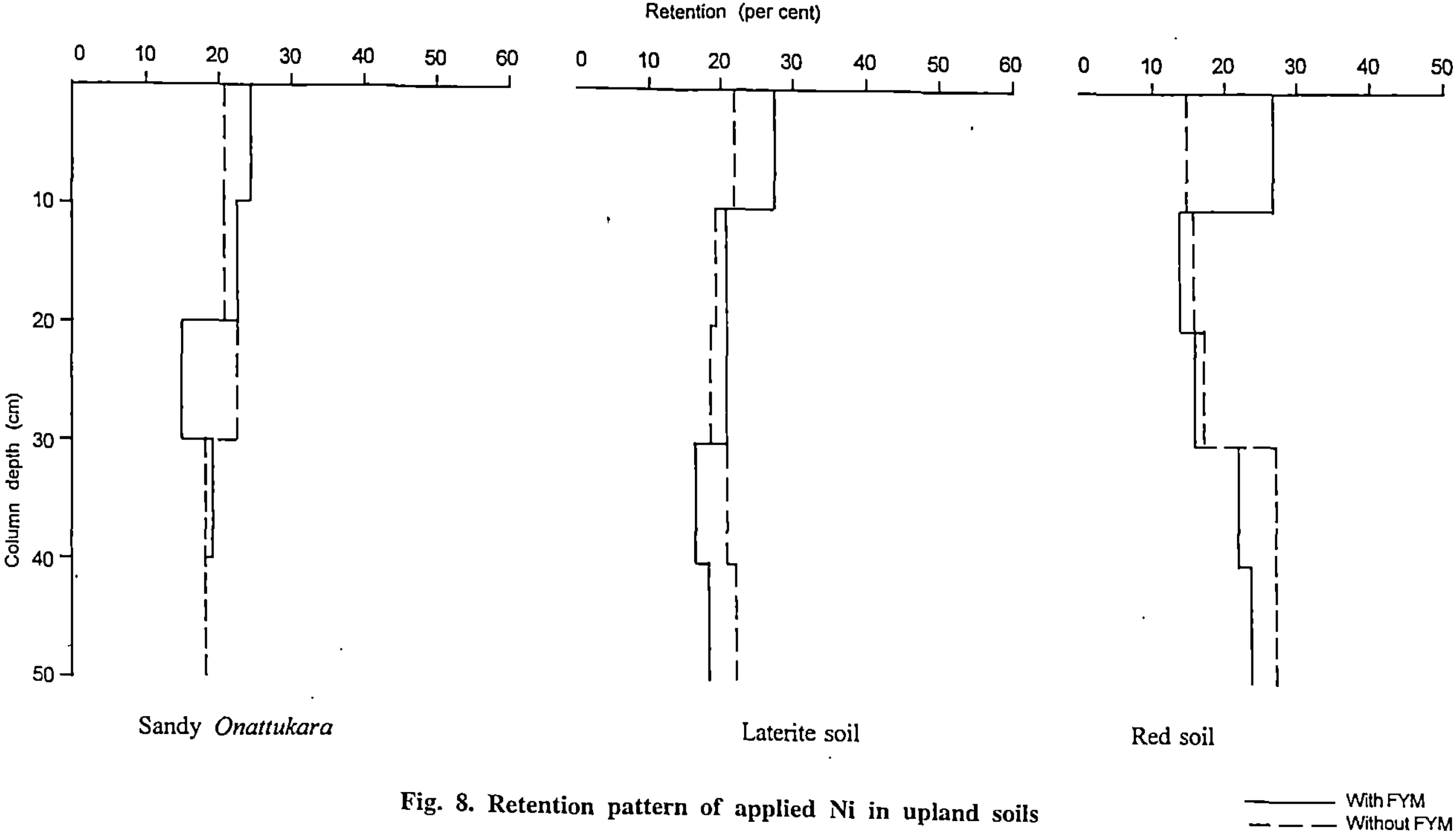

Fig. 8. Retention pattern of applied Ni in upland soils

the presence of added FYM in all these soils, inspite of a rather moderate content of initial organic matter in them. The effect may be as in the upland soils, due to the high metal binding ability of the freshly added humic substances in FYM as has been cited by Piccolo (1989).

The downward mobility of Ni in the soil column, as seen from Table 24, reveal a similar pattern as that of Cd, except that it was more uniformly distributed in the soil showing lesser difference between individual layers from top to bottom (Fig. 8). The mobility of Ni in soil thus appears to be more than Cd and is in agreement with the earlier report of Taylor and Griffin (1981). The higher mobility of Ni, compared to Cd may be explained based on the selectivity sequence for heavy metals cited by Alloway (1990) where he has stated that Ni is the least tenaceously sorbed heavy metal on the hydroxy functional groups on the edge of kaolinite crystals and Fe oxides in soils. He has given a selectivity sequence of these soil constituents for metals as Cd > Zn > Ni, indicating a preferential retention of Cd compared to Ni.

From the data given in Table 24 and 25 it may be computed that the retention of applied Ni in the upper 30 cm layer of the soil columns of the upland and wetland soils was less than that of Cd and range from 56.1 to 72.5 per cent. Anderson and Christensen (1988), have identified pH as the most important factor determining the distribution of Ni in soils.

Higher retention of Ni in the soils of higher pH, noted in the present study agrees with the report by Willaert and Verloo (1988), on the enhanced retention or lower mobility of Ni in soils of high pH.

Higher retention and lower leaching loss of applied Cd and Ni in the columns treated with FYM indicate that addition of FYM to soils is producing a negative effect on the downward mobility of Cd and Ni in general both in the upland and wetland soils studied. Accumulation of more than 55 to 85 per cent of applied Cd and Ni in the upper 30 cm of the soil column indicate that arable soils will continue to accumulate these elements in the feeding zone of plant roots. Fertilizers and manures contaminated with these elements thus tend to increase their status in the feeding zone of agricultural crops, contaminating the soil as well as crops to various extent.

Influence of applied Cd and Ni on the growth and yield of plants

Pot culture studies on rice, sesame and cowpea have very clearly revealed the specific effect of graded levels of Cd and Ni in the presence and absence of FYM, on their growth, yield, nutrient content and accumulation in various plant parts.

Although no phytotoxic symptoms could be noticed, a general reduction in growth, yield and nutrient uptake was clearly evident in the Cd and Ni treated plants. The important results obtained from the study are discussed with respect to each crop.

Rice

Effect of cadmium

The results presented in the preceding chapter (Tables 28 and 29) show that the vegetative growth characters of rice like height and number of tillers did not show any significant difference due to the effect of treatments. But, there was a significant reduction in the total dry weight as well as the most important yield components like the number of panicles and hundred seed weight resulting in a significant decrease in yield of grains. The reduction was evident at all levels of

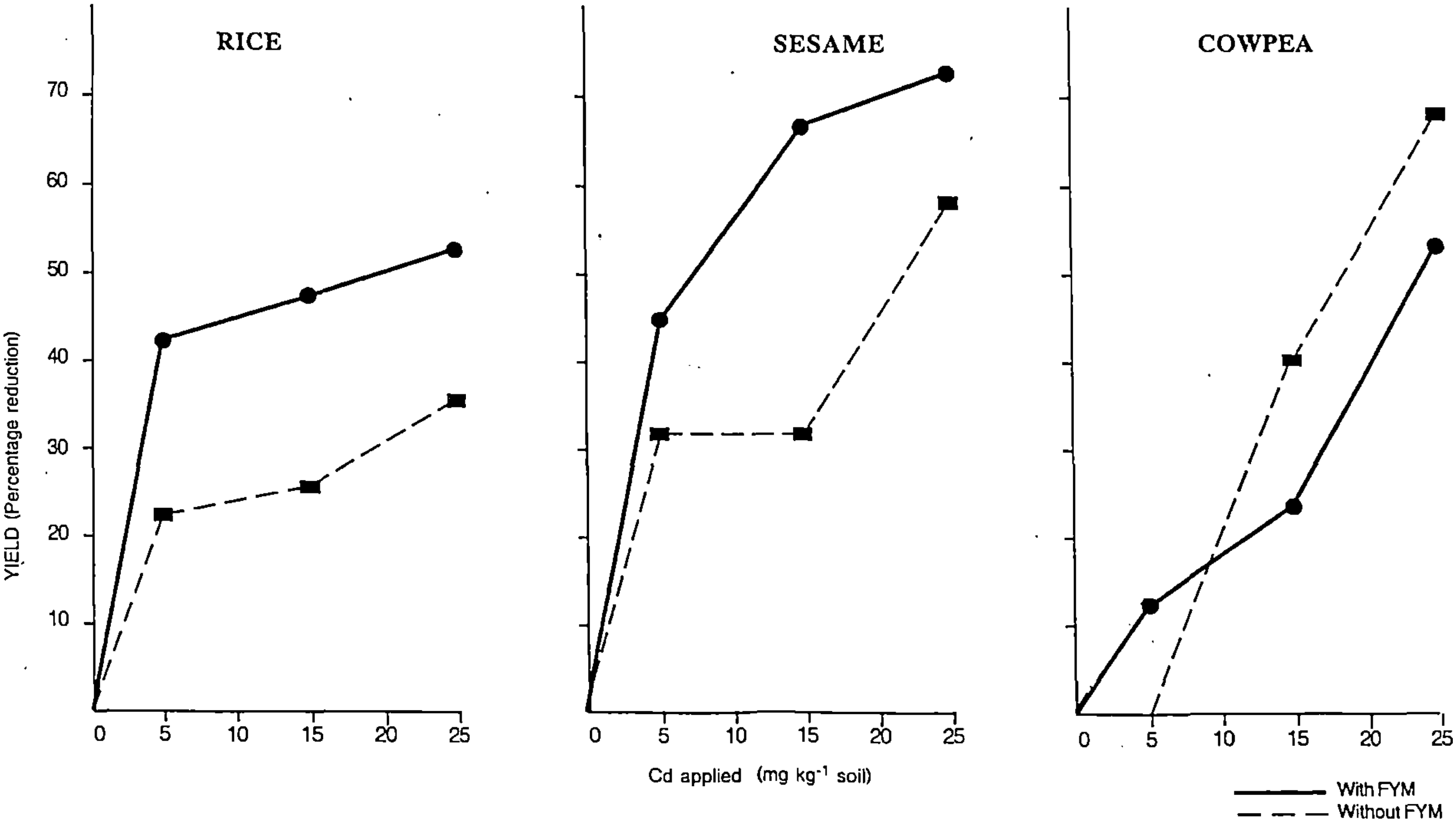

Fig. 9. Percentage yield reduction in crops as a function of Cd applied in soil

Cd applied with FYM and only with the highest level of Cd in the absence of FYM (Fig 9). The extent of reduction of all the parameters was very high in the FYM treated plants than in the corresponding treatments without FYM. FYM thus seems to aggravate the toxic effects of Cd on the growth and yield of rice plant.

