

LEAD BIOAVAILABILITY TO WHEAT AS INFLUENCED BY PHOSPHORUS, CATTLE MANURE AND SOIL TEXTURE

BY

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IN

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1996

**Dedicated
To
My Wife & Children**

CERTIFICATE - I

This is ^{to} certify that this dissertation entitled "**Lead bioavailability to wheat as influenced by phosphorous, cattle manure and soil texture**" submitted for the degree of **Doctor of Philosophy**, in the subject of Soil Science of the Chaudhary Charan Singh Haryana Agricultural University, is a bonafied research work carried out by **Shri Sat Pal Saini** under my supervision and that no part of this dissertation has been submitted for any other degree.

This assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE - II

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CHAPTER-1

INTRODUCTION

Lead is physiologically unessential and potentially hazardous metal which contaminates the environment. Lead reaches soil and plant cover as an aerial deposit and through precipitation, irrigation water, mine drainage, leaf litter or ground dust below. It is some times added to soil as a pesticide, i.e. lead arsenate or as an impurity in certain fertilizers, i.e. lime stone and superphosphate. Lead although demonstrated to be fairly immobile and unavailable for plant uptake, could also be of concern once deposited on plant tissue surface (Adriano, 1986).

It is not certain, however, whether toxicity symptoms in plants after heavy metal addition (e.g. cadmium or lead) are solely due to excessive levels of these metals in the plant tissue or whether it is associated with ionic imbalance involving other essential metal. No evidence of a biological requirements of lead had been established, and interest in the lead content of vegetation has been because of possible hazard to animal or human health. Deaths in livestock have frequently been attributed to lead poisoning resulting from the ingestion of paint or other materials containing lead, and the effects of lead poisoning, both acute and chronic in man are well known. The possibility that lead might be involved in such disorders as swayback in sheep (Innes and Shearer, 1940) or multiple sclerosis and cancer in man (Warren, 1963) has been discussed by several workers, but not confirmed.

Recently there are remediation technologies available for treating lead contaminated soils. Generally one deals with its total metal content of the soil. However, as far as food chain is concerned, one has to take into account its mobility and bioavailability because plant uptake of metal parallels the bioavailable fractions in the soil. A logical solution, therefore, to minimise its uptake by plant and also to protect the quality of food chain or to enhance revegetation, is to render the metal immobile in the soil (Kabata-Pendias and Pendias, 1992). Methods for reducing Pb availability to plants have not been widely reported.

Trace metals may be distributed among many components of the soil or sediment and may be associated with them in different ways. The nature of this association has often been referred to as speciation. It is the chemical species or form that determines the mobility and bioavailability of the soil metals to other environmental compartments (such as water, plants and biota) when physico-chemical conditions are favourable. The heavy metal bioavailability is determined by their chemical form related to solubility in soil. Chemical fractionation of Pb in contaminated soils has been used to identify the subfraction of the total metal content of soil best correlated with plant uptake. Xian (1989a, b) fractionated metals into exchangeable, carbonate bound, Fe-Mn oxide bound organic and residual forms and found that the sum of exchangeable and carbonate bound forms were strongly correlated with Pb uptake by cabbage and kidney bean plants.

Gorlach and Gambus (1991) found that P-fertilization reduced uptake of Pb to plants. Further PO_4 deficient plants accumulated 3 to 8 times greater Pb grown in nutrient solution (Miller and Koeppel, 1970). Addition of

organic matter residue and peat immobilized Pb in soil (Impens *et al.*, 1991).

In view of the scanty information on the effect of P and organic matter residue on bioavailability of Pb to plants, the present investigation has been undertaken with the following objectives :

1. To study the effect of P and Pb on yield and uptake of Pb by wheat grown in soils of variable texture.
2. To study the effect of cattle manure and Pb on yield and uptake of Pb by wheat grown in texturally different soils.
3. To evaluate the influence of P and cattle manure on Pb fractions and on the availability of Pb to wheat grown in texturally different soils.
4. To study the effect of cattle manure, P and soil texture on concentration of some polyvalent transition metals in wheat in Pb contaminated soils.

CHAPTER-2

REVIEW OF LITERATURE

There is an increasing literature on plant, soil and animal interrelations dealing with lead (American Chemical Society, 1970). This is probably so because of the intensified awareness and concern over contamination or pollution of the environment. Observations, therefore, have emphasized the presence and effects of higher soil contents which may produce toxicity to plants and animals.

The review of literature pertinent to study has been partitioned under the following heads :

- 2.1 Effect of Pb on plant growth
- 2.2 Effect of Pb on concentration and uptake of other elements
- 2.3 Pb-P interaction in plants
- 2.4 Pb-organic manure interaction in plants
- 2.5 Effect of P and organic manure on yield and P content of crops
- 2.6 Influence of P on the accumulation of polyvalent transition heavy metals (Zn, Mn, Fe and Cu) in plants
- 2.7 Influence of organic manure on the accumulation of polyvalent transition heavy metals (Zn, Mn, Fe and Cu) in plants
- 2.8 Significance of Pb in soils and its different fractions in crop production

2.1 Effect of Pb on plant growth

The response of plants and animals to increasing concentrations of metals resulting from either natural variability or pollution, uptake by plants

generally increases with concentrations of metals in soils, especially for the more mobile metals. Above certain concentrations, crop quality and yield, and animal or human health, may be affected. Although any of the heavy metals can be toxic to plants at some level of solubility, only a few have been generally observed to cause phytotoxicity, but because ^{of} plant uptake they move into the food chain (Braude *et al.*, 1975; Mahaffey *et al.*, 1975; Vallee and Ulmer, 1972).

Khan and Khan (1983) observed beneficial effect of Pb at the lower levels and toxicity at higher levels in tomato and egg plant and attributed it to increase in K, Ca and Mg content of plants at lower doses and decrease at higher doses of Pb. Walker *et al.* (1977) also signified that the heavy metal toxicity depends upon one or more nutrients concentration within plants.

Kansal *et al.* (1992) studied that dry matter yield of maize fodder was reduced significantly with the application of lead. Hampp *et al.* (1973) reported adverse effect of lead on enzymes of the reductive pentose phosphate pathway. Carlson *et al.* (1975) postulated the lead toxicity in the enzymes, involved in photosynthesis and respiration reactions.

Monem Balba *et al.* (1991) while studying the effect of $\text{Pb}(\text{NO}_3)_2$ either added to the soil or sprayed on the plants reported burning of leaves margins on the sprayed plants. The tomato fruits, fresh and dry weights significantly decreased with Pb increments and exponential equations were used to express this relationship. Comparison of the slopes of the equations indicated that the Pb effect on yield of plants grown on clay : CaCO_3 -rich : sandy soils is equivalent to 1 : 0.63 : 0.66 respectively. Among several factors, the soil system is very complex and contains compounds

which might cause dissolution or precipitation of elements applied to soil i.e., presence of soluble CO_3 , SO_4 and/or PO_4 as well as alkaline pH causes Pb precipitation (Nriagu, 1972).

Khan and Frankland (1983) found that PbCl_2 addition reduced the shoot and root growth of radish plants when the level exceeded $1000 \mu\text{g g}^{-1}$. Davis and Barnes (1973) reported that addition of PbCl_2 at concentration from 2×10^{-4} to 2×10^{-2} M reduced the growth of loblolly pine and red maples.

Landergarth (1972) found that the Pb concentration between 0.2 and 1.0 ppm has favourable effects on wheat and insignificant response of *Allium* seeding. The pasture herbage during the active period of growth contained only 0.3-1.5 ppm lead and by late winter or early spring, the amounts advanced to 30-40 ppm (Mitchell and Reith, 1966). MacLean *et al.* (1969) studied that PbCl_2 tended to increase yields of oat grain, but at higher rates it reduced yields of alfalfa in some soils. This may have been an indirect effect of the chloride ion rather than of the Pb.

An enhancement of barley (*Hordeum vulgare* L.) growth as a result of lead applications has been reported by Keaton (1937). Radishes (*Raphanus sativus* L.) grown in a soil with high extractable lead had greater root and top growth relative to radish growthⁿ in soils with a medium or low concentration of extractable lead (Lagerwerff, 1971). However, these same soils had varying concentration of Zn, suggesting that the growth response may have been due to other causes possibly an alleviation of zinc deficiency.

IL'IN and Stepanova (1980) found that Pb was highly accumulated in roots, intermediate in leaves and lowest in grains. A content of 4-5 mg Pb/kg dry matter in leaves of wheat at the tillering stage was the critical level and any further increase in it produced toxicity and decreased grain yield of wheat. Also the Pb content in oat plants was highest in the roots and lowest in the seed (Skripnichenko and Zolotareva, 1981). Pb was toxic to plants during the early than the later growth stage. Its highest uptake occurred during the heading grain maturation period. Plant growth and development decreased with 50 mg Pb/l and the plant were killed with 500 mg Pb/l.

Burton *et al.* (1984) showed that the levels of Cd and Pb in shoots and roots increased with their increased levels in the soil. With increase of Pb level in the shoot, the yield of plant shoots were significantly reduced. However, the plant yields were only affected by the highest level of lead. The length of the stika-spruce roots were reduced when lead levels in the soil exceeded certain threshold concentration (48 ppm total Pb, where 1-7 ppm was extractable). Root branching was apparently reduced by increases in the soil levels of cadmium, copper and lead. They also observed that a significant correlation between the shoot yields and the levels of Pb ($r = -0.63$, $P < 0.05$ where $n = 8^{14}$) showing that seedling growth had been affected.

2.2 Effect of Pb on concentration and uptake of other elements

Heavy metal pollutants rarely occur alone. Associated elements, frequently other heavy metals, and possibly major nutrients also, can affect the biological effectiveness of a particular metal by additive, synergistic or antagonistic effects (Cunningham *et al.*, 1975).

Khan and Khan (1983) observed that the Pb application to soil increased the Fe and Mn concentration significantly in tomato and decreased Mn, Fe, Cu, and Na content of the egg-plant and Zn in tomato.

Barber *et al.* (1963) reported that the soluble metal, soil organic matter complexes in soil moved to root zone and entered the root hair through cell membrane as such. The stability constant for most of the metals i.e. Na, K, Ca, Mg, Mn, Zn, Cu, Fe and Pb etc. were reported to be nearly equal in the fulvate model of Sposito *et al.* (1981). Thus the competitive effect in the complexation of metals with the organic ligands takes place and the selectivity rule of Frausto-da-Silva and Williams (1976) is followed.

When red and alluvial soils were treated with high levels of Pb, the uptake of Cu and Fe was significantly changed (Pandey *et al.*, 1984).

Lubben and Saurbeck (1991) conducted the long term field experiment to examine heavy metal distribution in spring wheat, they found that the Cd, Zn, Pb and Cr contents of the grain were appreciably lower than those of straw. Higher Ni and Pb content were found in the chaff than in the straw. To avoid health hazards, Pb content of toxic contaminants should be as low as possible.

Bjerre and Schierup (1985) carried out a pot experiment using sandy loam, sandy soil and organic soils. They found that the transfer of cadmium, lead, zinc and copper from soil to oat plant was greatest from sandy soil. Zinc and cadmium were mobile in the plant than were lead and copper. They also found that the concentrations of cadmium, lead and copper in the grain were lower than leaf and straw.

Walker *et al.* (1977) conducted an experiment to determine the availability of Ca, Mg, K and P to corn plants with different levels of Cd and Pb. They reported that at 24 days following emergence, there was a significant effect of Cd and Pb upon the concentration of Ca, Mg, K and P in corn plants. But one week later, P concentration in plants was unaffected. They explained that such type of affects might be due to the stage of development and certain type of interaction with Cd and Pb in the plant itself.

Lead uptake by young corn shoots has been found to depend upon the level of Pb in the soil, as well as the capacity of the soil to sorb it (Miller *et al.*, 1975). Alegria *et al.* (1991) found a negative correlation between extractable metal (Pb, Cd and Ni) content of soils and leaves-stems of vegetables. Anthropogenic and environmental factors play a more important role than the Pb in soils and the Pb content of vegetables.

Kabata-Pendias *et al.* (1993) studied that monitoring of trace metals (TM) levels in vascular and other terrestrial plants is essential for assessment of environmental pollution and metal transfer into food chain. Effect of soil pollution on Cd, Zn and Pb contents in barley grains was observed. It is suggested that legumes tend to be better biomonitors than cereals and other monocotyledonous plants and concluded that plant response to metal pollution of soils is controlled by several plant and soil factors.

Antosiewicz (1995) conducted an experiment with four population, two each of *Silene inflata* and *Biscutella daevigata* in a growth chamber in solution cultures containing 5, 10 or 20 mg Pb dm⁻³. Both *Silene* population were more Pb-tolerant than *Biscutella*. They found that root Pb concentration in all plants were several times higher than in shoot. The high

lead tolerance of the *Silene* population was accompanied by their higher Ca-status and high tolerance to Ca-deficit.

Ylaranta (1995) in a field experiment, found that the heavy metal concentrations varied from plant to plant but for a particular species, were similar at different experimental sites. The lead concentration of wheat shoot, *L. multiflorum* and lettuce at 22 m from the road side was 1.5 - 3 times that of the background level at 200 m. In wheat grain, the lead concentration was very low and did not change with distance from the road. The plant took up lead mainly from air deposition. In wheat the Zn, Cu, concentration were higher and the Pb and Cd much lower in grain than in shoot.

2.3 Pb-P interaction in plants

Translocation of Pb also reveals a complicated interaction among nutrients and plant metabolism. Plants growing on nutrient-deficient Pb mine spoils and waste heaps can have extremely high foliar Pb (Johnson *et al.*, 1977; Johnson and Proctor, 1977). In fertile soils, huge amounts of added Pb had little effect on foliar Pb (Baumhardt and Welch, 1972). Precipitation of Pb phosphates, especially in phosphate-rich organelles, seemed an obvious explanation to this fertility difference (Malone *et al.*, 1974); higher soil phosphate fertility reduced foliar Pb in corn (Miller *et al.*, 1975).

Santillan-Medrano and Jurinak (1975) have studied the solubility of cadmium and lead in soils in relation to the formation of phosphate, carbonate and hydroxide compounds. They concluded that both lead and cadmium solubility decreased as pH increased. In acid soils the solubility

of lead was controlled by the formation of $\text{Pb}(\text{OH})_2$, between pH 6.6 and 7.5, lead phosphate was a notable sink, but above this pH, PbCO_3 became important. It follows that calcareous soils are a more efficient sink than non-calcareous soils for both metals and some worker proposed that toxic trace metals could be removed effectively from sewage by percolation through calcareous soil material (Davies, 1980).

Kansal *et al.* (1992) observed significant interaction between P and Pb. Also found a negative and significant relationship ($r = -0.88^{**}$) between Pb concentration in plants and dry matter yield of maize. They also reported that mean concentration of Pb in the plants increased significantly from 15.1 to 23.5 $\mu\text{g/g}$ with increase in its rate of application from 0 to 10.0 $\mu\text{g/g}$ soil. P suppressed the Pb concentration in plants significantly.

A negative association rate of Pb and P content of corn leaves was reported by Miller and Koeppe (1970) and attributed it to the formation of relatively soluble lead phosphate. Lagerwerff (1972) attributed the reduced P accumulation in plant with Pb application either due to the reduced P availability in soils or its absorption by plants. Pandey *et al.* (1984) also reported a reduced uptake of P by maize in the Pb-treated red and alluvial soils and observed that Pb alongwith phosphate significantly affected the uptake by shoots and its yield.

Gorlach and Gambus (1991) observed that addition of P and peat alleviated Pb concentration in oat plants and concentration in the straw were about five times those in the oat grain and were usually highest in the low yielding crop of alfalfa grown after the oats. The concentration of Pb in the plants varied between soils. The effect of Pb on phosphorus concentration have been reported by Baumhardt and Welch (1972).

Biddappa *et al.* (1987) studied the effect of supplying various metals viz., Pb, Cd, Al, Bi, Cr, Cu and Ba to roots of coconut palms on the P, K, Ca and Mg concentration in leaves of coconut palm. The results showed that compared with the control, the amount of leaf phosphorus was reduced by all the metals. Obeslander and Roth (1978) reported that the inhibitory effect of the metal on P uptake by plants followed the sequences $Hg > Pb > Cu > Cd > Cr > Ni > Zn$.

Walker *et al.* (1977) also observed that 24 days following emergence, there was a significant effect of Cd and Pb upon the concentration of P, Ca, Mg and K in corn plants.

2.4 Pb-organic manure interaction in plants

Several soil factors play a role in metal binding although these are much less important than pH. The organic matter, clay and hydrous oxides can adsorb metal (Ellis and Knezek, 1972; Page, 1974); soils with higher metal sorption capacity have lower potential for plant uptake of metals. Every aspect of the chemistry of the heavy metals in soil and plants is related to the formation of complexes with organic matter. Metals are held by organic constituents, as soluble and insoluble forms through electrovalent and covalent co-ordinate linkage (Stevenson, 1982), the monovalent cations have the potentials to form co-ordinate linkages with organic molecules.

MacLean *et al.* (1969) studied that the Pb content of oats and alfalfa grown in four soils pretreated with $PbCl_2$ in pot tests varied with the organic matter content and pH of the soils. The amounts of Pb taken up by the plants were reduced upon addition of phosphate or of lime to the

acid soils. Furthermore, the beneficial effect of organic matter, phosphate and lime in reducing Pb in plants were usually in accord with corresponding reduction in extractable Pb in the soils. The beneficial effects of soil organic matter and phosphate in reducing extractable Pb in the soils and its uptake by plants provide a basis for adopting management practice to lessen the potential hazard of Pb-contaminated soil. The beneficial effects of organic matter was in accord with evidence and divalent metal ion form complexes with soil humic compounds (Scheffer and Ulrich, 1960).

Schnitzer and Hoffman (1967) found that the molar quantity of Pb complexed per unit of fulvic acid was relatively high compared with that of several other metals.

Kansal and Singh (1983) reported that the aggregate effect of soil pH, salt concentration, organic carbon and CaCO_3 significantly and negatively affected the content of Zn, Cd and Pb in plants.

IL'IN and Stepanova (1980) observed that the uptake of Pb and Cd by wheat plant was markedly less from chernozem soil of high humic and silt contents than derno-podzolic soil of low humus and silt contents. The accumulation of Pb was highest in roots, intermediate in leaves and lowest in grain. The high accumulation in roots is considered as a protective adaptation of the plant organism.

Pierzynski and Schwab (1993) conducted a study to investigate the effects of various soil amendments or combinations of amendments on Zn, Cd and Pb bioavailability in metal-contaminated alluvial soil. In greenhouse experiment, the combination of lime stone at 1.12 or 2.24 Mg/ha and 10 Mg/ha

of cattle manure produced significantly higher soybean yields as compared to either amendment alone for the first cutting. For the same cutting a significant lime stone by manure rate interaction was found for concentration of Zn, Cd and Pb in soybean tissue and for Zn, Cd and Pb uptake. Generally, the effect of increasing lime stone rate were diminished as the manure rate increased. Root tissue Cd or Pb concentration were not significantly influenced by manure rates.

Sims *et al.* (1986) indicated that sorption, ion exchange precipitation and attenuation were the primary in situ methods for reducing soil heavy metal availability to plants, although little information has been published with regard to evaluating the effectiveness of the soil treatments other than yield and plant tissue metal concentration data (Johnson *et al.*, 1977; Sopper, 1989).

Petruzzeli *et al.* (1981) reported the existence of two types of linkage between heavy metals and organic matter. Heavy metals were available to wheat seedling from humic subsoils with weaker sorption sites, but not from higher molecular weight humic materials which possessed strong linkage with heavy metals.

2.5 Effect of P and organic manure on yield and P content of crops

2.5.1 Phosphorus

Crop response to P application in India are economically attractive. There is lot of data on this aspect covering important crops and various soil climatic environments. Yield response to P have been obtained both at research farm as well as in numerous trials in cultivators field (Tomer *et al.*, 1985; Tandon, 1987).

uptake with increasing rates of P (101 kg P/ha). Neilsen *et al.* (1992) also reported that high level soil P resulted in elevated plant P which interfered with the uptake or translocation of other nutrients.

2.5.2 Organic manures

Ram and Verloo (1985) reported that addition of different organic materials like farm yard manure, peat, humic acid and tetra-ethylene-pentamine (Tetren) to a polluted Belgian soil enhanced the dry matter yield of corn by 16.3, 4.4, 8.5 and 11.5%, respectively over the control plots. The formation of insoluble metallo-organic complexes and increase in CEC of the soil, resulting from the addition of organic material, reduced the availability of heavy metals.

The application of FYM @ 12 t ha⁻¹ in conjunction with different fertilizer levles exhibited a significant increase in the yield of grain and straw of wheat over fertilizers treatment alone (Sharma, 1981). Grain and dry matter yield were significantly increased by manure at all the rates of NPK (Arora and Takkar, 1981; Sakal *et al.*, 1985). Gupta *et al.* (1989) observed that application of FYM on a highly contaminated soil increased the grain and straw yield of wheat with the increasing levels of FYM in the soil.

Organic wastes resulted in increased yield of wheat and rice. The relative efficiency of different organic waste in enhancing wheat and rice yield varied in the order : Poultry manure > Sewage sludge > FYM > Municipal waste > Press mud. Also in another study application of FYM at the rate of 0.5%, increased the grain and straw yield of wheat over no manure treatment in normal, polluted and spiked soil (Prasad *et al.*, 1983, 1989). However, manure was more effective in normal soil due to low organic matter content than polluted and spiked soils (Singh, 1990).

Gupta *et al.* (1992) reported increased yield of wheat with the application of poultry manure and FYM. They observed that poultry manure gave higher yield as compared to FYM, possibly due to higher contents of nutrients. Sood and Minhas (1994) reported that application of FYM @ 20 t ha⁻¹ significantly increased crop yield over no FYM treatment. They further reported that FYM application resulted in an increase uptake of N, P and K by maize and potatoes crops.

Tomer *et al.* (1986) found that application of FYM increased the efficiency of soluble and insoluble P source and retained more available P for longer period. Gupta *et al.* (1988) reported that the P increased upto 52 days after the application of FYM in the soil samples taken during the wheat growth in a long term field experiment. The available P content of soil remained in sufficient range with the application of FYM. Singh (1990) reported that application of FYM @ 0.5% in normal soil increased the P concentration and uptake by wheat grain and straw. Nayak and Gupta (1995) studied that phosphorus concentration and uptake in tops and roots increased with P and organic matter application.

2.6 Influence of P on the accumulation of polyvalent transition heavy metals (Zn, Mn, Fe and Cu) in plants

2.6.1 Zinc

In recent years numerous instances of P induced Zn deficiency in wheat crop with the application of P have been recorded at many places. Several explanations have been put forward for such a disorder. Many workers showed that the reduction in the availability of Zn was brought about by heavy doses of P application (Takkar *et al.*, 1976; Shrama and

Meelu, 1975; Mandal and Haldar, 1980; Patel and Somawanshi, 1982). The decreased availability of Zn due to excessive P fertilization has been attributed to formation of $\text{Zn}_3(\text{PO}_4)_2$ in the soil, which renders Zn unavailable to plants. This hypothesis, however, appears untenable due to the reason that zinc phosphate formed in soil releases Zn for plants and in fact its efficiency equals to that of soluble Zn sources (Gupta and Dabas, 1983; Takkar *et al.*, 1989).

Bingham and Garber (1960) and Burleson *et al.* (1961) suggested that P reduced uptake of Zn and Cu by some process external to the plant. Dev *et al.* (1983) reported that Zn concentration in wheat shoots decreased with P application except at 25 mg P kg^{-1} soil where a slight increase in Zn concentration was observed as compared to no P. In the absence of added Zn, application of P depressed both Zn concentration and uptake by leaves and stem of pigeonpea which showed antagonistic effect of P on Zn in the roots (Gupta, *et al.* 1985).

Singh *et al.* (1990) reported that application of P beyond 120 kg $\text{P}_2\text{O}_5 \text{ ha}^{-1}$ with Zn produced Zn deficiency symptoms and reduced yield, but a positive effect on Zn uptake was observed at each level of Zn, however, higher level (240 kg $\text{P}_2\text{O}_5 \text{ ha}^{-1}$) significantly reduced the Zn utilization by maize.

Gupta and Mehla (1991) reported that effect of higher level of P on tissue Zn and Cu was suppressive in maize. Yadav *et al.* (1991) observed that roots of groundnut contained more Zn than the pods and haulms as the P rates increased indicating less translocation to the above ground portions.

2.6.2 Manganese

Both antagonistic and synergistic inter-relationship of P and Mn, when applied alone or together have been reported in different crops. Saxena and Baser (1964) and Dev *et al.* (1983) reported a negative relationship between Mn content of grain and available P.

Dollar and Keeney (1971) working on oat crop grown on a soil of pH 6.5, reported that P fertilization resulted in greater plant uptake of Mn. Bingham (1963) reported that effect of P on Mn varied with the plant species.

Mishra and Tripathi (1973) observed that P as superphosphate with or without Mn application tended to lower the concentration of Mn in wheat grain. Gupta and Bhadra (1980) reported that addition of P decreased significantly the Mn content in grain and straw of rice. However, significant positive correlations between P and Mn uptake, and between available P and Mn were observed at all stages of the crop growth.

Badhe and Mundwaik (1982) conducted a field experiment on medium black soil treated with 0-40 mg P kg⁻¹ soil as single superphosphate and found that available Mn decreased with increasing level of applied P indicating an inverse relationship between the two. However, in a pot experiment conducted with hybrid maize on a loamy sand soil, P fertilization increased Mn uptake by plants due to improvement in yield (Hulagur and Dangarwala, 1982).

Dev *et al.* (1983) and Yadav *et al.* (1983) reported that concentration and uptake of Mn increased with increasing level of P, however, there was decreasing trend in Mn concentration upto 100 mg P kg⁻¹ soil application, due to dilution effect. A significant positive correlation was observed between P and Mn concentration in shoots and roots of wheat and pea, respectively.

Gupta and Mehla (1991) reported that Fe and Mn concentration decreased with P when compared with its lower levels in maize. Neilsen *et al.* (1992) reported that concentration of Mn was depressed in leaf tissue of wheat from limed soils and also in high P soils.

2.6.3 Iron

The availability of Fe is governed to some extent by available P status of various soils and usually an inverse relationship has been reported (Khan and Zende, 1976; Safaya, 1976) both in soils and plants. High P concentration obstructs the translocation of Fe in plants and is concentrated in the veins of chlorotic plants.

Singh and Singh (1983) reported that the increasing rates of P upto 100 mg kg⁻¹ soil decreased Fe concentration and uptake by rice. Antagonistic interaction between P and Fe in rice as increasing levels of both P and Fe tended to decrease each other availability (Venkata Subbaiah and Associates, 1985).

Gupta *et al.* (1987) studied that P fertilization depressed the Fe concentration and enhanced Fe uptake in shoot and leaves of pigeonpea, it is due to dilution effect. Malligawad *et al.* (1987) in field experiment conducted on a black clay soil reported that P application did not show any significant influence on uptake of Fe by lucerne forage crop.

Gupta and Mehla (1991) observed that iron concentration in maize crop decreased with higher when compared with its lower levels.

2.6.4 Copper

Wallace *et al.* (1978) reported that at high pH, increasing solution P concentration decreased the concentration of Cu in the leaves, stem and

roots of soybeans. In contrast, at low pH, increasing P concentration resulted in more Zn, Mn and Cu but less Fe in leaves, stem and roots.

Application of P to soils depressed Cu concentration in plants (Bingham *et al.*, 1958; Bingham, 1963). Safaya (1976) studied that P application in general decreased Cu content in corn tissue, but increased total Cu uptake which is attributed to the dilution effect. In acid soils P levels did not influence the Cu concentration in maize (Mishra and Dwivedi, 1976).

Patel (1978) reported that Cu reduced concentration of P only in wheat grain whereas, P showed non significant effect on Cu content and its uptake.

Badhe and Mundwaik (1982) observed that Cu concentration in wheat and sorghum was little affected by P addition. The adverse effect of P on Cu could be both by forming insoluble $\text{Cu}_3(\text{PO}_4)_2$ in the soil resulting in decreased solubility of Cu and interference during absorption (Datta and Gupta, 1983). Dev *et al.* (1983) reported decreased Cu concentration in wheat shoots with the increasing levels of P. However, the proportionate decrease was more with initial increment ($25 \text{ mg P kg}^{-1} \text{ soil}$) of P as compared to subsequent levels of P. Gupta *et al.* (1987) in pot experiments observed that P decreased the Cu content but increased its uptake in shoots and leaves of pigeonpea. Goyal *et al.* (1987) and Gupta and Mehla (1991) observed that Cu content in maize reduced due to P application. Higher amount of P in the presence of higher amount of Cu was necessary to get optimum yield of maize shoot.

2.7 Influence of organic manure on the accumulation of polyvalent transition heavy metals (Zn, Mn, Fe and Cu) in plants

2.7.1 Zinc

Incorporation of organic manure in soils has been found very effective in reducing Zn deficiency in crops. Zinc uptake by wheat was increased with the increased application of organic matter (Sood *et al.*, 1977). Shukla *et al.* (1978) found that application of farm yard manure and wheat straw increased Zn content and its uptake by maize in the absence of applied Zn, but when applied with Zn especially at 20 tons FYM ha⁻¹ tissue Zn content and uptake decreased^a as compared to Zn alone. Srivastava and Sethi (1981) reported that the application of farm yard manure once or twice in a year resulted in an increased uptake of Zn by wheat and pearl millet.

Maskina and Randhawa (1983) reported that highest efficiency of organic manures in increasing the Zn content may be owing to increased convective and diffusive flux of soluble Zn to plant roots. Sakal *et al.* (1985) reported that uptake of Zn by rice and barley crops progressively increased with increasing levels of Zn and organic manures. Prasad *et al.* (1989) found that Zn uptake and Zn-use efficiency in wheat and rice crop followed the sequence of poultry manure > compost > press mud > biogas slurry > sewage sludge > zinc sulphate. Zinc use efficiency in organic waste (2.0 - 8.1%) was greater than that of ZnSO₄ application (0.32 - 1.5%).

Gupta and Associates (1990-91) reported that application of 2.5 and 5.0 mg Zn kg⁻¹ soil on the basis of total Zn content through compost, wheat straw, dhaincha and cattle dung resulted in higher Zn content in wheat grain and straw over application of 2.5 and 5.0 mg Zn kg⁻¹ soil through inorganic

Zn sources. They further reported that enrichment of these composts with Zn sources before composting, increased the efficiency of added Zn and resulted in higher Zn uptake. Gupta *et al.* (1992) observed that application of poultry and piggery manures at the rate of 10 t ha^{-1} was found as effective as 5 mg Zn kg^{-1} soil applied from ZnSO_4 alone. The highest concentration of Zn in plant and uptake of Zn by wheat and soybean crop was recorded when poultry excreta was used as a source of manure alone or in combination with ZnSO_4 . Zn was so highly complexed in Zn humate that it did not affect the first crop wheat but the response was improved in the second crop of soybean due to residual effect.

2.7.3 Manganese

Addition of organic manure increased the Mn concentration and uptake by oat plants (Dahiya and Singh, 1980), while Rathore *et al.* (1980) found a significant and positive correlation between available Mn and organic matter levels of soil.

Patil and Patil (1981) observed that Mn content of sorghum increased with the application of organic matter. Raj (1984) conducted a pot experiment on loamy sand soil and observed that application of FYM, dhaincha and wheat straw resulted in an increased Mn content as compared to control. Mn content and uptake increased significantly upto 10 t ha^{-1} of FYM and decreased drastically at 20 t ha^{-1} . While Gupta *et al.* (1989) observed that application of farm yard manure decreased Mn concentration but increased Mn uptake in grain and straw grown on soil which was highly contaminated with heavy metals.

2.7.3 Iron

Prasad (1981) found that natural complexing agents such as organic manures were important in increasing availability of Fe to plants even under acute deficiency condition in calcareous soils.

Sakal *et al.* (1982) observed that the compost improved the percentage distribution of Fe in rice and maize grown on calcareous soils. Raj (1984) reported that Fe content and uptake by wheat shoots increased with application of 10 t ha^{-1} farm yard manure and dhaincha.

Patel and Dangerwala (1984) reported that a significant relationship existed between the available Fe contents and soil organic matter content. Prasad *et al.* (1989) suggested that complexing agents present in different organic waste played an important role in cyclically transporting insoluble Fe to root surface. Sinha *et al.* (1992) reported that in calcareous soils application of farm yard manure resulted in higher Fe concentration in rice seedlings and thus resulted in healthy growth of seedling.

2.7.4 Copper

Hue *et al.* (1988) observed that plant Cu and Fe were not significantly affected by sludge rate. But Sorteberg (1981) reported that the concentration of Cu was higher in oats grown on sludge amended soils.

MacLean *et al.* (1987) reported that when domestic sewage sludge was applied to farm fields at the rate of 44.9 t ha^{-1} in a mixture with lime and saw dust, the Cu content in grass and legume plants was higher.

Gupta *et al.* (1989) reported that application of FYM on highly contaminated soil, resulted in decreased Cu concentration in wheat grain and straw but the total uptake was increased with increasing FYM levels.

Singh (1990) reported that humic acid was found to have more affinity for Cu which indicates that organic matter producing humic acids would act as better sink for copper. Sakal *et al.* (1993) reported that availability of Cu in soil was positively related with the organic carbon content of the soil.

2.8 Significance of Pb in soils and in its different fractions in crop production

Environmental hazards caused by the presence and accumulation of heavy metals in compost or sludge amended soils have been extensively studied (Emmerich *et al.*, 1982; Sposito *et al.*, 1982). Studies have shown that heavy metal toxicity in crop plants is not always directly correlated with the total amount of heavy metals in soils. The suitability of several soil extractants to predict bioavailability of heavy metals was investigated by Petruzzelli and Lubrano (1987), who stressed the importance of the amount of heavy metal present in exchangeable (KNO_3 -extractable) or complexed (DTPA-extractable) forms in determining the mobility and bioavailability of Zn, Cd and Pb in compost and sludge amended soils. Adams and Kissel (1989) studied that soil solution concentrations of sludge amended soil were found to be better correlated than DTPA-extracted metal with plant uptake.