The humified organic matter in FYM might have chelated Cd and permitted a higher intake as evident from Table 34 resulting in the adverse effects noticed in the FYM treated plants. A higher intake of Cd in the presence of FYM has been reported earlier by several workers. (Letunova *et al.*, 1985; Keshan and Mukherjee 1992 and Wetzel and Werner, 1995). The increase in the availability of heavy metals as a result of an increase in organic matter content has been attributed to the existence of organometallic complexes in soil solution for longer period by Sharma and Kansal (1986). Piccolo (1989) has shown that these complexes are readily accessible to plants as they could be displaced by DTPA.

Once the Cd enters the plant, as reported by Ghoshroy and Nadakavukaran (1990), it is transported throughout the metabolically active sites in the shoots where it exerts the toxic effect. The low yield and TDM obtained in Cd treated rice plants may be due to the inhibition of growth and modification of the carbohydrate assimilation and distribution as stated by Moya *et al.* (1993). Krupa *et al.* (1993) attributed the inhibition of photosynthesis in Cd polluted plants to an increased stomatal and mesophyll resistance to CO_2 uptake. Heavy metals are also reported (Shoeran *et al.*, 1991) to reduce photosynthesis indirectly through a decrease in chlorophyll content and by alteration of stomatal conductance and electron transport. Inhibition of biosynthesis of chlorophyll and the interference of primary photosynthesis are suggested to be responsible for the low dry matter production and consequent yield reduction in Cd treated plants (Shrivastava and

Singh, 1986 and Atal *et al.*, 1991). Fuhrer (1982) attributed Cd toxicity to crops as a consequence of membrane damage and inactivation of vital enzymes through reaction with SH groups of proteins. Any specific effect of Cd on decreasing the number of panicles and hundred seed weight has not so far been reported. However it implies a harmful effect of Cd on the reproductive phase of the rice plant which needs to be investigated in detail.

Nutrient content and uptake

Nutrient content and uptake in the grain, straw and root of Cd treated rice plants showed slight variation, but did not reveal any specific pattern except in the case of N which was mostly higher in the grain, straw and root. It may partly be attributed to a higher N content in pots treated with Cd where a profuse growth of N fixing BGA was observed. The increase in N content observed in the Cd treated plants may possibly be due to the accelerated sorption of various N forms from polluted soils with a consequent detoxification of heavy metal ions by protein and free amino acids as postulated by Chernykh (1991) and Yevdokimova (1994).

The total uptake of all nutrients inspite of slight variations in content remained significantly low. A variable effect of Cd and Ni on the composition of major nutrients in plants has been reported by Biddappa *et al.* (1987) Hlusek and Richter (1992) and Brune and Dietz (1995). The excessive accumulation or depletion of nutrients, which may be deleterious to plants, may be attributed to the adverse effects imparted by metal toxicity. The increase noticed in the content of some nutrients however, may be due to a concentration effect in the tissues on account of the lower dry matter produced as proposed by Knight and Crooke (1956).

Barcelo and Poschenrider (1990) have identified retardation of water uptake, indicated as heavy metal induced dehydration in cells, as a major reason for reduced content and uptake of plant nutrients. A decrease in the content of plant nutrients due to Cd treatment may also be due to the disruption of cell membrane by metal toxicity leading to disproportionate loss of cations as stated by Prasad (1995).

Cd content

Cd content in the rice grain from the absolute control pot alone appears to be within the food safety level of 1.0 mg kg^{-1} suggested by Ito and Iimura (1976a). Incorporation of FYM along with inorganic fertilizers has raised the Cd content in grain from 1.7 to 2.1. Although this is not a significant increase, a possible higher contamination of rice grain with Cd in presence of FYM is suggested. Cd content in rice straw which is used to feed cattle has significantly increased from 1.2 to 2.7 due to the use of fertilizers and FYM as recommended in the POP (T1), again indicating fertilizers and FYM as a source of Cd contamination of rice grain and straw. Treatments with graded levels of Cd with and without FYM has further raised the Cd content in grain, straw and root and it has reached the highest level in T5 receiving 25 mg kg^{-1} Cd along with FYM.

The germination of such grains (T5) is drastically reduced to less than 50 per cent, whereas grains containing 3.2 mg kg^{-1} (T8) were only slightly affected. The effect of high levels of Cd and Ni in seeds is reported to depress the activities of hydrolytic enzymes in germinating seeds and inhibit dry matter mobilisation resulting in lower rate of germination (Rani and Paliwal, 1988 and Bishnoi *et al.*, 1993). The starch content of such seeds, however, do not show any difference showing that it is not affected by Cd.

Cd content in plants (Table 34) show that it is almost double in roots and slightly higher in the straw and grain of plants treated with Cd and FYM compared to the corresponding levels of Cd without FYM. This clearly shows that FYM has mobilised more Cd into the plants and such plants have retained most of it in the roots. Retention of Cd in the roots probably acts as a defensive mechanism of the plant to restrict its translocation to the shoot and reduce harmful effects on metabolic activities. Such a gradation in Cd content from roots to grain has been reported earlier by Culter and Rains (1974), Chino (1981) and Hardiman and Jacoby (1984). Complexation of heavy metals by phytochelators and metallothionines in roots as observed by Rauser (1990), Steffens (1990), Guo and Marschner (1995) and Prasad (1995) explain these results.

Effect of Ni

The adverse effect of Ni toxicity in rice was reflected in a reduction in plant height, total number of tillers, root growth and number of filled grains in the panicle. But a significant reduction in total dry matter and yield was there only when 100 mg Ni kg^{-1} soil was applied with FYM. A tendency to decrease the number of filled grains is evident at all levels of Ni, but became significant only at this level. This effect may be due to a reduction in photosynthesis and altered translocation of carbohydrates to the grain as discussed in the case of Cd. A reduction in starch content and germination observed in this treatment also may be considered as an expression of Ni toxicity. As in the case of Cd, Ni toxicity to rice is also aggravated in the presence of FYM. Ni content of 22.9 and 36.8 mg kg^{-1} observed in the grain and straw of such plant (Table 34) may therefore be considered as an upper critical level for imparting these adverse effects. This level, however is much above the critical level of 5-10 mg kg^{-1} for phytotoxicity prescribed by Nicol and Beckett (1985) and Etherington (1982). Retention of high amount of Ni in the roots, may be considered as a defensive mechanism to restrict the translocation of Ni into the above ground tissues as in the case of Cd. The mechanisms of differential retention of Cd/Ni in plant roots is not clear. According to Culter and Rains (1974) they may be bound to the cell walls, precipitated in roots as oxalate (Van Balan *et al.* 1980) or sequestered in Cd/Ni bearing granules in the cytoplasm and vacuoles as postulated by Rauser and Ackerlay (1987).

Sesame

The effect of Cd and Ni on the biometric and yield characters of sesame shows that it is a very sensitive plant compared to rice, where the addition of even 5 mg kg^{-1} Cd or Ni has resulted in a severe set back in almost all growth parameters and yield components reducing TDM as well as yield (Fig. 9). Sesame is a small shrub which normally produce a low dry matter and yield about 250 kg seeds ha^{-1}. Inspite of the low dry matter synthesis, plant in the control treatments (T0, T1 and T2) have absorbed more than an equal amount of Cd in the grain, stover and roots and very much more in the treated plants compared to rice in similar treatments. Such a high intake of Cd, leading to adverse physiological conditions might be responsible for the very low growth and yield. Plants are known to differ in their capacity to absorb cations and some physiological properties of the sesame plant might have prompted a higher intake of Cd compared to rice. A differential capacity of plant species and genotypes in their absorption and translocation of heavy metals has been reported by Petterson (1977), Woolhouse (1983) and Guo and Marschner (1995). As in the case of rice, intake of Cd is promoted by FYM indicating its role in aggravating Cd toxicity.

It may be seen from the results (Table 46) that Ni content in plant parts of sesame is very much lower than that of Cd eventhough similar levels of both elements were applied. Toxic effects of Ni was prominent even in plants not treated with FYM. The adverse effect of Ni was expressed at a lower level compared to Cd indicating that sesame is more sensitive to Ni than Cd.

While germination of sesame seeds was not seriously affected by Cd or Ni, the oil content was significantly reduced. Poor carbohydrate assimilation due to the reasons discussed earlier in the case of rice might have naturally reduced lipid synthesis and ultimately reduced the oil content in seeds. It may be noted that the weight of seeds was also significantly low in Cd and Ni treated plants. These results are in agreement with the finding of Kumar (1992) that Ni is very poisonous to plants even at low levels. As the stover of sesame is not used as a fodder, the high content of Cd in them may not be a problem as in the case of rice straw. Even sesame seeds in the absolute control and the other standard control had a very high content of Cd of the order of 3.2 to 4.7 mg kg^{-1}. The sesame seed cake, obtained after the extraction of nearly 50 per cent oil, will automatically register double the values of Cd which is much above the safety level of 0.5 mg Cd kg^{-1} feed on dry basis, proposed by Miller *et al.* (1995) prescribed for cattle feed and render the cattle suceptible for Cd poisoning.

Cowpea

Results of the pot culture experiment have very clearly revealed the adverse effect of not applying FYM along with inorganic fertilizers on the reduction in growth (Plate IV) and yield (Fig. 9) as well as nodulation and N content (Table 53) in cowpea. It may be also noted that, in the absence of FYM, lower levels of Cd tended to improve slightly the process of nodulation and other features and a higher level of 25 mg Cd kg^{-1} soil imparted its toxic effect to a greater extent than in the case of rice and sesame of comparable levels (Fig. 9).

At the same time, with FYM, the adverse effect of Cd became prominent even at the lowest level as seen from the significantly lower values for plant height, weight of root and shoot and number and weight of nodules at maximum flowering as well as yield and other characters at harvest. These results very clearly indicate the influence of FYM in inducing toxic effects of Cd even when it is present only at a low level. The role of FYM, as discussed earlier in assisting the uptake and mobilisation of Cd in plants to metabolic sites is evident in this case also. However, the negative effects of Cd on cowpea even in the presence of FYM were very much less at 5 and 15 and only at 25 mg Cd kg^{-1} soil, it decreased more than 50 per cent yield as in rice and sesame (Fig. 9). This shows that cowpea is more tolerant to Cd and a higher intake in plant tissues may not often be reflected in poor yield.

It also appears from the results that a low level of Cd is capable of overcoming the adverse effects due to the lack of FYM especially on nodulation (Plate III) and nitrogen content in root nodules as these characters were significantly improved in such treatments without FYM (T6 and T7). The crude protein content in cowpea grain at the lowest level of Cd without FYM also have registered a significantly higher value. Thus Cd appears to exert some not yet clearly understood physiological function in the nodulation and N fixation in cowpea. A similar observation on the stimulation of growth in cyanobacteria (BGA) is recently reported by Kapoor *et al.* (1998) where they have recorded a higher growth rate of BGA in culture solution under laboratory conditions. The profuse growth of BGA observed in the pots of Cd treated rice plants in the present study also lends support to this postulation.

A general reduction in nutrient content and uptake (Tables 59, 60 and 61) in the Cd treated cowpea plants followed a similar trend as in rice and sesame suggesting the existence of a similar mechanism of interaction of Cd in the physiological and metabolical activities of cowpea.

Cd content in the plant at maximum flowering stage was higher in Cd + FYM treated plants and this trend continued at harvest also. Partitioning of Cd in the plant parts was in the order root > haulm > grain as in other crops. Cd content in grain of control plants ranged from 1.2 - 1.7 which is slightly above the food safety level prescribed for vegetables. Cd content of 3.8 to 6.0 at the maximum flowering stage in the Cd treated plants was sufficiently high to exert harmful effects on carbohydrate synthesis and translocation finally leading to reduced TDM and yield as discussed in the case of rice and sesame. However, it has not affected the germination of seeds.

Application of lower levels of Ni to cowpea in the absence of FYM has also produced a non significant increase in the number of nodules and a significant increase in their weight and N content, suggesting a tendency of Ni in ameliorating the adverse effect of inorganic fertilizers in the absence of FYM as seen in the case of Cd.

An increase in nitrogen fixation due to the stimulation of nitrogenase and hydrogenase activity by the presence of Ni at low concentration in root nodules has been reported by David *et al.* (1985) and Vasundhara *et al.* (1997). Rees and Bekheet (1982) have observed that break down of ureids formed during N fixation produce urea which accumulate in Ni deficient plants and depress the activity of hydrogenase enzyme involved in nitrogen fixation. This process may probably maintain the activity of hydrogenase enzyme and lead to more nitrogen fixation in the presence of Ni.

Increase in crude protein content in cowpea grain at low levels of Cd and Ni (Table 62) may be the result of the high nitrogen content in the root nodules which was utilised by the crop. It may also be due to an accelerated sorption of N compounds by roots inorder to detoxify heavy metals by protein, free amino acids and nitrogen compounds as suggested by Yevdokimova (1994).

The high content of Ni in cowpea grain has not much affected its crude protein content or percentage germination unlike the case in sesamum or rice. Difference in plant species towards tolerance to heavy metal toxicity as stated by Guo and Marschner (1995) holds good under these situation also. Ni content in top and root of cowpea was greater than Cd, but the toxic effects on growth and yield parameters were of lesser magnitude compared to Cd. A stimulatory effect of Ni at low levels on growth and yield of plants as reported by Dalton *et al.* (1988), Hopkins (1995) and Singh (1995) is observed here also.

SUMMARY

SUMMARY

A detailed investigation was made to assess the status of heavy metals (Zn, Cu, Pb, Ni and Cd) in the soils and plants (rice, amaranthus, cowpea and fodder crops) as well as in some of the phosphatic fertilizers and manures by taking random samples from selected locations in Kerala. The retention pattern of applied Cd and Ni in the major soil types (upland and wetland) was also monitored in undisturbed soil columns and the specific effect of these two elements on three important crops (rice, sesame and cowpea) was studied in pot culture. The salient results emerged from the studies are summarised here under.

- Data on the status of Zn, Cu, Pb, Ni and Cd in 40 samples of wetland rice soils and 30 samples of upland soils revealed that Cu is the most abundant heavy metal in them followed by Zn, Ni, Pb and Cd. The DTPA extractable form is only a minor part of the total content.

- The status of Cu is high and above the critical level for phytotoxicity in the vegetable plots of Pathanamthitta and Alappuzha districts and wetland soils of the rice PME plots in Moncompu, Kayamkulam and Pattambi. High Cu contamination in Pathanamthitta district appears to have originated from Bordeaux mixture applied to adjacent rubber plantations in addition to the residual effect from fertilizers and manures used. Excessive Cu is likely to affect soil biochemical processes related to soil fertility.

- Status of Zn is within normal range and that of Ni and Pb is very low, except in the sandy soils of the sewage farm, Valiyathura where a likelihood of phytotoxicity exists due to excessive Ni content.

- The average content of Cd, the most hazardous element for human health is highest in the sewage farm soil followed by the upland and wetland rice soils. In some individual samples it exceeds the normal and critical levels proposed.

- The observation that the PME plots receiving high levels of organic manures and fertilizers had the highest and absolute control plots with no inputs at various locations the lowest status of all heavy metals tends to identify manures and fertilizers as the chief agents in contaminating cultivated soils of Kerala with these heavy metals.

Data on the heavy metal composition of fertilizers and manures have helped to arrive at the following conclusions :

- Rock phosphate and soluble P fertilizers derived from them (SSP and Factamphos) are major sources delivering heavy metals to cultivated soils, Zn being the highest contaminant followed by Pb, Ni, Cd and Cu.

- The highest content of the most dangerous element Cd is noticed in SSP and Factamphos and a much lower content of Cd is present in 17-17-17 complex.

- Commonly used manures are also rich in Zn, Cu and Ni, but have only a lesser amount of Pb and Cd. Sewage sludge recorded the highest content of all the metals and vermicompost made from assorted domestic wastes has a higher heavy metal load compared to that made from banana wastes alone.

- Dung from animals fed on fodder grass from sewage farm has a higher load of heavy metals compared to the dung from other animals.

- In view of the use of huge quantities of organic manures compared to inorganic fertilizers for various crops, the likelihood of heavy metal contamination of agricultural soils and food crops is more from organic manures.

As long as large inputs of organic manures are recommended as a waste management programme as well as in the currently popular system of organic farming, heavy metal contamination especially with hazardous elements of the soil and crop is inevitable.

The heavy metal content in the plant samples collected from selected locations for soil samples collection have also yielded valuable information as summarised below.

- All plant samples have the highest load of heavy metals in the root and least in grain, with Zn ranking highest and Cd lowest in status.
- Rice plants from the PME plots receiving a uniformly high level of organic manures and inorganic fertilizers for a long period recorded the highest content of all heavy metals in their roots, straw and grain.
- Almost all samples of rice grains exceeded the food safety standard of 1 mg Cd kg^{-1} indicating that rice, the staple food of the people of Kerala is contaminated with Cd, the most hazardous heavy metal for human health.
- Cu content in rice grain and straw is also high and exceeds the critical level proposed to express phytotoxicity.
- None of the heavy metals are present at phytotoxic levels in amaranthus and cowpea. However, the content of Cd, Pb and Zn in these crops is much above the food safety standards in GDR.
- The fodder plants from the sewage farm are found to be heavily contaminated with these heavy metals and animals feeding on them are likely to be exposed to their unfavourable clinical and physiological effects. The meat and manure from them also are likely to be contaminated with such heavy metals.

The pattern of retention of applied Cd and Ni in the undisturbed soil column of typical soils of Kerala revealed the following :

- Downward movement of Cd and Ni in soils was slow and 55-85 per cent were retained in the upper 30 cm soil column.

- Addition of FYM to the soil resulted in lesser downward movement and greater retention of Cd and Ni in the upper soil layers.

- Leaching loss of Cd and Ni was also less in flooded soil column in the presence of FYM.

- In the upland soil types, retention pattern in the upper 30 cm of soil column was in the order laterite > red > sandy *Onattukara* soil and in the case of wetland soils, the pattern was lateritic alluvium > *kayal* > *kari* soils.

- Ni was more mobile in soils than Cd.

- Greater accumulation of Cd and Ni in the upper 30 cm of the soil column indicated that arable soils will continue to accumulate these elements in the feeding zone of plant roots.

The specific effect of graded levels of Cd and Ni in the presence and absence of FYM, on the important growth and yield characters, nutrient content and accumulation in various plant parts of rice, sesame and cowpea are summarised.

- A significant reduction in the total dry weight as well as the most important yield components like number of panicles and hundred seed weight resulting in a significant decrease in yield was seen in rice at all levels of Cd when applied with FYM and only with the highest level in the absence of FYM.

- Nutrient content of the grain, straw and root of Cd treated rice plants showed slight variation, but did not reveal any specific pattern except in the case of N which was mostly higher in the grain, straw and root.

- Cd content in rice grain and straw from the control plants was in the range of 1.0 to 2.1 and 1.2 to 2.7 mg kg^{-1} respectively. Treatments with graded levels of Cd with and without FYM further raised the Cd content in grain. Cd content in grain was 6.3 mg kg^{-1} when 25 mg kg^{-1} Cd was applied along with FYM and seed germination was reduced to more than 50 per cent in this case.

- Cd content is almost double in rice roots and slightly higher in the straw and grain of plants treated with Cd and FYM compared to the corresponding levels of Cd in the absence of FYM.

- Reduction of total dry matter and yield of rice due to Ni treatment was significant only when 100 mg Ni kg^{-1} soil was applied with FYM. A reduction in starch content and germination of seeds was noticed in this treatment. Ni content of 22.9 and 36.8 mg kg^{-1} observed in the grain and straw of such plants may therefore be considered as an upper critical level for imparting adverse effects.

- The effect of Cd and Ni on sesame showed its higher sensitivity compared to rice and addition of even 5 mg kg^{-1} Cd and Ni resulted in significant reduction in growth and yield.

- Compared to rice, intake of Cd by sesame was higher and it was promoted in the presence of FYM. Eventhough the intake of Ni is much less compared to Cd, its toxic effects were more, suggesting a greater sensitivity of sesame to Ni than Cd.

- While germination of sesame seeds obtained from treated plants was not seriously affected by Cd or Ni, they reduced the oil content significantly.

- Nodulation and yield of cowpea showed a remarkable decrease when inorganic fertilizers were applied in the absence of FYM. A low level of Cd appeared to be capable of overcoming this adverse effect.

- Cd content in cowpea at maximum flowering stage was higher in Cd + FYM treated plants and this trend was continued at harvest also. Germination of seeds from Cd treated plants was not adversely affected even at a Cd content of 2.8 mg kg^{-1} in seeds.

- Application of lower levels of Ni to cowpea in the absence of FYM produced significant increase in the weight and N content of nodules in cowpea at maximum flowering stage.

- Ni content in top and root of cowpea at maximum flowering was higher than Cd, but the toxic effect on growth and yield parameters were of lesser magnitude compared to Cd.

- A general reduction in growth, yield and nutrient uptake was clearly evident in all crops due to Cd and Ni treatment and these effects were aggravated in the presence of FYM. It also favoured the intake of Cd and Ni by plants and partitioned in the plant parts in the order root > shoot > seed in all the three crops.