Exchangeable metals are directly available to plants by contact exchange through root interception. The amount of nutrients that directly contacts plant root is, however, small; mass flow and diffusion are the most important processes by which cations are made available to roots (Mengel and Kirkby, 1987). Moreover, the water-soluble fraction is certainly the most readily biologically active.

Leita and DeNobili (1991) study to determine the water extractable fraction of Cd, Zn, Cu and Pb and investigate changes in water-soluble organic carbon during the complete composting of a pile of ground municipal solid waste. Samples were collected every 3 to 5 d for 60 d. The progressive increase in total heavy metals concentration during the composting period was not accompanied by a corresponding increase in the water extractable amounts of metals. The water-extractable fractions of Pb and Zn decreased rapidly with composting time. No relationship was found between pH and extractable fractions of all metals, even if higher amount of Pb and Zn were extracted when pH of the composting material was below neutrality. There was a significant correlation between water extractable Pb ($r = 0.99^{**}$) and water soluble C of non humic decomposition products. The degree of stabilization reached by organic matter appear to be important in determining potential mobility of heavy metals.

Khan and Frankland (1983) also reported that a very high proportion of Cd and Pb added to soil in water soluble form became insoluble within 1 hour of its contact with the soil, although most of this water insoluble fraction was EDTA soluble.

Elliott *et al.* (1990) observed that from 76 to 87 per cent of the Cr, Cu, Ni, Pb and Zn were bound within an oxide or silicate matrix. For each of the six metals less than 6 per cent of the total concentration was in the exchangeable fraction, which is considered to represent the immediately available metal reservoir.

Burton *et al.* (1984) observed that the highest concentration of lead, approximately 10% of the amount added remained extractable after 17 days.

This suggests that perhaps the kinetics of the uptake of Pb by the soil are rather slow, and therefore, incomplete over a 100 days period, but this is marked at the lower Pb levels because of the inherent imprecision of the determination. The total concentration of heavy metals also approximately matched the sums of the amounts in the original soil and the extra quantities added, if the quartz sand is taken into account. Overall, however, there were no indications that heavy metals had been lost from the pots as a result of leaching. They also found a significant correlation between the shoot yields and the levels of Pb ($r = -0.63$, $P < 0.05$, where $n = 8^{14}$) showing that seedling growth had been affected.

Bohn *et al.* (1979) expressed that high P levels can affect soil properties which in turn may influence the availability of micronutrient metals to plants. When P is introduced into soil, there are at least four processes that can perturb the equilibria of the micronutrient metals.

- i) A shift in pH due to the fertilizer dissolving in soil solution.
- ii) A shift in pH due to reaction of both the phosphate and the associated cation with soil components.
- iii) Changes in surface charge due to the adsorption of phosphate on colloids, and
- iv) Direct precipitation of the micronutrient metals with phosphate. There is an initial rapid reaction involving adsorption and ligand exchange followed by a slower reaction involving mineral dissolution and /or precipitation of added P with exchangeable or mineral lattice cations.

Veith and Sposito (1977) concluded that the reaction with Al was a precipitation and not the formation of a surface O-phosphate phase. They

showed that the above reaction for allophanic soils could increase the pH to as high as 6.8. Such increase in pH would normally cause micronutrient metal to revert to loss plant available forms.

Xian (1989b) reported that the exchangeable and carbonate fraction contained 6% of the total Pb of each. The highest amount of Pb (43%)^{was} in organic fraction. Metal levels in cabbage plants were in accord with their levels in soil. He also observed that potential bioavailability of heavy metals is strongly controlled by their chemical forms related to solubility, and exchangeable and carbonate forms are the most important form for heavy metal uptake by plants.

Xian and Shokohifard (1989) reported that when soil pH values decreased from 7.0 to 4.55, levels of Cd, Zn and Pb in exchangeable form increased, decreased in carbonate and slightly lowered in Fe-Mn oxide forms. Their levels in organic and residual forms were unchanged. Although concentration of metals in plants increased with reduction in soil pH values. According to 'theory of plant nutrient uptake' in soluble form are easily taken up by plants. Heavy metals in exchangeable forms have the highest solubility to give the highest potential bioavailability in contrast to the other chemical forms. However, heavy metals associated with carbonates are also easily released to solution when the soil pH is sufficiently low to dissolve the carbonates. Metabolic products of plant root, such as, H_2CO_3 and other acid materials which are secreted during root physiological activities, would lower the pH of rhizosphere to promote plant absorbing heavy metals from carbonate form. An enrichment amount of Pb was found in organic fraction because Pb^{2+} has strong affinity to humic

acid (Takenaga and Aso, 1975) so usually combines with organic matter to form stable Pb-organic complexes.

Ramos *et al.* (1994) reported that Pb and Zn were mainly associated with the crystalline Fe-Mn oxide fraction. Zinc and Pb oxides have stability constants high enough to be concentrated in this fraction. Pb formed more stable complexes with Fe and Mn oxides than did Zn. They further stated that 50% Pb was found in the Fe-Mn oxide fraction. The contribution from the carbonate, from the residual fraction were approximately equal (i.e. 20%) and virtually undetectable level were found in the exchangeable and organic fractions. Therefore, the amount of Pb in each fraction followed the order Fe-Mn oxides > carbonates > residual >> organic = exchangeable. Several other workers have found Zn and Pb to be highly associated with Fe and Mn oxides (Kuo *et al.*, 1983; Rapin *et al.*, 1982). The presence of Zn and Pb in the carbonate fraction might indicate a pH suitable for metal precipitation, calcium carbonate may act as a strong absorbant for heavy metals and could complex as double salts like $\text{CaCO}_3 \cdot \text{ZnCO}_3$ and $\text{CaCO}_3 \cdot \text{PbCO}_3$.

McKenzie (1980) determined^d the mechanism by which lead accumulated in the manganese oxides in soil. Absorption of lead by the manganese oxides was upto 40 times greater than that by the iron oxides, and lead was adsorbed more strongly than any other ions studied by all of oxides except goethite. The accumulation of lead in the Mn-oxide in the soils and resulting reduction of lead uptake by plants is due to the high specific adsorption of lead by the Mn-O over a wide range of pH value.

Chemical fraction of zinc and lead was studied (EL-Falaky, 1990) in six polluted and four non polluted soils of an Egyptian industrial district.

Less than 0.1 and 0.3% respectively of Zn and Pb was in exchangeable form in both group of soils. Zn and Pb fractions sorbed by the soil were twice as great in polluted soils representing 25% of the total exchangeable fraction for both metals in polluted soils and 3 to 10% in non polluted ones. The organically complexed fraction for both metal doubled in polluted soils. Most ^{of} Zn and Pb entering the soil from industrial waste water is adsorbed by the soil by mechanism which appear to be stronger than normal exchangeable reactions. They are very immobile and difficult to leach.

AL-Afifi (1994) tested six extractants under green house conditions for soil Pb and as predictors of plant available Pb for wheat (*Triticum aestivum*). With the application of 0, 200 and 400 mg Pb/kg soils as Pb (NO₃)₂, Pb₀, Pb₁ and Pb₂, respectively, 0.1 M HNO₃ was the most effective extractant for Pb₀ whereas 0.1 M EDTA and 0.025 M Ca DTPA. B₄O₇ were best and equally effective in Pb₁ and Pb₂ treatment. With regression analysis he found that 0.025 M Ca DTPA. B₄O₇ extractant was best in predicting Pb uptake by wheat in Pb₀ ($r = 0.79^{**}$), $P = 0.001$, Pb₁ ($r = 0.72^{**}$) and Pb₂ ($r = 0.94^{**}$) treatments.

CHAPTER-3

MATERIALS AND METHODS

The materials used and the methods followed in pursuance of the study on lead bioavailability to wheat as influenced by phosphorus, cattle manure and soil texture are described as follows :

3.1 Soil

The bulk surface soil samples (0-15 cm) of sand and clay loam soils were collected from village Balsamand and Kanoh, respectively (Hisar). These soils belong to Typic Ustipsamments and Typic Ustochrept, respectively. Soils were air dried, ground and passed through 2mm stainless steel sieve. After mixing thoroughly, soils were analysed for physico-chemical characteristics (Table 1). The same soils were also used for laboratory and pot studies.

3.2 Cattle manure

Bulk sample of well decomposed cattle manure was taken from the manure pit. After air drying, it was ground, sieved and mixed thoroughly. The chemical composition of cattle manure used is given in Table 2.

3.3 Experimentation

To access the effect of lead, phosphorus and cattle manure application on growth, yield and nutrients composition of wheat crops, pot experiments were conducted in screen house. Different fractions of Pb were estimated for its bioavailability to wheat crop in soils of variable texture.

Table 1. Physico-chemical characteristics of the soils

Properties		Sandy soil	Clay loam soil		
1.	*pH	8.40	8.20		
2.	*EC (ds m ⁻¹)	0.11	0.27		
3.	Organic carbon (%)	0.09	0.37		
4.	CEC [C mol(P ⁺)kg ⁻¹]	3.20	12.50		
5.	CaCO3 (%)	-	2.00		
6.	Mechanical composition (%)				
a.	Sand	91.23	43.30		
b.	Silt	2.82	27.70		
c.	Clay	5.95	29.00		
7.	Taxonomic classification	Typic Ustipsamment	Typic Ustochrept		
8.	Olsen's extractable P(mg kg ⁻¹)	3.00	8.00		
9.	Total P(mg kg ⁻¹)	115.50	214.50		
10.	DTPA extractable and total metals content (mg kg ⁻¹)				
		DTPA	Total	DTPA	Total
	Iron	4.08	371.70	2.68	379.20
	Manganese	2.52	137.20	2.92	165.60
	Copper	0.91	2.92	1.04	11.25
	Zinc	0.43	20.09	0.96	40.83
	Lead	1.10	13.20	1.80	20.80

*1:2 Soil : Water Suspension

Table 2. Chemical composition of cattle manure (on oven dry weight basis)

Characteristics		Content
1.	Organic carbon (%)	29.80
2.	*pH	8.25
3.	*EC (ds m ⁻¹)	8.95
4.	Total P (mg kg ⁻¹)	6100.00
5.	Total metals content (mg kg ⁻¹)	
	Iron	1450.00
	Manganese	150.00
	Copper	16.56
	Zinc	60.70
	Lead	22.00

*1:4 Cattle manure : Water suspension

3.3.1 Effect of phosphorous on lead absorption by wheat grown on texturally different Pb contaminated soils

3.3.1.1 Experimental details

- (i) Treatments :
- (a) Pb levels : Six (0, 5, 10, 20, 40 and 80 mg Pb kg⁻¹ soil)
- (b) P levels : Four (0, 25, 50 and 100 mg P kg⁻¹ soil)
- (ii) Soil texture : (a) Sand (b) Clay loam
- (iii) Replication : Three
- (iv) Design : Factorial CRD
- (v) Crop : Wheat (Cv. WH-533)
- (vi) Harvesting : At maturity
- Total No. of pots : 6 x 4 x 2 x 3 = 144

3.3.1.2 Treatment imposition and fertilizer application

Lead was applied as Pb (NO₃)₂ and phosphorus as (NH₄)₂ HPO₄ as analytical grade reagents in solution form. Pots were filled with sandy and clay loam soil @ 5 kg each. Basal doses of N, K, Mn, Fe and Zn were applied @ 90, 62, 10, 10 and 5 mg kg⁻¹ soil through (NH₂)₂ CO, KCl, MnSO₄·H₂O, FeSO₄·7H₂O and ZnSO₄·7H₂O, respectively. The adjustment of nitrogen was made through (NH₄)₂ HPO₄ and Pb (NO₃)₂. The entire material in the pots was taken out and treatment and nutrients solution mixed thoroughly and refilled. Second dose of nitrogen was applied @ 20 mg N/kg soil at ear initiation stage in solution form. The pots were kept at field capacity for 17 days using deionized water.

Thereafter, representative soil samples from each pot was taken with the help of stainless steel tube auger. Soil samples were air dried ground and sieved for the analysis of Olsen's P and DTPA extractable Pb. In figures P₀, P₂₅, P₅₀ and P₁₀₀ indicates 0, 25, 50 and 100 mg P kg⁻¹ soil, respectively.

3.3.2 Studies on cattle manure and Pb on yield and absorption of Pb by wheat grown on texturally different soils

3.3.2.1 Experimental details

(i)	Treatments	:	
(a)	Pb levels	:	Six (0, 5, 10, 20, 40 and 80 mg Pb kg ⁻¹ soil)
(b)	Cattle manure levels	:	Three (0, 0.5 and 1.0% on DWB)
(ii)	Soil texture	:	(a) Sand (b) Clay loam
(iii)	Replication	:	Three
(iv)	Design	:	Factorial CRD
(v)	Crop	:	Wheat (Cv. WH-533)
(vi)	Harvesting	:	At maturity
Total No. of pots		:	6 x 3 x 2 x 3 = 108

3.3.2.2 Treatment imposition and fertilizer application

Bulk samples of sandy and clay loam soils were prepared by mixing the above treatments and filled in earthen pots @ 5 kg each. Analytical grade reagents were used as applied in the form of solution. A basal dose of N, P, K, Mn, Fe and Zn was applied @ 90, 50, 62, 10, 10 and 5 mg kg⁻¹ soil, respectively through their AR grade chemicals ie (NH₂)₂ CO, (NH₄)₂HPO₄, KCl, MnSO₄·H₂O, FeSO₄·7H₂O and ZnSO₄·7H₂O, respectively and mixed gently. Second dose of nitrogen was applied @ 20 mg N kg⁻¹ soil at ear initiation stages. The pots were kept at field capacity for 17 days.

Thereafter, representative soil samples from each pot was taken with the help of stainless steel tube auger. Soil samples were air dried, ground sieved and stored for estimation of DTPA extractable Pb.

3.3.2.3 Date of sowing

Ten seed of wheat (cv. WH-533) were sown in each pot on December 26, 1994 in both the experiments. After ten days of emergence four plants/pot were allowed to grow upto maturity. The pots were irrigated with deionised water as and when required.

3.3.2.4 Harvesting

The crop of both experiments was harvested on April, 17, 1995. The harvested plant samples were washed with deionised water, distilled water, at last with double distilled water. The excess of water was removed by gentle shaking and pressing against the filter paper. The washed plant samples were first air dried by keeping them in paper bags and then in an oven at $65 \pm 2^\circ\text{C}$ in an air draft oven to a constant weight. Thereafter, the straw and grains were separated and weighed. The straw yield represents the combined weight of stems, leaves and earhead straw portion.

Straw samples were ground in a stainless steel grinder, and stored in polyethylene bags. Lead, P and polyvalent transition heavy metals (Zn, Mn, Fe and Cu) were analysed in wheat grain and straw.

3.3.2.5 Post-harvest soil sampling

After harvesting the crop, soil samples from each pot were taken with stainless steel tube auger. These soil samples were air dried, ground, sieved and stored in polyethylene bags for their chemical analysis.

3.3.2.6 Root sampling

To complete the above process, the polyethylene bags were taken out from the pots of both experiments (section 3.3.1 and 3.3.2). The soil was washed with tap water from each polyethylene bags. The roots were

separated from wheat stubble and put in the stainless steel sieve and washed with tap water pressure, water Jet, deionized water and finally with double distilled water. The washed root samples were air dried, by keeping them in paper bags then in an oven at $65 \pm 2^\circ\text{C}$ in an air draft oven to a constant weight. The root samples were ground in a stainless steel grinder, mixed and stored in polyethylene bags for estimation of Pb, P and polyvalent transition heavy metals.

3.3.3 Laboratory studies

To study influence of phosphorus and cattle manure on various chemical fractions of Pb and their bioavailability to wheat. Soil samples were collected before and after harvest of the crop (Section 3.3.1 & 3.3.2).

3.3.3.1 Studies on the effect of P and cattle manure on various chemical fractions of Pb and their bioavailability to wheat

Soil texture, Pb levels, P levels and cattle manure rates are same as described under experimentation (Section 3.3.1 and 3.3.2).

3.3.3.2 Sequential extraction of soil samples

The different chemical forms or fraction of Pb, extracted were exchangeable + water soluble, carbonates, organic matter complexed, Mn-oxide bound, occluded in amorphous and crystalline Fe-oxide and residual mineral fractions.

3.3.3.3 Fractionation procedure

Several methods of fractionation of heavy metals have been proposed by several workers (Chao, 1972; Tessier *et al.*, 1979; Chao and Zhou, 1983; Shuman, 1985; 1988). Here, sequential extraction procedure adopted by Singh *et al.* (1988) was used which is described in Table 3 and

Table 3. Sequential Extraction Technique for analysis of Pb in lead contaminated soils

Sr. No.	Fractions	Solution	Soil (g)	Solution (ml)	Conditions	Reference
1.	Exchangeable + Water soluble (EX+W)	1 M Mg (NO ₃) ₂	10	40	Shake 2 h at 25°C	Shuman (1985)
2.	Carbonates (CARB)	1 M NaOAc (pH 5.0, CH ₃ COOH)	10	40	Shake 5 h at 25°C	Tessier <i>et al.</i> (1979)
3.	Organically bound (OM)	0.7 M NaOCl (pH 8.5)	10	20	Shake 30 min. in boiling water bath. Stir occasionally repeat extraction.	Shuman (1983)
4.	Mn-Oxides bound (MnOX)	0.1 M NH ₂ OH HCl Sol ⁿ in 0.01 M HNO ₃ (pH 2.0)	5 ^a	50	Shake 30 min.	Chao (1972)
5.	Amorphous Fe-Oxide bound (AFeOX)	0.25 M NH ₂ OH HCl + 0.25 M HCl	5	50	Shake 30 min. at 50° C in water bath.	Chao & Zhou (1983)
6.	Crystalline Fe-Oxide bound (CFeOX)	0.2 M (NH ₄) ₂ C ₂ O ₄ + 0.2 M H ₂ C ₂ O ₄ (pH 3.0) + 0.1 M ascorbic acid	5	50	30 min. in boiling water bath. Stir occasionally.	Shuman (1982)
7.	Residual bound (RES)	Conc. HF, Conc. HClO ₄ and Conc. HCl in sequence				Tessier <i>et al.</i> (1979)

^a 5g soil from residue of step 3 after air drying

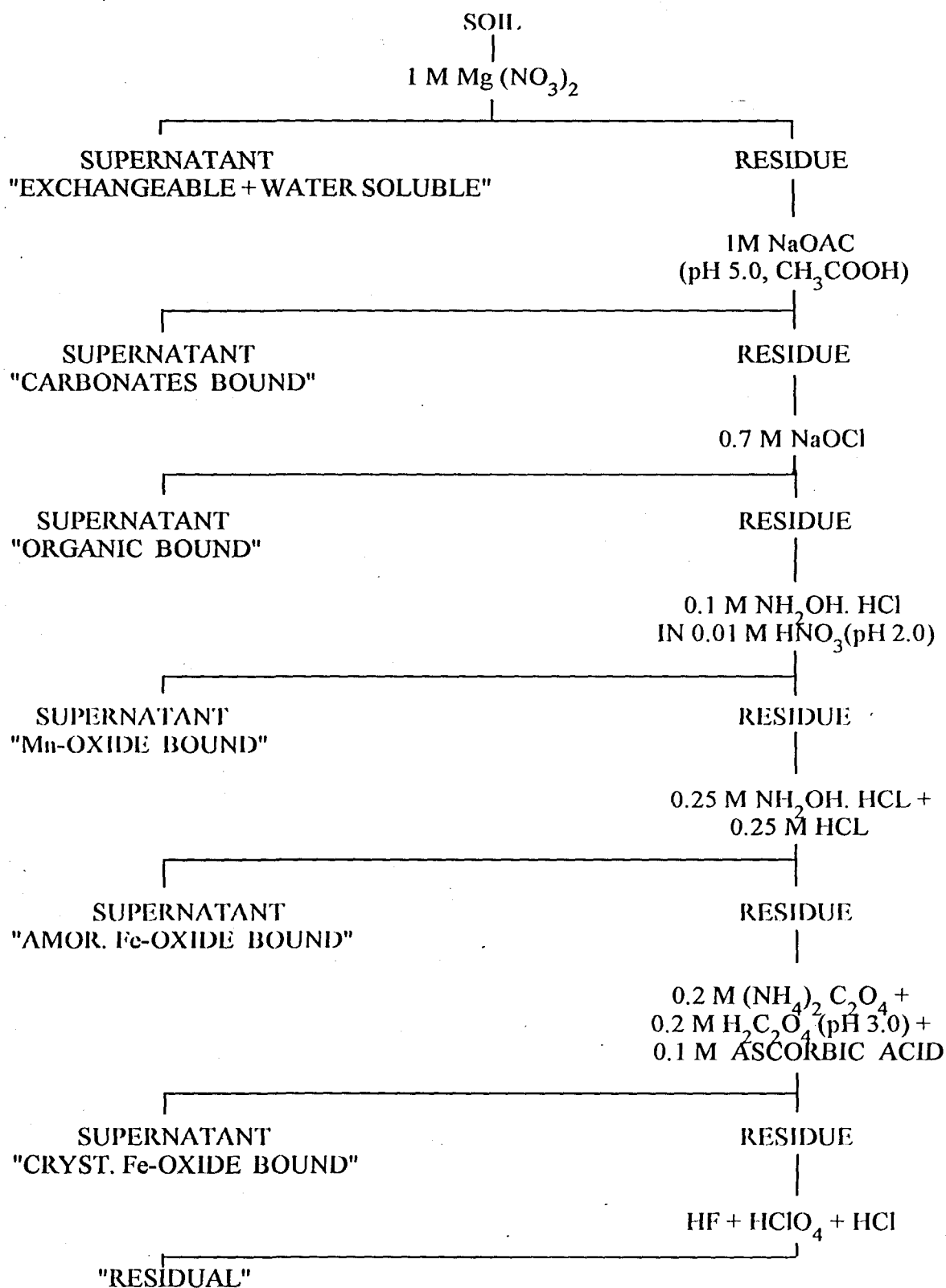


FIG. 1. FLOW SHEET OF SEQUENTIAL FRACTION SCHEME FOR HEAVY METALS.

Fig. 1. Reagents used in the fractionation scheme were selected from those cited in the literature as being selective for specific chemical form in soil. All procedures were carried out in duplicate.

Ten gram of each soil sample was taken in centrifuge tube. the extractant was added to it in required ratio. The contents of tube were centrifuged and filtered after fulfilling essential conditions such as shaking, boiling, digestion etc. The soil residue was washed twice with 100 ml of double distilled water before determining the next chemical fraction. The soil residue from organic fraction was dried after washing with double distilled water. Then five gram of soil sample was taken in centrifuge tube for determining Mn-oxides form and so on.

3.3.3.4 Residual or total metal analysis

Residual from CFeOX extraction was washed twice with double distilled water. It ^{was} subsequently dried and ground to pass through 2 mm stainless steel sieve. A 0.5 g sample was digested with 10 ml conc. HF and 2-3 ml conc. HClO_4 using Teflon beaker, over sand bath heater. Remaining material taken up in 6N HCl and volume was made to 10 ml. The procedure as described by Tessier *et al*, (1979) was adopted. Supernatant liquids for all chemical forms were stored in plastic bottles. The amounts of lead in each fractions were estimated by atomic absorption spectrophotometer (GBC-902).

3.4 Analytical methods

3.4.1 Soil analysis

The following methods were used for soil analysis

- (i) Mechanical analysis was done as per International Pipette method (Piper, 1950).

- (ii) pH and electrical conductivity were determined in 1:2 soil water suspension with the help of glass electrode pH meter and conductivity bridge, respectively.
- (iii) Organic carbon was estimated by following Walkley and Black's rapid titration method as described by Jackson (1973).
- (iv) Cation exchange capacity was determined by ammonium acetate method as outlined in USDA Hand Book No. 60 (Richards, 1954).
- (v) Calcium carbonate was estimated by following the method of Puri (1949).
- (vi) Olsen's P was extracted by 0.5 N NaHCO_3 (pH 8.5) and determined colorimetrically (Jackson, 1958).
- (vii) DTPA extractable in polyvalent transition heavy metals were extracted by using the procedure of Lindsay and Norvell (1978) and estimated on Atomic Absorption Spectrophotometer (AAS), GBC-902.

3.4.2 Analysis of cattle manure

(i) Digestion of cattle manure

1 gm of dried cattle manure sample was digested in 20 ml of distilled conc. nitric acid. Mix the contents of the flask by swirling and start heating at low heat on a hot plate to oxidise organic matter. Add 10 ml of perchloric acid and digest the mixture until dense white fumes of acid appear. Dilute the digest with double distilled water to a known volume.

- (ii) Total polyvalent transition heavy metals in the digested samples of cattle manure were determined by using atomic absorption spectrophotometer (GBC-902).

- (iii) Total phosphorus in the acid digest of cattle manure was estimated by using the vanadomolybdo phosphoric acid yellow coloured method Jackson (1973).
- (iv) Organic carbon in the cattle manure was determined by Walkley and Black's method as described by Piper (1950).
- (v) DTPA extractable polyvalent transition heavy metals were determined by following the method of Lindsay and Norvell (1978).

3.4.3 Analysis of grain, straw and root

In order to determine P, Pb and micronutrients (Fe, Mn, Zn, Cu) in grain, straw and roots, 0.5 g of grounded and mixed material was digested in diacid mixture of nitric acid and perchloric acid (4:1). After digestion the volume was made to 25 ml with double distilled water, filtered and stored in well washed plastic bottles. All the estimation in the aliquote were made according to the following procedure.

- (i) Phosphorus was determined by using the vanadomolybdo phosphoric acid yellow colour method (Jackson, 1973).
- (ii) Fe, Mn, Zn, Cu and Pb were estimated by using the atomic absorption spectro photometer (GBC-902).

3.5 Statistical Analysis of Data

Factorial CRD for three factor were employed to study the effect of different treatments in various experiments (Panse and Sukhatme, 1967). The analysis was carried out with the help of computer of the Department of Soil Science, CCS, Haryana Agricultural University, Hisar. The effect of treatments were compared with the help of the interaction CD where the interaction effect of 'P, cattle manure levels with Pb levels was found to be significant. Therefore only interaction CD (S) are reported here.

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Studies on the yield, chemical composition and nutrient availability to wheat as influenced by Pb, P and soil texture

4.1.1 Influence of Pb, P and soil texture on yield of wheat

4.1.1.1 Grain yield

A perusal of data (Table 4) revealed that overall grain yield increased significantly with 5 mg Pb kg⁻¹ soil and decreased at higher rates of applied Pb, over control. The overall reduction in grain yield due to 10, 20, 40 and 80 mg Pb kg⁻¹ soil was 4.08, 8.22, 11.42 and 16.44 per cent over control, respectively.

In sharp contrast to sandy soil where reduction in yield appeared at 5 mg Pb kg⁻¹ soil, the yield decreased significantly at 20 mg Pb kg⁻¹ soil in clay loam soil. Application of 80 mg Pb kg⁻¹ soil over control alleviated mean grain yield by 20.23 per cent in sandy soil, compared with 14.06 per cent in clay loam soil. This showed that the effect of Pb on crop growth varied with soil texture, being more adverse in coarse textured than fine textured soils.

Application of 5 mg Pb kg⁻¹ soil enhanced relative yield at 0, 25 and 50 mg P kg⁻¹ soil over 0 mg Pb kg⁻¹ soil in sandy soil, while in clay loam soil, the relative yield increased upto 100 mg P kg⁻¹ soil at similar level of Pb (Fig. 2).

Table 4. Influence of Pb, P and soil texture on grain yield of wheat

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Grain yield (g pot ⁻¹)								
Sand	0	6.60	7.17	6.17	5.77	5.70	5.63	6.17
	25	11.17	11.97	11.20	10.53	10.43	10.23	10.92
	50	15.13	15.50	13.67	13.47	13.00	11.40	13.69
	100	16.13	14.20	13.53	13.33	12.57	11.87	13.60
	Mean	12.26	12.21	11.14	10.77	10.42	9.78	11.09
Clay loam	0	15.37	16.60	16.10	15.63	14.17	13.33	15.20
	25	19.90	21.30	19.87	19.27	18.77	17.50	19.43
	50	20.90	22.40	20.93	19.43	18.83	17.93	20.07
	100	22.30	22.76	20.90	19.67	19.53	18.70	20.64
	Mean	19.62	20.76	19.45	18.50	17.82	16.86	18.83
Overall Mean		15.94	16.48	15.29	14.63	14.12	13.32	14.96

C.D. (P = 0.05)

Pb = 0.27

Pb x P = 0.54

P = 0.22

Pb x Soil = 0.38

Soil = 0.15

P x Soil = 0.31

Pb x P x Soil = 0.76

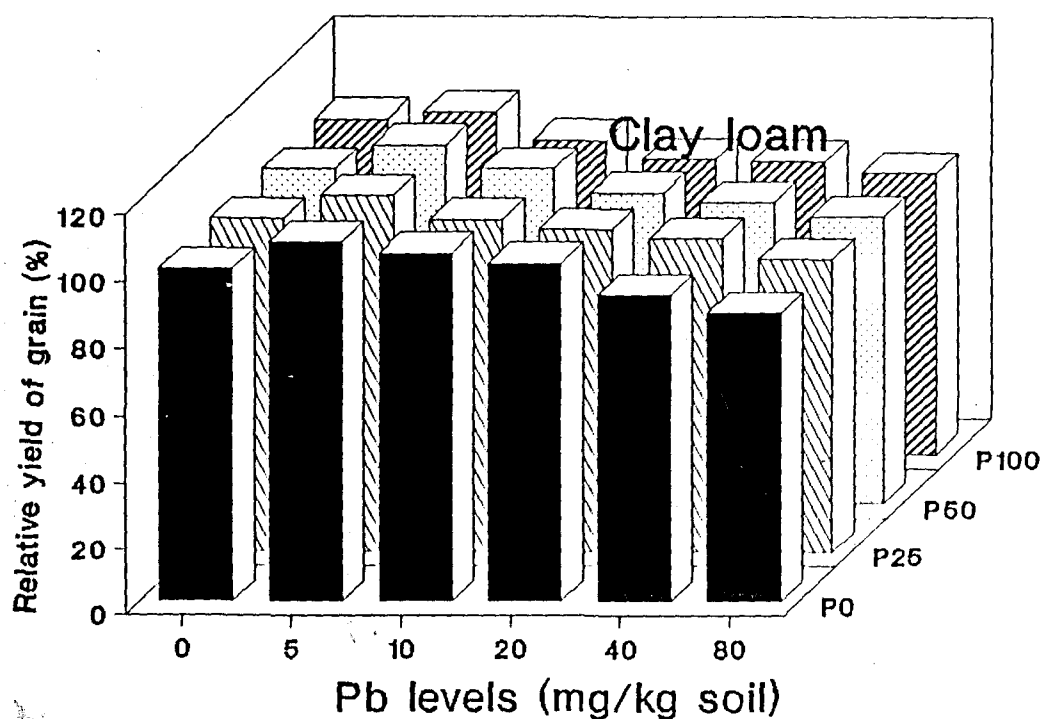
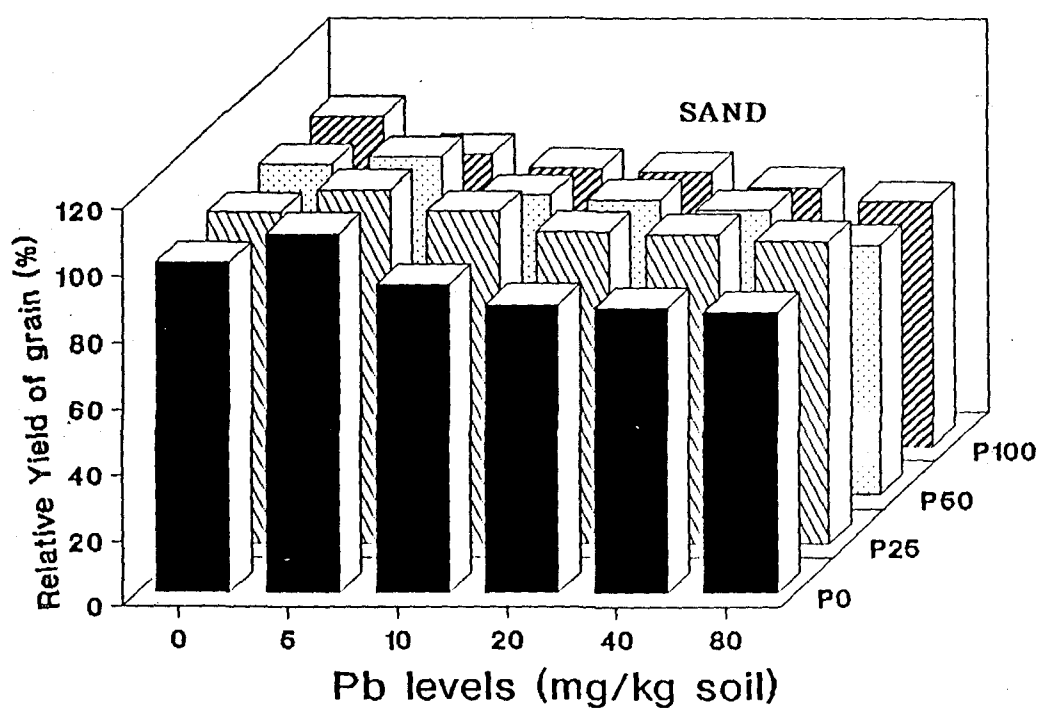


FIG. 2. INFLUENCE OF Pb, P AND SOIL TEXTURE ON RELATIVE YIELD OF WHEAT GRAIN

Application of 80 mg Pb kg⁻¹ soil reduced relative yield to 85.30, 91.58, 75.35 and 73.59 per cent at 0, 25, 50 and 100 mg P kg⁻¹ soil, respectively, compared with 100 per cent at 0 mg Pb kg⁻¹ soil in sandy soil. The relative grain yield increased at 25 mg P kg⁻¹ soil and decreased at higher levels when compared with 0 mg P kg⁻¹ soil in both soils (Annexure-1). The effect of added Pb on yield was related with levels of P and varied significantly with soil texture.

In the absence of added P, application of 80 mg Pb kg⁻¹ soil resulted in 14.69 and 13.27 per cent reduction in grain yield in sandy and clay loam soil, respectively. Application of 100 mg P kg⁻¹ soil alone increased the grain yield by 144.3 and 45.0 per cent over control (P₀Pb₀) in sandy and clay loam soil, respectively. The combined application of 80 mg Pb and 100 mg P kg⁻¹ soil enhanced grain yield by 79.8 and 21.6 per cent over 0-Pb 0-P treatment in sandy and clay loam soil, respectively. The various interaction between Pb, P and soil texture were found significant. The results vividly showed that application of higher rates of Pb, nipped the beneficial effect of P on wheat yield.