A critical analysis of the status of Cu, Zn, Ni, Pb and Cd in soils give room for concern with regard to Cu, which may affect soil fertility and Cd, in view of its potential toxicity to human health. Considering the higher retention of Cd in the top soil contaminated from fertilizers and manures, regulatory steps are to be taken to prevent its entry into soil and other biological systems through agricultural inputs. Considering the enhancing effect of FYM in promoting soil retention and plant intake of Cd, FYM application cannot be recommended as an ameliorative measure in heavy metal polluted soils.

Among the three crops studied, sesame was found to be the highest accumulator of Cd. Further studies have to be taken up to monitor the status of Cd in sesame seeds, oil and the oil cake considering the food safety of humans and cattle. In choosing crops for polluted soils, such accumulator species have to be avoided. In the light of the high status of some of the dangerous heavy metals in soils and plants as revealed from the study, it is imperative to fix standards for their maximum permissible limit in food grains, vegetables and fodder in our country also as in the case of US, UK, Japan, The Netherlands and Germany.

REFERENCES

REFERENCES

Adriano, D.C. 1986. *Trace Elements in the Terrestrial Environment.* Springer Verlag, New York, pp. 1-84

*AL-Helal, A.A. 1995. Effect of Cd and Hg on seed germination and early seedling growth of rice and alfalfa *J. University Kuwait* 22(1) : 76-83

Allaway, W.H. 1968. Agronomic controls over environmental cycling of trace elements. *Adv. Agron.* 20 : 235-274

Allen, H.E. 1993. The significance of trace metal speciation for water, sediment and soil quality criteria and standards. *Science of the Total Environment.* 93 : 23-45

Allinson, D.W. and Dzialo, C. 1981. The influence of lead, cadmium and nickel on the growth of ryegrass and oats. *Pl. Soil* 62 : 81-89.

Alloway, B.J. 1990. *Heavy metals in soils.* Blackie, Glasgow, p. 330.

*Almas, A., Singh, B.R. and Sveistrup, T.E. 1995. The impact of the nickel industry in Russia on concentrations of heavy metals in agricultural soils and grass in sor-varanger, Norway. *Norwegian J. agrl. Sci.* 9 : 1-2, 61-74

Anderson, P.R. and Christensen, T.H. 1988. Effect of pH and CEC on heavy metal distribution in soil. *J. Soil Sci.*. 39 : 37-52

Anderson, A. and Nielson, K.O. 1976. Influence on the level of heavy metals in soil and plant from sewage sludge used as a fertilizer. *Swedish J. agric. Res.* **6** : 151-159.

Anon. 1989. Cadmium in phosphates : One part of a wider environmental problem. *Phosphorus and potassium* 162(4) : 23-30

AOAC. 1980. *Official and tentative methods of Analysis.* Association of Official Agricultural Chemists, Washington, p. 721.

Arora, C.L., Nayyar, V.K. and Randhawa, N.S. 1975. Note on secondary and micronutrient contents of fertilizers and manures. *Indian J. agric. Sci.* 45 : 80-85

Atal, N., Saradhi, P.P. and Mohanty, P. 1991. Inhibition of the chloroplast photochemical reactions by treatments of wheat seedlings with low concentrations of cadmium - Analysis of electron transport activities and changes in fluorescence yield. *Pl. Cell Physiol.* 32 : 945-951

Azad, A.S. 1981. Pollution of agricultural land from sewage and industrial wastes. Ph.D thesis, Punjab Agricultural University, Ludhiana.

Barcelo, J. and Poschenreider, C. 1990. Plant water relations as affected by heavymetals, a review. *J. Pl. Nutr.* 13 : 1-37

Basta, N.T., Pantone, D.J. and Tabatabai, M.A. 1993. Path analysis of heavy metal absorption by soil. *Agron. J.* 85 : 1054-1057

Baath, E., Frostegard, A., Diaz-Ravina, M. and Tunlid, A. 1998. Microbial community based measurements to estimate heavy metal effects in soil. Ambio 27 : 58-61

Bauchauer, M.J. 1973. Contamination of soil and vegetation near a zinc smelter by zinc, cadmium, copper and lead. *Environ. Sci. Technol.* 7 : 131

Becerril, J.M., Murua, G.C., Rueda, M.C. and De Felipe, M.R. 1989. The changes induced by cadmium and lead in gas exchange and water relations of clover and lucerne. *Pl. Physiol. Biochem.* 27 : 913-918

Bengtsson, G., Gunnarsson, T. and Rundgrens. 1986. Effects of metal pollution on the earthworm, *Dendrobaena rubida* in acidified soils. Water Air Soil Pollut. 28 : 361-383

Bergmann, W. 1992. *Nutritional Disorders of Plants*. Gustav, New York, pp. 282-331

Berthelsen, B.O. and Steinnes, E. 1995. Accumulation patterns of heavy metals in soil properties as affected by forest clear cutting. *Geoderma* 66 : 1-14

*Bezvodova, B. 1995. The mobility of heavy metals in soils in the krusne hory and slavkovsky loss mountains. *Environmental Monitoring Assessment* 34(2) : 163-166

*Bhagat, R. 1992. Water in tannery polluted. Indian Express, May 27, 1992, Chandigarh.

Bhatia, N.L., Yadav, S.N. and Agarwal, R.P. 1990. Pollution problems of sugar industry. *Recent Advances in Environmental Pollution and Management.* Haryana Agricultural University, Hisar, pp. 147-152

Biddappa, C.C., Khan, H.H., Joshi, O.P. and Manikandan, P. 1987. Effect of root feeding of heavy metals on the leaf concentration of P, K, Ca and Mg in coconut. *Pl. Soil.* 101 : 295-297

Bilski, J.J. and Alva, A.K. 1995. Transport of heavy metals and cations in a fly ash ammended soil. *Bull. Environmental Contamination Toxicology*, University of Florida, 55 : 502-509.

Bingham, F.T., Page, A.L., Mahler, R.J. and Ganje, J.J. 1975. Growth and Cd accumulation of plants grown in a soil treated with Cd enriched sewage. *J. environ. Qual.* 4 : 207-211

Bingham, F.T., Page, A.L., Mahler, R.J. and Ganje, J.J. 1976. Cadmium availability to rice in sludge amended soil under flood and non-flood culture. *Soil Sci. Soc. Am. J.* 40 : 715-722

*Bishnoi, N.R., Sheoran, I.S. and Singh, R. 1993. Effect of cadmium and nickel on mobilisation of food reserves and activities of hydrolytic enzymes in germinating pigeon pea seeds. *Biologia plantarum* 35 : 583-589

Bjerre, G.K., Schierup, H.H. 1985. Influence of water logging on availability and uptake of heavy metals by oat grown in different soils. *Pl. Soil* 88 : 45-56

Bolt, G.H. and Bruggenwert, M.G.M. 1978. *Soil Chemistry A Basic Elements.* Elsevier Scientific Publishing Company, New York p. 280.

*Boluda, R., Andreu, V., Gilabert, M.A. and Sobrino, P. 1993. Relationship between reflectance of rice crop and indices of pollution by heavy metals in soils of Albufera a natural park, valencia, Spain. *Soil Technol.* 6 : 351-363

Bould, C., Hewitt, E.J. and Needham, P. 1984. *Diagnosis of Mineral Disorder in Plants.* Chemical Publishing, New York, pp. 248-295

Bowen, H.J.M. 1979. *Environmental Chemistry of the Elements.* Academic Press, London. p. 1-284

Brallier, S., Harrison, R.B., Henry, C.L. Yue, D.S. 1996. *Water Air Soil Pollut.* 86 : 195-206

Bridges, E.M. 1989. Polluted and contaminated soils. *A. Rep.* ISRIC, The Netherlands, 6-23

Brown, S.L, Chaney, R.L., Angle, J.S., and Baker, A.J.M. 1995. Zinc and cadmium uptake by hyper accumulator, *Thlaspi caerulescens* grown in nutrient solution. *Soil Sci. Soc. Am. J.* 59 : 125-133

Brune, A. and Dietz, K.J. 1995. A comparative analysis of element composition of roots and leaves of barley seedlings grown in the presence of toxic cadmium, molybdenum, nickel and zinc concentrations. *Pl. Nutr.* 18 : 853-868

Brummer, G.W., Gerth, J. and Tiller, K.G. 1983. Reaction kinetics of adsorption and desorption of nickel, zinc, calcium by geothite. 1. Adsorption and diffusion of metals. *J. Soil Sci.* 39 : 37-52

Buchauer, M.J. 1973. Contamination of soil and vegetation near a zinc smelter by zinc, cadmium, copper and lead. *Environ. Sci. Technol.* 7 : 131

Buchter, B., Hinz, C., Gfeller, M. and Flubler, H. 1996. Cadmium transport in an unsaturated stony subsoil monolith. *Soil Sci. Soc. Am. J.* 60 : 716-721

Cataldo, C.D., Garland, T.R. and Wildung, R.E. 1983. Cadmium uptake kinetics in intact soybean plants. *Pl. Physiol.* 73 : 844-848

Chaney, R.L. 1973. Crop and food chain effects of toxic elements in sludges and effluents. *Recycling Muncipal Sludges and Effluents on Land.* National Assoc. State Univ. and Land Grand Coll., Washington, pp. 129-141

Chaney, R.L. 1983. Potential effects of waste constituents on the food chain. *Land Treatment of Hazardous Wastes* (ed. Parr, J.F.) Noyes Data Corp. Park Ridge, New Jersey, pp. 50-76

Chaney, W.R., Strickland, R.C. and Lamoreaux, R.J. 1977. Phytotoxicity of cadmium inhibited by lime. *Pl. Soil* 47 : 275-278

Chatterjee, R.K. and Rathore, G.S. 1974. Plant available copper in black soils of Madhya Pradesh and its relationship with soil and clay mineral properties. *J. Indian Soc. Soil Sci.* 22 : 383-385

Chen, S.L. and Kao, C.H. 1995. Cd induced changes in proline level and peroxidase activity in roots of rice seedlings. *Plant Growth Regulation* 17 : 67-71

Chernykh, N.A. 1991. Alteration of the concentrations of certain elements in plants by heavy metals in the soil. *Soviet Soil Sci.* 23(6) : 45-53

Chino, M. 1981. Metal stress in rice plants, *The Heavy Metal Pollution in Soils in Japan* (eds. Kitagishi, K. and Yamane, I.). *Jap. Sci. Soc.* Press, Tokyo, pp. 65-80

*Chrenekova, E., Polacek, S. and Brabcova, M. 1987. Evaluation of power station waste from the aspect of possible contamination of soils by heavy metals. Part II, Pol' nohospodarstvo 33 : 646-654.