4.1.1.2 Straw yield

It is evident from data (Table 5) that application of Pb upto 5 mg Pb kg⁻¹ soil enhanced straw yield over 0 mg Pb kg⁻¹ soil in both the soils. A significant depression in yield was noticed at 20 mg Pb kg⁻¹ soil over corresponding levels of Pb irrespective of soil texture.

The straw yield was reduced by 6.16 and 12.53 per cent in sandy soil due to the mean effect of 40 and 80 mg Pb kg⁻¹ soil, respectively, over no Pb treatment while corresponding decrease in clay loam soil was 4.57 and

Table 5. Influence of Pb, P and soil texture on straw yield of wheat

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Straw yield (g pot ⁻¹)								
Sand	0	12.07	13.43	13.13	12.90	12.03	11.63	12.53
	25	18.43	19.43	18.97	18.30	18.10	16.13	18.22
	50	22.03	24.30	24.00	22.73	22.40	20.47	22.65
	100	26.63	25.93	23.03	22.53	21.77	21.03	23.49
	Mean	19.79	20.77	19.78	19.11	18.57	17.31	19.22
Clay loam	0	21.47	23.47	21.50	21.03	19.63	18.20	20.88
	25	25.13	26.57	25.23	24.17	23.90	23.77	24.79
	50	26.40	27.27	26.80	26.40	26.10	25.77	26.46
	100	31.07	31.73	31.63	30.90	29.70	29.17	30.70
	Mean	26.02	27.26	26.29	25.62	24.83	24.23	25.71
Overall Mean		22.90	24.01	23.03	22.36	21.70	20.77	22.46

C.D. (P = 0.05)

Pb = 0.44

P = 0.36

Soil = 0.25

Pb x P = 0.89

Pb x Soil = NS

P x Soil = 0.51

Pb x P x Soil = 1.26

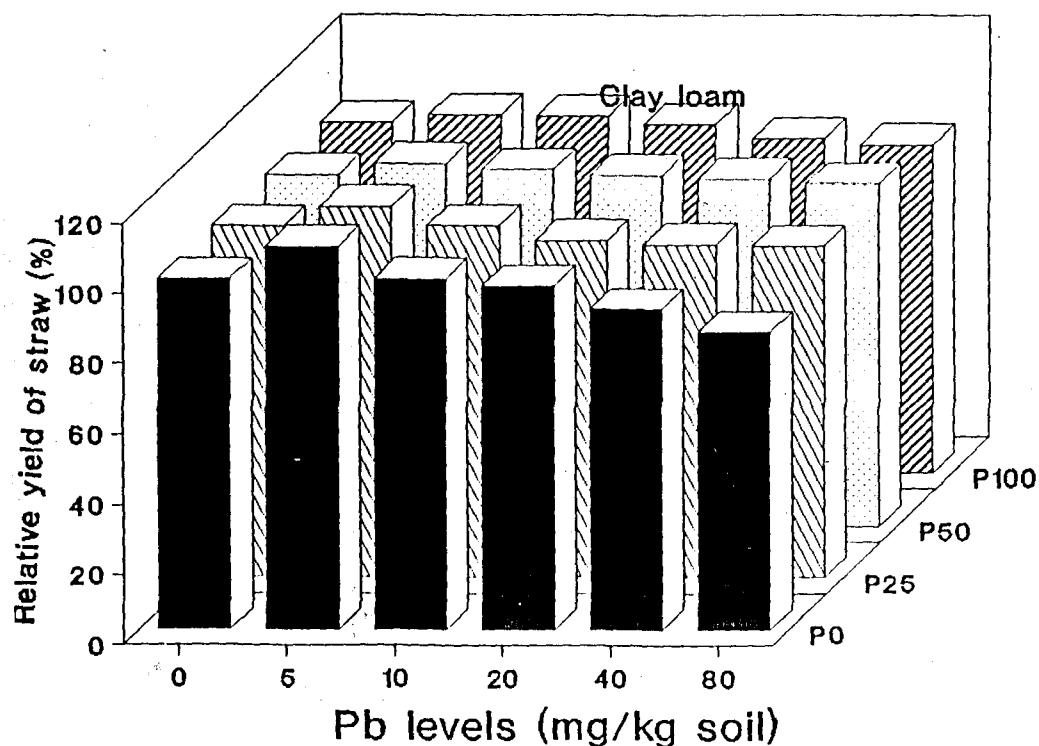
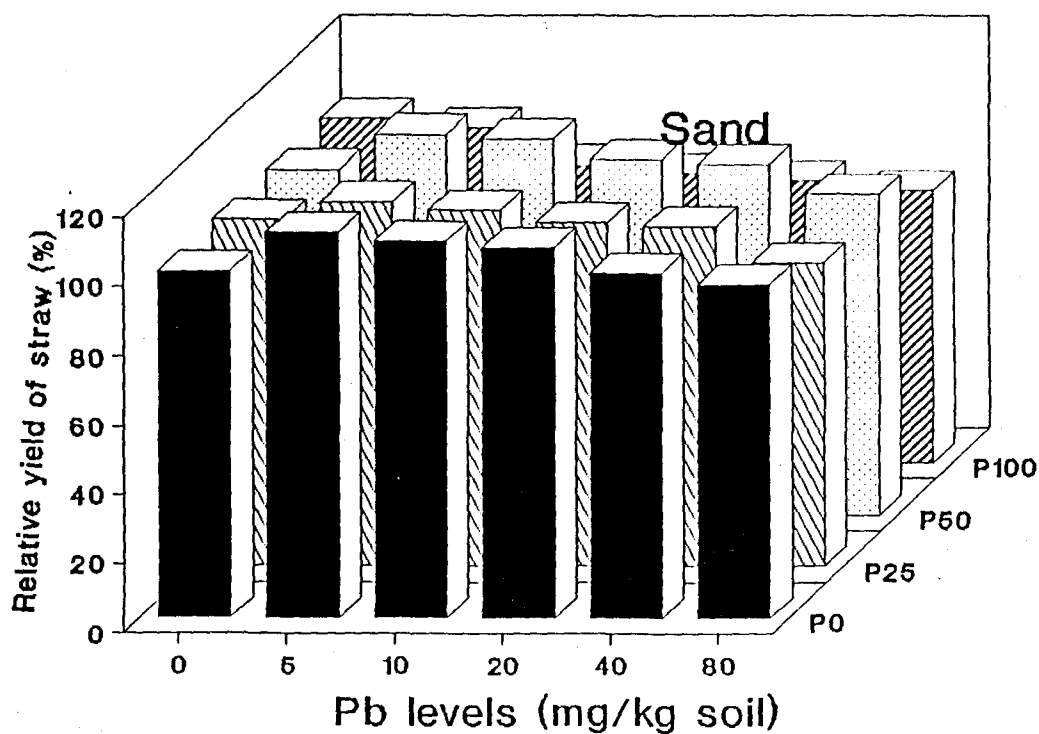


FIG.3. INFLUENCE OF Pb, P AND SOIL TEXTURE ON RELATIVE YIELD OF WHEAT STRAW

6.87 per cent, respectively. Like grain, the straw yield was also significantly higher in clay loam soil than sandy soil. Application of 80 mg Pb kg⁻¹ soil resulted in relative yield of 96.36, 87.52, 92.92 and 78.97 per cent in sandy soil compared with 84.77, 94.59, 97.61 and 93.88 per cent in clay loam soil at 0, 25, 50 and 100 mg P kg⁻¹ soil, respectively (Fig. 3, Annexure-1).

Like grain, application of P significantly increased the straw yield. The mean straw yield increased by 45.4, 80.7 and 87.4 per cent in sandy 18.7, 26.7 and 47.0 per cent in clay loam soil, respectively, due to 25, 50 and 100 mg P kg⁻¹ soil over no P treatment. The effect of P on straw yield varied significantly with soil texture. The differences among various added P levels were found significant in both the soils. The results showed that response to added P was more pronounced in sandy soil and the magnitude of response was higher with 25 mg P kg⁻¹ soil as compared to other P levels, over no P treatment. The effect of P varied significantly with Pb levels and soil texture. Levels of Pb when applied with P, increased the straw yield over Pb level alone in both soils tested.

4.1.1.3 Root yield

Root yield increased with initial level of Pb and decreased with further increase in Pb levels in both the soils (Table 6). In sandy soil, significant reduction in yield was recorded at 10 mg Pb kg⁻¹ soil while in clay loam soil the reduction appeared at 20 mg Pb kg⁻¹ soil. The mean root yield was significantly reduced by 6.15, 13.40, 20.28 and 26.08 per cent at 10, 20, 40 and 80 mg Pb kg⁻¹ soil in sandy soil and 5.88, 11.76 and 18.23 per cent with 20, 40 and 80 mg Pb kg⁻¹ soil in clay loam soil, respectively. The overall mean per cent reduction in yield was 21.75 at 80 mg Pb kg⁻¹ soil

Table 6. Influence of Pb, P and soil texture on root yield of wheat

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Root yield (g pot ⁻¹)								
Sand	0	1.55	1.95	1.55	1.35	1.30	1.25	1.49
	25	2.65	2.75	2.50	2.45	2.20	2.10	2.44
	50	3.30	3.35	3.05	2.80	2.55	2.30	2.89
	100	3.55	3.50	3.25	2.95	2.77	2.52	3.09
	Mean	2.76	2.89	2.59	2.39	2.20	2.04	2.48
Clay loam	0	3.05	3.25	3.00	2.73	2.27	1.95	2.71
	25	3.25	3.35	3.15	2.85	2.64	2.53	2.96
	50	3.45	3.80	3.68	3.59	3.50	3.24	3.54
	100	3.85	3.80	3.70	3.65	3.58	3.40	3.66
	Mean	3.40	3.55	3.38	3.20	3.00	2.78	3.22
Overall Mean		3.08	3.22	2.98	2.79	2.60	2.41	2.85

C.D. (P = 0.05)

Pb = 0.06

P = 0.05

Soil = 0.03

Pb x P = 0.13

Pb x Soil = 0.09

P x Soil = 0.07

Pb x P x Soil = 0.18

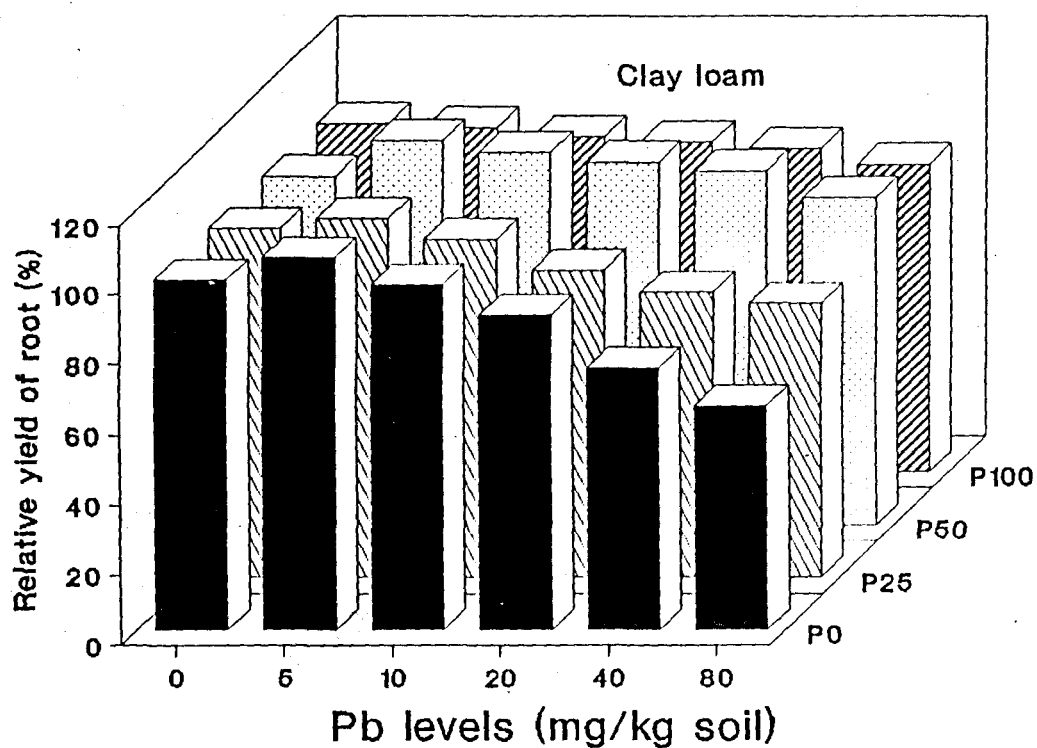
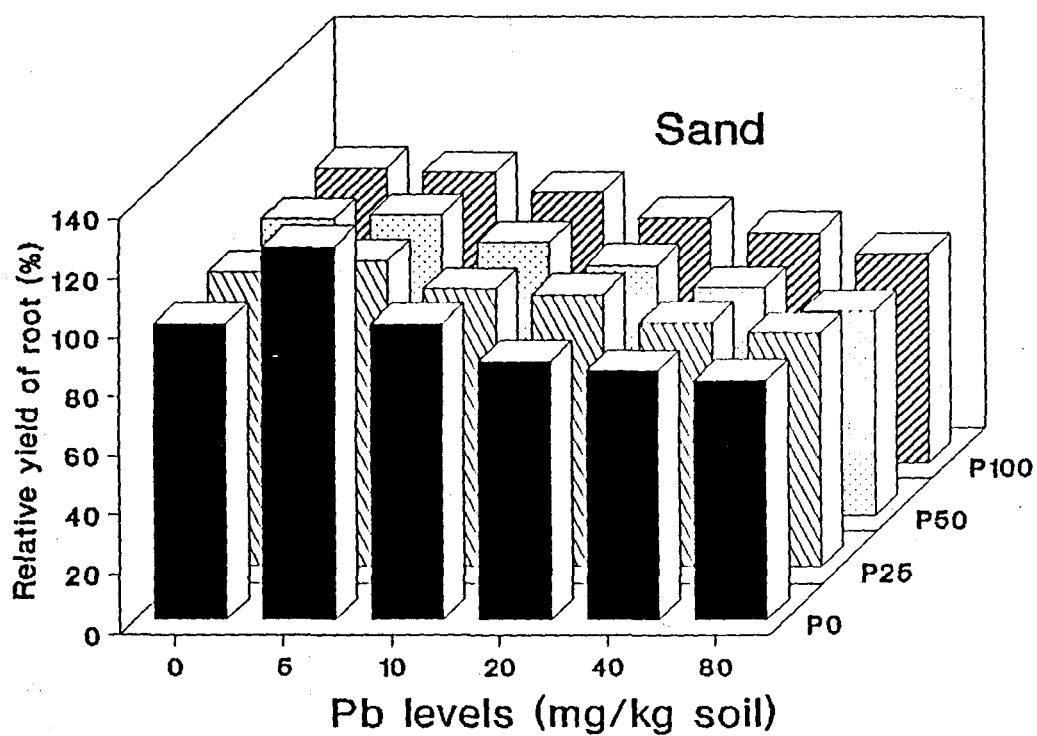


FIG.4. INFLUENCE OF Pb, P AND SOIL TEXTURE ON RELATIVE YIELD OF WHEAT ROOT

over control. Thus, the reduction in yield due to Pb was more in sandy than clay loam soil.

Like grain and straw, relative yield of root increased with lower levels of applied Pb and alleviated with increasing rates of Pb in both the soils (Fig. 4). The relative yield of roots in the presence of 80 mg Pb kg⁻¹ soil at 0 and 100 mg P kg⁻¹ soil was 80.64 and 70.98 per cent in sandy soil and 63.93 and 88.31 per cent in clay loam soil, respectively (Annexure-1). Application of P significantly increased the root yield over control in both the soils.

Application of 80 mg Pb kg⁻¹ soil alone resulted in 19.35 and 36.06 per cent reduction in root yield over no P and no Pb treatment in sandy and clay soil, respectively, while 100 mg P kg⁻¹ soil alone increased root yield by 129.0 and 26.2 per cent over no P and no Pb treatment in sandy and clay loam soil, respectively. The combined application of 80 mg Pb and 100 mg P kg⁻¹ soil also increased in root yield of wheat by 62.5 and 11.4 per cent over no P, no Pb treatment in sandy and clay loam soil, respectively. The various interaction between Pb, P and soil were found significant.

The foregoing results indicated that 5 mg Pb kg⁻¹ soil had beneficial effect on grain, straw and root yield of wheat, however, higher rates of Pb had a significant depressing effect on yield. This is ascribed to increase in P and Cu concentration and mayⁿ other nutrients at lower level of Pb application and decrease at higher level of applied Pb may be due to the adverse effect of Pb on some essential metabolic reactions in plants. A somewhat similar beneficial effect of Pb and its lower levels and toxicity at higher levels in tomato and egg plant was observed by Khan and Khan (1983) who attributed it to increase in K, Ca and Mg content of plant at lower doses and decrease at

higher doses of Pb. Similar observations were recorded by MacLean *et al.* (1969) in oat grain. Hampp *et al.* (1973) reported adverse effect of lead on enzymes of the reductive pentose phosphate pathway. Carlson *et al.* (1975) postulated the lead toxicity in the enzymes involved in photosynthesis and respiration. The results are also in consonance with Kansal *et al.* (1992) who reported adverse effect of Pb on maize. Monem Balba *et al.* (1991) in tomato and Khan and Frankland (1983) in radish plants also observed adverse effect of Pb when the level exceeded $1000 \mu\text{g g}^{-1}$. Burton *et al.* (1984) found that with increase of Pb level in the shoot, yield of plant shoot were significantly reduced. The length of the stika-spruce root were also reduced when Pb levels in the soil exceeded certain threshold concentration (48 ppm total Pb, where 1-7 ppm was extractable).

The results showed that the effect of Pb on crop growth varied with soil texture, being more adverse in coarse textured than fine textured soil. It could be due to greater availability of Pb in the former soil. The CEC of clay loam soil is an indication of greater Pb retention capacity which modified the effect on plant. The organic matter, clay and hydrous oxides can adsorb metal (Ellis and Knezek, 1972; Page, 1974); soils with higher metal sorption capacity have lower potential for plant uptake of metals.

In general, application of P increased the yield of wheat grain, straw and root significantly. The higher response of P in sandy soil than clay loam soil, was due to low P status of former soil and better utilization of added P. Yield response to P have been obtained both at research farm as well as in cultivator field by Tomer *et al.* (1985); Tandon (1987); Yadav *et al.* (1983) also reported that application of P markedly improved root yield of oat.

Increase in wheat due to P application were recorded by Vig *et al.* (1983) and Dev *et al.* (1983).

Application of P either alone or in combination with Pb levels, increased the wheat yield over Pb level alone. The increase in yield was more in sandy soil than clay loam soil. Translocation of Pb also reveals a complicated interaction among nutrients and plant metabolism. In fertile soils, huge amounts of added Pb had little effect on foliar Pb (Baumhardt and Welch, 1972). Precipitation of Pb phosphates, especially in phosphate-rich organelles, seemed an obvious explanation to this fertility difference (Malone *et al.*, 1974); higher soil phosphate fertility reduced foliar Pb in corn (Miller *et al.*, 1975). Kansal *et al.* (1992) observed significant interaction between P and Pb. Also found a negative and significant relationship ($r = -0.88^{**}$) between Pb concentration in plants and dry matter yield of maize. They also found that P suppressed the Pb concentration in plant significantly and reduced Pb toxicity to plant.

4.1.2 Effect of Pb, P and soil texture on concentration and uptake of Pb and P by wheat grain, straw and root.

4.1.2.1 Lead concentration and uptake by wheat grain

(a) Pb-concentration

The overall Pb concentration increased from $1.12 \mu\text{g g}^{-1}$ at 0 mg Pb to $7.12 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil irrespective of soil texture (Table 7). The effect of Pb on its concentration in grain varied significantly with soil texture. Mean concentration of Pb in grain was higher in sandy soil than clay loam soil.

Table 7. Effect of Pb, P and soil texture on Pb concentration of wheat grain

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb concentration (µg g ⁻¹)								
Sand	0	1.65	2.50	3.80	5.50	6.95	8.73	4.85
	25	1.31	2.18	3.23	4.97	6.62	8.04	4.39
	50	1.15	2.01	2.92	4.77	6.20	7.30	4.05
	100	0.95	1.85	2.35	4.20	5.93	6.83	3.68
	Mean	1.26	2.13	3.07	4.86	6.42	7.72	4.24
Clay loam	0	1.23	2.22	3.02	4.33	5.63	7.20	3.93
	25	1.03	2.13	2.72	4.05	5.10	6.89	3.65
	50	0.89	1.84	2.23	3.92	4.75	6.13	3.29
	100	0.78	1.28	2.00	3.35	4.07	5.85	2.88
	Mean	0.98	1.87	2.49	3.91	4.88	6.52	3.44
Overall Mean		1.12	2.00	2.78	4.38	5.65	7.12	3.84

C.D. (P = 0.05)

Pb = 0.05

P = 0.04

Soil = 0.02

Pb x P = 0.10

Pb x Soil = 0.07

P x Soil = 0.05

Pb x P x Soil = 0.14

Application of P, significantly decreased the Pb concentration in grain. Mean concentration of Pb in grain depressed significantly from 4.85 to 3.68 $\mu\text{g g}^{-1}$ in sandy soil and 3.93 to 2.88 $\mu\text{g g}^{-1}$ in clay loam soil due to 100 mg P kg^{-1} soil when compared with 0 mg P kg^{-1} soil, respectively. The effect of Pb x P interaction on Pb concentration was significant in both the soils. The combined application of 80 mg Pb and 100 mg P kg^{-1} soil alleviated Pb concentration in grain by 21.7 and 18.7 per cent over 80 mg Pb kg^{-1} soil alone in sandy and clay loam soil, respectively indicating thereby, that, depressing effect of P on Pb concentration was more pronounced in sandy soil.

The results depicted that interaction effect of Pb and P on grain Pb was more in sandy than clay loam soil. The effect of interaction between Pb, P and soil was significant and antagonistic.

(b) Pb-uptake

Uptake of Pb by wheat grain increased significantly with increasing levels of Pb (Table 8, Fig. 5). The overall Pb uptake by wheat grain was 16.69, 31.74, 40.27, 61.48, 76.03, and 91.43 $\mu\text{g pot}^{-1}$ at 0, 5, 10, 20, 40 and 80 mg Pb kg^{-1} soil. However, the magnitude of increase in Pb uptake varied significantly with soil. The mean Pb uptake by grain varied from 14.53 to 73.87 $\mu\text{g pot}^{-1}$ in sandy and 18.85 to 108.99 $\mu\text{g pot}^{-1}$ with the increasing level of Pb application from control to 80 mg kg^{-1} soil, respectively. The uptake of Pb by grain was significantly higher (61.95 $\mu\text{g pot}^{-1}$) in clay loam soil than sandy soil (43.93 $\mu\text{g pot}^{-1}$) due to higher yield.

Table 8. Uptake of Pb by wheat grain as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb uptake (µg pot ⁻¹)								
Sand	0	10.81	17.94	23.44	31.70	36.97	48.91	28.74
	25	14.66	26.04	36.21	52.29	69.09	82.29	46.76
	50	17.42	31.14	39.87	64.19	80.60	83.20	52.73
	100	15.26	26.26	31.82	55.98	74.56	81.10	47.49
	Mean	14.53	25.34	32.83	51.04	65.98	73.87	43.93
Clay loam	0	18.95	36.79	48.56	67.72	79.79	96.00	57.96
	25	20.56	45.43	53.97	78.03	95.67	120.65	69.05
	50	18.53	41.29	46.51	76.12	89.50	109.94	63.64
	100	17.39	29.07	41.80	65.88	79.44	109.39	57.16
	Mean	18.85	38.14	47.71	71.93	86.10	108.99	61.95
Overall Mean		16.69	31.74	40.27	61.48	76.03	91.43	52.94

C.D. (P = 0.05)

Pb	= 1.32	Pb x P	= 2.64
P	= 1.08	Pb x Soil	= 1.87
Soil	= 0.76	P x Soil	= 1.52
		Pb x P x Soil	= 3.74

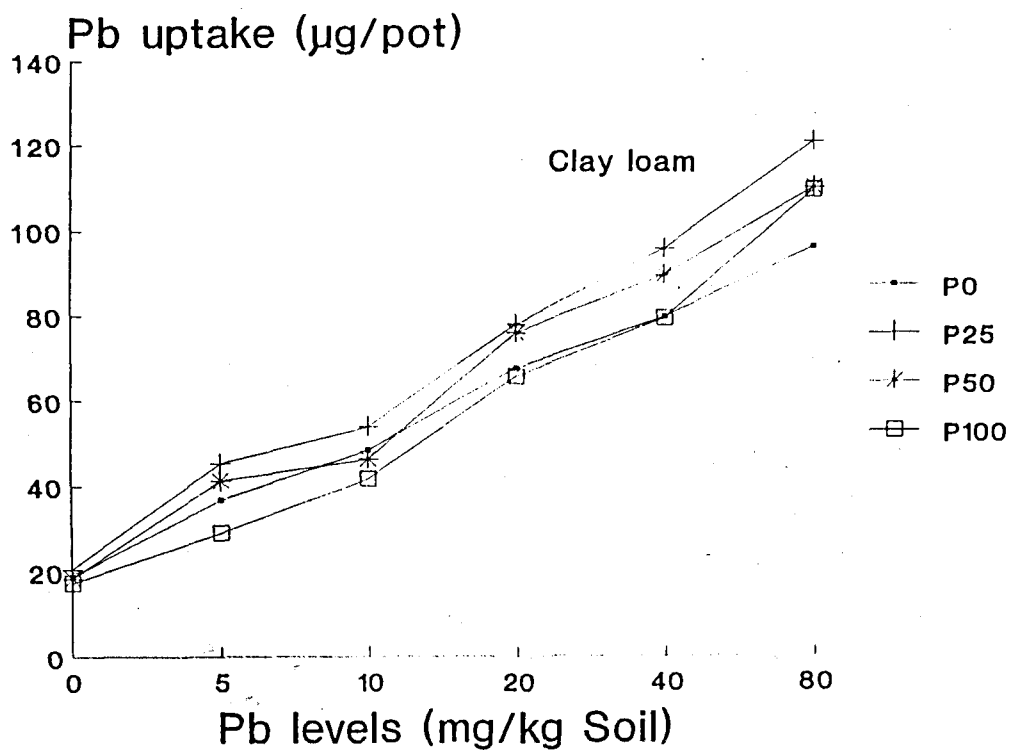
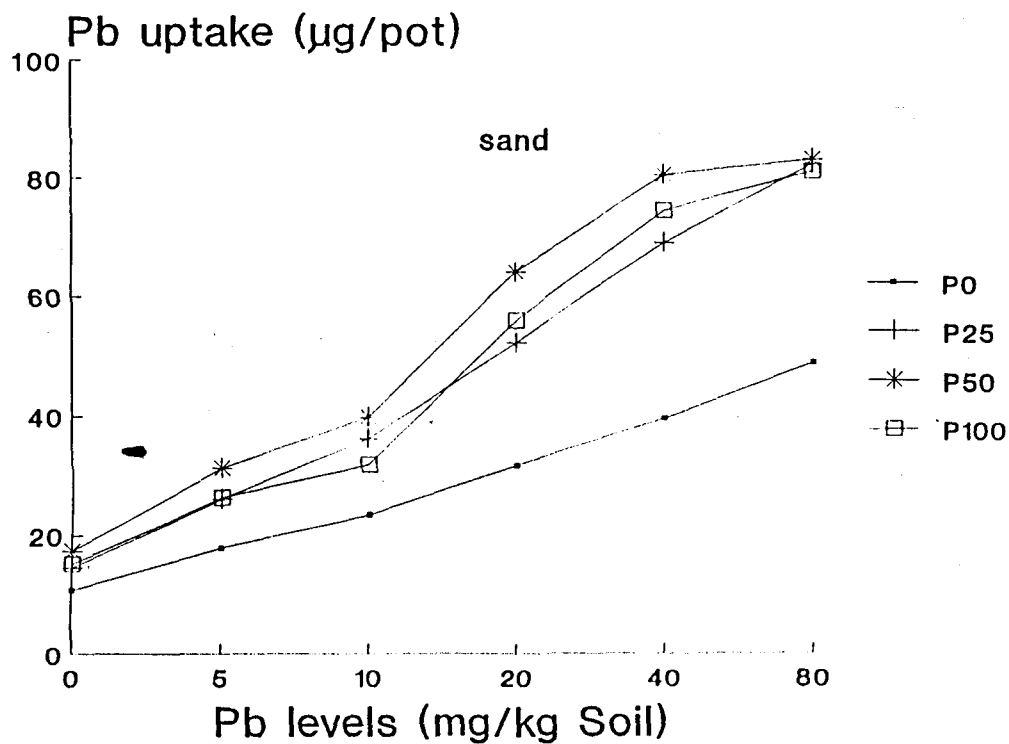


FIG. 5. UPTAKE OF Pb BY WHEAT GRAIN AS AFFECTED BY Pb, P AND SOIL TEXTURE

Phosphorus application enhanced Pb uptake by grain but the effect of P varied with soil texture. Application of 100 mg P kg⁻¹ soil alleviated Pb uptake significantly when compared with 50 mg P kg⁻¹ soil in both the soils.

The effect of Pb x P interaction was significant and varied with soil texture. Uptake of Pb by grain in sandy soil increased with escalating levels of both Pb and P either alone or in combination, upto 50 mg P kg⁻¹ soil and decreased slightly with 100 mg P kg⁻¹ soil. Application of 25, 50 and 100 mg P kg⁻¹ in sandy soil in combination with 80 mg Pb kg⁻¹ soil improved Pb uptake by 68.2, 70.1 and 65.8 per cent over 80 mg Pb kg⁻¹ soil alone, respectively. However, in clay loam soil interactive effect of Pb and P varied with their levels. Lead uptake improved significantly with 25 mg P kg⁻¹ soil with increasing levels of Pb, while increasing level of P with the decreased Pb uptake over their proceeding levels.

4.1.2.2 Lead concentration and uptake by wheat straw

(a) Pb-concentration

Mean values revealed that concentration of Pb in wheat straw increased as a consequent of increasing rates of Pb regardless of soil texture (Table 9). The overall mean Pb concentration of straw increased from 2.48 µg g⁻¹ in control to 12.22 µg g⁻¹ straw at 80 mg Pb kg⁻¹ soil. The effect of Pb x soil interaction on Pb concentration in wheat straw was significant. The mean effect of Pb on its concentration indicated that wheat straw grown in sandy soil contained higher Pb than plants grown in clay loam soil. The Pb content of straw was found to be higher in straw than grain.

Like grain, application of P resulted in significant reduction in Pb concentration of straw, which varied significantly with soil texture. The

Table 9. Effect of Pb, P and soil texture on Pb concentration of wheat straw

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb concentration (µg g ⁻¹)								
Sand	0	3.12	4.20	6.57	9.52	11.80	15.60	8.46
	25	2.80	3.80	5.73	8.90	11.00	14.72	7.82
	50	2.52	3.60	5.00	8.10	10.02	13.20	7.07
	100	2.00	3.02	4.38	7.27	8.83	11.83	6.22
	Mean	2.61	3.65	5.42	8.44	10.41	13.84	7.39
Clay loam	0	2.67	3.35	4.87	6.92	8.07	11.48	6.22
	25	2.53	3.18	4.02	6.53	7.80	10.97	5.83
	50	2.22	3.00	3.85	6.05	7.50	10.05	5.44
	100	2.03	2.67	3.75	5.65	7.25	9.92	5.21
	Mean	2.36	3.05	4.12	6.28	7.65	10.60	5.67
Overall Mean		2.48	3.35	4.77	7.36	9.03	12.22	6.53

C.D. (P = 0.05)

Pb = 0.11

Pb x P = 0.23

P = 0.09

Pb x Soil = 0.16

Soil = 0.06

P x Soil = 0.13

Pb x P x Soil = 0.32

depression in straw Pb grown in sandy soil was 7.5, 16.4 and 26.4 per cent compared with 6.2, 12.5 and 16.2 per cent in clay loam soil due to application of 25, 50 and 100 mg P kg⁻¹ soil over no P treatment, respectively. This indicated that suppressing effect of P on Pb concentration was more pronounced in soils having low clay content.

The interaction between Pb, P and soil was also found significant. Application of Pb without P, elevated straw Pb significantly, while P alone showed significant depression, in both the soils. Similar to grain combined application of Pb and P, decreased Pb concentration significantly over Pb levels in both soils. The results indicated that application of P had an antagonistic effect on Pb concentration in wheat straw. The various interaction between Pb, P and soil were also significant.

(b) Pb-uptake

A perusal of data (Table 10, Fig. 6) evinced that Pb uptake by wheat straw increased with Pb application. The magnitude of increase in Pb uptake varied with Pb levels and soil texture. The mean Pb uptake by straw increased significantly and progressively with the increasing rate of Pb application in both the soils.

Increasing rate of P significantly increased Pb uptake by straw over control, however, uptake of Pb decreased at 100 mg P kg⁻¹ soil when compared with 50 mg P kg⁻¹ soil at all levels of Pb in sandy soil. Contrary to this the uptake of Pb increased consistently in clay loam soil due to P application. The uptake of Pb was significantly higher in clay loam soil due to mean effect of soil texture.