Christensen, T.H. 1984. Cadmium soil sorption at low concentrations - effect of lime, cadmium load, pH and calcium. *Water Air Soil Pollut.* 21 : 105-114

Cochran, W.G. and Cox, G.M. 1962. *Experimental Designs.* John Wiley and Sons, New York. p. 611

Cong, T. and Tu, C. 1996. Study on transfer of Ni in soil plant system using ^{63}Ni tracer method. *Pedosphere* 6 : 273-278

Crooke, W.M. 1956. Effect of soil reaction on uptake of Ni from a serpentine soil. *Soil Sci.* 81 : 269-276

Culter, J. and Rains, D. 1974. Characterisation of cadmium uptake by plant tissue. *Pl. Physiol.* 54 : 67-71

Dalton, D.A., Russel, S.A. and Evans, H.J. 1988. Nickel as a micro nutrient element for plants. *Biofactors* 1(1) : 11-16

Davies, B.E. 1992. Inter relationships between soil properties and the uptake of Cd, Cu, Pb and Zn from contaminated soils by radish. *Water Air Soil Pollut.* 63 : 331-342

David, A.D., Harold, J.E. and Hanus, F.J. 1985. Stimulation by nickel of soil microbial urease activity and urease and hydrogenase activities in soybeans grown in a low nickel soil. *Pl. Soil* 88 : 96-105

Davis, R.D., Beckett, P.H.T and Wallan, E. 1978. Critical levels of twenty potentially toxic elements in young spring barley. *Pl. Soil* 48 : 509-523

Donald, J.L. 1972. Trace metals in soils plants and animals. *Adv. Agron.* 24 : 267-297

Dubey, R.C. and Dwivedi, R.S. 1987. Effect of heavy metals on seed germination and seedling growth of soybean. *Science Letters*. National Academy of Sciences, India, 10 : 121-123.

Emmerich, W.E., Lund, L.J., Page, A.L. and Chang, A.C. 1982. Solid phase forms of heavy metals in sewage sludge treated soil. *J. environ. Qual.* 2 : 178-182.

Etherington, J.R. 1982. *Environment and Plant Ecology.* John Wiley and Sons Publishers, New York, pp. 131-204

Everson, R.J. 1975. A modification in the official methods for the determination of metals in feeds and fertilizers by atomic absorption spectrophotometry. *J. AOAC.* 58: 158

Fergusson, J.E. 1990. The Heavy Elements Chemistry, Environmental Impact and Health Effects. Pergamon press, Oxford, U.K., p. 614

Fleming, G.A. and Parle, P.J. 1977. Heavy metals in soils, herbage and vegetables from an industralised area west of Dubling city. *Irland J. agric. Res.* 16 : 35-48

Foy, C.D., Chaney, R.L. and White, M.C. 1978. The physiology of metal toxicity in plants. *Rev. Pl. Physiol.* 29 : 511-566

Frossard, R., Stadelmann, F.X. and Niederhauser, J. 1989. Effects of different heavy metals on fructan, sugar and starch content of ryegrass. *J. Pl. Physiol.* 134 : 180-185

Fuhrer, J. 1982. Ethylene biosynthesis and cadmium toxicity in leaf tissue of beans *Phaseolus vulgaris* L. *Pl. Physiol.* 70 : 162-167

Gabbreilli, R., Pandolfini, T., Vergnano, O. and Palandri, M.R. 1990. Comparison of two *serpentine species with different nickel tolerance strategies. Pl. Soil.* 122 : 271-277

Gangapadhhyay, S. and Santra, S.C. 1996. Effect of heavy metal on chlorophyll content and nitrogenase activity of *Azolla pinnata* R. Br. *Pollut. Res.* 15 : 95-97

Gaston, L.A. and Selim, H.M. 1990. Transport of exchangeable cations in an aggregated clay soil. *Soil Sci. Soc. Am. J.* 54 : 31-38

Ghoshroy, S. and Nadakavukaran, M.J. 1990. Influence of cadmium on the ultra structure of developing chloroplast of soybean and corn. *Environ. exp. Bot.* 30 : 187-192

Giordani, P.M., Mortvedt, J.J. and Mays, D.A. 1975. Effect of municipal waste on crop yield and uptake of heavy metals. *J. environ. Qual.* 4(3) : 338

Giusquiani, P.L., Gigliotti, G. and Businelli, D. 1992. Mobility of heavy metals in urban waste amended soils. *J. environ. Qual.* 21 : 330-335

Godbold, D.L. and Knetter, C. 1991. Use of root elongation studies to determine aluminium and lead toxicity in *Picea abies* seedlings. *J. Pl. Physiol.* 138 : 231-235

Goodroad, L.L. and Coldwell, A.C. 1979. Effect of phosphorus fertilizers and lime on the As, Cr, Pb and V content of soils and plants. *J. environ. Qual.* 8(4) : 493

Gorlach, E. and Gambus, F. 1992. A comparison of sensitivity to the toxic action of heavy metals in various plant species. *Polish J. Soil Sci.* 25(2) : 207-213

Groten, J.P. and Vanbladeren, P.J. 1994. Cadmium bioavailability and health risk in food. *Trends Food Sci. Technol.* 5 : 50-55.

Gunnarsson, O.C. 1983. Heavy metals in fertilizers - Do they cause environmental and health problems. *J. Fertil. Agri.* 85 : 27-41

Guo, Y. and Marschner, H. 1995. Uptake, distribution and binding of cadmium and nickel in different plant species. *J. Pl. Nutr.* 18 : 2691-2706

Gupta, A.P., Antil, R.S. and Singh, A. 1986. Composition of some sewer waters and their effect on soil properties. *Proc. Nat. Sem. Monitoring and Control of Environmental pollution*, Central Scientific and Industrial Organisation, Chandigarh, p. 22-25

Gupta, V.K. and Dixit, M.L. 1992. Influence of soil applied cadmium on growth and nutrient composition of plant species. *J. Inidan Soc. Soil Sci.* 40 : 878-880.

Gutierrez, R.M.E., Siebe, C. and Sommer, I. 1995. Effects of land application of waste water from Mexico city on soil fertility and heavy metal accumulation, a bibliographical review. *Environ. Rev.* 3 : 318-330

Guttormsen, G., Singh, B.R. and Jeng, A.S. 1995. Cadmium concentration in vegetable crops grown in a sandy soil as affected by Cd levels in fertilizer and soil pH. *Fertil. Res.* 41 : 27-32

Hagemeyer, J., Kahle, H., Breckle, S.W. and Waisel, Y. 1986. Cadmium in *Fagus sylvatica* (trees and inter connection with transpiration. *Water Air Soil Pollut.* 29 : 347-359

Haghiri, F. 1976. Release of Cd from clays and plant uptake of Cd from soil as affected by potassium and calcium amendments. *J. environ. Qual.* 5 : 395-397

Harada, Y., Haga, K., Osada, T. and Koshino, M. 1993. Quality of compost produced from animal wastes. *Japan Agricultural Research Quarterly* 26 : 238-246

Hardiman, R.T. and Jacoby, B. 1984. Absorption and translocation of Cd in bush beans. *Physiol. Plant* 61 : 670-674

Harter, R.D. 1979. Adsorption of copper and lead by Ap and B2 horizons of several northeastern United States soils. *Soil Sci. Soc. Am. J.* 43 : 679-683

Harter, R.D. 1983. Effect of soil pH on adsorption of lead, copper, zinc and nickel. *Soil Sci. Soc. Am. J.* 47 : 47-51

He, Q.B. and Singh, B.R. 1993. Effect of organic matter on the distribution extractablity and uptake of cadmium in soils. *J. Soil Sci.* 44 : 641-650

He, G.B. and Singh, B.R. 1994a. Crop uptake of cadmium from phosphorus fertilizers. 1. Yield and cadmium content. *Water Air Soil Pollut.* 74 : 251-265

He, Q.B. and Singh, B.R. 1994b. Crop uptake of cadmium from phosphorus fertilizers. II. Relationship with extractable soil cadmium. *Water Air Soil Pollut.* 74 : 251-265

Heale, E.L. and Ormrod, D.P. 1983. Effect of Ni and Cu on seed germination and growth and development of seedlings of *Acer ginnala, Betula papyrifera, Picea abies* and *Pinus banksiana. Reclamation Revegetation Research.* 2 : 41-54

Herstein, U. and Jager, H.J. 1986. Tolerance of different populations of three grass species to cadmium and other metals. *Environ. Experimental Bot.* 26 : 309-319

Hinz, C. and Selin, H.M. 1994. Transport of Zn and Cd in soils : Experimental evidence and modelling appraoches. *Soil Sci. Soc. Am. J.* 58 : 1316-1317

*Hlusek, J. and Richter, R. 1992. Concentration of major nutrients in potatoes growing in soil contaminated with heavy metals to which soil improvers were applied. *Rostlinna - Vyroba,* 38(1): 97-106

Holmgren, G.G.S., Meyer, M.W., Chaney, R.L. and Daniel, S.R.B. 1993. Cadmium, lead, zinc, copper and nickel in agricultural soils of the United States of America. *J. environ. Qual.* 22 : 335-348

Hooda, P.S. and Alloway, B.J. 1996. The effect of liming on heavy metal concentrations in wheat, carrots and spinach grown on previously sludge applied soils. *J. agric. Sci.* 127 : 289-294

Hopkins, W.G. 1995. *Introduction to Plant Physiology.* John Willey and Sons, New York, p. 464

Huang, J.W. and Cunniangham, S.D. 1996. Lead phytoextraction : species variation in lead uptake and translocation, *New phytologist* 134(1) : 75-84

*Iimura, K. 1973. Forms of cadmium in the soils and its absorption by rice plants. *Studies on Soils and Fertilizer Applications in Modern Agricultural Technologies.* Japan Society of Soil Science and Plant, Yokendo, Tokyo, pp. 46-52

Iimura, K. 1981. Background contents of heavy metals in Japanese soils. *Heavy Metal Pollution in Soils of Japan. (eds. Kitagishi, K. and Vamane, I.) Japan. Sci. Soc. Press*, Tokyo, pp. 19-26

Il'in, V.B. 1991. Heavy metal pollution of vegetable garden soils and crops in the cities of the Kuzbass. *Soviet Soil Sci.* 23 : 104-114

Ito, H. and Iimura, K. 1975. Absorption of cadmium by rice plants in response to the change in oxidation reduction conditions of soils. *J. Sci. Soil Manure Jap.* 46 : 82-86

Ito, H. and Iimura, K. 1976. The Cd absorption by rice plants grown in the water solution with a constant level of Cd concentration. *J. Sci. Soil manure, Jap.* 47 : 482-487

Ito, H. and Iimura, K. 1976a. Studies on heavy metal pollution of soils. The adsorption and translocation of cadmium in rice plants and its influence on their growth. *Bull. Hokuriku Nat. agric. Exp. Stn.* 19 : 71-109.