Table 10. Uptake of Pb by wheat straw as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb uptake (µg pot ⁻¹)								
Sand	0	37.61	56.43	86.24	122.76	141.99	181.48	104.41
	25	51.63	73.84	108.70	162.88	199.10	237.84	138.99
	50	55.46	87.51	123.92	184.14	224.39	270.18	157.60
	100	53.28	78.21	100.97	163.75	190.52	248.90	139.27
	Mean	49.49	73.99	104.95	158.38	189.00	234.60	135.07
Clay loam	0	57.25	78.61	104.65	145.49	158.41	209.01	125.57
	25	63.63	84.57	101.35	157.85	185.89	260.64	142.32
	50	58.52	81.80	103.20	159.72	195.74	258.96	142.99
	100	63.00	84.62	118.63	174.58	215.32	289.25	157.56
	Mean	60.60	82.40	106.95	159.41	188.84	254.46	142.11
Overall Mean		55.04	78.19	105.95	158.89	188.92	244.53	138.59

C.D. (P=0.05)

Pb = 3.32

P = 2.71

Soil = 1.92

Pb x P = 6.65

Pb x Soil = 4.70

P x Soil = 3.84

Pb x P x Soil = 9.41

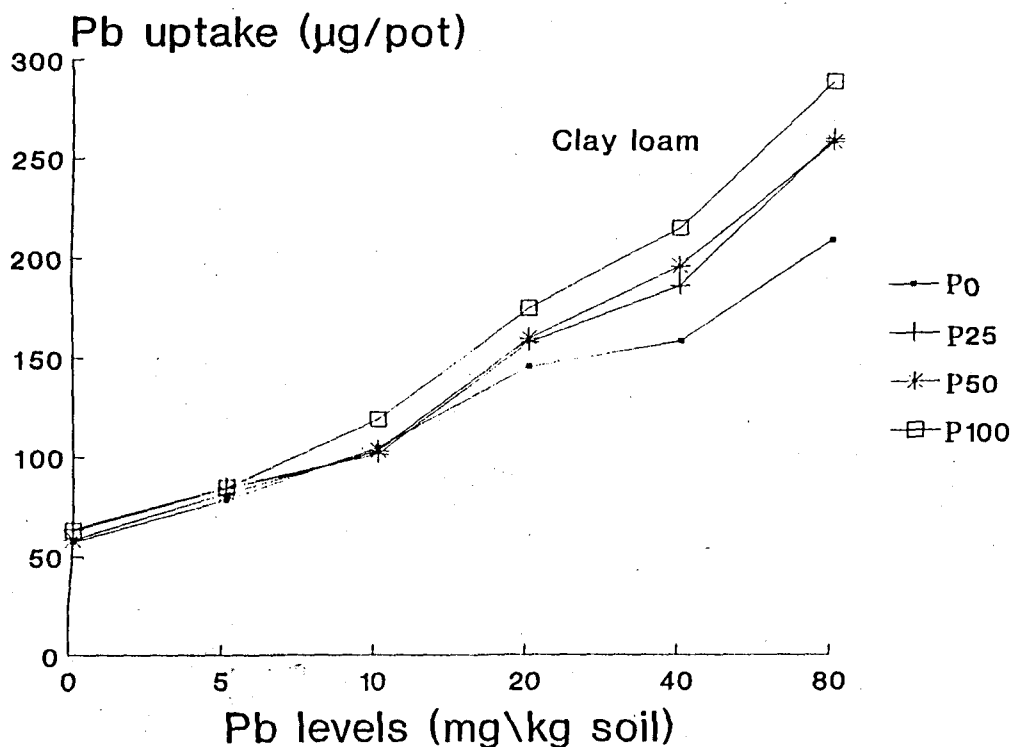
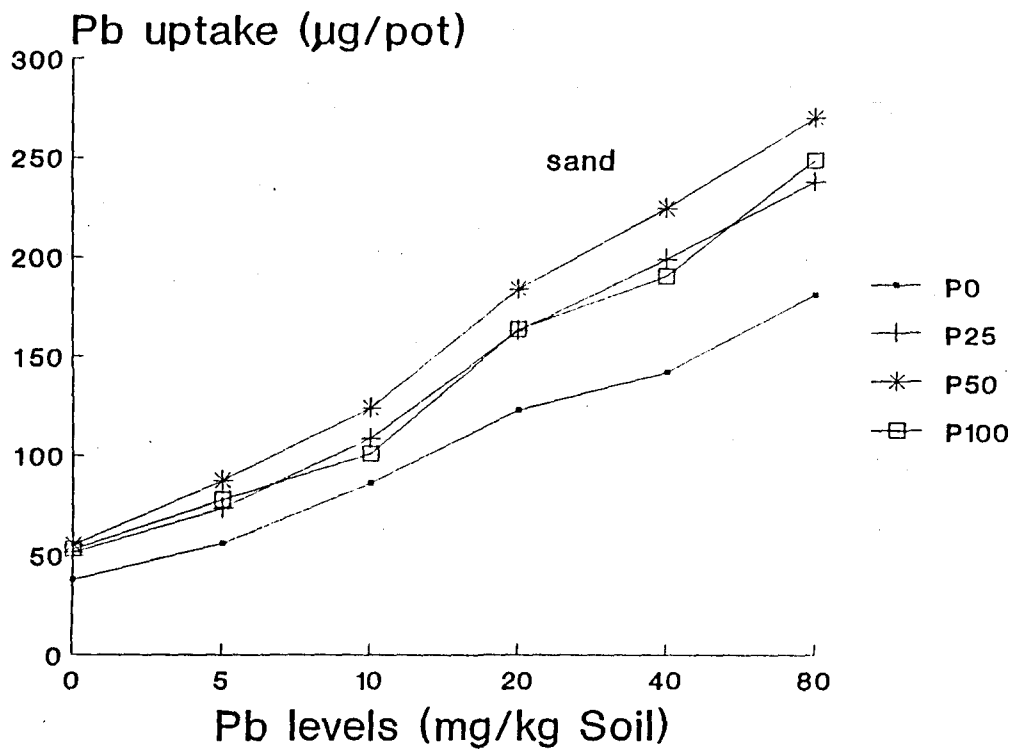


FIG. 6. UPTAKE OF Pb BY WHEAT STRAW AS AFFECTED BY Pb, P AND SOIL TEXTURE

The effect of Pb x P interaction was significant and varied with soil texture. The various interaction between Pb, P and soil texture were found to be significant.

4.1.2.3 Lead concentration and uptake by wheat root

(a) Pb-concentration

It is evident from data (Table 11) that the overall mean concentration of wheat root increased significantly from 5.44 to 22.75 $\mu\text{g g}^{-1}$ root due to increase in Pb levels from 0 to 80 mg kg^{-1} soil. The effect of Pb on its concentration in root also varied significantly with soil texture. In comparison to 5.62, 7.49, 9.72, 12.33, 15.76 and 24.44 $\mu\text{g g}^{-1}$ root Pb grown in sandy soil. The concentration in clay loam soil was 5.26, 6.85, 8.45, 10.91, 14.83 and 21.06 $\mu\text{g Pb g}^{-1}$ root at 0, 5, 10, 20, 40 and 80 mg Pb kg^{-1} soil respectively. The results revealed that root Pb in sandy soil was higher than the clay loam soil.

Like grain and straw, application of P had a significant effect on Pb concentration of root, which varied significantly with soil texture. Lead concentration of wheat root reduced by 4.4, 10.7 and 16.7 per cent grown in sandy soil compared with 5.0, 10.7 and 19.5 per cent in clay loam soil with application of 25, 50 and 100 mg P kg^{-1} soil over control respectively.

The various interactions between Pb, P and soil were significant. Application of Pb alone enhanced grain Pb, while P alleviated it significantly. Combined application of Pb and P decreased Pb content of root significantly in both soils. The reduction was 12.6 and 15.5 per cent at 80 mg Pb and 100 mg P kg^{-1} soil treatment level over 80 mg Pb kg^{-1} soil alone in sandy and clay loam soil, significantly. The Pb content in root was suppressed by the increasing application of P in the soil.

Table 11. Effect of Pb, P and soil texture on Pb concentration of wheat root

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb concentration (µg g ⁻¹)								
Sand	0	6.25	8.00	10.28	13.78	17.67	25.93	13.65
	25	6.00	7.83	9.98	12.87	16.35	25.25	13.04
	50	5.32	7.20	9.82	11.78	15.02	23.95	12.18
	100	4.93	6.95	8.82	10.90	14.02	22.65	11.37
	Mean	5.62	7.49	9.72	12.33	15.76	24.44	12.56
Clay loam	0	5.92	7.27	9.37	12.03	16.00	22.73	12.22
	25	5.45	7.02	8.80	11.30	15.22	21.85	11.60
	50	5.05	6.85	8.00	10.37	14.73	20.47	10.91
	100	4.63	6.25	7.65	9.95	13.38	19.20	10.17
	Mean	5.26	6.85	8.45	10.91	14.83	21.06	11.22
Overall Mean		5.44	7.17	9.08	11.62	15.29	22.75	11.89

C.D. (P = 0.05)

Pb = 0.09

Pb x P = 0.18

P = 0.07

Pb x Soil = 0.13

Soil = 0.05

P x Soil = 0.10

Pb x P x Soil = 0.26

(b) Pb-uptake

The uptake of Pb_{by} roots of wheat plant was affected differentially depending on the levels of Pb and P (Table 12, Fig. 7). The mean effect of Pb uptake varied with Pb levels and soil texture. The mean Pb uptake by root increased significantly and progressively with the addition of Pb application in both the soils. Like grain and straw mean Pb uptake tended to be the higher in clay loam than sandy soil.

In sandy soil increasing level of P significantly increased Pb uptake by roots. In clay loam soil, application of 100 mg P kg⁻¹ soil alleviated Pb uptake by roots over 50 mg P kg⁻¹ soil.

Data showed a significant interaction between Pb and P which varied with soil texture. The interactive effect of Pb and P was 67.0 and 105.1 per cent in sandy soil and 24.5 and 49.5 per cent in clay loam soil with 25 and 50 mg P kg⁻¹ soil in combination with 80 mg Pb kg⁻¹ soil over 80 mg Pb kg⁻¹ soil alone, respectively. Further increase in P level interaction effect reduced the uptake of Pb over its preceeding dose in both the soils. The interaction between Pb, P and soil was found non significant.

The results clearly indicated that Pb concentration and uptake by wheat grain, straw and root increased due to its application in the growth medium. Increase in Pb in wheat tissue due to increased levels of applied Pb is attributed to its higher availability to plants, in soil. The findings are in agreement with Jarvis, *et al.* 1977; Largerwerff, *et al.* 1973 and MacLean, *et al.* 1969 who also made similar observation in different crops. Kansal *et al.* (1992) reported that mean concentration of Pb in maize fodder increased significantly with increase in Pb levels. Lead uptake

Table 12. Uptake of Pb by wheat root as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb uptake (µg pot ⁻¹)								
Sand	0	9.70	15.58	15.94	18.61	22.91	32.33	19.17
	25	15.90	21.54	24.94	31.52	35.97	53.03	30.48
	50	17.54	24.12	29.94	32.98	38.67	55.08	33.05
	100	17.51	24.31	28.65	32.15	38.78	57.08	33.08
	Mean	15.16	21.38	24.87	28.81	34.08	49.38	28.95
Clay loam	0	18.04	23.62	28.10	32.88	36.24	44.34	30.53
	25	17.71	23.50	27.72	32.21	40.19	55.21	32.76
	50	17.42	26.03	29.47	37.22	51.58	66.31	38.00
	100	17.83	23.75	28.29	36.33	47.91	65.28	36.56
	Mean	17.75	24.22	28.39	34.66	43.98	57.78	34.46
Overall Mean		16.45	22.80	26.63	31.73	39.03	53.58	31.70

C.D. (P = 0.05)

Pb = 1.80

Pb x P = 3.60

P = 1.47

Pb x Soil = 2.54

Soil = 1.04

P x Soil = 2.08

Pb x P x Soil = NS

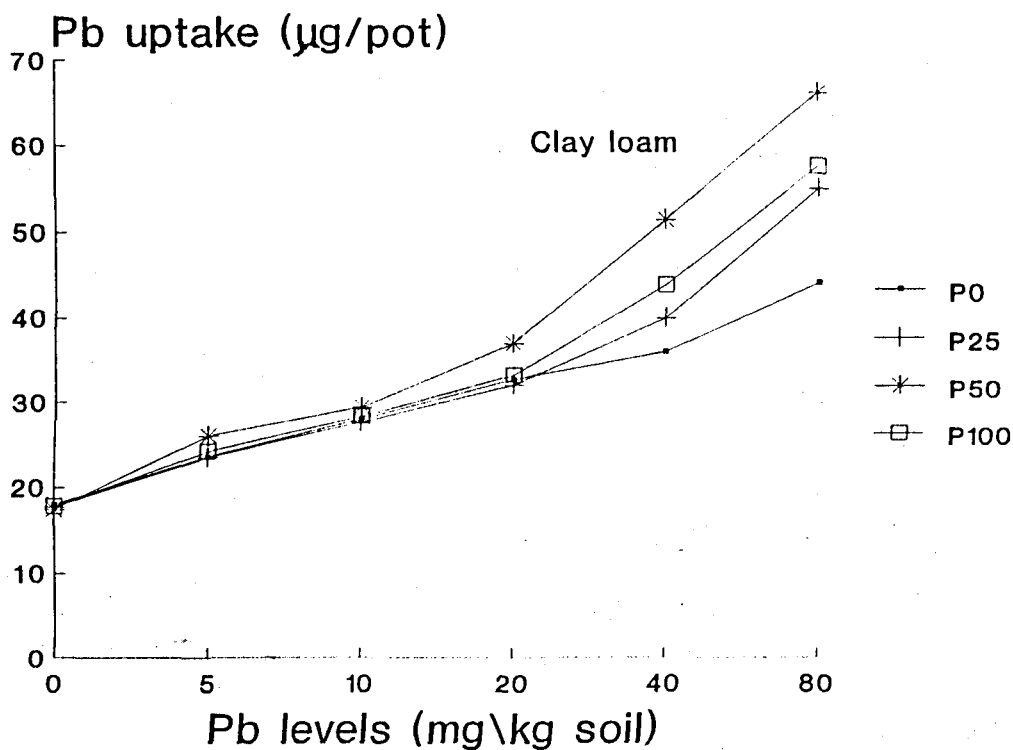
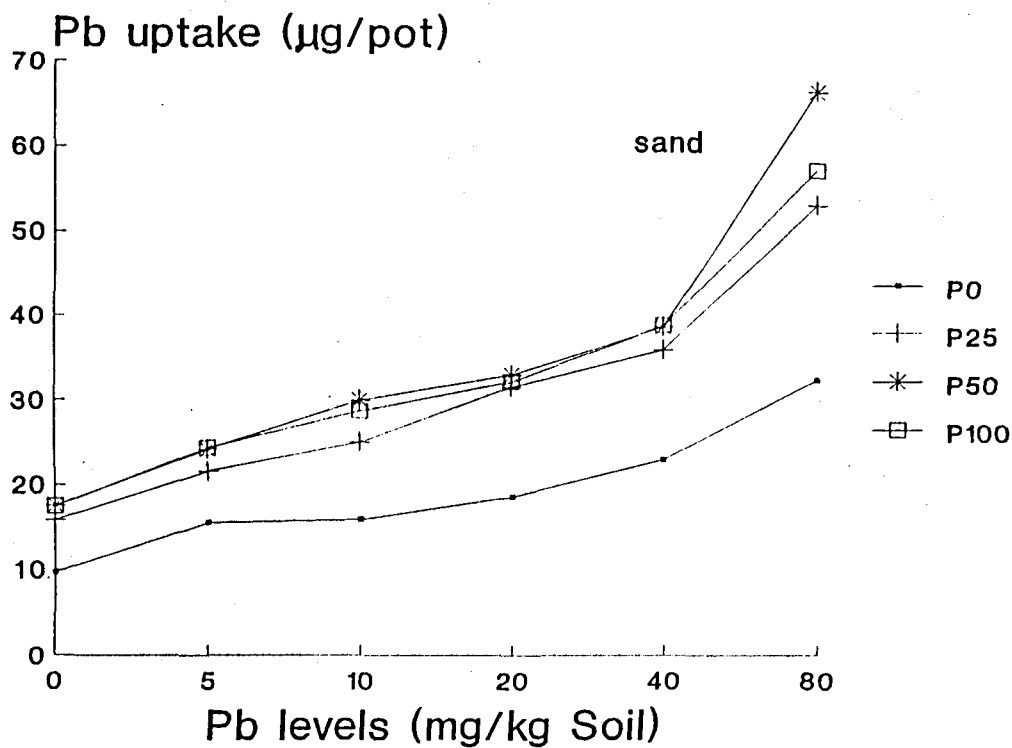


FIG.7. UPTAKE OF Pb BY WHEAT ROOT AS AFFECTED BY Pb, P AND SOIL TEXTURE

by young corn shoots has been found to depend upon the level of Pb in the soil, as well as the capacity of the soil to sorb it (Miller *et al.*, 1975).

Lower concentration of Pb in wheat plant parts in clay loam soil compared with sandy soil, may possibly be due to higher Pb fixation capacity of former soil. Since, the clay loam soil had the higher CEC ($12.50 \text{ C mole kg}^{-1}$), added Pb had probably been adsorbed strongly by colloidal particles, depressing its availability to plants tissue. The results are in consonance with the finding of Bjerre and Schierup (1985), they found that the transfer of Pb from soil to oat plant was greatest from sandy soil than sandy loam and organic soil. But the uptake by different plant parts was higher in clay loam soil than sandy soil due to higher yield in clay loam soil. The Pb concentration in roots was greater than straw and lowest in grain which is due to lower translocation of Pb in a aerial parts. These findings are in agreement with those of IL'IN and Stepanova (1980) and Lubben and Sauerbeck (1991) found that Pb was highly accumulated in roots, intermediate in leaves and lowest in grains of wheat.

Application of P significantly reduced the Pb concentration in wheat plant parts which is attributed to the formation of relatively less soluble lead phosphate. If the P status of a soil is adequate for normal plant growth, plants do not accumulate Pb (Baumhardt and Welch, 1972); phosphate forms insoluble Pb compounds in soils and roots. Gorlach and Gambus (1991) also reported that addition of P alleviated Pb concentration in oat plants and concentration in straw were about five times those in the oat grain. Higher soil phosphate fertility reduced foliar Pb in corn (Miller *et al.*, 1975; Kansal *et al.*, 1992 observed that P supressed the Pb concentration in plants significantly.



Decrease in Pb concentration in all fractions of wheat as a result of P application and reduction in uptake of Pb at higher levels of P could be ascribed to dilution at lower levels of P and an antagonistic effect at higher levels as both concentration and uptake decreased due to higher rate of P. The two nutrients perhaps vied with each other either at root surface or in the soil resulting in the formation of sparingly soluble $Pb_3(PO_4)_2$. Pandey *et al.* (1984) also reported that phosphate reducing the uptake of Pb in plants provides a basis for adopting management practices to lessen the potential hazard of Pb through contamination. A negative association of rate of Pb and P content of corn leaves was reported by Miller and Koeppe (1970) and attributed it to the formation of relatively less soluble lead phosphate.

4.1.2.4 Relationship between Pb uptake by wheat plant parts with its fractions.

Attempts were made to workout relationship of Pb fractions and uptake of Pb by grain, straw and root of wheat. The soil samples taken before wheat sowing (17 days incubation) in experiment (section 3.3.1) in which P was applied with Pb were analysed for different fractions of Pb (Table 63). The results of correlation coefficients analysis (Table 13) showed that all Pb fractions of the pre-sowing soil samples were significantly correlated with Pb uptake by wheat plant parts in both the soils.

The results indicated that all corresponding values of correlation coefficients were higher in clay loam soil as compare to sandy soil. In sandy soil, amorphous Fe-oxide bound fraction showed the highest ($r = 0.84^{**}$) correlation with Pb uptake by wheat grain, followed by carbonate bound

Table 13. Correlation coefficients for amount of Pb in various fractions and Pb-uptake by wheat plant parts

	EX + W	CARB	OM	MnOX	AFeOX	CFeOX	RES
				SAND			
Pb-uptake by wheat grain	0.76	0.83	0.72	0.81	0.84	0.81	0.68
Pb-uptake by wheat straw	0.84	0.89	0.81	0.88	0.90	0.88	0.78
Pb-uptake by wheat root	0.79	0.87	0.74	0.85	0.88	0.76	0.67
				CLAY LOAM			
Pb-uptake by wheat grain	0.89	0.90	0.91	0.90	0.88	0.92	0.95
Pb-uptake by wheat straw	0.89	0.93	0.89	0.94	0.93	0.85	0.97
Pb-uptake by wheat root	0.86	0.93	0.87	0.93	0.94	0.82	0.94

All values are significant at 1% level of significance.

Table 14. Correlation coefficients among various fractions (In soil samples taken before seeding)

	EX + W	CARB	OM	MnOX	AFeOX	CFeOX	RES
SAND							
EX + W	-	0.98	0.99	0.98	0.97	0.97	0.95
CARB			0.96	0.99	0.99	0.95	0.90
OM				0.97	0.96	0.97	0.95
MnOX					0.99	0.95	0.91
AFeOX						0.95	0.90
CFeOX							0.93
CLAY LOAM							
EX + W	-	0.97	0.99	0.97	0.95	0.92	0.91
CARB			0.96	0.99	0.99	0.87	0.93
OM				0.96	0.94	0.95	0.93
MnOX					0.99	0.86	0.92
AFeOX						0.84	0.92
CFeOX							0.92

All values are significant at 1% level of significance.

($r = 0.83^{**}$), Mn-oxide bound = Crystalline Fe-oxide bound ($r = 0.81^{**}$) and lowest with residual bound. While in clay loam soil the highest residual bound ($r = 0.95^{**}$) followed by Crystalline Fe-oxide bound, organically bound and carbonate bound = Mn-oxide bound. Similarly, the highest correlations of Pb uptake by wheat straw with Pb fractions were found with amorphous Fe-oxide bound, followed by carbonate bound, Mn-oxide bound = C Fe-oxide bound and lowest in residual bound in sandy soil and corresponding to clay loam soil it was highest with residual bound than by Mn-oxide bound, carbonate bound = amorphous Fe-oxide bound lowest in crystalline Fe-oxide bound. The trend of correlation coefficient of Pb uptake by root with Pb fraction was in the sequence of amorphous Fe-oxide bound > carbonate bound > Mn-oxide bound > exchangeable + water soluble and lowest with residual bound in sandy soil, while, in clay loam soil the trend was different, it was residual bound = amorphous Fe-oxide > carbonate bound = Mn-oxide bound > organically bound fractions.

Further the various Pb fractions like EX + W, CARB, OM, MnOX, AFeOX, CFeOX and RES. were significantly correlated with each other (Table 14) indicating that the various pools of Pb in the soil are probably in dynamic equilibrium with each other.

4.1.2.5 Phosphorus concentration and uptake by wheat grain

(a) Phosphorus concentration

A perusal of data (Table 15, Fig. 8) revealed that initial level of 5mg Pb kg^{-1} soil significantly, improved P concentration in wheat grain, but higher rates of Pb decreased it significantly in both the soils. The grain P decreased by 15.1 per cent in sandy soil and 16.2 per cent in clay

Table 15. Effect of Pb, P and soil texture on P concentration of wheat grain

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
P concentration (mg/100 g)								
Sand	0	152.0	160.4	156.2	143.7	134.0	127.3	145.6
	25	314.1	318.1	310.6	303.7	277.3	263.7	297.9
	50	360.4	365.6	358.4	345.8	326.8	309.3	344.4
	100	414.3	414.2	400.1	383.5	368.1	352.4	388.8
	Mean	310.2	314.6	306.3	294.2	276.5	263.2	294.1
Clay loam	0	250.6	252.4	247.1	232.1	224.9	217.9	237.5
	25	340.4	339.1	333.2	315.8	291.9	282.9	317.2
	50	381.2	388.1	372.9	352.0	329.9	302.5	354.4
	100	422.3	422.0	407.8	398.1	375.4	364.2	398.3
	Mean	348.6	350.4	340.2	324.5	305.5	291.9	326.8
Overall Mean		329.4	332.5	323.2	309.3	291.0	277.5	310.4

C.D. (P = 0.05)

Pb = 2.8

Pb x P = 5.6

P = 2.3

Pb x Soil = 4.0

Soil = 1.6

P x Soil = 3.2

Pb x P x Soil = 8.0

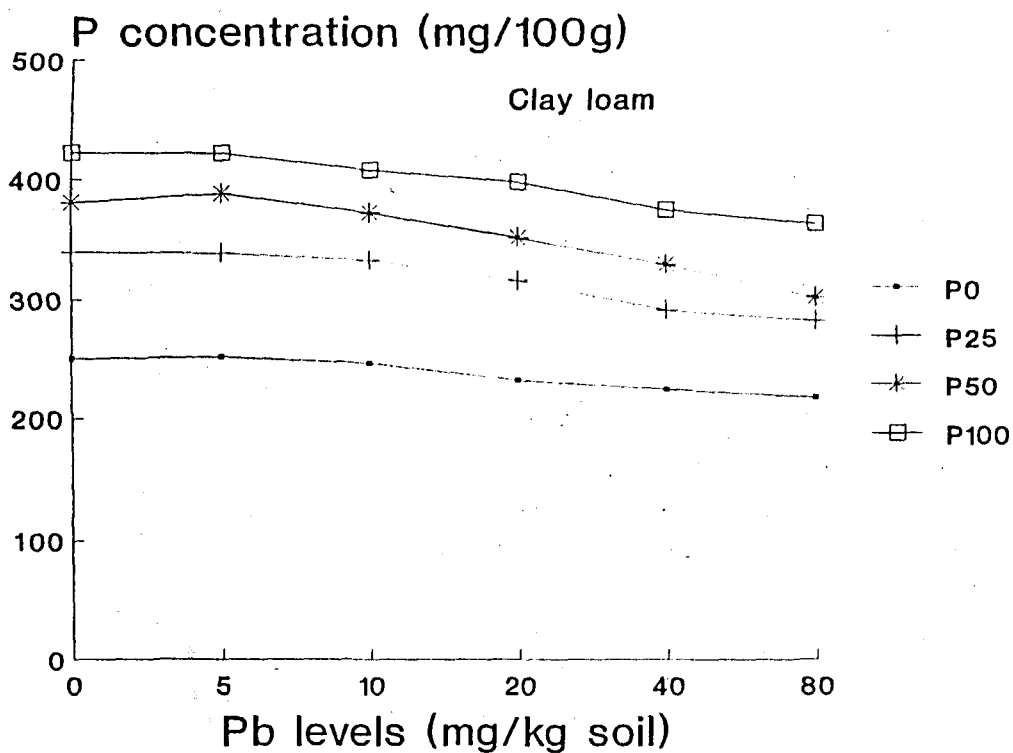
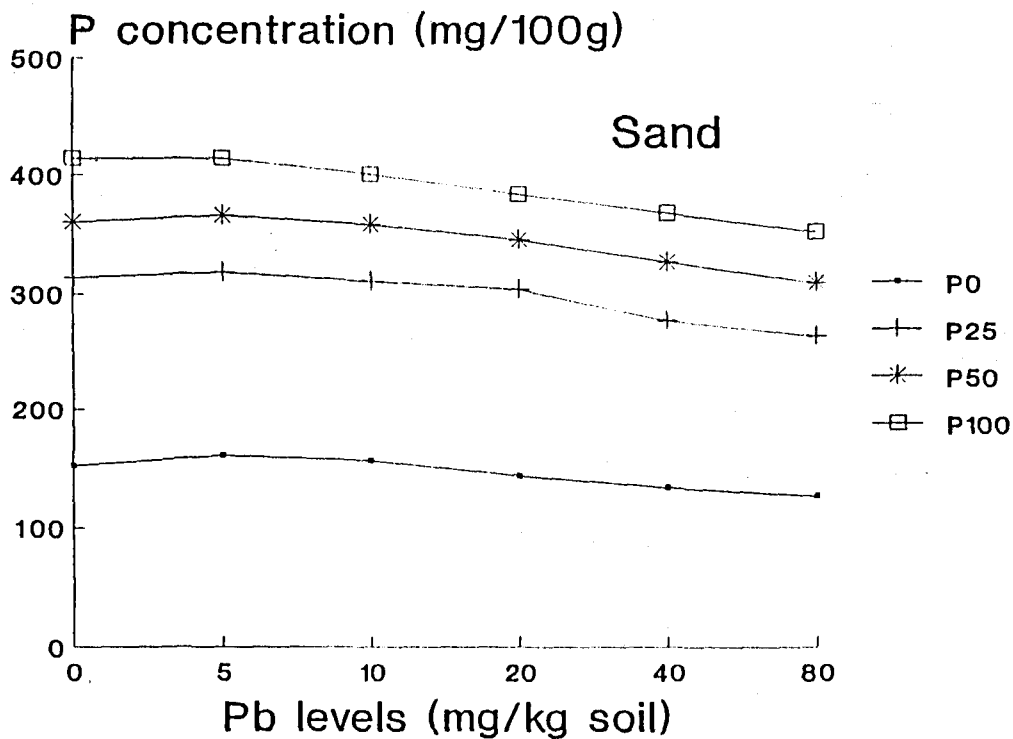


FIG.8. EFFECT OF Pb, P AND SOIL TEXTURE ON P CONCENTRATION OF WHEAT GRAIN

loam soil due to mean effect of 80 mg Pb kg^{-1} soil respectively, over control. The effect of $\text{Pb} \times \text{soil}$ interaction was found to be significant.

Application of P significantly and progressively increased grain P concentration in both the soil. The P content of grain varied from 145.6 to 388.8 mg/100g in sandy soil and 237.5 to 398.3 mg/100g in clay loam soil with increasing rate of P from 0-P to 100 mg P kg^{-1} soil, respectively.

The interaction between Pb, P and soil was found to be statistically significant. In the absence of added P application of 80 mg Pb kg^{-1} soil resulted in 16.2 and 13.0 per cent reduction in P content in sandy and clay loam soil, respectively. It is apparent from results that the effect of higher rates of Pb on grain P was antagonistic in both the soils.

(b) Phosphorus uptake

A perusal of data (Table 16) revealed that overall mean uptake of P by grain increased due to application of 5 mg Pb kg^{-1} soil, over control and decreased at higher levels of Pb, irrespective of soil texture.

A significant depression in P uptake commenced at 10 mg Pb kg^{-1} sandy and clay loam soil, respectively. Application of 80 mg Pb kg^{-1} soil caused reduction in P uptake by 33.2 per cent over control in sandy soil, compared with 28.2 per cent in clay loam soil. The mean P uptake was significantly higher in clay loam than in sand.

Increasing rate of P application markedly increased its uptake by grain. However, the magnitude of increase in grain uptake was more pronounced at 25 mg P kg^{-1} soil level as compared to higher P levels and varied with soil texture. Uptake of P by grain increased from 9.04 to $53.30 \text{ mg pot}^{-1}$ due to mean effect of increasing P application from

Table 16. Uptake of P by wheat grain as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
P uptake (mg pot ⁻¹)								
Sand	0	10.04	11.49	9.63	8.29	7.64	7.17	9.04
	25	35.08	38.09	34.81	31.98	28.93	27.00	32.65
	50	54.54	56.67	48.98	46.56	42.49	35.26	47.42
	100	66.85	58.82	54.97	51.12	46.25	41.82	53.30
	Mean	41.63	41.27	37.10	34.49	31.33	27.81	35.60
Clay loam	0	38.51	41.90	39.78	36.29	31.87	29.04	36.23
	25	67.74	76.65	66.20	60.85	54.77	49.52	62.62
	50	79.67	86.94	78.06	68.41	62.17	54.24	71.58
	100	94.17	96.07	85.23	78.29	73.26	68.09	82.52
	Mean	70.02	75.39	67.32	60.96	55.52	50.22	63.24
Overall Mean		55.82	58.33	52.21	47.72	43.42	39.01	94.42

C.D. (P = 0.05)

Pb = 1.27

P = 1.04

Soil = 0.73

Pb x P = 2.54

Pb x Soil = 1.80

P x Soil = 1.47

Pb x P x Soil = NS

0 to 100 mg kg⁻¹ soil in sandy soil and 36.23 to 85.52 mg pot⁻¹ in clay loam, respectively.

The Pb and P interacted significantly affecting P uptake by grain which varied with soil texture. Application of 80 mg Pb kg⁻¹ soil alone decreased the P uptake 28.5 and 24.6 per cent in sand and clay loam soil, respectively over no Pb and no P treatment. However, when 80 mg Pb kg⁻¹ soil was applied with 100 mg P kg⁻¹ soil, it decreased by 37.4 and 27.7 per cent in sandy and clay loam soil, respectively over 100 mg P kg⁻¹ soil alone. The interaction between Pb, P and soil texture was found non-significant.

4.1.2.6 Phosphorus concentration and uptake by wheat straw

(a) Phosphorus concentration

The overall P concentration in straw increased slightly at 5 mg Pb kg⁻¹ soil and repressed significantly at higher levels of Pb (Table 17, Fig. 9). The effect of soil texture on straw P was significant, P concentration being higher in plants grown in sandy than clay loam soil. The depression in P concentration was 5.6, 11.2, 15.4 and 24.5 per cent in sandy soil compared with 5.5, 10.5, 18.5 and 22.8 per cent in clay loam soil over control at 10, 20, 40 and 80 mg Pb kg⁻¹ soil, respectively. This showed that depending effect of Pb on P concentration of straw was higher in clay loam soil at higher rates of applied P.

Straw P concentration increased significantly due to P application, irrespective of soil texture. The effect of P x Pb interaction was significant and Pb had antagonistic effect on P concentration in both the soils. The various interaction between Pb, P and soil were found to be significant.