Iwai, I., Hara, T. and Sonada, Y. 1975. Factors affecting Cd uptake by corn plants. *Soil Sci. Pl. Nutr.* 21 : 37-46

Jackson, M.L. 1973. *Soil Chemical Analysis.* Prentice Hall of India, New Delhi, p. 498

Jaakola, A. 1977. The effect of cadmium contained in fertilizer on the Cd content of vegetables. *J. Sci. agric. Soc. Finland* 51 : 158-162

Jarvis, S.C., Jones, L.H.P. and Hopper, M.J. 1976. Cadmium uptake from solution by plants and its transport from root to shoot. *Pl. Soil* 44 : 179-191

Jayabaskaran, K.J. and Sreeramulu, U.S. 1996. Distribution of heavy metals in soils of various sewage farms in Tamil Nadu. *J. Indian Soc. Soil Sci.* 44 : 401-404.

Jones, K.C. and Johnston, A.E. 1989. Cadmium in cereals grain and herbage from long term experimental plots at Rothamsted, U.K. *Environ. Pollut.* 57 : 199-216

Kabata - Pendias, A. and Dudka, S. 1991. Baseline data for cadmium and lead in soils and some cereals of poland. *Water, Air, Soil Pollution.* (57-58) : 723-731

Kabata - Pendias, A. and Pendias, H. 1984. Trace Elements in Soils and Plants. CRC press, Boca Raton, p. 281

Kansal, B.D. 1992. Effect of waste disposal on soils and plants. (eds. Dhaliwal, G.S., Hansra, B.S. and Jerath, N.) *Changing Scenario of our Environment.* Punjab Agricultural University, Ludhiana pp. 197-206

Kanwar, J.S. and Randhawa, N.S. 1974. *Micronutrient Research in Soils and Plants in India.* Indian Council of Agricultural Research, New Delhi, p. 172.

Kapoor, K., Arorá, L. and Bamniya, B.R. 1998. Cyanobacterial growth responses in presence of combinations of ions of heavy metals. *Res. J. Chem. Environ.* 2(1) : 59-62

Karapanagoitis, N.K., Sterritt, R.M. and Lester, J.N. 1991. Heavy metal complexation in sludge - amended soil, the role of organic matter in metal retention. *Environ. Technol.* 12 : 1107-1116

Kartha, A.R.S. and Seth, A.S. 1957. A cold percolation method for rapid gravimetric estimation of oil in small quantities of oil seeds. *Indian J. agric. Sci.* 27 : 217

Karunakaran Nair, G. 1987. Continuous use of Muncipal sewage effluents on soil physical and chemical properties. M.Sc. (Ag.) thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

KAU, 1993. *Package of Practices Recommendations Crops 93.* Kerala Agricultural University, Thrissur.

KAU, 1998. Impact of continuous application of copper fungicides on eco-systems of the major rubber growing tracts of Kerala and Tamil Nadu. *Status report,* 1, Collaborative project of the Kerala Agricultural University and Rubber Research Institute of India, NARP(SR), College of Agriculture, Vellayani, pp. 14

Keller, C. and Vedy, J.C. 1994. Distribution of copper and cadmium fractions in two forests soils. *J. environ. Qual.* 23 : 987-999

Keshan, U. and Mukherji, S. 1992. Effect of cadmium toxicity on chlorophyll content, Hill activity and chlorophyllase activity in *Vigna radiata* L. leaves. *Indian J. Pl. Physiol.* 35 : 225-230

Khalid, K.B.Y. and Tinsley, J. 1980. Some effects of Ni toxicity on rye grass. *Pl. Soil* 55 : 139-144

Khalid, R.A., Gambrell, R.P. and Patrick, W.H. 1981. Chemical availability of Cd in Mississippi river sediment. *J. environ. Qual.* 10 : 523-528

*Kim, B.Y., Kim, K.S., Lee, C.S. and Yoo, S.H. 1993. Survey on the natural heavy metal contents in fruits and orchard soils in Korea. *J. Agrl. Sci. Soil fert.* 35 : 280-290.

King, L.D. and Hajjar, L.M. 1990. The residual effect of sewage sludge on heavy metal content of tobacco and peanut. *J. environ. Qual.* 19 : 738-748

Kireicheva, L.A. and Glazunova, I.V. 1994. New organomineral sorbing amendments for detoxication of soils polluted with heavy metals. *Russian agric. Sci.* 7 : 25-29

Knight, A.H. and Crooke, W.M. 1956. Interaction between Ni and Ca in plants. *Nature* 178 : 220

*Koch, D. and Grupe, M. 1993. Mobility of heavy metals of geogenic / anthropogenic origin *Mitteilungen - der - Deutschen Bodenkundlichen - Ge sellschaft* 72(1) : 385-388

*Kohiyama, M., Kanematsu, H. and Niiya, I. 1992. Heavy metals particularly Ni content in oilseeds and edible vegetable oils. *J. Jap. Soc. Food Sci, Technol.* 39 : 439-445.

Komulainen, M. and Mikola, J. 1995. Soil processes ad influenced by heavy metals and the composition of soil fauna. *J. applied Ecol.* 32(1) : 234-241

Kongshaug, G., Bockman, O.C., Kaarstad, O. and Merka, H. 1992. Inputs of trace elements to soils and plants. *Proc. Chemical Climatology and Geomedical Problems Norsk. Hydro.* Oslo, Norway pp. 28-35.

Korte, N.E., Skopp, J., Fuller W.H., Niebla, E.E. and Alesii, B.A. 1976. Trace element movement in soils, influence of soil physical and chemical properties. *Soil Sci.* 122: 350-359

Kostial, K. 1986. Cadmium. *Trace Elements in Human and Animal Nutrition* (ed. Mertz, M.) Academic Press, London, pp. 319-325

Krupa, Z. 1988. Cadmium induced changes in the composition and structure of the light harvesting chlorophyll a/b protein complex 11 in radish cotyledons. *Physiol. Planta* 73, 518-524

Krupa, Z., Oquist, G. and Huner, N.P.A. 1993. The effects of cadmium on photosynthesis of *Phaseolus vulgaris*, a fluorescence analysis. *Physiol. Planta* 88 : 626-630

Kumar, P.B.A.N., Dushenkov, V., Motto, H. and Raskin, I. 1995. Phytoextraction : the use of plants to remove heavy metals from soils. *Environmental Sci. Technol.* 29 : 1232-1238

Kumar, R. 1992. The extent of Ni build up in polluted soils and evaluation of its toxicity in plants. M.Sc. thesis, Punjab. Agric. Univ., Ludhiana.

Kumar, S. and Banerjee, D. 1992. Effect of some heavy metals on *in vitro* activities of certain enzymes. *Plant Physiol. Biochem.* 19 : 33-35

Lagerwerff, J.V., Brower, D.L. and Biersdorf, G.T. 1973. Accumulation of cadmium, copper, lead and zinc in soil and vegetation in the proximity of a smelter. *Trace substances in Environmental* Health, University of Mississipi, Columbia, pp. 71-78

Larsen, V.J. and Schierup, H.H. 1981. The use of straw for removal of heavy metals from waste water. *J. environ. Qual.* 10 : 188-190

Leblova, S., Mucha, A. and Spirhanzlova, E. 1986. Compartmentation of cadmium, copper, lead and induction of metallothionein. *Biologia* 41 : 777-785

Legret, M., Divet, L. and Juste, c. 1988. Movement and speciation of heavy metals in a soil amended with sewage sludge containing large amount of Cd and Ni. *Water Res.* 22: 953-959

Lehoczky, E., Szabados, I. and Marth, P. 1996. Cadmium content of plants as affected by soil Cd concentration. *Commun. Soil Sci. Pl. anal.* 27 : 1765-1777.

Leidmann, P., Fischer, K., Bieniek, D. Nusslein, F. and Kettrup, A. 1994. Removal of heavy metals from polluted soil with grass silage juice. *Chemosphere* 28 : 383-390

Letunova, S.V., Umarov, M.M., Niyazova, G.A. and Melekhin, Y.I. 1985. Nitrogen fixation activity as a possible criterion for determining permissible concentrations of heavy metals in soil. *Soviet. Soil Sci.* 17(6) : 88-92

Logan, T.J. and Robert, E. 1985. Plant uptake of cadmium from acid extracted and anaerobically digested sewage sludge. *J. environ. Qual.* 9 : 495-500.

Lubben, S., and Sauerbeck, D. 1991. The uptake and distribution of heavy metals by spring wheat. *Water Air Soil Pollut.* 57-58 : 239-247

Lund, L.J., Betty, E.E., Page, A.L. and Elliot, R.A. 1981. Occurrance of naturally high Cd levels in soils and its accumulation by vegetation. *J. environ. Qual.* 10 : 551-553

Mann, S.S. and Ritchie, G.S.P. 1993. The influence of pH on the forms of Cd in four western Australian soils. *Australian J. Soil. Res.* 31(3) : 255-270

Mathew, U. and Abraham, A. 1998. Effect of cadmium and nickel on germination of rice and cowpea. *Proc. of 10th Kerala Science Congress.* State Committee on Science Technology and Environment, Kerala, pp. 421-422

Ma, W. 1982. The influence of soil properties and worm related factors on the concentrations of heavy metals in earthworms. *Pedobiologia* 24 : 109-119

Ma, W. 1984. Sublethal toxic effects of copper on growth, reproduction and litter break down activity in the earthworm, *Lunbricus rubellus. Environ. Pollut.* 33 : 207-219

Mc Bridge, M.B., Tyler, L.D. and Horde, 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

Mc Bride, M.B. 1989. Reactions controlling heavy metal solubility in soil. *Adv. Soil. Sci.* 10: 1-56

Mc Grath, S.P., Chaudri, A.M. and Giller, K.E. 1995. Long term effects of metals in sewage sludge on soils, micro organisms and plants. *J. Industrial Microbiology.* 14(2) : 94-104

Mc Lean, A.J. 1976. Cadmium in different plant species and its availability in soils as influenced by organic matter and addition of lime, P, Cd and Zn. *Canadian J. Soil Sci.* 56(3): 129-138

*Merry, R.H. 1989. Cadmium and crops. Agronomy conference papers, South Australian Department of Agriculture, Adelaide, p. 64-67.

Michael, R. 1983. Studies on aspects of some micronutrients for plants and in animal nutrition and trace elements as phytotoxicants. Ph.D. thesis, University of Agricultural Sciences, Bangalore.

Miller, J.E., Hassette, J.J. and Hoeppe, D.E. 1977. Interaction of lead and cadmium in metal uptake and growth of corn plant. *J. environ. Qual.* 6(4) : 18-20

Miller, R.W., Azzari, A.S. and Gardiner, D.I. 1995. Heavy metals in crops as affected by soil types and sewage sludge rates. *Commun. Soil Sci. Pl. Anal.* 26 : 703-711

*Mineev, V.G. and Gomonova, N.F. (1993). Accumulation of heavy metals in soil and their absorption by plants in long term agrochemical experiments. Dokladv-Rossiiskoi-akademii-Sel Skokhozvaistvennvkh-nauk (Russian federation) 6 : 20-22.

Mitchell, C.A., Bingham, F.T. and Page, A.L. 1978. Yield and metal composition of lettuce and wheat grown on soil amended with sewage sludge enriched with Cd, Cu, Ni and Zn. *J. environ. Qual.* 7 : 165-168

*Mortvedt, J.J. and Giordano, P.M. 1977. Crop uptake of heavy metal contaminants in fertilizers. *Biological implications of Heavy Metals in the Environment* (eds. Wildung, R.A. and Drucker, H.). *ERDA Rep. Conf.,* Oak Ridge, pp. 402-416

Mortvedt, J.J. and Osborn, G. 1982. Studies on the chemical form of Cd contaminants in phosphatic fertilizers. *Soil Sci.* 134: 185-192

Mortvedt, J.J., Mays, D.A. and Osborn, G. 1981. Uptake by wheat of cadmium and other heavy metal contaminants in phosphatic fertilizers. *J. environ. Qual.* 10 : 193-194

Mortvedt, J.J. 1987. Cadmium levels in soils and plants from long term soil fertility experiments in the Uniter States of America. *J. environ. Qual.* 16 : 137-142

Mortvedt, J.J. (1996). Heavy metal contaminants in inorganic and organic fertilizers. *Fertil. Res.* 43 : 55-61.

Moya, J.L., Ros, R. and Picazo, I. 1993. Influence of cadmium and nickel on growth, net photosynthesis and carbohydrate distribution in rice plants. *Photosynth. Res.* 6 : 75-80

Mulla, D.J., Page, A.L. and Ganje, T.J. 1980. Cadmium accumulation and bioavailability in soils from long term phosphorus fertilization. *J. environ. Qual.* 9 : 408-412

Mulla, D.J. 1978. Cadmium accumulation in soils resulting from long term use of inorganic fertilizers. *Agron. Abstr.* 1978 : 3-8.

Muthuchelian, K., Rani, S. and Paliwal, K. 1988. Differential action of Cu and Cd on chlorophyll biosynthesis and nitrate reductase activity in *Vigna sinensis* L. *Indian J. Pl. Physiol.* 31 : 169-173

Nicol, M.R.D. and Beckett, P.H.T. 1985. Critical tissue concentrations of potentially toxic elements. *Pl. Soil* 85 : 107-129

Norwal, R.P., Mahendra Singh, A., Gupta, A.P. and Kuliad, M.S. 1994. Ni and Zn interactions in corn grown on sewer irrigated soil. *Crop. Res.* 7 : 366-372

*Obata, H. and Umebayashi, M. 1988. Influences of submerging periods on the cadmium content in brown rice. *Bull. Environ. Sci.* Mie University, Japan, 12 : 33-37

Oborn, I., Jasson, G., Johnsson, L. Grennfelt, P., Rodhe, H., Thornel of E and Wisniewski, J. 1995. A field study on the influence of soil pH on trace element levels in spring, wheat, potatoes and carrots. *Water Air Soil Pollut.* 85 : 835-840

Ogawa. 1994. Studies on the actual situation of cadmium pollution to paddy rice in Akita prefecture and its control. *Bull. Akita Agric. Expt. Stn.* 35 : 1-64

*Okamoto, T., Matsuzaki, T. Wacho, K. and Yabuki, S. 1989. Background contents of heavy metals of farm land soils in Kanagawa prefecture. *Bull. Agric. Res. Inst.* Kanagawa prefecture, 131, pp. 23-30

Oliver, D.P., Tiller, K.G., Conyers, M.K., Slattery, W.J., Alston, A.M. and Merry, A.H. 1996. Effectiveness of liming to minimise uptake of cadmium by wheat and barley grown in the field. *Australian J. agric. Res.* 47 : 1181-1193

Page, A.L., Binghan, F.T. and Nelson, C. 1972. Cadmium absorption and growth of various plant species as influenced by solution cadmium concentration. *J. environ. Qual.* 1: 288-291

*Paino, V., Peillex, J.P., Montlahave, O., Cambon, A. and Bianchini, J.P. 1996. Muncipal tropical compost : effects on crops and soil properties. *Compost Science and Utilization* 4(2) : 62-69.

Panse, V.G. and Sukhatme, P.V. 1967. *Statistical Methods of Agricultural Workers.* Indian Council of Agricultural Research, New Delhi, 97-128

Petruzzelli, G., Guich, G. and Lubrano, L.I. 1978. Organic matter as an influencing factor of copper and cadmium by soils. *Water Air Soil Pollut.* 9 : 263-269

Pettersson, O. 1977. Differences in cadmium uptake between plant species and cultivars. *Swedish J. Agric. Res.* 7 : 21-24

Piccolo, A. 1989. Reactivity of added humic substances towards plant available heavy metals in soils. *Science of the Total Environment.* 81-82 : 607-614

Piper, C.S. 1944. *Soil and Plant Analysis.* Inter Science Publishers, New York. p. 368

Prasad, M.N.V. 1995. Cadmium toxicity and tolerance in vascular plants. *Environ. Expt. Bot.* 35 : 525-545

Rana, R.P. and Kansal, B.D. 1983. Sorption and release of Cd and some sewage irrigated soils. *J. Indian Soc. Soil Sci.* 31 : 439-443

Rani, S.M.V. and Paliwal, K. 1988. Germination as a screening index of heavy metal tolerance of forage crops. *Indian J. Range Management* 9 : 113-118

Rao, K.J. and Shantharam, M.V. 1994. Heavy metal pollution of agricultural soils due to application of garbage *Indian J. Environ.* 36 : 31-39.

Raskin, I., Kumar, P.B.A.N., Dushenkov, S. and Salt, D.E. 1994. Bioconcentration of heavy metals by plants. *Current Opinion in Biotechnology* 5 : 285-290

Rauser, W.E. 1990. Phytochelatins. *A. Rev. Biochem.* 59 : 61-86

Rauser, W.E. and Ackerley, I. 1987. Localization of cadmium in granules within differentiating and mature root cells. *Canadian J. Bot.* 65 : 643-646

Reddy, K.J., Wang, L., Gloss, S.P. 1995. Solubility and mobility of copper, zinc and lead in acidic environments. *Pl. Soil* 171 : 53-58

Rees, T.A.V. and Bekheet, I.A. 1982. The role of nickel in urea assimilation by algae. *Planta* 156 : 385-387

Reuss, J.O., Dooly, H.L. and Griffs, W. 1978. Cadmium uptake from phosphate fertilizers by pear, radish and lettuce. *J. environ. Qual.* 6 : 259-263

Rivai, I.F., Koyama, H and Suzuki, S. 1990. Cadmium content in rice and rice field soils in China, Indonesia and Japan with special reference to soil type and daily intake from rice. *Jap. J. Health Human Ecol.* 56 : 168-177.

Rose, A.W., Hawkes, H.E. and Webb, J.S. 1979. *Geochemistry in Mineral Exploration.* 2nd ed. Academic press, London, p. 290.

Rothbaum, H.P., Goguel, R.L., Johnson, A.E. and Mattingly, G.E.G. 1986. Cadmium accumulation in soils from long continued applications of superphosphate. *J. Soil Sci.* 37 : 99-107

Saini, S.P. and Kansal, B.D. 1990. Abatement of toxicity of sewâge water and industrial effluents in maize fodder. *J. Pl. Sci. Res.* 6 : 55-59

Sakal. R., Prasad, A.K. and Singh, A.P. 1992. Depthwise distribution of heavy metals in soils receiving sewage sludge. *J. Indian Soc. Soil Sci.* 40 : 732-737.

Sanchez, M.M.J. and Sanchez, C.M. 1993. Adsorption and mobility of cadmium in natural uncultivated soils. *J. environ. Qual.* 22 : 737-742

Sarkunan, V., Misra, A.K. and Mohaptra, A.R. 1995. Effect of Cd on yield and uptake of Cd by different rice varieties. *J. Indian Soc. Soil Sci.* 43 : 298-300

Satakopan, V.N. and Rajendran, L. 1989. $Cd2^{+}$ interaction with RNA in germinating. *Arachis hypogea. Indian J. Plant Physiol.* 32 : 129-132

Sathyaprakasan, S. 1989. Heavy metal in fertilizers in relation to their accumulation in soils due to continuous fertilizer use. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Thrissur.

Sauerbeck, D.R. 1991. Plant, element and soil properties governing uptake and availability of heavy metals desired from sewage sludge. *Water Air Pollution*. 57-58 : 227-237

Scott, M.L. 1972. Trace Elements in Animal Nutrition. *Micronutrients in Agriculture.* Soil Sci. Soc. Am. Inc., Madison, USA, pp. 555-587.

Semu, E and Singh, B.R. 1996. Accumulation of heavy metals in soils and plants after long-term use of fertilizers and fungicides in Tanzania. *Fertil. Res.* 44 : 241-248.

Shah, K. and Dubey, R.S. 1995. Effect of cadmium on RNA level as well as activity and molecular forms of ribonuclease in growing rice seedlings. *Pl. Physiol. Biochem.* 33 : 557-584

Sharma, V.K. and Kansal, B.D. 1986. Heavy metal contamination of soils and plants with sewage irrigation. *Pollu. Res.* 4 : 86-91

Shoeran, I.S., Singal, H.R. and Singh, R. 1991. Effect of cadmium and nickel on photosynthesis and the enzymes of the photosynthetic carbon reduction cycle in pigeonpea (*Cajanus cajan*). *Photosynthesis Res.* 23 : 345-351

Shrivastava, G.K. and Singh, V.P. 1986. Effect of Cd on chlorophyll and carotenoid contents in three varieties of *Abelmoschus esculentus L. Moench. Pl. Physiol. Biochem.* 13 :20-24

Singh, B.R. and Jeng, A.S. 1993. Uptake of zinc, cadmium, mercury, lead, chromium and nickel by rye grass grown in a sandy soil. *Norw. J. agric. Sci.* 7 : 147-157

Singh, B.R., Narwal, R.P., Jeng, A.S. and Almas, A. 1995. Crop uptake and extractability of cadmium in soils naturally high in metals at different pH levels. *Commun. Soil Pl. Anal.* 26 : 2123-2142

Singh, B. and Sekhon, G.S. 1977. Impact of fertilizer use on environmental pollution in Punjab - present status and future projections. *Fert. News* 23(2) : 7-11.

Singh, J. and Kansal, B.D. 1985. Amount of nutrients and heavy metals in the sewage water of different towns of Punjab and its evaluation for irrigation. *J. Res. Punjab agric. Univ.* 22 : 17-24.