Table 17. Effect of Pb, P and soil texture on P concentration of wheat straw

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
P concentration (mg/100 g)								
Sand	0	23.0	22.7	21.5	20.9	20.3	18.5	21.1
	25	45.3	45.8	42.3	37.0	35.6	33.2	39.9
	50	83.9	85.3	80.4	77.8	74.6	71.0	78.8
	100	154.4	157.0	145.2	136.4	128.7	108.5	138.4
	Mean	76.6	77.7	72.3	68.0	64.8	57.8	69.5
Clay loam	0	21.1	21.4	20.4	19.6	18.7	16.9	19.7
	25	41.9	41.8	39.6	38.6	35.7	32.9	38.4
	50	79.6	78.8	72.6	72.1	67.4	63.5	72.3
	100	129.3	130.7	124.4	112.9	99.9	96.9	115.7
	Mean	68.0	68.2	64.2	60.8	55.4	52.5	61.5
Overall Mean		72.3	72.9	68.2	64.4	60.1	55.1	65.5

C.D. (P = 0.05)

Pb = 1.3

P = 1.0

Soil = 0.7

Pb x P = 2.6

Pb x Soil = 1.8

P x Soil = 1.5

Pb x P x Soil = 3.7

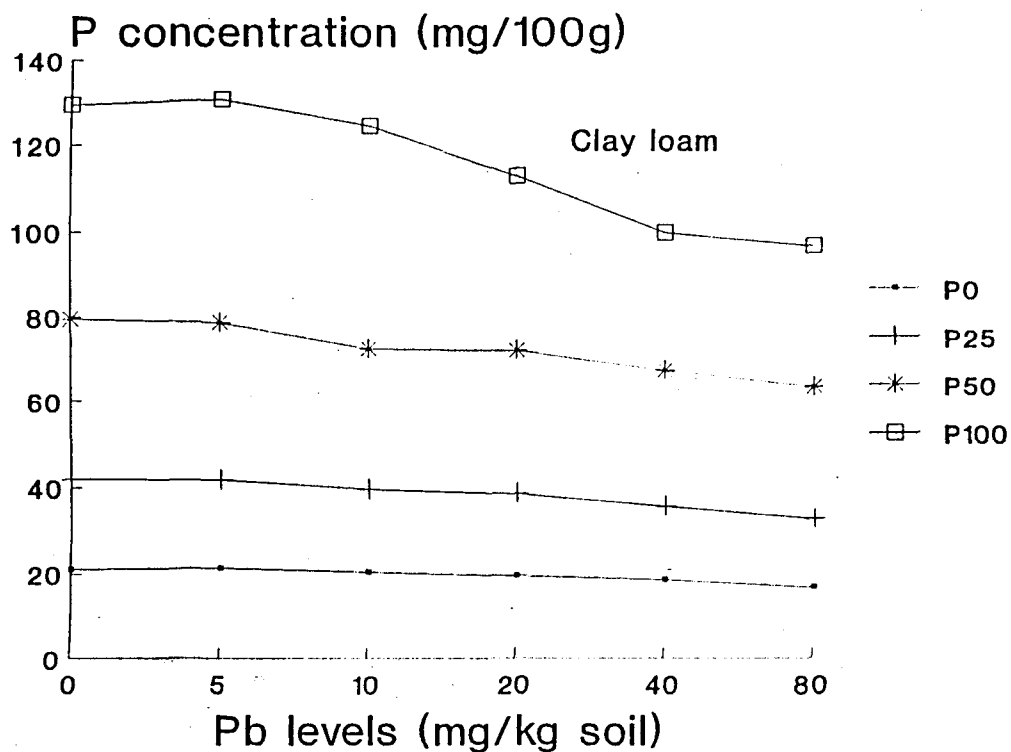
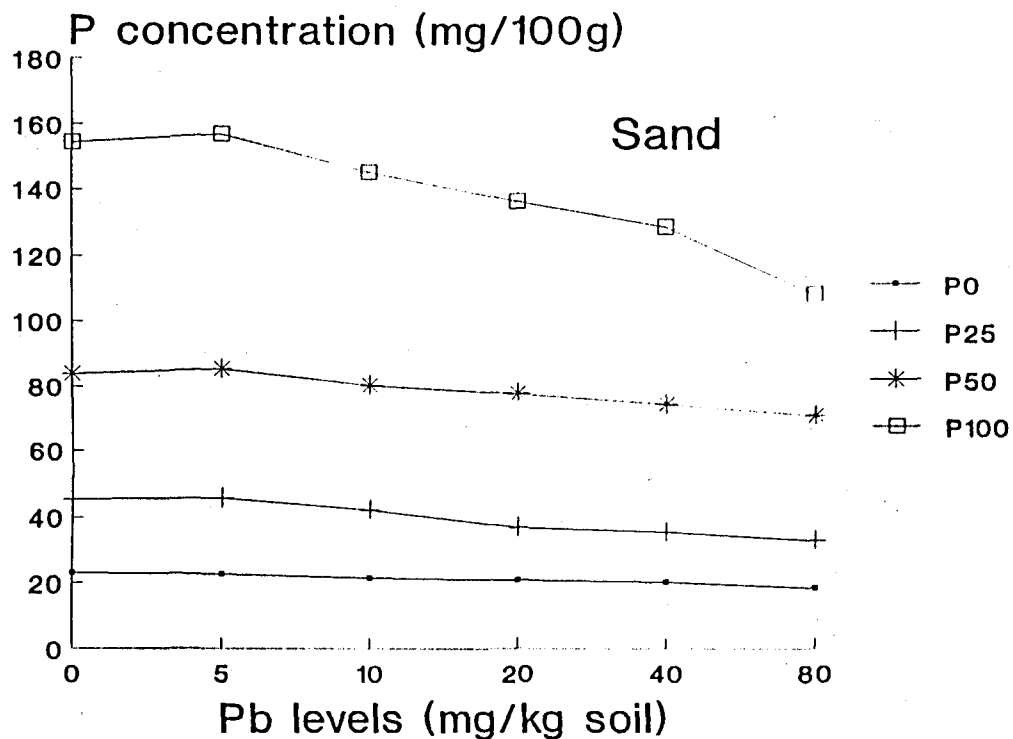


FIG.9. EFFECT OF Pb, P AND SOIL TEXTURE ON P CONCENTRATION OF WHEAT STRAW

(b) Phosphorus uptake

Similar to P uptake by grain, the overall P uptake by straw increased significantly up to 5 mg Pb kg⁻¹ soil and thereafter, decreased significantly with further increase in Pb levels (Table 18). The Pb and soil interacted significantly in affecting P uptake by straw. Application of 80 mg Pb kg⁻¹ soil decreased the straw mean P uptake by 5.69 mg pot⁻¹ and 4.51 mg pot⁻¹ in sandy and clay loam soil, respectively over control. Uptake of P by straw was significant higher in clay loam soil than sandy soil.

Phosphorus uptake by straw increased significantly due to its application in both the soils, but the magnitude of increase varied with soil texture. In sandy soil, P uptake increased by 4.55, 15.19 and 30.28 mg pot⁻¹ over control due to 25, 50 and 100 mg P kg⁻¹ soil, respectively, and the corresponding, increase in clay loam soil was 5.42, 15.02 and 31.50 mg pot⁻¹.

The interactions between Pb, P and soil were found significant. Application of 100 mg P kg⁻¹ soil in conjunction with 40 and 80 mg Pb kg⁻¹ soil depressed P uptake by 31.8 and 41.9 per cent over Pb₀ P₁₀₀ in sandy soil, respectively and the corresponding decrease in clay loam soil was 26.1 and 29.6 per cent.

4.1.2.7 Phosphorus concentration and uptake by wheat root

(a) Phosphorus concentration

A perusal of data (Table 19, Fig. 10) revealed that overall P concentration in root increased significantly with increase in Pb levels. However, the magnitude of increase in P concentration varied with Pb levels. The P content of wheat root grown in sandy soil increased significantly from 92.7 to 115.0 mg P/100g tissue, compared with 67.9 to

Table 18. Uptake of P by wheat straw as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
P uptake (mg pot ⁻¹)								
Sand	0	3.13	3.05	2.83	2.70	2.44	2.15	2.71
	25	8.10	8.90	8.02	6.77	6.45	5.36	7.26
	50	18.50	20.72	19.30	17.67	16.71	14.54	17.90
	100	41.12	40.71	33.44	30.75	28.03	23.88	32.99
	Mean	17.71	18.34	15.90	14.47	13.41	11.48	15.21
Clay loam	0	4.52	5.01	4.39	4.11	3.68	3.07	4.13
	25	10.54	11.09	9.98	9.32	8.52	7.84	9.55
	50	21.00	21.48	19.45	19.02	17.59	16.37	19.15
	100	40.16	41.47	39.36	34.90	29.67	28.27	35.63
	Mean	19.05	19.76	18.29	16.84	14.86	13.88	17.11
Overall Mean		18.38	19.05	17.09	15.65	14.13	12.68	16.16

C.D. (P = 0.05)

Pb = 0.37

P = 0.30

Soil = 0.21

Pb x P = 0.75

Pb x Soil = 0.53

P x Soil = 0.43

Pb x P x Soil = 1.06

Table 19. Effect of Pb, P and soil texture on P concentration of wheat root

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
P concentration (mg/100 g)								
Sand	0	53.6	57.1	61.1	62.5	65.4	71.3	61.8
	25	71.9	72.3	75.2	78.1	85.9	92.8	79.3
	50	89.0	90.7	95.4	96.9	103.1	108.8	97.3
	100	156.2	158.8	158.5	165.4	169.2	187.2	165.8
	Mean	92.7	94.7	97.5	100.7	105.9	115.0	101.1
Clay loam	0	44.8	48.4	48.1	50.5	53.5	58.5	50.6
	25	48.4	55.2	61.7	65.9	72.3	83.4	64.4
	50	72.5	73.4	82.2	85.4	91.9	96.3	83.6
	100	105.9	107.6	109.4	112.6	118.4	130.2	113.9
	Mean	67.9	71.1	75.3	78.6	84.0	92.1	78.1
Overall Mean		80.3	82.9	86.4	89.6	94.9	103.5	89.6

C.D. (P = 0.05)

Pb	= 1.2	Pb x P	= 2.4
P	= 1.0	Pb x Soil	= NS
Soil	= 0.7	P x Soil	= 1.4
		Pb x P x Soil	= 3.5

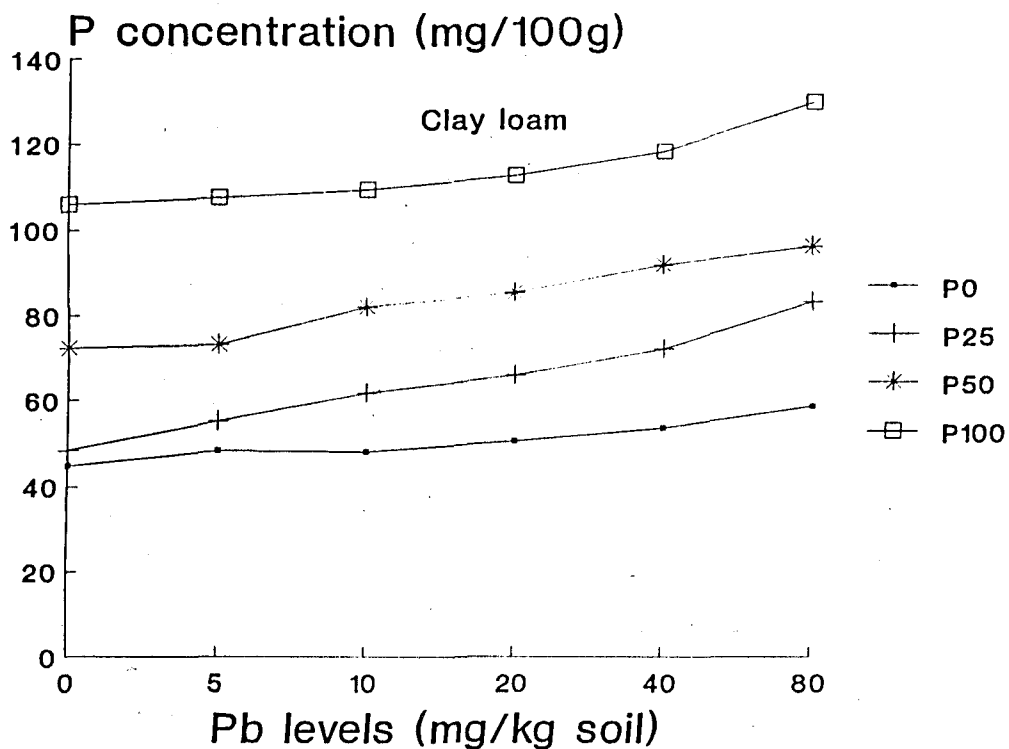
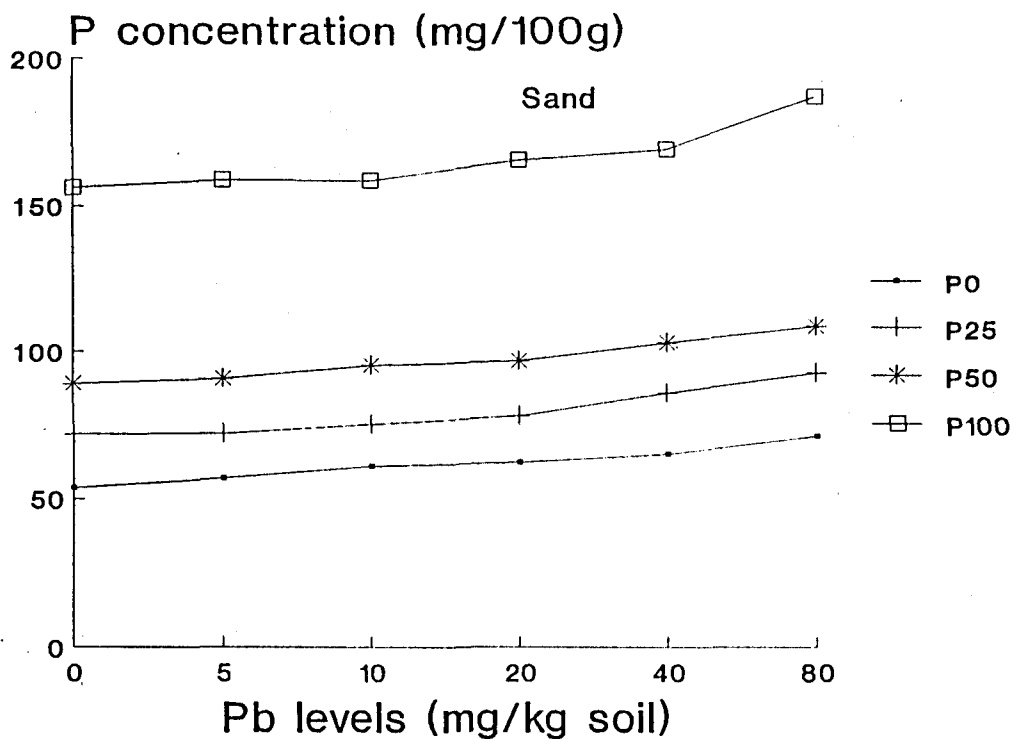


FIG. 10. EFFECT OF Pb, P AND SOIL TEXTURE ON P CONCENTRATION OF WHEAT ROOT

92.1 mg P/100g root with the increase in Pb levels from 0 to 80 mg Pb kg⁻¹ soil, respectively.

Phosphorus concentration in roots of wheat grown in sandy soil was markedly higher than that of clay loam soil. Phosphorus application enhanced P concentration significantly, but the effect of P was variable with soil texture.

The effect of Pb and P interaction was significant and positive. Combined application of 80 mg Pb and 100 mg P kg⁻¹ soil enhanced root P content by 3.5 and 2.0 times over no Pb and no P in sandy and clay loam soil, respectively. The interaction between Pb, P and soil was found significant.

(b) Phosphorus uptake

Data (Table 20) revealed that overall P uptake by root increased upto 10 mg Pb kg⁻¹ soil and decreased at higher levels. The Pb and soil interacted significantly in affecting P uptake by root. Phosphorus uptake by root decreased significantly above 10 mg Pb kg⁻¹ soil in sandy soil. But in clay loam soil, P uptake by root was significantly higher at all level of Pb over control. Application of 80 mg Pb kg⁻¹ soil reduced mean P uptake by roots by 10.3 per cent, in sandy soil, and enhanced it by 13.0 per cent in clay loam soil, respectively over control.

Application of P enhanced its uptake by straw significantly in both the soils, however, the magnitude of increase varied with soil texture, being slightly higher in sandy than clay loam soil.

The effect of Pb x P interaction was significant and varied with soil texture. When 80 mg Pb kg⁻¹ soil was applied with 100 mg P kg⁻¹ soil,

Table 20. Uptake of P by wheat root as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
P uptake (mg pot ⁻¹)								
Sand	0	0.83	1.11	0.95	0.84	0.85	0.89	0.91
	25	1.91	1.99	1.88	1.91	1.89	1.95	1.92
	50	2.93	3.04	2.90	2.71	2.63	2.50	2.35
	100	5.54	5.56	5.15	4.88	4.68	4.72	5.08
	Mean	2.80	2.92	2.72	2.58	2.51	2.51	2.67
Clay loam	0	1.37	1.57	1.45	1.38	1.21	1.14	1.35
	25	1.57	1.85	1.94	1.88	1.91	2.10	1.87
	50	2.50	2.79	3.03	3.06	3.21	3.12	2.95
	100	4.08	4.08	4.05	4.11	4.10	4.43	4.14
	Mean	2.38	2.57	2.61	2.60	2.61	2.69	2.58
Overall Mean		2.59	2.74	2.66	2.59	2.56	2.60	2.62

C.D. (P = 0.05)

Pb = 0.07

Pb x P = 0.13

P = 0.05

Pb x Soil = 0.09

Soil = 0.04

P x Soil = 0.08

Pb x P x Soil = 0.19

P uptake by root decreased by 14.8 per cent in sandy soil, and increased by 8.5 per cent in clay loam soil, respectively over 100 mg P kg⁻¹ soil alone.

The results indicated that P concentration and uptake by different part of wheat increased at lower levels of Pb and decreased at higher levels. The increase in tissue P at lower levels of Pb might be due to stimulation of certain metabolic processes which resulted in higher uptake of P. The decrease in P concentration at higher levels of Pb is in agreement with the findings of Miller and Koepe, (1970) who reported that Pb decreased P concentration in young corn plants grown in nutrient solution. Largewerff (1972) attributed the reduced P accumulation in plant with Pb application either due to reduced P availability in soils or its absorption by plants. Pandey *et al.* (1984). also reported a reduced uptake of P by maize in the Pb treated red and alluvial soils and observed that Pb along with phosphate significantly affected the uptake by shoots. The effect of Pb on phosphorus concentration have also been reported by Baumhardt and Welch, (1972) and Biddappa *et al.* (1987). In case of root, P concentration was increased significantly with the increase in Pb levels which may be due to yield reduction and restricted translocation of P from root to shoot.

Increased P concentration and uptake by wheat grain, straw and root with increasing P levels is attributed to enhanced availability of P in the soil, resulting in more absorption of P by plant as there may be increase in feeding power of the root system due to the development of root mass in the fertilizer rhizosphere. Neilsen *et al.* (1992) also reported a significant increase in P content of wheat due to increasing levels of P in the soil. Halvarson and Havlin (1992) observed increase in P uptake with increasing rates of P.

Interaction occur between metals and nutrients and metals and soluble salts. Interactions could vary with crop and soil. If metal toxicity inhibited root growth absorption of elements like P, K and Fe could be reduced because they are mostly absorbed by diffusion, this is an indirect interaction, may be an important mechanism in metal phytotoxicity.

4.1.3 Polyvalent transition heavy metals (Zn, Mn, Fe and Cu) concentration in different plant parts of wheat as affected by Pb, P and soil texture

4.1.3.1 Zinc concentration

(a) Grain

The mean Zn content in sandy soil depressed from $31.87 \mu\text{g g}^{-1}$ at 0 mg Pb kg^{-1} soil to $23.36 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil (Table 21). The reduction in Zn concentration of wheat grain due to Pb was higher in clay loam than sandy soil.

Application of P either alone or in conjunction with Pb decreased grain Zn significantly irrespective of soil type. The magnitude of reduction in Zn concentration of grain due to P application was more or less the same in both the soils. The effect of Pb x P interaction on Zn concentration was highly antagonistic and significant and the interaction effect of increasing rates of P enhanced with increased levels of Pb. The effect of Pb x soil interaction was non significant. Addition of 100 mg P and 80 mg Pb kg^{-1} soil reduced the Zn content by 21.4 and 31.8 per cent in sandy and clay loam soil respectively, over 80 mg Pb kg^{-1} soil alone.

(b) Straw

Zinc concentration in wheat straw was antagonistically and

Table 21. Effect of Pb, P and soil texture on Zn concentration of wheat grain

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Zn concentration (µg g ⁻¹)								
Sand	0	36.05	34.51	32.01	30.37	29.67	26.20	31.46
	25	33.52	32.51	30.19	27.27	25.27	24.79	28.92
	50	29.29	28.68	27.91	24.61	23.29	21.87	25.94
	100	28.64	27.40	25.18	24.25	23.15	20.59	24.87
	Mean	31.87	30.77	28.82	26.62	25.34	23.36	27.80
Clay loam	0	33.13	31.31	29.40	27.43	25.51	23.75	28.42
	25	29.09	28.70	26.13	24.64	23.91	21.37	25.64
	50	25.01	24.26	22.44	20.74	19.19	17.09	21.45
	100	23.36	22.53	20.11	19.56	17.17	16.18	19.81
	Mean	27.65	26.70	24.52	23.09	21.44	19.60	23.83
Overall Mean		29.76	28.73	26.67	24.85	23.39	21.48	25.81

C.D. (P = 0.05)

Pb	= 0.45	Pb x P	= 0.90
P	= 0.36	Pb x Soil	= NS
Soil	= 0.26	P x Soil	= 0.52
		Pb x P x Soil	= NS

significantly affected due to Pb addition in soils. Application of 80 mg Pb kg⁻¹ soil due to mean effect alleviated tissue Zn to 12.47 µg g⁻¹ compared with 18.76 µg g⁻¹ at 0 level of Pb (Table 22) soil texture also influenced the Zn concentration of straw which was significantly higher in sandy soil than clay loam soil. Zinc concentration in straw, in both the soils repressed markedly as a result of Pb application. The mean Zn concentration reduced by 6.85 and 5.73 µg g⁻¹ with 80 mg Pb kg⁻¹ soil in sandy and clay loam soil, respectively over control.

Addition of P significantly reduced straw Zn and the effect varied significantly with soil texture. The mean Zn concentration in straw was reduced by 14.6, 30.3 and 35.5 per cent in sandy soil and 16.8, 26.4 and 34.9 per cent in clay loam soil due to 25, 50 and 100 mg P kg⁻¹ soil over control, respectively. The combined application of 80 mg Pb and 100 mg P kg⁻¹ soil markedly alleviated tissue Zn from 24.39 µg g⁻¹ at 0 Pb and 0 mg P kg⁻¹ soil to 9.68 µg g⁻¹ straw in sandy soil. Addition of 100 mg P and 80 mg Pb kg⁻¹ soil reduced the straw Zn concentration by 44.0 and 38.4 per cent in sandy and clay loam soil, respectively over 80 mg Pb kg⁻¹ soil alone.

(c) Root

The overall Zn concentration in root increased from 45.65 µg g⁻¹ in control to 51.47 µg g⁻¹ due to addition of 80 mg Pb kg⁻¹ soil (Table 23). Root Zn was significantly higher in sandy soil than clay loam soil. Zinc concentration in root, in both the soils increased as a result of Pb application.

Data indicated that P applied either alone or in conjunction with Pb increased root Zn significantly irrespective of soil type. The effect of P on Zn

Table 22. Effect of Pb, P and soil texture on Zn concentration of wheat straw

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Zn concentration (µg g ⁻¹)								
Sand	0	24.39	23.52	22.17	20.11	18.86	17.30	21.05
	25	21.04	20.60	19.52	17.57	15.49	13.61	17.97
	50	17.37	16.81	15.33	14.44	12.74	11.31	14.66
	100	16.49	15.59	15.00	13.81	10.85	9.68	13.57
	Mean	19.82	19.13	18.00	16.48	14.48	12.97	16.81
Clay loam	0	21.76	21.01	19.92	18.20	17.15	15.33	18.89
	25	18.73	17.60	16.05	15.20	14.35	12.28	15.70
	50	16.03	15.38	15.00	13.52	12.62	10.85	13.90
	100	14.27	13.60	13.15	12.55	10.72	9.43	12.28
	Mean	17.70	16.89	16.03	14.86	13.71	11.97	15.19
Overall Mean		18.76	18.01	17.01	15.67	14.09	12.47	16.00

C.D. (P = 0.05)

Pb = 0.36

P = 0.29

Soil = 0.20

Pb x P = 0.72

Pb x Soil = 0.51

P x Soil = 0.41

Pb x P x Soil = NS

Table 23. Effect of Pb, P and soil texture on Zn concentration of wheat root

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Zn concentration (µg g ⁻¹)								
Sand	0	42.20	42.86	43.07	44.68	45.00	47.87	44.28
	25	45.33	45.98	46.05	46.81	48.05	50.94	47.19
	50	50.22	50.81	51.76	52.93	55.01	58.00	53.12
	100	56.17	56.67	58.02	57.78	60.29	65.03	58.99
	Mean	48.48	49.08	49.72	50.55	52.08	55.46	50.89
Clay loam	0	38.29	38.79	39.00	40.40	41.23	43.00	40.11
	25	40.81	41.00	42.22	42.61	43.82	45.00	42.57
	50	44.33	44.73	45.23	45.92	47.64	49.10	46.15
	100	47.89	48.00	48.18	49.13	50.69	52.82	49.48
	Mean	42.83	43.13	43.66	44.56	45.84	47.48	44.58
Overall Mean		45.65	46.10	46.69	47.55	48.96	51.47	47.73

C.D. (P = 0.05)

Pb = 0.45	Pb x P = 0.90
P = 0.37	Pb x Soil = 0.64
Soil = 0.26	P x Soil = 0.52
	Pb x P x Soil = NS

concentration of root also varied significantly, due to soil texture. The mean root Zn concentration increased from $44.28 \mu\text{g g}^{-1}$ at 0 mg P kg^{-1} soil to $58.99 \mu\text{g g}^{-1}$ root in sandy soil and from 40.11 to $49.48 \mu\text{g g}^{-1}$ root in clay loam soil due to 100 mg P kg^{-1} soil, respectively.

The Pb and P interaction also varied significantly due to soil texture. Both Pb and P applied alone or combined together increased Zn concentration in root. Application of 80 mg Pb kg^{-1} soil and 100 mg P kg^{-1} soil alone increased Zn concentration by 54.1 and 37.9 per cent over no P and no Pb treatment in sandy and clay loam soil, respectively. The Pb x P x soil interaction affected root Zn non significantly.

Results clearly demonstrated that Pb alleviated Zn in grain and straw but elevated it in roots. This may possibly be due to the antagonistic effect of Pb on Zn absorption due to the competition for root absorption sites resulting in lower uptake of Zn metals, as Pb^{+2} and Zn^{+2} have similar ionic charge and possibly the same carrier sites. Khan and Khan (1983) also observed that the applied Pb decreased Zn concentration in egg plant and tomato. Root Zn concentration increased with increasing level of Pb application, may be due to competition for soil adsorption site resulting in greater availability and possibility of greater uptake of Zn. Zinc concentration in wheat tissue was significantly higher grown in sandy soil than clay loam soil. Similar observation were recorded by Bjerre and Schierup (1985) who reported that transfer of Zn from soil to oat plant was greater from sandy soil than sandy loam and organic soils and found that Zn were more mobile in the plant, therefore, wheat grain has higher Zn than the straw.

The data demonstrated that P application irrespective of Pb levels significantly reduced Zn concentration in wheat grain and straw. The sharp

reduction in Zn concentration at 25 mg P kg⁻¹ soil with or without Pb may be attributed to dilution effect caused by marked increase in yield. The depression in Zn concentration largely attributed to the antagonistic effect of P on Zn absorption by plants. The results are in full agreement with the finding of Sharma and Meelu (1975), Gupta and Mehla (1991) and Yadav *et al.* (1991) who made similar observation in wheat, maize and peanut, respectively. The Zn concentration was increased with P application in wheat root, there can be competition for soil adsorption sites.

4.1.3.2 Manganese concentration

(a) Grain

Overall mean Mn concentration of grain decreased from 21.06 µg g⁻¹ at 0 Pb to 17.05 µg g⁻¹ grain at 80 mg Pb kg⁻¹ soil (Table 24). The effect of soil texture on Mn concentration of grain was also significant, being significantly higher in sandy soil than clay loam soil.

Interaction between Pb and soil was also significant. Grain Mn decreased from 23.27 µg g⁻¹ at 0 mg Pb kg⁻¹ to 18.56 µg g⁻¹ at 80 mg Pb kg⁻¹ soil in sandy soil, while the corresponding decrease in clay loam soil was from 18.85 to 15.54 µg g⁻¹.

Addition of P enhanced the grain Mn significantly. The mean concentration of Mn in grain increased by 18.8, 52.1 and 68.2 per cent in sandy soil and 27.3, 55.7 and 90.1 per cent in clay loam soil due to 25, 50 and 100 mg P kg⁻¹ soil over 0 mg P kg⁻¹ soil, respectively. The effect of P x soil interaction on grain Mn was significant. The Pb, P and soil texture did not interact mutually in affecting the grain Mn content. The interaction between Pb and P was found to be non significant.

Table 24. Effect of Pb and P on Mn concentration of wheat grain grown in texturally different soils

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Mn concentration (µg g ⁻¹)								
Sand	0	17.83	17.67	16.58	15.29	14.28	13.71	15.89
	25	20.74	20.71	19.89	18.57	17.14	16.28	18.88
	50	26.11	26.10	25.28	24.53	22.05	21.05	24.18
	100	28.41	28.29	28.31	26.45	25.75	23.23	26.74
	Mean	23.27	23.19	22.51	21.21	19.80	18.56	21.42
Clay loam	0	13.61	13.49	12.86	11.98	11.07	10.25	12.21
	25	16.96	16.87	16.07	15.41	14.39	13.61	15.55
	50	20.28	20.27	20.05	18.70	17.79	17.03	19.02
	100	24.56	24.53	23.87	23.00	22.05	21.29	23.21
	Mean	18.85	18.79	18.21	17.27	16.32	15.54	17.50
Overall Mean		21.06	20.99	20.36	19.24	18.06	17.05	19.46

C.D. (P = 0.05)

Pb = 0.41

P = 0.33

Soil = 0.23

Pb x P = NS

Pb x Soil = 0.58

P x Soil = 0.47

Pb x P x Soil = NS

(b) Straw

A perusal of data (Table 25) indicated that like grain the overall mean straw Mn decreased as a result of increasing level of Pb. Like grain concentration of Mn in straw was significantly higher in sandy soil than clay loam soil. Application of 80 mg Pb kg⁻¹ soil resulted in 28.5 and 27.3 per cent reduction in Mn concentration in plant tissue in sandy and clay loam soil, respectively when compared with no Pb treatment.

Application of P significantly and progressively increased the straw Mn concentration in both the soil. The Mn content of straw varied from 25.93 to 35.49 µg g⁻¹ in sandy soil and 22.96 to 32.53 µg g⁻¹ straw in clay loam soil, respectively, with increasing level of P from no P to 100 mg P kg⁻¹ soil. The various interactions between Pb, P and soil texture were non significant.

(c) Root

Data (Table 26) indicated that the concentration of Mn in wheat root elevated significantly due to mean effect of Pb, P and soil. Application of 80 mg Pb kg⁻¹ soil resulted in 15.3 and 10.9 per cent increase in Mn concentration in root in sandy and clay loam soil, respectively when compared with no Pb treatment.

Addition of P either alone or in conjunction with Pb significantly increased root Mn. The mean root Mn concentration increased from 83.52 to 129.28 µg g⁻¹ in sandy soil and 72.95 to 108.45 µg g⁻¹ in clay loam soil, respectively when P levels were enhanced from 0 to 100 mg P kg⁻¹ soil. The P x soil interaction was also statistically significant.

The interaction effect of Pb x P was additive and varied with soil type. Application of 80 mg Pb and 100 mg P kg⁻¹ soil increased the root Mn

Table 25. Effect of Pb and P on Mn concentration of wheat straw grown in texturally different soils

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Mn concentration (µg g ⁻¹)								
Sand	0	30.28	28.57	27.19	25.33	23.33	20.90	25.93
	25	31.67	30.28	29.33	27.68	25.52	22.29	27.79
	50	35.35	33.19	32.48	29.62	27.22	25.28	30.52
	100	36.76	37.95	37.27	35.19	33.33	29.48	35.49
	Mean	34.26	32.49	31.56	29.45	27.35	24.48	29.93
Clay loam	0	26.47	25.52	24.42	22.71	20.19	18.48	22.96
	25	28.14	27.67	26.14	24.00	22.52	20.19	24.77
	50	32.33	31.05	30.95	28.14	26.43	24.61	28.91
	100	37.20	35.19	34.18	32.09	29.57	26.98	32.53
	Mean	31.03	29.85	28.92	26.73	24.67	22.56	27.29
Overall Mean		32.64	31.17	30.24	28.09	26.01	23.52	28.61

C.D. (P = 0.05)

Pb = 0.74	Pb x P	= NS
P = 0.61	Pb x Soil	= NS
Soil = 0.43	P x Soil	= NS
	Pb x P x Soil	= NS

Table 26. Influence of Pb and P on Mn concentration of wheat root grown in texturally different soils

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Mn concentration (µg g ⁻¹)								
Sand	0	76.10	78.78	80.65	85.46	89.13	91.00	83.52
	25	86.56	88.68	92.00	101.00	103.43	105.00	96.11
	50	104.00	104.87	106.57	107.84	110.00	115.60	108.15
	100	123.13	123.84	127.07	129.75	134.00	137.90	129.28
	Mean	97.45	99.04	101.57	106.51	109.14	112.37	104.26
Clay loam	0	67.92	69.43	71.42	73.62	76.47	78.89	72.95
	25	74.96	77.04	78.05	80.39	83.36	86.67	80.07
	50	93.29	93.84	94.12	95.70	97.19	99.10	95.54
	100	105.48	105.81	106.07	107.01	112.07	114.30	108.05
	Mean	85.41	86.53	87.41	89.18	92.27	94.74	89.25
Overall Mean		91.43	92.78	94.49	97.59	100.07	103.55	96.75

C.D. (P = 0.05)

Pb = 0.43

P = 0.35

Soil = 0.25

Pb x P = 0.87

Pb x Soil = 0.61

P x Soil = 0.50

Pb x P x Soil = 1.23

concentration by 51.5 and 44.8 per cent over 80 mg Pb kg⁻¹ soil alone and by 12.0 and 8.3 per cent over 100 mg P kg⁻¹ soil alone, in sandy and clay loam soil, respectively. The results showed that Pb and P when combined together were more effective in enhancing Mn concentration in wheat root.

The results demonstrated that Pb decreased Mn concentration in wheat grain, straw and enhanced it in root. Application of Pb perhaps prevented the translocation of Mn from root to shoot and grain. A gradual decrease in Mn concentration in egg plant at lower availability of Pb and than a substantial drop support the selectivity rule (Khan and Khan, 1983). Mn concentration was higher in plant tissue grown in sandy soil compared to clay loam soil. Generally the Mn transfer from sandy soil is higher compared with the other soils, which reflects the lower adsorption ability of sandy soil.

Application of P significantly and progressively increased the grain, straw and root Mn concentration in both the soils irrespective of Pb. Synergistic effect of P was observed by Gupta and Bhadra (1980) in rice, Khan and Zende (1976) in wheat and Yadav *et al.* (1983) in oats. Contrary to this Heintze (1968) concluded that P detoxifies Mn by precipitation within plant roots.

4.1.3.3 Iron concentration

(a) Grain

Data (Table 27) revealed that Fe concentration of wheat grain depressed with increasing rates of Pb. The overall Fe concentration of grain was reduced significantly from 65.58 µg g⁻¹ in control to 49.01 µg g⁻¹ at 80 mg Pb kg⁻¹ soil. The effect of soil texture on Fe concentration of grain was also significant, being significantly higher in clay loam than sandy soil.

Table 27. Effect of Pb, P and soil texture on Fe concentration of wheat grain

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Fe concentration (µg g ⁻¹)								
Sand	0	67.09	63.30	62.38	56.00	51.85	49.04	58.27
	25	61.04	58.92	56.40	52.22	45.38	42.67	52.77
	50	57.85	55.84	52.29	46.67	43.81	38.80	49.21
	100	52.24	51.51	50.74	43.62	36.66	34.75	44.92
	Mean	59.55	57.39	55.45	49.63	44.42	41.31	51.29
Clay loam	0	76.04	74.43	73.81	69.00	64.46	61.56	69.88
	25	74.38	73.05	71.14	65.95	62.20	58.38	67.51
	50	71.20	70.37	67.78	62.35	60.01	54.86	64.42
	100	64.86	64.09	62.46	58.92	56.42	52.08	59.80
	Mean	71.62	70.48	68.79	64.05	60.77	56.72	65.40
Overall Mean		65.58	63.93	62.12	56.84	52.59	49.01	58.34
C.D. (P = 0.05)								

Pb = 1.04

Pb x P = NS

P = 0.85

Pb x Soil = 1.48

Soil = 0.60

P x Soil = 1.21

Pb x P x Soil = NS

Application of P significantly repressed Fe concentration in grain and the effect varied with soil texture. The reduction in Fe concentration of grain due to 25, 50 and 100 mg P kg⁻¹ soil over no P was 9.4, 15.5 and 22.9 per cent in sandy soil and 3.4, 7.8 and 14.4 per cent in clay loam soil, respectively. The combined effect of P and Pb was highly negative as application of 80 mg Pb and 100 mg P kg⁻¹ soil reduced Fe to 34.75 µg g⁻¹ compared with 67.0 µg g⁻¹ at 0 mg P and Pb. The interaction between Pb and P was non significant. The Pb x P x soil interaction was also non significant.

(b) Straw

It is apparent from data (Table 28) that Fe concentration in wheat straw decreased as a result of Pb application. The overall mean concentration of Fe was significantly decreased in straw from 325.3 to 262.2 µg g⁻¹ with increase in Pb levels from 0 to 80 mg kg⁻¹ soil. The effect of soil texture on Fe concentration of straw was also significant, being significantly higher (319.4 µg g⁻¹) in clay loam soil than sandy soil (280.9 µg g⁻¹).

Application of P alleviated straw Fe significantly and magnitude of reduction due to P application varied with soil texture. The straw Fe concentration in sandy soil decreased by 4.9, 11.7 and 14.3 per cent and 6.7, 15.2 and 18.2 per cent in clay loam soil with 25, 50 and 100 mg P kg⁻¹ soil, over no P treatment, respectively. The effect of Pb x P interaction was significant and varied with soil texture.

Combined application of 80 mg Pb and 100 mg P kg⁻¹ soil reduced straw Fe to 231.9 in sandy soil and 263.2 µg g⁻¹ in clay loam soil compared with 340.6 µg g⁻¹ in sandy soil and 380.5 µg g⁻¹ straw in clay loam soil at 0 mg P and 0 mg Pb kg⁻¹ soil, respectively. The antagonistic effect of Pb and

Table 28. Effect of Pb, P and soil texture on Fe concentration of wheat straw

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Fe concentration (µg g ⁻¹)								
Sand	0	340.6	325.5	324.2	292.0	285.2	260.3	304.6
	25	320.6	317.3	306.2	282.9	263.7	246.6	289.5
	50	281.3	281.1	279.5	273.3	256.3	241.9	268.9
	100	275.2	270.6	267.7	262.4	257.5	231.9	260.8
	Mean	304.4	298.6	294.4	277.6	265.6	245.1	280.9
Clay loam	0	380.5	379.1	377.3	367.9	326.2	300.0	355.1
	25	359.5	356.2	345.2	323.1	317.2	285.6	331.1
	50	330.3	327.1	310.3	290.1	280.4	268.6	301.1
	100	315.0	311.8	305.3	276.1	271.5	263.2	290.4
	Mean	346.3	343.5	334.5	314.3	298.8	279.3	319.4
Overall Mean		325.3	321.0	314.4	295.9	282.2	262.2	300.1

C.D. (P = 0.05)

Pb = 2.2

Pb x P = 4.5

P = 1.8

Pb x Soil = 3.2

Soil = 1.3

P x Soil = 2.6

Pb x P x Soil = 6.5

P on Fe accumulation was more pronounced in clay loam soil when both Pb and P were applied together.

(c) Root

Iron concentration in wheat root (Table 29) increased significantly as a result of Pb application. The overall Fe concentration of root was increased significantly from $2301 \mu\text{g g}^{-1}$ in control to $2483 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil. The Fe concentration in root in sandy soil was significantly higher than clay loam soil.

Interaction between Pb and soil was also significant. Root Fe increased from $2333 \mu\text{g g}^{-1}$ at 0 mg Pb kg^{-1} soil to $2550 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil in sandy soil, while the corresponding increase in clay loam soil was from 2301 to $2483 \mu\text{g g}^{-1}$.

Addition of P either alone or in conjunction with Pb significantly enhanced root Fe. The mean concentration of Fe in root was increased by 12.0, 27.6 and 37.5 per cent in sandy soil and 13.3, 26.9 and 41.5 per cent in clay loam soil due to 25, 50 and 100 mg P kg^{-1} soil over control, respectively. The Pb x P, Pb x P x soil interactions were non significant.

The results vividly demonstrated that application of Pb alleviated Fe concentration in grain and straw and enhanced it in roots of wheat, which is ascribed to antagonistic effect of Pb on Fe which inhibited the translocation of Fe from roots to above ground parts. The antagonistic effect of Pb on Fe seems to have occurred in the roots. Khan and Khan (1983) observed that the Pb application to soil decreased Fe content of egg plant. Fe concentration was higher in wheat grain and straw grown in clay loam soil than sandy soil, which is attributed to higher available Fe status of clay loam soil.

Table 29. Effect of Pb, P and soil texture on Fe concentration of wheat root

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Fe concentration (µg g ⁻¹)								
Sand	0	1950	1975	2000	2036	2084	2142	2031
	25	2207	2239	2256	2269	2290	2390	2275
	50	2490	2551	2557	2597	2660	2729	2592
	100	2685	2718	2758	2798	2867	2940	2794
	Mean	2333	2363	2393	2425	2475	2550	2423
Clay loam	0	1879	1897	1910	1926	1959	2022	1932
	25	2130	2150	2169	2187	2220	2285	2190
	50	2392	2404	2430	2446	2490	2555	2452
	100	2676	2692	2721	2738	2778	2804	2734
	Mean	2269	2285	2307	2324	2361	2416	2327
Overall Mean		2301	2324	2350	2374	2418	2483	2375

C.D. (P = 0.05)

Pb = 22	Pb x P = NS
P = 18	Pb x Soil = 32
Soil = 13	P x Soil = 26
	Pb x P x Soil = NS

The reduction in Fe concentration in grain and straw due to P application is attributed to antagonistic effect of P on Fe absorption and translocation. Badhe and Mundwaik (1982) and Singh and Singh (1983) also reported a reduction in Fe concentration in various parts of sorghum, wheat and rice, respectively due to P application. Pandey *et al.* (1984) also observed that Pb added alongwith phosphate considerably reduced the uptake of Fe by shoots and roots.

4.1.3.4 Copper concentration

(a) Grain

The results (Table 30) indicated that Cu concentration of wheat grain slightly increased with initial rates of Pb. Higher level of Pb caused significant reduction in grain Cu when compared with 0, 5 and 10 mg Pb kg⁻¹ soil. The pattern in reduction of the concentration of wheat grain was similar in both the soils. The Cu concentration in wheat grain in clay loam soil was significantly higher than sandy soil.

Application of P depressed grain Cu significantly and magnitude of depression due to P application varied with soil texture. In sandy soil, application of 25, 50 and 100 mg P kg⁻¹ soil depressed Cu concentration significantly from 4.20 µg g⁻¹ in control to 3.00, 2.68 and 2.57 µg g⁻¹ grain, respectively, while in clay loam soil, the Cu concentration at the corresponding P levels was reduced from 4.43 µg g⁻¹ to 3.41, 3.24 and 3.01 µg g⁻¹, respectively. The interaction between Pb x P, Pb x soil and Pb x P x soil were non significant.

Table 30. Effect of Pb, P and soil texture on Cu concentration of wheat grain

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Cu concentration (µg g ⁻¹)								
Sand	0	4.28	4.26	4.25	4.30	4.13	4.00	4.20
	25	3.00	3.10	3.08	3.05	3.04	2.75	3.00
	50	2.77	2.78	2.73	2.71	2.64	2.50	2.68
	100	2.65	2.66	2.66	2.60	2.52	2.37	2.57
	Mean	3.17	3.20	3.18	3.16	3.08	2.90	3.11
Clay loam	0	4.50	4.53	4.53	4.50	4.40	4.17	4.43
	25	3.45	3.50	3.48	3.45	3.42	3.16	3.41
	50	3.25	3.30	3.40	3.31	3.21	2.98	3.24
	100	3.00	3.17	3.14	3.10	3.00	2.68	3.01
	Mean	3.55	3.62	3.63	3.59	3.50	3.24	3.52
Overall Mean		3.36	3.41	3.40	3.37	3.29	3.07	3.31

C.D. (P = 0.05)

Pb = 0.05

P = 0.04

Soil = 0.03

Pb x P = NS

Pb x Soil = NS

P x Soil = 0.06

Pb x P x Soil = NS

(b) Straw

The overall mean concentration of Cu in straw slightly increased with 5 and 10 mg Pb kg⁻¹ soil then it was decreased. Higher level of Pb caused significant reduction in shoot Cu when compared with 0, 5 and 10 mg Pb kg⁻¹ soil (Table 31). However, straw Cu decreased from 4.45 µg g⁻¹ in control to 4.08 µg g⁻¹ due to 80 mg Pb kg⁻¹ soils application. Straw Cu varied significantly with soil type and its mean concentration was higher in clay loam (4.70 µg g⁻¹) than sandy soil (4.03 µg g⁻¹). The interaction between Pb and soil was non significant.

With increasing level of P significantly reduced the Cu accumulation in straw and the effect of P on Cu concentration varied with soil texture. In sandy soil, application of 25, 50 and 100 mg P kg⁻¹ soil depressed Cu concentration significantly from 5.29 µg g⁻¹ in control to 3.97, 3.59 and 3.29 µg g⁻¹ straw, respectively, while in clay loam soil, the Cu content at the corresponding P levels was reduced from 5.56 µg g⁻¹ to 4.92, 4.38 and 3.93 µg g⁻¹, respectively. The interaction between Pb x P, Pb x soil and Pb x P x soil were non significant.

(c) Root

Copper content of wheat root decreased with increasing level of Pb (Table 32). However, differences were significant from 10 mg Pb kg⁻¹ soil to onward. The Cu content of root decreased from 25.94 to 23.10 µg g⁻¹ with an increase in the level of Pb from 0 to 80 mg Pb kg⁻¹ soil, respectively. Copper content in root varied significantly with soil type and its mean concentration was higher in clay loam (26.05 µg g⁻¹) than sandy soil (23.49 µg g⁻¹). The interaction between Pb and soil was non significant.

Table 31. Effect of Pb, P and soil texture on Cu concentration of wheat straw

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Cu concentration (µg g ⁻¹)								
Sand	0	5.40	5.43	5.35	5.36	5.19	5.04	5.29
	25	4.05	4.05	4.03	4.01	3.98	3.71	3.97
	50	3.70	3.69	3.68	3.69	3.52	3.27	3.59
	100	3.40	3.39	3.38	3.42	3.19	2.90	3.29
	Mean	4.13	4.14	4.11	4.12	3.97	3.73	4.03
Clay loam	0	5.70	5.72	5.70	5.49	5.44	5.35	5.56
	25	5.00	5.10	5.05	5.05	4.71	4.64	4.92
	50	4.40	4.50	4.50	4.45	4.37	4.09	4.38
	100	4.00	4.10	4.05	3.90	3.85	3.70	3.93
	Mean	4.77	4.85	4.82	4.72	4.59	4.44	4.70
Overall Mean		4.45	4.49	4.46	4.42	4.28	4.08	4.36

C.D. (P = 0.05)

Pb = 0.14

P = 0.12

Soil = 0.08

Pb x P = NS

Pb x Soil = NS

P x Soil = 0.16

Pb x P x Soil = NS

Table 32. Effect of Pb, P and soil texture on Cu concentration of wheat root

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Cu concentration (µg g ⁻¹)								
Sand	0	28.45	28.01	27.75	26.25	24.37	24.00	26.47
	25	26.00	25.92	25.70	25.05	23.07	22.92	24.77
	50	23.50	23.35	23.00	22.75	22.25	21.00	22.65
	100	21.25	21.15	20.25	20.00	19.25	18.75	20.10
	Mean	24.80	24.60	24.17	23.51	22.23	21.66	23.49
Clay loam	0	30.15	29.95	29.45	29.15	28.65	27.86	29.20
	25	28.23	28.00	27.80	27.30	26.00	25.45	27.13
	50	26.00	25.80	25.65	25.05	24.10	22.95	24.92
	100	23.95	23.72	23.25	22.85	22.00	21.90	22.94
	Mean	27.08	26.86	26.53	26.09	25.19	24.54	26.05
Overall Mean		25.94	25.73	25.35	24.80	23.71	23.10	24.77

C.D. (P = 0.05)

Pb = 0.36

P = 0.29

Soil = 0.21

Pb x P = NS

Pb x Soil = NS

P x Soil = NS

Pb x P x Soil = NS

Phosphorus application alone or in combination with Pb significantly reduced the root Cu concentration. The mean Cu concentration decreased by 6.4, 14.4 and 24.0 per cent in sandy soil and 7.0, 14.6 and 21.4 per cent in clay loam soil with 25, 50 and 100 mg P kg⁻¹ soil, respectively over control. The various interaction between Pb, P and soil were found non significant.

The results revealed that Pb application slightly increased Cu concentration in wheat grain and straw with initial rates of Pb, further increase in Pb levels, decreased the Cu concentration. Thus, lower levels of Pb had somewhat additive effect on Cu concentration, while higher level of Pb had antagonistic effect. Copper concentration of wheat root decreased with increasing Pb levels. Khan and Khan (1983) observed that Pb application decreased Cu content of egg plant. Pandey *et al.* (1984) found that Cu uptake was significantly changed in shoot and roots with the application of Pb with phosphate. The clay loam soil has the highest total quantities of copper compared with the sandy soils the concentration of copper in the wheat plant tissue was higher.

On application of P, the decrease in Cu concentration in wheat tissue might be due to the formation of copper phosphate, which is not readily available to plants. A mutual antagonism between P and Cu in plants was also recorded by Dev *et al.* (1983), Goyal *et al.* (1987), Bingham *et al.* (1958) and Datta and Gupta (1983).

4.1.4 Effect of Pb, P and soil texture on DTPA-extractable Pb in soil

4.1.4.1 DTPA-extractable Pb in pre-sowing soil samples

The DTPA extractable Pb increased significantly with increasing levels of Pb in soil (Table 33). The overall DTPA Pb increased from 0.87 to

Table 33. Effect of Pb, P and soil texture on DTPA extractable Pb in soils before seedling

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
DTPA-Pb (μg g ⁻¹)								
Sand	0	0.89	3.89	4.44	9.44	18.20	31.00	11.31
	25	0.72	3.45	4.00	8.70	17.60	28.40	10.47
	50	0.55	2.92	3.00	6.43	13.55	27.20	8.94
	100	0.42	2.59	2.79	5.90	11.78	26.06	8.25
	Mean	0.64	3.21	3.55	7.61	15.28	28.16	9.74
Clay loam	0	1.60	2.55	6.22	8.80	14.60	27.60	10.22
	25	1.20	2.20	5.00	7.07	11.30	26.10	8.81
	50	0.87	1.87	4.30	6.30	9.21	23.50	7.67
	100	0.74	1.40	3.60	5.80	7.98	21.70	6.87
	Mean	1.10	2.00	4.78	6.99	10.77	24.72	8.39
Overall Mean		0.87	2.60	4.16	7.30	13.02	26.44	9.06

C.D. (P = 0.05)

Pb	= 0.11	Pb x P	= 0.23
P	= 0.09	Pb x Soil	= 0.16
Soil	= 0.06	P x Soil	= 0.13
		Pb x P x Soil	= 0.32

26.44 $\mu\text{g g}^{-1}$ soil with an increase in its level in soil from 0 to 80 mg Pb kg^{-1} soil, respectively. In sandy soil, application of 80 mg Pb kg^{-1} soil increased the extractable Pb from 0.64 mg kg^{-1} soil at 0 Pb to 28.16 $\mu\text{g g}^{-1}$ soil. The corresponding Pb increase in clay loam soil was 1.10 to 24.72 $\mu\text{g g}^{-1}$ soil. The extractable Pb was significant higher in sandy soil than in clay loam soil.

Application of P decreased DTPA - Pb in soil significantly and magnitude of depression due to P application varied with soil texture. In sandy soil, application of 25, 50 and 100 mg P kg^{-1} soil decreased extractable Pb significantly from 11.31 $\mu\text{g g}^{-1}$ in control to 10.47, 8.94 and 8.25 $\mu\text{g g}^{-1}$ soil respectively, while in clay loam soil, the DTPA - Pb at the corresponding P levels was reduced from 10.22 to 8.81, 7.67 and 6.87 $\mu\text{g g}^{-1}$, respectively.

The Pb and P interacted significantly in affecting the Pb extractability and the magnitude of interaction varied with soil texture. Application of Pb without P, increased DTPA - Pb significantly, while P alone showed significant depression in both soils.

The results show that application of P has a antagonistic effect on extractable Pb in soil. The various interaction between Pb, P and soil texture were also significant.

4.1.4.2 DTPA-extractable Pb in post-harvest soil samples

The overall DTPA extractable Pb increased from 0.79 to 23.07 $\mu\text{g g}^{-1}$ as the Pb levels raised from 0 to 80 mg kg^{-1} soil (Table 34). In contrast to 23.94 $\mu\text{g Pb g}^{-1}$ soil in sandy soil at 80 mg Pb kg^{-1} soil, the extractable Pb in clay loam soil was 22.20 $\mu\text{g g}^{-1}$ soil. The extractable Pb was significantly higher in sandy soil than in clay loam soil.

Table 34. Post harvest DTPA-extractable Pb in soils as influenced by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
DTPA-Pb (µg g ⁻¹)								
Sand	0	0.77	3.43	4.00	8.80	14.19	29.21	10.07
	25	0.67	3.29	3.92	8.46	13.11	25.44	9.14
	50	0.48	2.70	2.77	6.07	11.89	21.90	7.63
	100	0.37	2.39	2.45	5.81	10.52	19.23	6.79
	Mean	0.57	2.95	3.28	7.28	12.42	23.94	8.41
Clay loam	0	1.47	2.41	6.03	8.30	13.52	25.11	9.47
	25	1.19	2.15	4.77	6.86	9.80	23.93	8.11
	50	0.77	1.77	4.11	5.92	8.49	21.00	7.01
	100	0.63	1.31	3.33	5.00	7.20	18.78	6.04
	Mean	1.01	1.91	4.56	6.52	9.75	22.20	7.66
Overall Mean		0.79	2.43	3.92	6.90	11.08	23.07	8.03

C.D. (P = 0.05)

Pb = 0.07

P = 0.05

Soil = 0.04

Pb x P = 0.14

Pb x Soil = 0.10

P x Soil = 0.08

Pb x P x Soil = 0.20

DTPA extractable Pb decreased significantly with increasing levels of P in both the soil. The various interaction between Pb, P and soil were found significant.

The higher lead content was observed in sandy soil compared to clay loam soil, since Pb in fine texture soils is more strongly complexed with organic matter, therefore it would not be easily extractable by DTPA. Largerwerff (1972) had observed that soil organic matter strongly adsorbed Pb. The lower magnitude of increase in extractable Pb, with its increasing rate in clay loam soil than sandy soil, is due to the finer texture and higher CEC and O.C. content of this soil. Therefore, in this soil Pb had probably been adsorbed strongly by clay colloids, thereby reducing the amounts of DTPA extractable Pb.

DTPA extractable Pb decreased significantly due to increase in P levels. Bohn *et al.* (1979). also reported that high P levels can affect soil properties which in turn may influence the availability of micronutrient metals to plants. Santillan-Medrano and Jurinak, (1975) have studied the solubility of Cd and Pb in soils in relation to the formation of phosphate, carbonate and hydroxide compounds. They concluded that both Pb and Cd solubility decreased as pH increases. A part of P x Pb interaction seems to have occurred in soil, due to formation of sparingly soluble lead phosphate

4.1.5 Effect of Pb, P and soil texture on Olsen's - P in soil

4.1.5.1 Olsen's - P in pre-sowing soil samples

It is evident from data (Table 35) that increasing level of Pb decreased Olsen's extractable P in the pre-sowing soil samples. The overall mean

Table 35. Effect of Pb, P and soil texture on Olsen's-P in soil before seedling

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Olsen's-P (μg g ⁻¹)								
Sand	0	3.30	3.30	3.26	3.09	2.94	2.75	3.10
	25	18.00	17.82	17.66	17.05	16.75	15.25	17.09
	50	28.80	28.40	27.70	27.05	26.50	25.00	27.24
	100	52.40	52.10	50.80	49.20	47.30	44.70	49.41
	Mean	25.62	25.40	24.85	24.10	23.37	21.92	24.21
Clay loam	0	6.30	6.20	6.00	5.70	5.62	5.20	5.83
	25	12.62	12.58	12.57	12.00	11.70	11.00	12.07
	50	19.50	19.27	19.22	18.55	17.85	16.18	18.43
	100	37.80	37.65	37.20	36.00	34.60	32.00	35.87
	Mean	19.05	18.92	18.75	18.06	17.44	16.09	18.05
Overall Mean		22.34	22.16	21.80	21.08	20.40	19.01	21.13

C.D. (P = 0.05)

Pb = 0.20

P = 0.16

Soil = 0.11

Pb x P = 0.41

Pb x Soil = 0.29

P x Soil = 0.23

Pb x P x Soil = 0.58

extractable P content of soil was 22.34, 22.16, 21.08, 20.40 and 19.01 $\mu\text{g g}^{-1}$ at 0, 5, 10, 20, 40 and 80 mg Pb kg^{-1} soil, respectively. In sandy soil extractable P decreased significantly from 25.62 to 21.92 $\mu\text{g g}^{-1}$ soil with increasing levels of Pb from 0 to 80 mg kg^{-1} soil, respectively. While, in clay loam soil it decreased significantly from 19.05 in control to 16.09 $\mu\text{g g}^{-1}$ soil as a result of 80 mg Pb kg^{-1} soil, respectively.

Application of P significantly elevated extractable P in the soil. The available P content of sandy soil increased from 3.10 to 17.09, 27.24 and 49.41 $\mu\text{g g}^{-1}$ soil due to application of P from 0 to 25, 50 and 100 mg kg^{-1} soil. The corresponding increase in clay loam soil was from 5.83 to 12.07, 18.43 and 35.87 $\mu\text{g g}^{-1}$ soil, respectively. The magnitude of increase in available P due to its application was more pronounced in sandy soil, probably due to its low fixation capacity. The interaction between Pb, P and soil were significant.

4.1.5.2 Olsen's - P in post - harvest soil samples

The data (Table 36) indicated that application of Pb decreased available P content in post- harvest soils from 12.05 $\mu\text{g g}^{-1}$ soil in control to 10.17 $\mu\text{g g}^{-1}$ soil at 80 mg Pb kg^{-1} soil irrespective of soil texture. However, the magnitude of decrease in available P due to Pb application varied with soil texture. In sandy soil, the mean extractable P decreased significantly from 11.43 at 0 Pb to 10.85 and 9.91 $\mu\text{g g}^{-1}$ soil as a result of 40 and 80 mg Pb kg^{-1} soil, respectively. While, in clay loam soil, it decreased significantly from 12.68 at control to 11.91, 11.73 and 10.43 $\mu\text{g g}^{-1}$ soil as a result of 20, 40 and 80 mg Pb kg^{-1} soil, respectively.

Application of P enhanced extractable P in both the soils. The various interaction between Pb, P and soil were found to be significant. In the absence

Table 36. Effect of Pb, P and soil texture on Olsen's-P in soil after harvesting

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Olsen's-P (µg g ⁻¹)								
Sand	0	1.75	1.75	1.68	1.68	1.60	1.50	1.66
	25	7.00	6.93	6.92	6.85	6.80	5.63	6.68
	50	13.00	13.00	12.82	12.67	12.00	10.00	12.24
	100	24.00	24.00	23.90	23.80	23.00	22.50	23.53
	Mean	11.43	11.42	11.33	11.25	10.85	9.91	11.03
Clay loam	0	4.67	4.33	4.50	4.35	4.25	4.00	4.35
	25	9.75	9.65	9.65	9.00	8.50	7.60	9.02
	50	14.30	14.00	14.00	13.30	13.25	12.00	13.47
	100	22.00	21.93	21.73	21.00	20.92	18.13	20.95
	Mean	12.68	12.48	12.47	11.91	11.73	10.43	11.95
Overall Mean		12.05	11.95	11.90	11.58	11.29	10.17	11.49

C.D. (P = 0.05)

Pb = 0.24	Pb x P = 0.48
P = 0.19	Pb x Soil = 0.34
Soil = 0.13	P x Soil = 0.27
	Pb x P x Soil = 0.68

of added P application of 80 mg Pb kg⁻¹ soil alone resulted in 14.2 and 14.3 per cent reduction in extractable P in sandy and clay loam soil, respectively.

The results indicated that application of Pb decreased Olsen's- P in both the soils which might be due to the immobilization of soil P by heavy metals or due to interaction of Pb x P in soil and formation of lead phosphate. The soil system is very complex and contains compounds which might cause dissolution or precipitation of elements applied to soil i.e., presence of soluble CO₃, SO₄ and/or PO₄ as well as alkaline pH causes Pb precipitation (Nriagu, 1972).

The magnitude of increase in available P due to its application was more pronounced in sandy soil, probably due to low fixation capacity. But clay loam soil has higher P fixation capacity due to higher CaCO₃, organic carbon and the fine texture, phosphorus could be adsorbed on the surface of CaCO₃ and might precipitate as calcium phosphate also. Kanwar and Grewal (1971) also reported that higher clay content resulted in higher P fixation.

4.2 Studies on the yield, chemical composition and nutrient availability to wheat as influenced by Pb, cattle manure and soil texture

4.2.1 Influence of Pb and cattle manure on yield of wheat grown in texturally different soils

4.2.1.1 Grain yield

Data (Table 37) revealed that overall grain yield increased significantly with 5 mg Pb kg⁻¹ soil and decreased at higher level when compared with control. The reduction in grain yield caused by 10, 20, 40 and 80 mg Pb kg⁻¹ soil was 2.6, 7.6, 11.8 and 16.4 per cent over control,

Table 37. Influence of Pb and cattle manure on grain yield of wheat grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Grain yield (g pot ⁻¹)								
Sand	0	15.13	15.50	13.67	13.47	13.00	11.40	13.69
	0.5	17.30	17.43	16.73	15.80	14.70	13.60	15.92
	1.0	18.03	17.77	16.80	16.33	15.63	14.43	16.50
	Mean	16.82	16.90	15.73	15.20	14.44	13.14	15.37
Clay loam	0	20.90	22.40	20.83	19.43	18.83	17.93	20.05
	0.5	21.33	22.60	21.90	19.87	19.77	19.30	20.79
	1.0	23.33	24.23	23.10	22.30	20.40	20.27	22.27
	Mean	21.85	23.07	21.94	20.53	19.67	19.16	21.04
Overall Mean		19.33	19.98	18.83	17.86	17.05	16.15	18.20

C.D. (P = 0.05)

Pb = 0.41

Pb x Manure = NS

Manure = 0.29

Pb x Soil = 0.58

Soil = 0.23

Manure x Soil = 0.41

Pb x Manure x Soil = NS

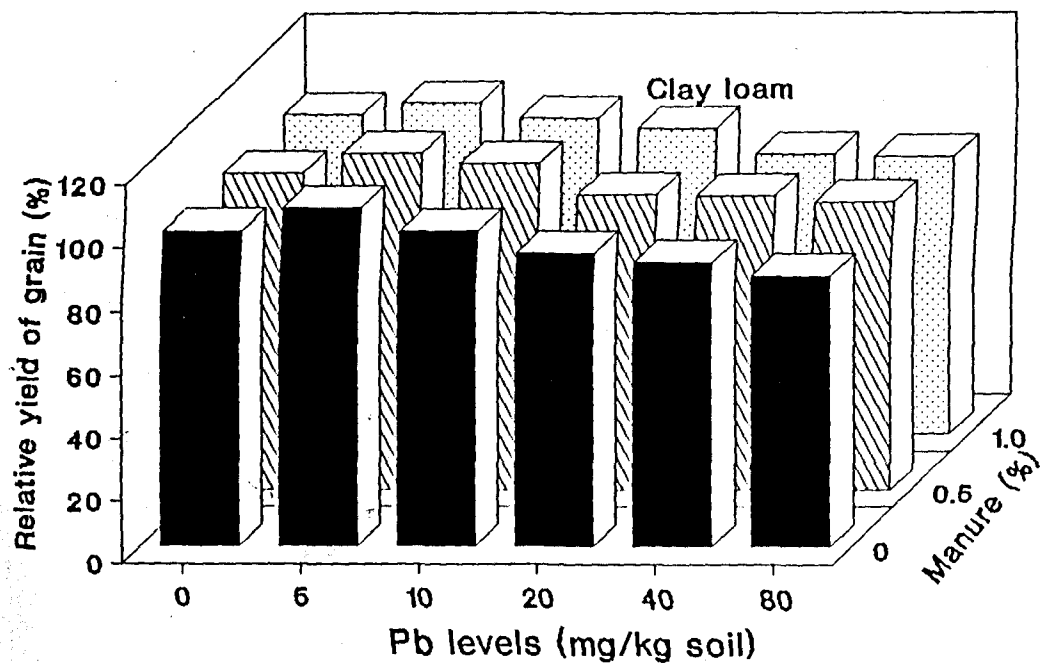
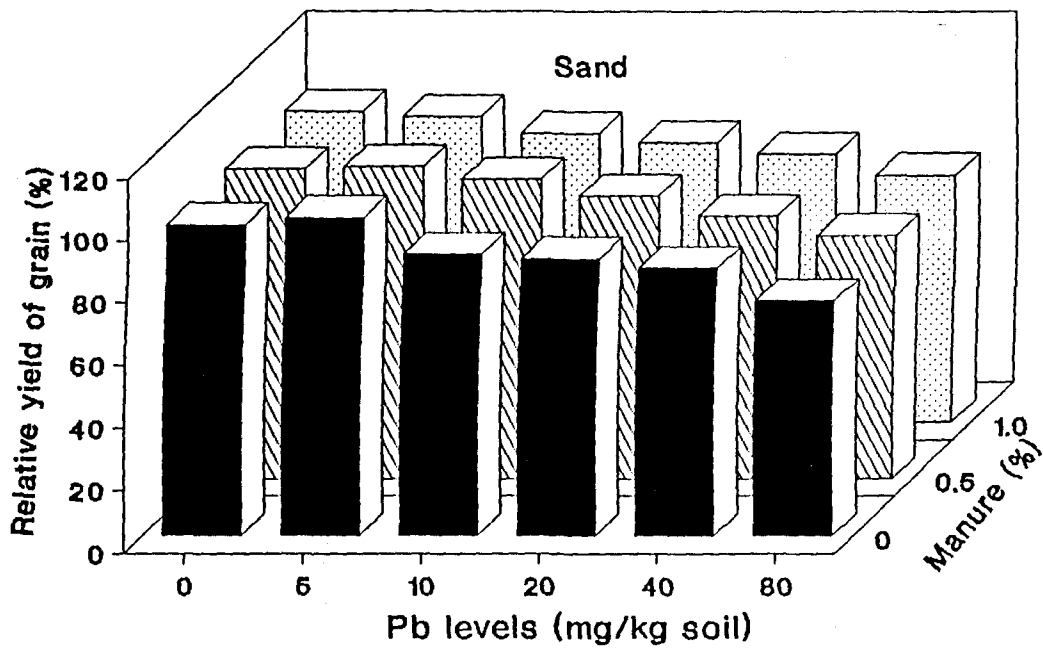


FIG.11. INFLUENCE OF Pb, CATTLE MANURE AND SOIL TEXTURE ON RELATIVE YIELD OF WHEAT GRAIN

respectively, irrespective of the soils. The response to added Pb varied with the soil texture. The mean grain yield decreased significantly to 13.14 and 19.16 g pot⁻¹ as a result of 80 mg Pb kg⁻¹ soil in sandy and clay loam soil compared with 16.82 and 21.85 g pot⁻¹ at 0 mg Pb kg⁻¹ soil, respectively. The mean grain yield was significantly affected due to soil texture being higher (21.04 g pot⁻¹) in clay loam than sandy soil (15.37 g pot⁻¹).