Singh, P. and Kanwar, R.S. 1991. Preferential solute transport through macropores in large undisturbed satured soil columns. *J. environ. Qual.* 20 : 295-300

Singh, R.P., Bharti, N. and Kumar, G. 1994. Differential toxicity of heavy metals to growth and nitrate reductase activity of sesamum indicum seedlings. *Phytochemistry* 35 : 1153-1156

Singh, S.P. and Nayyar, V.K. 1994. Accumulation characteristics of Cd in selected forage species. *J. Indian Soc. Soil Sci.* 42 : 96-100

Singh, S.P. 1995. Plant availability of Ni as influenced by lime and its toxic level in cowpea. *Proc. Nat. Sem. Developments in Soil Science,* Indian society of soil science, New Delhi, pp. 160-161

Singh, S.S. 1981. Uptake of cadmium by lettuce as influenced by its addition to a soil as inorganic forms or in sewage sludge. *Canadian J. Soil Sci.* 61 : 19-28

Soldatini, G.F., Riffaldi, R. and Levi-Minzi, R. 1976. Lead adsorption by soils. *Water Air Soil Pollut.* 6 : 111-118

Sposito, G., Lund, L.J. and Chang, A.C. 1982. Tracemetal chemistry in Arid-zone field soils amended with sewage sludge 1. Fractionation of Ni, Cu, Zn, Cd and Pb in solid phases. *Soil Sci. Soc. Am. J.* 46 : 260-264

Srikant, R., Rao, V. and Venugopal, N.B.R.K. 1994. The effect of application of phosphatic fertilizer on cadmium concentration in ground waters around vine yards of Hyderabad. *Environmental Monitoring and Assessment.* 33 : 71-74

Steffens, J.C. 1990. The heavy metals binding peptides of plants. *A. Rev. Pl. Physiol. Pl. Mol. Biol.* 41 : 553-575

Stobart, A.K., Griffiths, W.T., Bukhari, A.A. and Sherwood, R.P. 1985. The effect of Cd on the biosynthesis of chlorophyll in leaves of barley. *Physiol. Pl.* 63 : 291-293

Strickland, R.C., Chaney, W.R. and Lanoreaux, R.J. 1979. Organic matter influences phytotoxicity of cadmium to soybeans. *Pl. Soil* 52 : 393-402

Subramani, A., Saravanan, P. Tamizhiniyan, P. and Lakshmanachary, A.S. 1997. Influence of heavy metals on germination and early seedling growth of *Vigna mungo* (L.) hepper. *Pollut. Res.* 16 : 29-31

*Swaine, D.J. 1962. The trace element content of fertilizers. *Common Wealth Agricultural Bureau Technical Communication* No. 52 pp. 52-54.

Swarup, F.A. and Ulrich, B.B. 1994. Movement of Zn, Pb and Cd through undisturbed column of a soil under forest. *J. Indian. Soc. Soil Sci.* 42 : 182-184

Takijima, Y. and Katsumi, F. 1973. Use of soil amendment material for control of Cd uptake. *Soil Sci. Pl. Nutr.* 19 : 235-244

Tam, N.F.Y. and Wong, Y.S. 1995. Spent pig litter as fertilizer for growing vegetables. *Bioresource Technology*.53 : 151-155.

Taylor, R.W. and Allinson, D.W. 1981. Influence of lead, cadmium and nickel on the growth of *Medicago Sativa* (L). *Pl. Soil* 60 : 223-236

Taylor, R.W. and Griffin, G.F. 1981. The distribution of topically applied heavy metals in the soil. *Pl. Soil*. 62 : 147-152

*Taylor, S.R. 1964. Abundance of chemical elements in the continental crust - a new table. *Geochin cosmochin Acta.*, 28 : 1273-1286.

Tiller, K.G. 1989. Heavy metals in soils and their environmental significance. *Adv. Soil Sci.* 9 : 113-137

Tisdell, S.E. and Breslin, V.T. 1995. Characterisation and leaching of elements from municipal solid waste compost. *J. environ. Qual.* 24 : 827-833

Tiwana, N.S. 1985. Nature and magnitude of water pollution in Punjab. *Proc. Sem. Status of Environmental Pollution in Punjab*, Ludhiana, pp. 1-39

*Toharisman, A. 1994. Heavy metal content in several composts from sugar manufacturing wastes. *Berita Pusat penelitian perkebunan Gula Indonesia,* 11 : 88-90

Trivedi, M.L. and Singh, R.S. 1995. Reduction in protein content. *Pollut. Res.* 14 : 269-273

*Truby, P. and Raba, A. 1991. Heavy metal uptake by vegetables. *Angewandte Botanik.* 65 : 3-4, 253-264

Tyler, L.D. and Mc Bride, M.B. 1982. Mobility and extractibility of Cd, Cu, Ni and Zn in organic and mineral soil columns. *Soil Sci.* 134 : 198-205

Ure, A.M. and Berrow, M.L. 1982. *The Elemental Constituents of Soils Environmental Chemistry.* Vol. 2. Royal Society of Chemistry, London, p. 42-79.

Van Balen, E., Vande Geijn, S.C. and Desmet, G.M. 1980. Auto radiographic evidence for the incorporation of cadmium into calcium oxalate crystals. *J. Pl. Physiol.* 97 : 123-133

Vasundhara, G., Muraleedhara Kurup, G., Sethuraj, M.R. and Kothandaraman, R. 1997. Heavy metal stress and nitrogen fixing ability of azotobacter. *Proc. 9th Kerala Science Congress.* State Committee on Science, Technology and environment, Kerala, pp. 381-383

Wagner, G.J. 1993. Accumulation of cadmium in crop plants and its consequences to human health. *Adv. Agron.* 51 : 173-212.

Wallace, G.A. and Wallace, A. 1994. Lead and other potentially toxic heavy metals in soil. *Commun. Soil Sci. Plant Anal.* 25(1-2) : 137-141

Webber, M.D., Kloke, A. and Tyell, J. 1984. A review of current sludge use guidelines for the control of heavy metal contamination in soils. *Processing and use of sewage sludge.* (eds. Hermite, P.L. and Ott, H.) Reidel publishing Co., Dordrecht, The Netherlands, p. 73-94

Weigel, H.J. 1985. Inhibition of photosynthetic reactions of isolated spinach chloroplasts by cadmium. *J. Pl. Physiol.* 65 : 480-482

Wetzel, A. and Werner, D. 1995. Ecotoxicological evaluation of contaminated soil using the legume root nodule symbiosis as effect parameter. *Environ. Toxicol. Water Qual.* 10 : 127-133

White, M.C. and Chaney, R.L. 1980. Zinc, cadmium and manganese uptake by soybeans. *Soil Sci. Soc. Am. J.* 44 : 308-310

Willaert, G. and Verloo, M. 1988. Biological effects of nickel species and their determination in plant and soil. *Pl. Soil* 107 : 285-292

Williams, C.H. and David, D.J. 1973. The effect of super phosphate on the cadmium content of soils and plants. *Aust. J. Soil Res.* 11 : 43-56.

Wong, Y.S., Lam, H.M., Dhillon, E., Tam, N.F.Y. and Leung, W.N. 1988. Physiological effects and uptake of Cd in *Pisum sativum*. *Environ. Int.* 14 : 535-543

Woolhouse, H.W. 1983. Toxicity and tolerance in the responses of plants to metals. *Encyclopedia of Plants Physiology*, New series, Vol. 12c, Springer - Verlag, Berlin, pp. 245-300

*Yamagata, N. and Shigematsu, I. 1970. Cadmium pollution in perspective. *Bull. Instn. Publ. Health*, Tokyo, 19. pp. 24-29

Yevdokimova, G.A. 1994. Accumulation of nitrates in plants on sois with increased heavy metal content. *Eurasian Soil Sci.* 26(7) : 116-122

Yoshikawa, T., Jikihara, T. and Tanaka, H. 1986. Effects of managanese for the absorption control of cadmium in rice plants. *J. Sci. Soil Manure Jap.* 57 : 77-80

*Zang, J.Q., Wang, Y.G., Bang, J.H., Zhang, M.Z., Zu, Y.M., Yie, Z.J. and Yuan, B. 1987. The relationship between the organic matter and pH in soil and the heavy metals of soil in Tai lake valley. *Acta Agriculturae Shanghai.* 3(3) : 31-38

* Original not seen

STATUS AND IMPACT OF HEAVY METALS IN SELECTED SOILS AND CROPS OF KERALA

By

USHA MATHEW

ABSTRACT OF THE THESIS
SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENT FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN AGRICULTURE
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM

1999

ABSTRACT

Status of Cu, Zn, Ni, Pb and Cd in samples of selected soils, fertilizers, manures and crops were estimated. A critical analysis of the total content of these heavy metals in the soils studied here revealed that Cu and Cd are existing beyond the critical level in the some of the samples. In the wetland soils, content of all heavy metals was lowest for phytotoxicity and food safety in samples from absolute control plots of rice PME at Pattambi, Moncompu and Kayamkulam and highest in samples from plots receiving maximum quantity of organic manures and inorganic fertilizers. The DTPA extractable form is only a very minor part of their total content. The heavy metal load of the commonly used P fertilizers in Kerala is found to be highly variable. Zn is the highest contaminant followed by Pb, Ni, Cd and Cu. With respect to manures commonly used in Kerala, Zn is the most abundant among the five elements studied followed by Cu.

Retention of heavy metals was found to be more in the roots of all plants compared to the above ground portions except Zn in amaranthus. The grain, straw and root of rice plants collected from PME plots which were receiving organic manures and inorganic fertilizers continuously for several years had a distinctly higher content of all heavy metals compared to the samples obtained from absolute control plots. The content of Cu in rice samples and that of Zn and Cu in the fodder samples from sewage farm exceeded the critical level to express phytotoxicity. In some of the samples of amaranthus and cowpea, content of Zn, Pb and Cd exceeded the food safety standards prescribed in Germany.

Studies on the pattern of retention of applied Cd and Ni in undisturbed soil columns of important soil types of Kerala showed that retention of Cd and Ni was more in the top than in the bottom layers. Higher retention and lower leaching loss of applied Cd and Ni was observed in the columns not treated with FYM.

Pot culture studies have shown a significant reduction in yield of rice, sesame and cowpea at various levels of Cd and Ni with and without FYM. Nutrient content of seed, shoot and root showed variations but did not reveal any specific pattern in various crops. In cowpea, low levels of Cd and Ni in the absence of FYM stimulated nodulation and nitrogen content. Intake of Cd and Ni in various plant parts of rice, sesame and cowpea was in the order root > shoot > seed. It was more in the presence of FYM than in its absence. The toxic effects of Ni on growth and yield parameters were of lesser magnitude compared to Cd especially in rice and cowpea. Maximum accumulation of Cd in edible portions was recorded by sesame with no ill effect on germination. However a moderate accumulation of Cd in rice seeds resulted in significant reduction in germination.

An alarming observation obtained from the study was that almost all samples of rice grains exceeded the food safety standard of 1 mg Cd kg^{-1} indicating that rice, the staple food of the people of Kerala is contaminated with Cd, the most hazardous heavy metal for human health. This pioneer study on the heavy metal status of selected soils and crop plants of Kerala has brought out the need for conducting detailed studies on these aspects.