In general relative yield increased at 5 mg Pb kg⁻¹ soil over 0 mg kg⁻¹ soil, but for sandy soil at 1.0% applied manure where it decreased at higher rates of applied Pb (Fig. 11, Annexure-2). The relative yield decreased over control, however, application of manure increased it when compared with no manure. The grain yield drastically decreased with higher level of Pb application. Application of manure significantly increased the grain yield in both the soils. In sandy soil mean grain yield increased from 13.69 g pot⁻¹ in control to 15.92 and 16.50 g pot⁻¹ grain at 0.5 and 1.0 per cent manure rate, respectively, while in clay loam soil it was increased from 20.05 to 20.79 and 22.27 g pot⁻¹ at the corresponding manure levels, respectively.

In the absence of added manure, application of 80 mg Pb kg⁻¹ soil alone resulted in 24.6 and 14.2 per cent reduction in grain yield in sandy and clay loam soil, respectively. Application of 1.0% manure alone increased the grain yield by 19.1 and 11.6 per cent over no manure, no Pb treatment in sandy and clay loam soil, respectively. Application of 1.0% manure almost eliminated the adverse effect of 40 mg Pb kg⁻¹ soil in both the soils. Combined application of 1.0% manure and 80 mg Pb kg⁻¹ soil resulted in 26.5 and 13.0 per cent higher grain yield over 80 mg Pb kg⁻¹ soil in sandy and clay loam soil, respectively. The interaction between Pb x manure and

Pb x manure x soil were non significant. It is deduced that application of manure was more effective in off-setting the harmful effects of Pb on grain yield of wheat in sandy soil, particularly at higher Pb levels.

4.2.1.2 Straw yield

Yield of wheat straw increased at 5 and 10 mg Pb kg⁻¹ soil and decreased significantly at higher levels (Table 38). The magnitude of reduction due to Pb application also varied significantly with soil type. Application of Pb higher than 10 mg kg⁻¹ soil caused significant reduction in straw yield over control in clay loam soil. The mean per cent reduction in straw yield at 80 mg Pb kg⁻¹ soil over no Pb treatment was 6.9 and 4.2 per cent in sandy and clay loam soil, respectively. The straw yield was significantly higher in clay loam as compared to sandy soil. Relative straw yield was also higher in clay loam soil than sandy soil (Fig. 12, Annexure-2).

The mean straw yield increased from 22.65 g pot⁻¹ at 0% manure to 26.11 g pot⁻¹ at 1.0% applied manure in sandy soil and 26.45 to 27.97 g pot⁻¹ in clay loam soil, respectively. The magnitude of increase in straw yield due to manure application also varied significantly with soil texture. The effect of Pb x manure and Pb x soil were non significant on straw yield of wheat.

Application of 80 mg Pb kg⁻¹ soil in the absence of manure, resulted in 7.1 per cent reduction in straw yield over no Pb and no manure treatment, respectively, in sandy soil, while, the corresponding reduction in clay loam soil was only 2.4 per cent. The adverse effect of 80 mg Pb kg⁻¹ soil on shoot yield was counteracted by adding 0.5% manure in sandy soil and clay loam soil, respectively.

Table 38. Influence of Pb and cattle manure on straw yield of wheat grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Straw yield (g pot ⁻¹)								
Sand	0	22.03	<u>24.30</u>	<u>24.00</u>	<u>22.73</u>	22.40	20.46	22.65
	0.5	<u>25.10</u>	25.20	<u>24.93</u>	<u>24.67</u>	23.90	23.00	24.46
	1.0	<u>26.77</u>	<u>26.77</u>	<u>26.13</u>	25.90	25.77	25.33	26.11
	Mean	24.63	25.42	25.02	24.43	24.02	22.93	24.41
Clay loam	0	26.40	27.27	26.80	26.40	26.10	25.77	26.45
	0.5	27.67	28.50	28.20	27.40	27.03	26.57	27.56
	1.0	28.57	29.27	28.87	27.47	26.87	26.77	27.97
	Mean	27.54	28.34	27.95	27.09	26.66	26.37	27.32
Overall Mean		26.08	26.88	26.48	25.76	25.34	24.65	25.86

C.D. (P = 0.05)

Pb = 0.42

Manure = 0.30

Soil = 0.24

Pb x Manure = NS

Pb x Soil = NS

Manure x Soil = 0.42

Pb x Manure x Soil = 1.05

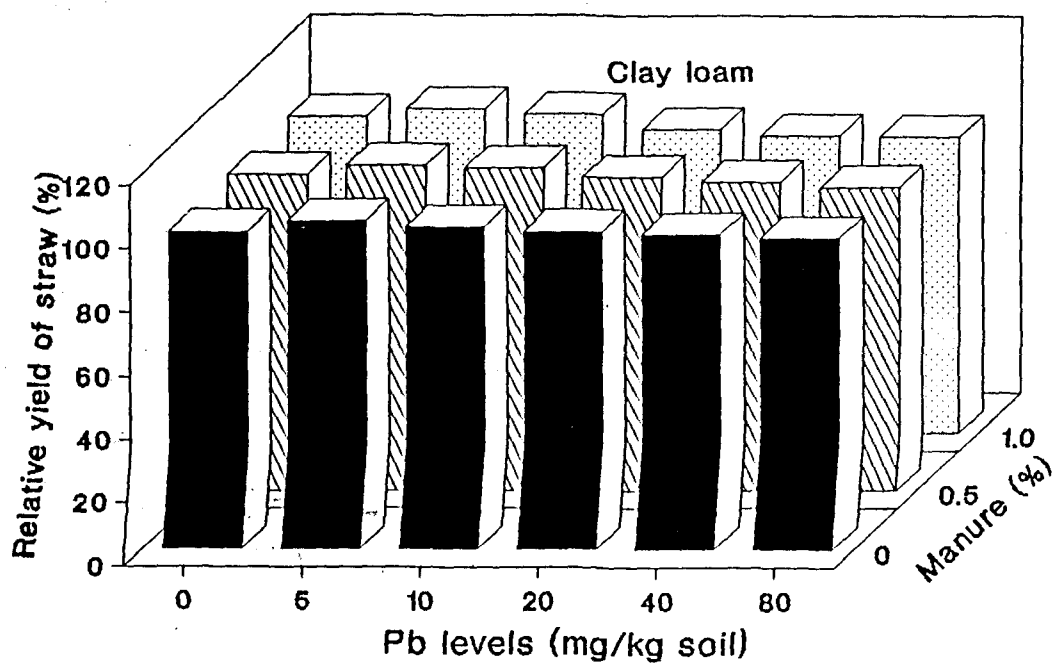
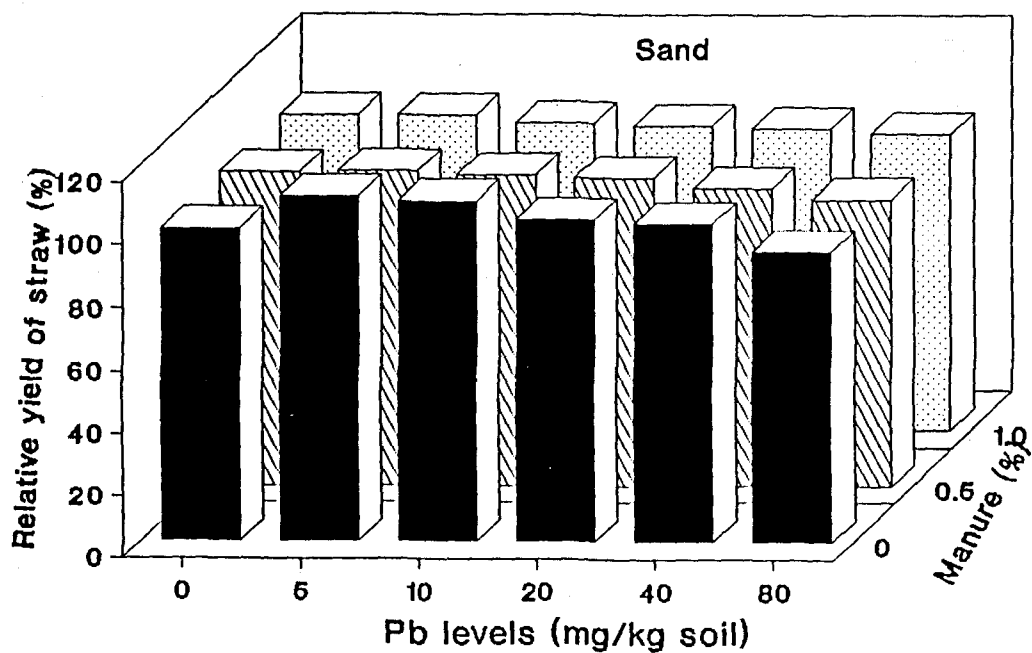


FIG.12. INFLUENCE OF Pb, CATTLE MANURE AND SOIL TEXTURE ON RELATIVE YIELD OF WHEAT STRAW

4.2.1.3 Root yield

Overall mean root yield increased with 5 mg Pb kg⁻¹ soil, thereafter it decreased with increase in Pb application (Table 39). In sandy soil, mean root yield was reduced significantly from 3.62 at 0 Pb to 3.46, 3.19, 2.99 and 2.77 g pot⁻¹ as a result of 10, 20, 40, 60 and 80 mg Pb kg⁻¹ soil, respectively. While, in clay loam soil it decreased significantly from 3.75 to 3.61 and 3.44 g pot⁻¹ as a result of 40 and 80 mg Pb kg⁻¹ soil, respectively. The per cent relative yield of root was increased with 5 mg Pb kg⁻¹ soil, but at higher levels it was decreased in both the soils (Fig. 13, Annexure-2).

Increasing rates of manure, enhanced root yield significantly over no manure in both the soils. It increased from 2.89 to 3.53 g pot⁻¹ in sandy soil and from 3.54 to 3.84 g pot⁻¹ in clay loam soil with increasing levels of manure from 0 to 1.0%, respectively. Application of 80 mg Pb kg⁻¹ soil alone resulted in 30.3 and 6.1 per cent reduction in root yield over no manure and no Pb treatment in sandy and clay loam soil, respectively. While 1.0% manure alone increased root yield by 15.7 and 15.0 per cent over no manure and no Pb treatment in sandy and clay loam soil, respectively. The interaction between Pb x manure was non significant. The results show that manure application reduced the adverse effect of Pb in both the soil.

The results of this experiment also indicated that initial rates of lead (5 mg kg⁻¹ soil) elated yield of all fractions of wheat, while higher levels of Pb had depressing effect on yield. Increase in yield at lower Pb level may be attributed to increased absorption of some nutrients and phytotoxicity at higher level of Pb application could be ascribed due to

Table 39. Influence of Pb and cattle manure on root yield of wheat grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Root yield (g pot ⁻¹)								
Sand	0	3.30	3.35	3.05	2.80	2.55	2.30	2.89
	0.5	3.75	3.77	3.67	3.23	3.18	2.94	3.42
	1.0	3.82	3.82	3.67	3.55	3.26	3.08	3.53
	Mean	3.62	3.65	3.46	3.19	2.99	2.77	3.28
Clay loam	0	3.45	3.80	3.68	3.59	3.50	3.24	3.54
	0.5	3.83	3.85	3.76	3.70	3.64	3.47	3.70
	1.0	3.97	4.03	3.95	3.81	3.70	3.62	3.84
	Mean	3.75	3.89	3.79	3.70	3.61	3.44	3.69
Overall Mean		3.68	3.77	3.62	3.44	3.30	3.10	3.48

C.D. (P = 0.05)

Pb = 0.06

Manure = 0.04

Soil = 0.03

Pb x Manure = NS

Pb x Soil = 0.08

Manure x Soil = 0.06

Pb x Manure x Soil = 0.14

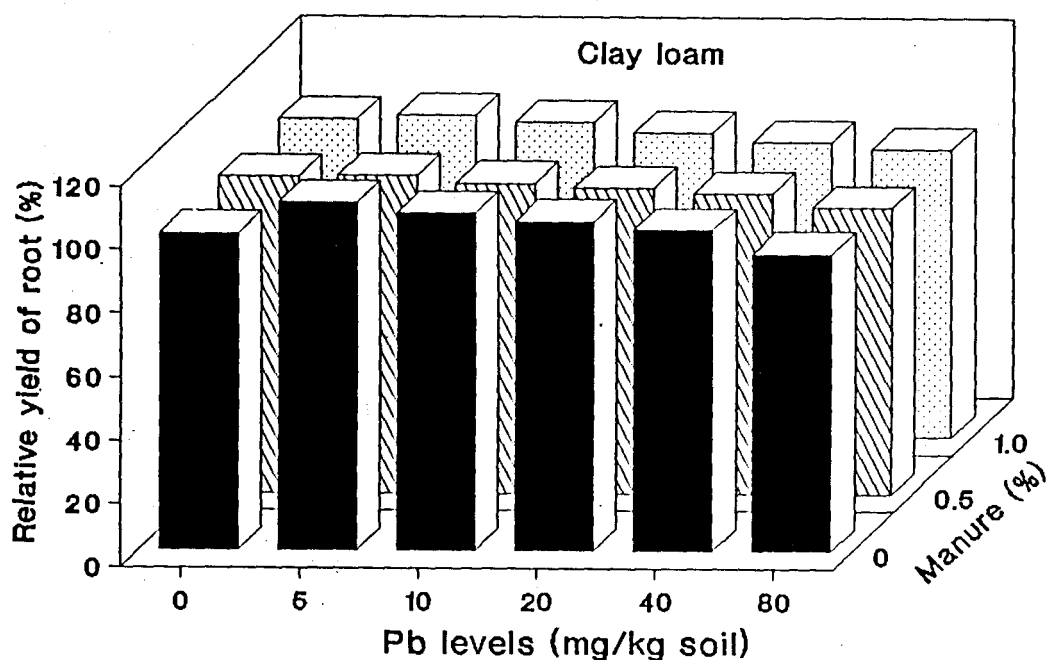
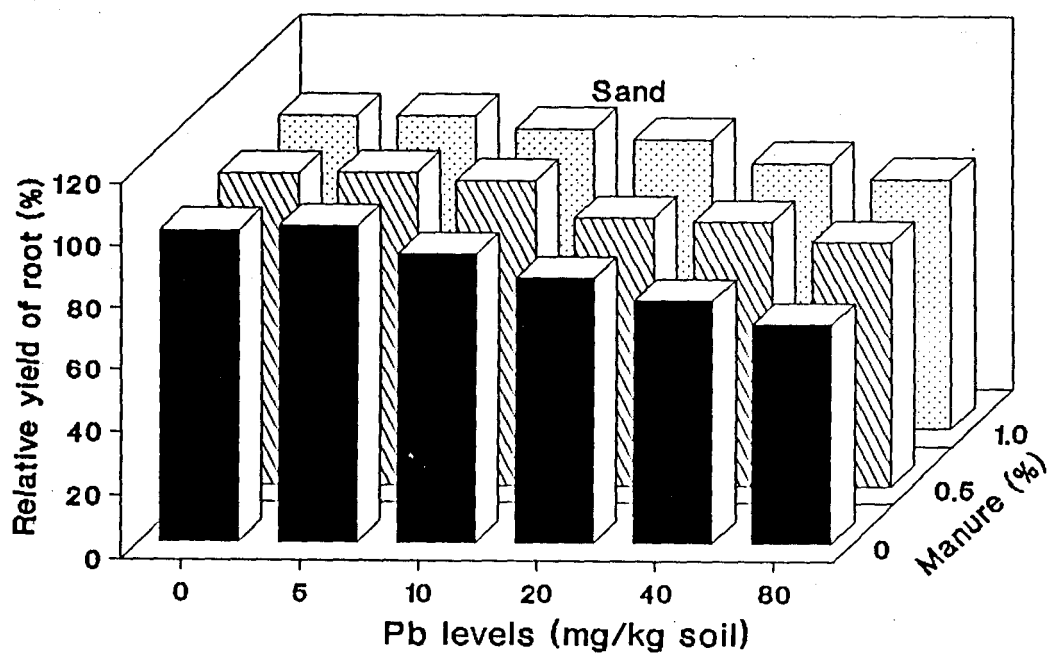


FIG.13. INFLUENCE OF Pb, CATTLE MANURE AND SOIL TEXTURE ON RELATIVE YIELD OF WHEAT ROOT.

adverse effect of Pb on some essential metabolic reactions in plants. Hampp *et al.* (1973) reported adverse effect of Pb on enzymes of the reductive pentose phosphate pathway, while others (Bazzaz *et al.*, 1974a, 1974b; Bittell *et al.*, 1974; Carlson *et al.*, 1975 and Huang *et al.*, 1974) postulated the Pb toxicity in enzymes involved in transpiration, nodulation, gas exchange, photosynthesis and respiration reactions. Khan and Khan (1983) also observed beneficial effect of Pb at lower level and toxicity at higher level in tomato and egg plants. Adverse effect of Pb was also observed by Kansal *et al.* (1992) in maize, MonemBalba *et al.* (1991) in tomato, Khan and Frankland (1983) in radish and Burton *et al.* (1984) in stika-spruce.

Higher yield in clay loam soil is ascribed to higher organic matter content and clay content which complexed and fixed Pb and reduced availability of Pb. Such soils were recommended to act as an improved sink for the disposal of Pb contaminated wastes. Kiekens and Camerlynck (1983) had also reported that transfer of heavy metals and their accumulation in plants depended on the the chemical form of the metals in the growth medium, soil factors like pH, CEC and organic matter content and the plant genotype.

The results showed that application of manure reduced Pb toxicity and improved the yield in both the soils significantly. Sharma (1981), Arora and Takkar (1981), Sakal *et al.* (1985) also reported that application of manure increases the wheat grain and dry matter yield significantly. Gupta *et al.* (1992) noticed increased yield of wheat with application of poultry manure and FYM. Similar observation were recorded by Sood and Minhas (1994) in maize and potatoes crops.

Application of manure reduced Pb toxicity in both the soils. The response to added manure was higher in sandy as compared to clay loam soil due to low carbon content of the former soil. The better yield of wheat plant parts in manure treated Pb amended soil may be attributed to the possible decrease in Pb availability to plants due to its complexation of chelation with organic matter and by improving the physico-chemical properties and biological process in soil. Ram and Verloo (1985) also observed that addition of different organic materials like farm yard manure, peat, humic acid and tetra-ethylene pentamine (Tetren) to a polluted Belgian soil enhanced the dry matter yield of corn, resulting in reduced availability of heavy metals due to formation of insoluble metallo-organic complexes. Similarly, Gupta *et al.* (1989) reported that straw and grain yield of wheat grown in highly contaminated soil improved with the increasing levels of FYM in the soils.

4.2.2 Effect of Pb, manure and soil texture on concentration and uptake of Pb in wheat

4.2.2.1 Pb concentration and uptake by grain

(a) Pb concentration

The perusal of data (Table 40) indicated that overall mean grain Pb increased significantly with Pb application. The mean effect indicated that Pb concentration in grain in both the soils improved as a result of Pb application. Application of 80 mg Pb kg⁻¹ soil enhanced mean concentration of Pb in grain from 1.03 to 6.76 µg g⁻¹ in sandy soil and from 0.79 to 5.70 µg g⁻¹ in clay loam soil, respectively over no Pb treatment. The data

Table 40. Effect of Pb, cattle manure and soil texture on Pb concentration of wheat grain

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb concentration (µg g ⁻¹)								
Sand	0	1.15	2.01	2.92	4.77	6.20	7.30	4.06
	0.5	1.00	1.75	2.48	4.00	6.03	6.73	3.66
	1.0	0.93	1.57	2.08	3.70	5.43	6.25	3.32
	Mean	1.03	1.77	2.49	4.15	5.88	6.76	3.68
Clay loam	0	0.89	1.84	2.23	3.92	4.75	6.13	3.29
	0.5	0.78	1.54	2.00	3.63	4.25	5.73	2.99
	1.0	0.72	1.23	1.83	3.17	3.97	5.25	2.69
	Mean	0.79	1.53	2.02	3.57	4.32	5.70	2.99
Overall Mean		0.91	1.65	2.25	3.86	5.10	6.23	3.33

C.D. (P = 0.05)

Pb = 0.05

Manure = 0.04

Soil = 0.03

Pb x Manure = 0.10

Pb x Soil = 0.08

Manure x Soil = 0.05

Pb x Manure x Soil = 0.14

indicated that Pb in grain was significantly higher in sandy soil than in clay loam soil.

Application of manure significantly decreased Pb concentration by 9.8 and 18.2 per cent in sandy soil and by 9.1 and 18.2 per cent in clay loam soil, due to application of 0.5 and 1.0% manure, respectively. The reduction in Pb concentration of grain due to manure was affected by soil texture. The various interactions between Pb, manure and soil were also significant.

Application of 5, 20, 40 and 80 mg Pb kg⁻¹ soil in combination with 1.0% manure, escalated grain Pb by 0.64, 1.15, 4.50 and 5.32 µg g⁻¹ in sandy soil and 0.51, 2.45, 3.25 and 4.53 µg g⁻¹ grain in clay loam soil over control. The interaction effect due to Pb x manure x soil on grain Pb was significant.

(b) Pb uptake

The overall Pb uptake by wheat grain increased significantly from 17.26 µg pot⁻¹ in control to 98.91 µg pot⁻¹ at 80 mg Pb kg⁻¹ soil, irrespective of soil texture (Table 41, Fig. 14). The effect of Pb and manure interaction was found to be significant on uptake of Pb by grain. The uptake of Pb increased from 17.20 to 88.96 µg pot⁻¹ and 17.32 to 108.87 µg g⁻¹ grain in sandy and clay loam, respectively with increase in its application from 0 to 80 mg kg⁻¹ soil.

Application of manure enhanced Pb uptake upto 0.5% level and repressed it at 1.0% level in sandy soil. In clay loam soil, manure application consistently alleviated Pb uptake and the effect was significant. The various interaction between Pb, manure and soil were also significant.

Table 41. Influence of Pb, cattle manure and soil texture on uptake of Pb by wheat grain

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb uptake (µg pot ⁻¹)								
Sand	0	17.42	31.14	39.87	64.19	80.60	83.20	52.73
	0.5	17.35	30.58	41.56	63.24	88.68	91.58	55.50
	1.0	16.85	27.83	34.99	60.42	84.83	92.12	52.84
	Mean	17.20	29.85	38.80	62.61	84.70	88.96	53.69
Clay loam	0	18.53	41.29	46.51	76.12	89.50	109.94	63.64
	0.5	16.63	34.85	43.80	72.04	83.99	110.65	60.32
	1.0	16.80	29.90	42.31	70.61	80.88	106.02	57.75
	Mean	17.32	35.35	44.20	72.92	84.79	108.87	67.57
Overall Mean		17.26	32.60	41.50	67.76	84.74	98.91	57.13

C.D. (P = 0.05)

Pb	= 1.77	Pb x Manure	= 3.07
Manure	= 1.25	Pb x Soil	= 2.50
Soil	= 1.02	Manure x Soil	= 1.77
		Pb x Manure x Soil	= 4.34

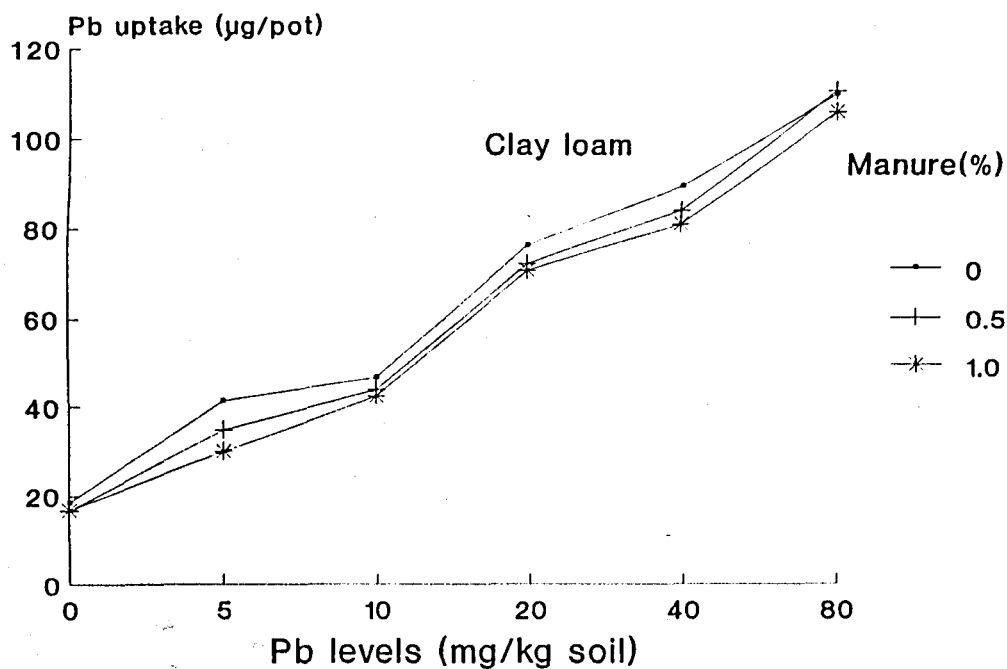
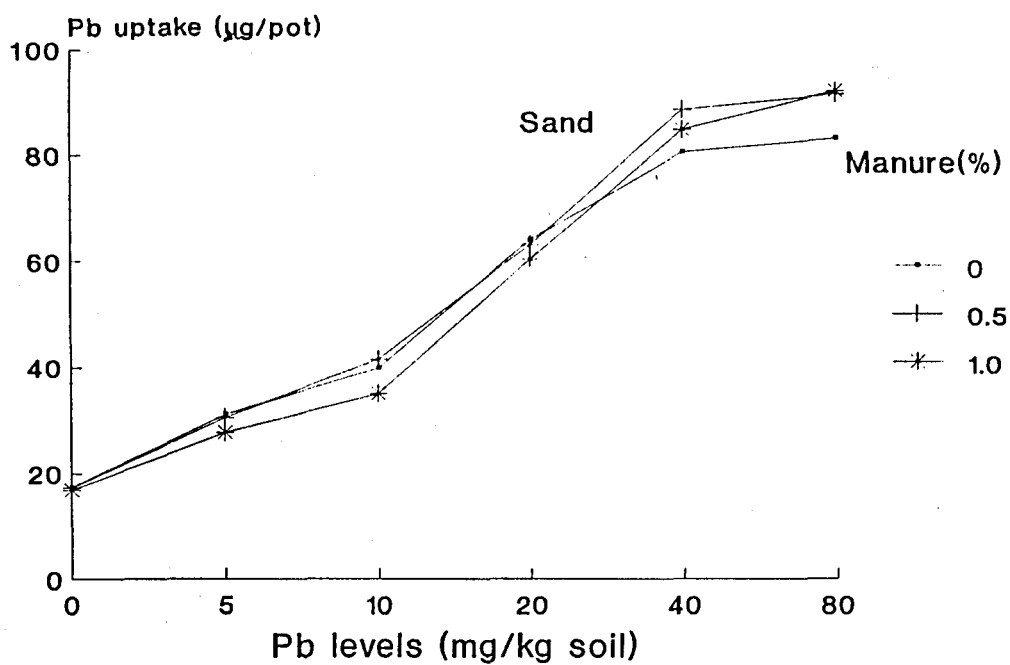


FIG.14. UPTAKE OF Pb BY WHEAT GRAIN AS INFLUENCED BY Pb, CATTLE MANURE AND SOIL TEXTURE

4.2.2.2 Pb concentration and uptake by wheat straw

(a) Pb concentration

Data (Table 42) revealed that like grain, straw Pb also increased significantly with graded levels of Pb, irrespective of soil texture. The overall straw Pb increased from 2.11 to 11.17 $\mu\text{g g}^{-1}$ straw when Pb was raised from 0 to 80 mg kg^{-1} soil. Wheat straw raised in sandy soil contained higher Pb than clay loam soil. Straw Pb due to its mean effect increased from 2.20 $\mu\text{g g}^{-1}$ in control to 3.30, 7.76, 9.19 and 12.42 $\mu\text{g g}^{-1}$ straw in sandy soil and from 2.03 $\mu\text{g g}^{-1}$ to 2.82, 5.72, 7.29 and 9.92 $\mu\text{g g}^{-1}$ in clay loam soil at 5, 20, 40 and 80 mg Pb kg^{-1} soil, respectively.

Application of 0.5 and 1.0 per cent manure significantly reduced straw Pb by 6.9 and 14.2 per cent in sandy soil, 3.5 and 7.1 per cent in clay loam, respectively over control. The Pb and manure mutually interacted significantly and magnitude of interaction varied significantly with soil texture.

Application of 1.0% manure in association with 80 mg Pb kg^{-1} soil in sandy soil alleviated Pb concentration to 11.69 $\mu\text{g g}^{-1}$ compared with 13.2 $\mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil alone, while in clay loam soil it decreased marginally from 10.05 to 9.75 $\mu\text{g g}^{-1}$ straw. Wheat straw tended to accumulate more Pb than grain, irrespective of Pb, manure application and soil texture.

(b) Pb uptake

A perusal of data (Table, 43 Fig. 15) showed that Pb uptake by straw increased significantly with graded levels of Pb in both the soils tested, but differed markedly with soil texture. Uptake of Pb by straw, in clay loam soil,

Table 42. Effect of Pb, cattle manure and soil texture on Pb concentration of wheat straw

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb concentration (µg g ⁻¹)								
Sand	0	2.52	3.60	5.00	8.10	10.02	13.20	7.07
	0.5	2.17	3.25	4.58	7.83	9.27	12.38	6.58
	1.0	1.93	3.07	4.02	7.35	8.30	11.68	6.06
	Mean	2.20	3.30	4.53	7.76	9.19	12.42	6.57
Clay loam	0	2.22	3.00	3.85	6.05	7.50	10.05	5.44
	0.5	1.98	2.80	3.65	5.82	7.27	9.98	5.25
	1.0	1.90	2.67	3.58	5.30	7.10	9.75	5.05
	Mean	2.03	2.82	3.69	5.72	7.29	9.92	5.24
Overall Mean		2.11	3.06	4.11	6.74	8.24	11.17	5.90

C.D. (P = 0.05)

Pb = 0.10

Manure = 0.07

Soil = 0.06

Pb x Manure = 0.18

Pb x Soil = 0.15

Manure x Soil = 0.10

Pb x Manure x Soil = 0.26

Table 43. Influence of Pb, cattle manure and soil texture on uptake of Pb by wheat straw

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb uptake (µg pot ⁻¹)								
Sand	0	55.46	87.51	123.92	184.14	224.39	270.18	157.60
	0.5	54.38	81.94	114.27	193.23	221.26	284.84	158.35
	1.0	51.77	82.11	104.94	192.94	213.87	296.07	156.95
	Mean	53.87	83.35	114.38	190.10	219.90	283.69	157.63
Clay loam	0	58.52	81.80	103.20	159.72	195.74	258.96	142.99
	0.5	54.87	79.79	102.91	159.41	196.46	265.26	143.12
	1.0	54.27	78.03	103.44	145.57	190.76	260.99	138.84
	Mean	55.88	79.87	103.18	154.90	194.32	261.73	141.65
Overall Mean		54.87	81.86	108.78	172.50	207.11	272.71	149.64

C.D. (P=0.05)

Pb = 4.51

Pb x Manure = 7.82

Manure = NS

Pb x Soil = 6.39

Soil = 2.60

Manure x Soil = NS

Pb x Manure x Soil = 11.06

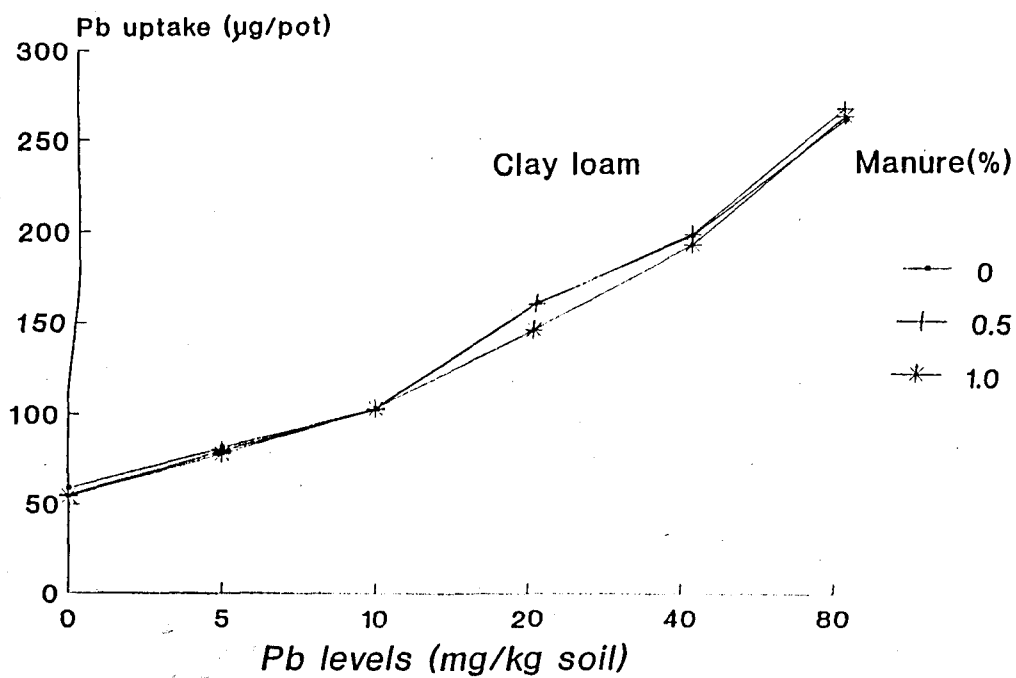
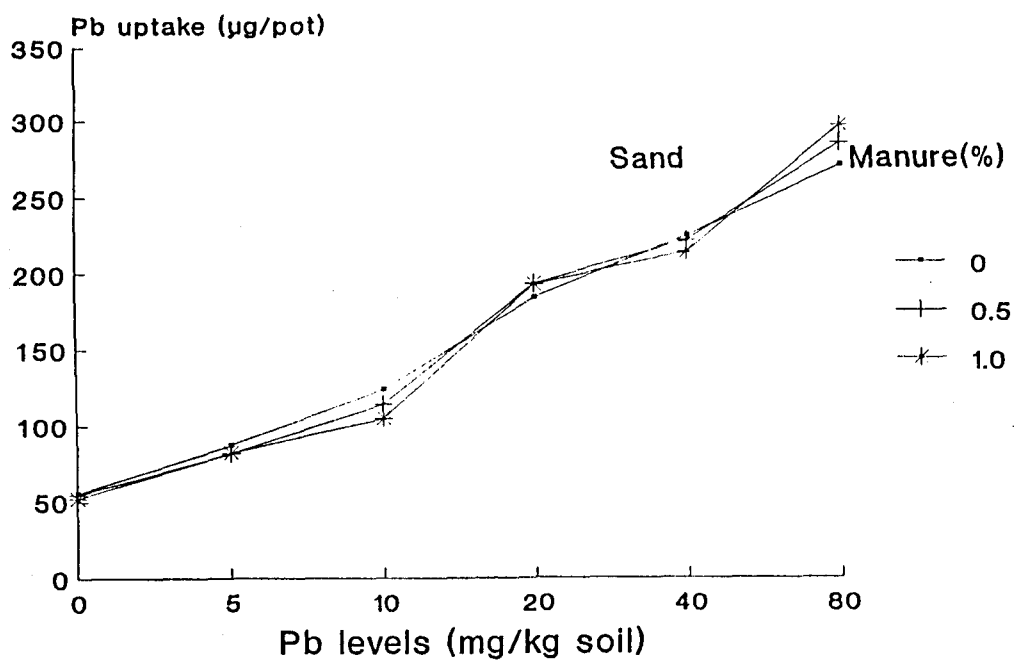


FIG.15. UPTAKE OF Pb BY WHEAT STRAW AS INFLUENCED BY Pb, CATTLE MANURE AND SOIL TEXTURE

increased significantly from 55.88 $\mu\text{g pot}^{-1}$ in control to 261.73 $\mu\text{g pot}^{-1}$ in 80 mg Pb kg^{-1} soil treatment, while in sandy soil, Pb uptake increased significantly from 53.87 to 283.69 $\mu\text{g pot}^{-1}$, respectively. The Pb uptake by straw was significantly higher (157.63 $\mu\text{g pot}^{-1}$) in sandy than clay loam soil (141.65 $\mu\text{g pot}^{-1}$).

The effect of manure on Pb uptake was negative and non significant. In both the soils Pb uptake increased as a result of 0.5% applied manure but 1.0 per cent manure depressed it.

The manure x soil was non significant, Pb x manure, Pb x soil and Pb x manure x soil interactions were significant. Cattle manure when applied alone decreased Pb uptake by straw non significantly but when combined with 80 mg Pb kg^{-1} soil, it increased Pb uptake over control in both the soils.

4.2.2.3 Pb concentration and uptake by wheat root

(a) Pb concentration

The overall Pb concentration in root increased significantly from 4.96 $\mu\text{g g}^{-1}$ in control to 21.76 $\mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil, irrespective of soil texture (Table 44). In sandy soil, root Pb increased from 5.09 to 23.51 $\mu\text{g g}^{-1}$ compared with 4.84 to 20.02 $\mu\text{g g}^{-1}$ in clay loam soil at 0 to 80 mg Pb kg^{-1} soil. The root Pb was found to be higher in sandy soil than clay loam soil.

Like grain and straw, application of manure significantly depressed root Pb, which varied significantly with soil texture. The decrease in Pb concentration of wheat root grown in sandy soil was 1.9 and 5.3 per cent compared with 3.9 and 6.6 per cent in clay loam soil with application of 0.5 and 1.0% manure over control.

Table 44. Effect of Pb, cattle manure and soil texture on Pb concentration of wheat root

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb concentration (µg g ⁻¹)								
Sand	0	5.32	7.20	9.82	11.78	15.02	23.95	12.18
	0.5	5.10	7.00	9.58	11.57	14.87	23.52	11.94
	1.0	4.87	6.73	9.00	11.32	14.23	23.07	11.53
	Mean	5.09	6.98	9.46	11.55	14.71	23.51	11.88
Clay loam	0	5.05	6.85	8.00	10.37	14.73	20.47	10.91
	0.5	4.85	6.23	7.77	10.02	14.05	20.00	10.48
	1.0	4.62	6.02	7.30	9.82	13.80	19.60	10.19
	Mean	4.84	6.36	7.69	10.07	14.19	20.02	10.53
Overall Mean		4.96	6.67	8.57	10.81	14.45	21.76	11.20

C.D. (P = 0.05)

Pb = 0.11
 Manure = 0.07
 Soil = 0.06

Pb x Manure = 0.19
 Pb x Soil = 0.15
 Manure x Soil = NS
 Pb x Manure x Soil = NS

The interaction between manure x soil and Pb x manure x soil were found non significant. Application of Pb alone increased root Pb significantly, while manure alone showed significant depression in both the soils. The results indicate that application of cattle manure has a antagonistic effect on Pb concentration in wheat root.

(b) Pb uptake

The data (Table 45, Fig. 16) indicated that like grain and straw, increasing rates of Pb application enhanced Pb uptake by root significantly. The overall Pb uptake by roots ranged from 18.15 to 68.87 $\mu\text{g pot}^{-1}$ irrespective of the soil texture. However, the effect of soil texture on Pb uptake by root was non significant. The uptake of Pb by root was slightly higher in clay loam soil than sandy soil.

Application of manure significantly increased Pb uptake by root in sandy soil, while the effect was non significant in clay loam soil. The Pb x manure and Pb x manure x soil interactions were non significant. Application of 0.5 and 1.0% manure in sandy soil in combination with 80 mg Pb kg^{-1} soil improved Pb uptake by 4.3 and 7.0 per cent over 80 mg Pb kg^{-1} soil alone while in clay loam soil at corresponding levels it was improved by 4.6 and 7.0 per cent, respectively.

The results showed an increase in Pb concentration and uptake by wheat grain, straw and root due to Pb application, which is ascribed to increased availability of Pb in growth medium. Lower yield of the plant with increased application of Pb, as described earlier, might be the other possibility for increased Pb concentration. Burton *et al.* (1984) and IL'IN and Stepanova (1980) had reported that addition of Pb decreased the plant

Table 45. Influence of Pb, cattle manure and soil texture on uptake of Pb by wheat root

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Pb uptake (µg pot ⁻¹)								
Sand	0	17.54	24.12	29.95	32.98	38.67	66.32	34.93
	0.5	18.46	26.41	35.14	37.39	47.22	69.23	38.97
	1.0	18.57	25.72	33.01	40.13	46.45	70.98	39.14
	Mean	18.19	25.41	32.70	36.83	44.11	68.84	37.68
Clay loam	0	17.42	26.03	29.47	37.22	51.58	66.31	38.00
	0.5	18.59	23.98	29.20	37.03	51.15	69.40	38.22
	1.0	18.31	24.26	28.81	37.42	51.02	71.01	38.47
	Mean	18.11	24.75	29.16	37.23	51.25	68.90	38.23
Overall Mean		18.15	25.08	30.93	37.03	47.68	68.87	37.95

C.D. (P = 0.05)

Pb = 2.32

Manure = 1.64

Soil = NS

Pb x Manure = NS

Pb x Soil = 3.29

Manure x Soil = 2.32

Pb x Manure x Soil = NS

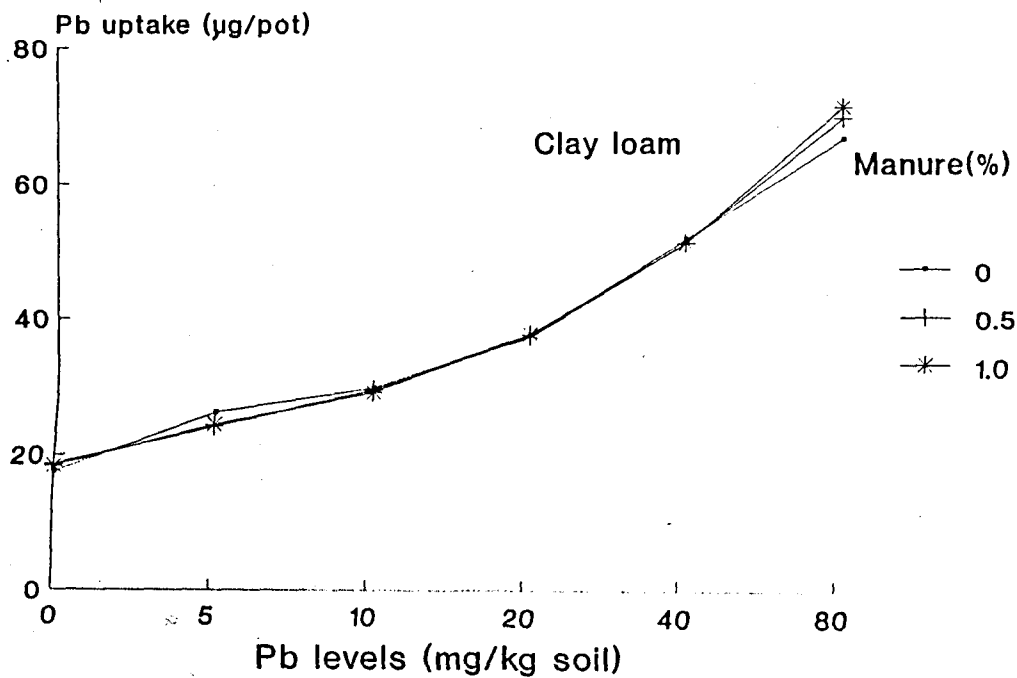
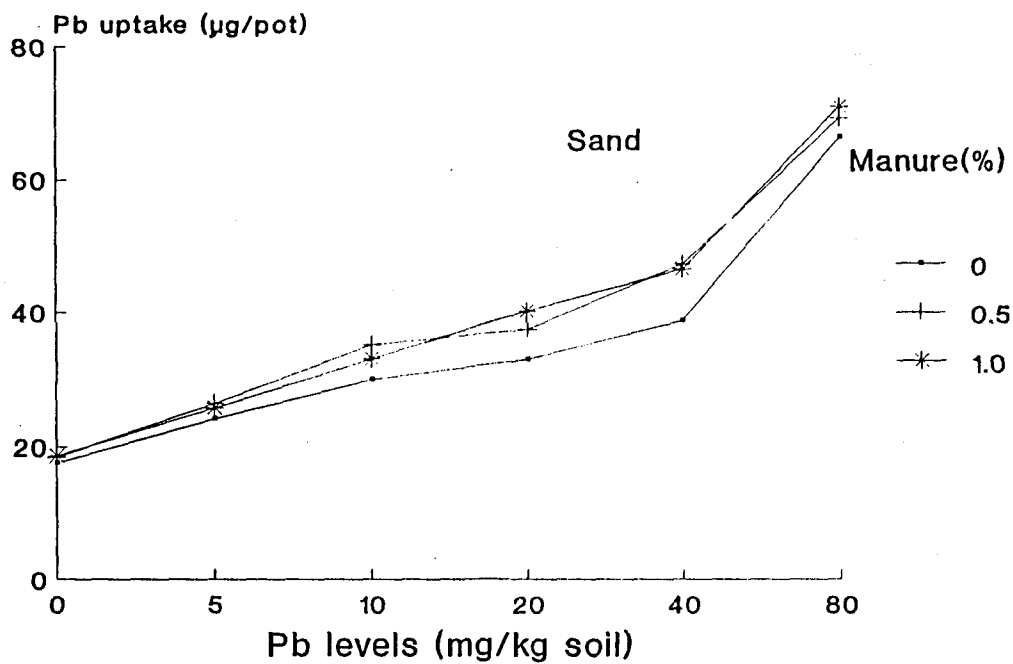


FIG.16. UPTAKE OF Pb BY WHEAT ROOT AS INFLUENCED BY Pb, CATTLE MANURE AND SOIL TEXTURE

growth, which resulted in their higher accumulation in the plants. The finding are also in agreement with Jarvis *et al.*, 1977; Largerwerff *et al.*, 1973 and MacLean *et al.*, 1969 who made similar observation in different crops. Kansal *et al.* (1992) reported that mean concentration of Pb in maize plant increased significantly with increase in Pb levels.

Significantly higher Pb concentration of wheat tissue grown on sandy soil could be attributed to greater Pb availability in this soil. Since the light texture soil have lower retention capacity, therefore, addition of Pb through various treatments readily increased its available status in the closed system of pot studies. The results are in agreement with the finding of Bjerre and Schierup (1985), who found that the transfer of Pb from soil to oat plants was greatest from sandy soil than sandy loam and organic soil. The higher content of Pb in root than grain and straw is due to restricted translocation of Pb in aerial parts and retention in the root. Similar results were shown by IL'IN and Stepanova (1980) and Lubben and Sauerbeck (1991).

The result indicated that application of manure significantly depressed Pb concentration in grain, straw and root grown in both soils. A possibility was suggested by Largerwerff (1972), he observed that soil organic matter strongly adsorbed the heavy metals and formation of insoluble organo-metal complexes. The organic matter, clay and hydrous oxide can adsorb metal (Ellis and Knezek, 1972; Page, 1974); soils with higher metal sorption capacity have lower potential for plant uptake of metal. Metals are held by organic constituents, in soluble and in insoluble forms through electrovalent and covalent co-ordinate linkage (Stevenson, 1982).

MacLean *et al.* (1969) studied the beneficial effects of organic matter in reducing Pb in plants were usually in accord with corresponding reduction in extractable Pb in the soils. The beneficial effect of organic matter in reducing extractable Pb in the soil and its uptake by plants provide a basis for adopting management practice to lessen the potential hazard of Pb contaminated soil. Schnitzer and Hoffman (1967) found that the molar quantity of Pb complexed per unit of fulvic acid was relatively high compared with that of several other metals. Petruzzelli *et al.* (1981) also reported humic materials has strong linkage with heavy metals.

4.2.2.4 Relationship between Pb uptake by wheat plant parts with its fractions.

The relationship of Pb fractions with uptake Pb by wheat grain, straw and root were worked out and found significant. The soil samples taken before seeding (17 days incubation) in experiment (section 3.3.2) in which cattle manure was applied with Pb, were analysed for different sequential fractions of Pb (Table 46).

It is evident from data that all corresponding values of correlation coefficients are better correlated in clay loam soil than in sandy soil. In wheat grain, the correlation coefficient of Pb uptake with different fractions was in the sequence of crystalline Fe-oxide bound ($r = 0.90^{**}$) > carbonate bound = amorphous Fe-oxide bound ($r = 0.88^{**}$) > exchangeable + water soluble = Mn-oxide bound ($r = 0.87^{**}$) and lowest with residual ($r = 0.78^{**}$) in sandy soil, while in clay loam soil, residual ($r = 0.96^{**}$) > crystalline Fe-oxide ($r = 0.95^{**}$) > organically bound ($r = 0.94^{**}$) lowest with amorphous Fe-oxide bound ($r = 0.90^{**}$). The correlation coefficient in

Table 46. Correlation coefficients for amount of Pb in various fractions and Pb-uptake by wheat plant parts

	EX + W	CARB	OM	MnOX	AFeOX	CFeOX	RES
				SAND			
Pb-uptake by wheat grain	0.87	0.88	0.86	0.87	0.88	0.90	0.78
Pb-uptake by wheat straw	0.92	0.93	0.90	0.92	0.93	0.92	0.84
Pb-uptake by wheat root	0.96	0.97	0.97	0.96	0.98	0.89	0.85
				CLAY LOAM			
Pb-uptake by wheat grain	0.92	0.91	0.94	0.91	0.90	0.95	0.96
Pb-uptake by wheat straw	0.96	0.96	0.97	0.95	0.95	0.95	0.97
Pb-uptake by wheat root	0.98	0.97	0.99	0.97	0.97	0.95	0.97

All values are significant at 1% level of significance.

Table 47. Correlation coefficients among various fractions (In soil samples taken before seeding)

	EX + W	CARB	OM	MnOX	AFeOX	CFeOX	RES
SAND							
EX + W	-	0.99	0.96	0.99	0.99	0.94	0.93
CARB			0.98	0.99	0.99	0.92	0.91
OM				0.96	0.98	0.86	0.83
MnOX					0.99	0.94	0.94
AFeOX						0.92	0.90
CFeOX							0.93
CLAY LOAM							
EX + W	-	0.99	0.97	0.99	0.99	0.93	0.92
CARB			0.98	0.99	0.99	0.90	0.92
OM				0.97	0.97	0.94	0.96
MnOX					0.99	0.90	0.91
AFeOX						0.88	0.91
CFeOX							0.94

All values are significant at 1% level of significance.

case of wheat straw and root were as $CARB = AFeOX > EX+W = MnOX = CFeOX$; and $AFeOX > CARB = OM > EX + W = MnOX$ bound in sandy soil, respectively, while corresponding to it in clay loam soil was $OM > EX + W = CARB = RES > MnOX = AFeOX = CFeOX$ bound and $OM > EX + W > CARB = MnOX = AFeOX$. Further the values of correlation coefficient with in the Pb fractions showed significant correlation, which indicated that the various pools of Pb in the soil are probably in dynamic equilibrium with each other (Table 47).

4.2.3 Effect of Pb, cattle manure and soil texture on polyvalent transition heavy metal (Zn, Mn, Fe and Cu) concentration in wheat plant parts

4.2.3.1 Zinc concentration

(a) Grain

It is apparent from data (Table 48) that overall Zn concentration in grain decreased from $31.22 \mu\text{g g}^{-1}$ in control to $23.13 \mu\text{g g}^{-1}$ grain at 80 mg Pb kg^{-1} soil, irrespective of soil texture. The magnitude of reduction in Zn concentration due to Pb varied significantly with soil type. In sandy soil, grain Zn decreased significantly above 5 mg Pb kg^{-1} soil over no Pb treatment and the reduction was 1.44, 4.39, 5.73 and $7.16 \mu\text{g g}^{-1}$ grain due to mean effect of 10, 20, 40 and 80 mg Pb kg^{-1} soil treatment, respectively. In clay loam soil, Zn concentration in grain decreased significantly by 1.91, 4.51, 6.93 and $9.02 \mu\text{g g}^{-1}$ grain at 5, 20, 40 and 80 mg Pb kg^{-1} soil, respectively over control. Higher Zn concentration in grain was recorded in sandy soil than clay loam soil.

Table 48. Effect of Pb and cattle manure on Zn concentration of wheat grain grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Zn concentration (µg g ⁻¹)								
Sand	0	29.29	28.68	27.91	24.61	23.29	21.87	25.94
	0.5	33.09	32.58	32.00	28.72	27.37	25.92	29.94
	1.0	35.95	35.48	34.08	31.82	30.47	29.04	32.80
	Mean	32.77	32.24	31.33	28.38	27.04	25.61	29.56
Clay loam	0	25.01	24.26	22.44	20.74	19.19	17.09	21.45
	0.5	30.10	28.20	27.54	25.84	22.99	20.76	25.90
	1.0	33.92	30.82	29.66	28.92	26.05	24.11	28.91
	Mean	29.67	27.76	26.54	25.16	22.74	20.65	25.42
Overall Mean		31.22	30.00	28.93	26.77	24.89	23.13	27.49

C.D. (P = 0.05)

Pb	= 0.66	Pb x Manure	= NS
Manure	= 0.46	Pb x Soil	= 0.93
Soil	= 0.38	Manure x Soil	= NS
		Pb x Manure x Soil	= NS

Application of manure with or without Pb augmented Zn concentration in grain. Grain Zn increased by 15.4 and 26.4 per cent in sandy soil and by 20.7 and 34.7 per cent, in clay loam soil due to mean effect of 0.5 and 1.0% manure respectively, over no manure treatment. The manure and soil interaction was non significant. The Pb x manure and Pb x manure x soil interactions also were non significant. Application of 1.0% manure with 40 and 80 mg Pb kg⁻¹ soil increased the Zn concentration in grain by 30.8 and 32.7 per cent in sandy soil and 35.7 and 41.0 per cent in clay loam soil, over 40 and 80 mg Pb kg⁻¹ soil, respectively.

(b) Straw

Overall mean values indicated that the straw Zn concentration decreased from 20.50 µg g⁻¹ in control to 14.78 µg g⁻¹ straw at 80 mg Pb kg⁻¹ soil, irrespective of soil texture (Table 49). The effect of Pb on Zn concentration varied with soil texture. In sandy soil, reduction in Zn concentration was 20.9 and 29.5 per cent in straw, against 16.6 and 26.1 per cent in clay loam soil due to the mean effect of 40 and 80 mg Pb kg⁻¹ soil, respectively over no Pb treatment.

Like grain, Zn concentration of straw also increased due to addition of cattle manure or in combination with Pb. The mean Zn concentration increased from 14.66 to 22.17 µg g⁻¹ in sandy soil, while from 13.90 to 21.11 µg g⁻¹ in clay loam soil, due to increase in manure levels from 0 to 1.0%, respectively. The effect of manure of Zn concentration was almost at par in both the soils tested.

The Pb x manure and Pb x manure x soil interactions were found non significant. Application of 1.0% manure with 80 mg kg⁻¹ soil increased the Zn

Table 49. Effect of Pb and cattle manure on Zn concentration of wheat straw grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Zn concentration (µg g ⁻¹)								
Sand	0	17.37	16.81	15.33	14.44	12.74	11.31	14.66
	0.5	21.37	20.92	19.43	18.84	16.84	15.42	18.80
	1.0	25.10	23.80	23.48	21.48	20.92	18.25	22.17
	Mean	21.28	20.51	19.41	18.25	16.83	14.99	18.54
Clay loam	0	16.03	15.38	15.00	13.52	12.62	10.85	13.90
	0.5	20.12	19.15	18.98	18.42	16.82	14.88	18.06
	1.0	23.00	22.43	22.00	21.42	19.88	17.98	21.11
	Mean	19.72	18.98	18.66	17.78	16.44	14.57	17.69
Overall Mean		20.50	19.74	19.03	18.01	16.63	14.78	18.11

C.D. (P = 0.05)

Pb = 0.35

Pb x Manure = NS

Manure = 0.25

Pb x Soil = 0.50

Soil = 0.20

Manure x Soil = NS

Pb x Manure x Soil = NS

concentration by 61.3 and 65.7 per cent of straw in sandy and clay loam soil, respectively over the 80 Pb kg⁻¹ soil.

(c) Roots

Root Zn increased by 13.1 per cent over control at the highest (80 mg kg⁻¹ soil) level of Pb, irrespective of the soils (Table 50). Soil texture had a significant effect on the Zn concentration of root which was significantly higher in sandy soil (60.33 µg g⁻¹) than clay loam soil (52.99 µg g⁻¹). The mean Zn concentration of root increased by 14.7 per cent in sandy soil and 11.2 per cent in clay loam soil at 80 mg Pb kg⁻¹ soil over control, respectively.

Like straw and grain, Zn concentration of root also increased significantly to addition of manure alone or in conjunction with Pb, irrespective of the soil. The manure and soil interaction was found non significant. Zinc concentration in grain increased by 15.2 and 25.5 per cent in sandy soil, 16.2 and 28.2 per cent in clay loam due to addition of 0.5 and 1.0% manure respectively, in the presence of Pb over no manure treatment. Application of 80 mg Pb kg⁻¹ soil and 1.0% manure alone increased the Zn concentration by 25.5 and 30.8 per cent over 80 mg Pb kg⁻¹ soil in sandy and clay loam soil, respectively. The Pb x manure x soil interaction affected root Zn non significantly.

The depressing effect of Pb application on Zn concentration in wheat plant parts is attributed to the antagonistic effect of Pb on Zn absorption, possibly the two ions compete for same absorption sites at root surface resulting in lower uptake of Zn metals. Khan and Khan (1983) also observed that the applied Pb repressed Zn concentration in egg and

Table 50. Effect of Pb and cattle manure on Zn concentration of wheat root grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Zn concentration (µg g ⁻¹)								
Sand	0	50.22	50.80	51.75	52.93	55.01	58.00	53.11
	0.5	58.08	59.78	60.36	61.44	62.27	65.77	61.23
	1.0	63.00	64.43	65.95	66.75	67.00	72.82	66.65
	Mean	57.10	58.34	59.35	60.27	61.42	65.53	60.33
Clay loam	0	44.33	44.73	45.23	45.92	47.64	49.10	46.15
	0.5	51.83	52.01	52.85	53.12	55.00	57.10	53.65
	1.0	57.05	57.35	58.00	58.37	60.00	64.25	59.17
	Mean	51.07	51.36	52.03	52.47	54.21	56.81	52.99
Overall Mean		54.08	54.85	55.69	56.37	57.81	61.17	56.66

C.D. (P = 0.05)

Pb = 0.55

Manure = 0.39

Soil = 0.31

Pb x Manure = 0.95

Pb x Soil = 0.78

Manure x Soil = NS

Pb x Manure x Soil = NS

tomato plants. The results indicated that Zn concentration in wheat tissue was significantly higher in sandy than clay loam soil. Bjerre and Schierup (1985) observed that transfer of Zn from soil to oat plant was greater from sandy soil than sandy loam and organic soil they found that Zn was more mobile in the plant, therefore wheat grain has higher Zn than the straw.

The elevated Zn concentration in wheat tissue due to manure application could be ascribed to the competitive effect in the complexation of metals with the organic ligands and the selectivity rule of Frausto-da-Silva and Williams (1976) is followed. Zinc in egg plant and tomato plant seem to complex with the same organic ligands (White *et al.*, 1982) to which heavy metals competed and resulted their decrease in the plant. Similarly, Sood *et al.* (1977) in wheat, Maskina and Randhawa (1983) and Gupta *et al.* (1992) in wheat also recorded an increase in Zn content and uptake with the application of organic manures.

4.2.3.2 Mn concentration

(a) Grain

A perusal of data (Table 51) showed that overall mean Mn concentration in grain decreased from $29.05 \mu\text{g g}^{-1}$ in control of $23.08 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil. However, the magnitude of decrease in Mn concentration due to Pb application varied with soil texture. The mean Mn concentration in wheat grain grown on sandy soil decreased due to Pb addition and was significant only above 5 mg Pb kg^{-1} soil over control and the differences among increasing Pb levels above 20 mg kg^{-1} soil were significant. Increasing rates of Pb from 0 to 80 mg Pb kg^{-1} soil depressed Mn content from 28.01 to $22.05 \mu\text{g g}^{-1}$, respectively in clay loam soil.

Table 51. Effect of Pb, cattle manure and soil texture on Mn concentration of wheat grain

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Mn concentration (µg g ⁻¹)								
Sand	0	26.11	26.10	25.23	24.53	22.05	21.15	24.19
	0.5	30.19	29.79	29.33	28.33	27.24	24.02	28.15
	1.0	34.00	33.27	32.75	30.31	28.40	27.20	30.98
	Mean	30.10	29.72	29.10	27.72	25.89	24.12	27.77
Clay loam	0	23.28	23.27	23.05	21.70	20.79	20.03	22.02
	0.5	27.54	26.77	26.13	24.33	23.02	22.23	25.00
	1.0	33.21	30.52	29.20	27.28	24.34	23.90	28.07
	Mean	28.01	26.85	26.12	24.44	22.71	22.05	25.03
Overall Mean		29.05	28.28	27.61	26.08	24.30	23.08	26.40

C.D. (P = 0.05)

Pb = 0.90

Manure = 0.64

Soil = 0.52

Pb x Manure = 1.57

Pb x Soil = NS

Manure x Soil = NS

Pb x Manure x Soil = NS

The mean Mn concentration in grain was significantly higher ($27.77 \mu\text{g g}^{-1}$) in sandy soil as compared to clay loam ($25.03 \mu\text{g g}^{-1}$) soil.

Application of manure enhanced Mn concentration in grain significantly. The increase in mean Mn concentration due to 0.5 and 1.0% applied manure was 16.3 and 28.0 per cent in sandy soil and 13.5 and 27.4 per cent in clay loam soil over control, respectively. The differences among increasing manure levels were also significant. The effect of manure x soil, Pb x soil and Pb x manure x soil interactions were non significant. The combined application of 1.0% manure and 80 mg Pb kg^{-1} soil increased grain Mn concentration by 19.3 per cent in clay loam and 28.6 per cent in sandy soil over 80 mg Pb kg^{-1} soil alone, respectively.

(b) Straw

The overall Mn concentration in straw decreased significantly from $37.92 \mu\text{g g}^{-1}$ in control to $28.53 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil, irrespective of soil texture (Table 52). The Pb x Soil interaction was found to be significant. The mean Mn concentration in straw 40 and 80 mg Pb kg^{-1} soil decreased by 19.1 and 27.3 per cent in sandy soil, compared with 15.3 and 22.0 per cent in clay loam soil at 40 and 80 mg Pb kg^{-1} soil over control, respectively. The mean Mn concentration in straw was significantly higher in sandy than clay loam soil.

Application of cattle manure augmented in Mn concentration in straw and its effect was almost identical in both the soils. Straw Mn increased significantly by 10.3 and 28.5 per cent in sandy soil and 14.2 and 31.1 per cent in clay loam soil due to mean effect of 0.5 and 1.0% manure over no manure treatment.

Table 52. Effect of Pb, cattle manure and soil texture on Mn concentration of wheat straw

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Mn concentration (µg g ⁻¹)								
Sand	0	35.35	33.19	32.48	29.62	27.22	25.28	30.52
	0.5	38.25	36.48	35.47	32.30	31.69	28.00	33.69
	1.0	44.26	42.33	41.52	38.47	36.43	32.41	39.23
	Mean	39.28	37.33	36.49	33.46	31.78	28.56	34.48
Clay loam	0	32.33	31.05	30.95	28.14	26.43	24.61	28.92
	0.5	36.30	36.12	34.24	33.33	29.94	28.28	33.03
	1.0	41.04	40.57	38.90	37.90	36.47	32.62	37.92
	Mean	36.56	35.91	34.69	33.12	30.94	28.50	33.29
Overall Mean		37.92	36.62	35.59	33.29	31.36	28.53	33.88

C.D. (P = 0.05)

Pb	= 0.81	Pb x Manure	= NS
Manure	= 0.57	Pb x Soil	= 1.15
Soil	= 0.47	Manure x Soil	= NS
		Pb x Manure x Soil	= NS

The Pb x manure; manure x soil and Pb x manure x soil interaction had non significant effect on Mn concentration in straw. Application of 1.0% manure without Pb, increased the straw Mn content by 25.2 and 26.9 per cent in sandy and clay loam soil, respectively.

(c) Root

The data (Table 53) revealed that the overall Mn concentration of root increased from $89.31 \mu\text{g g}^{-1}$ at control to $96.78 \mu\text{g g}^{-1}$ at 80 mg Pb kg^{-1} soil significantly, irrespective of soil texture. Root Mn increased by 9.8 and 6.7 per cent in sandy soil and clay loam soil, respectively due to mean effect of 80 mg Pb kg^{-1} soil over control.

Application of manure decreased Mn concentration in root, significantly. The decrease in mean Mn concentration due to 0.5 and 1.0% application of manure was 10.0 and 17.7 per cent in sandy soil, 9.9 and 19.4 per cent in clay loam soil over control, respectively. The differences among increasing levels were also significant. The effect of manure x soil was significant. The Pb x manure and Pb x manure x soil interactions were significant. Application of 1.0% manure coupled with 80 mg Pb kg^{-1} soil reduced, root Mn by 18.3 and 21.5 per cent over 80 mg Pb kg^{-1} soil alone and by 9.2 and 14.3 per cent over 0 manure and 0 Pb level in sandy and clay loam soil, respectively.

The data vividly demonstrated that Mn concentration decreased in grain and straw while increased in root due to Pb application. Perhaps Pb application prevented the translocation of Mn from root to aerial parts. A gradual decrease in Mn concentration in egg plant at lower Pb availability than a substantial drop support the selectivity rule (Khan and Khan, 1983). Higher Mn concentration observed in plant tissue grown in sandy compared

Table 53. Influence of Pb, cattle manure and soil texture on Mn concentration of wheat root

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Mn concentration (µg g ⁻¹)								
Sand	0	104.00	104.87	106.57	107.84	110.00	115.60	108.14
	0.5	95.22	95.35	95.45	96.95	98.25	102.65	97.31
	1.0	85.40	86.40	86.85	88.20	92.75	94.35	88.99
	Mean	94.87	95.54	96.29	97.66	100.33	104.20	98.14
Clay loam	0	93.29	93.84	94.12	95.70	97.20	99.10	95.54
	0.5	82.16	84.32	84.85	86.75	88.85	89.05	85.99
	1.0	75.80	75.85	76.00	76.85	77.35	79.95	76.96
	Mean	83.75	84.67	84.99	86.43	87.80	89.36	86.16
Overall Mean		89.31	90.10	90.64	92.04	94.06	96.78	92.15

C.D. (P = 0.05)

Pb	= 0.38	Pb x Manure	= 0.67
Manure	= 0.27	Pb x Soil	= 0.54
Soil	= 0.22	Manure x Soil	= 0.38
		Pb x Manure x Soil	= 0.95

to clay loam soil may be attributed to transfer of Mn from sandy soil is higher compared to other soils, which reflects the lower adsorption.

The additive effect of organic manure on Mn concentration and uptake by oat plants (Dahiya and Singh, 1980), could be due to increased availability of Mn caused by application of organic matter (Rathore *et al.*, 1980). Divergent results were reported by Gupta *et al.* (1989) who observed that application of farm yard manure decreased Mn concentration but increased Mn uptake in wheat grain and straw.

4.2.3.3 Fe concentration

(a) Grain

Data (Table 54) showed that over all mean Fe concentration in grain decreased significantly with increasing Pb levels. It depressed from 78.62 $\mu\text{g g}^{-1}$ in control to 61.51 $\mu\text{g g}^{-1}$ in 80 mg Pb kg^{-1} soil treatment. The mean Fe concentration in grain was reduced by 3.7, 17.1 and 30.2 per cent in sandy soil and 1.3, 11.5 and 21.7 per cent in clay loam soil over control due to 5, 20 and 80 mg Pb kg^{-1} soil, respectively. The Pb x soil interaction was significant.

Application of manure irrespective of soil enhanced Fe concentration in wheat grain significantly. The mean Fe concentration in grain increased by 22.6 and 40.3 per cent in sandy soil compared with 12.8 and 18.9 per cent in clay loam soil due to 0.5 and 1.0% manure over no manure, respectively. The mean Fe concentration in grain was significantly higher in clay loam soil as compared to sandy soil. The Pb x manure and Pb x manure x soil interaction were non significant. The depressing effect of Pb on Fe concentration was counteracted with manure application.

Table 54. Effect of Pb, cattle manure and soil texture on Fe concentration of wheat grain

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Fe concentration (µg g ⁻¹)								
Sand	0	57.85	55.84	52.29	46.67	43.81	38.80	49.21
	0.5	69.39	67.25	63.99	57.87	54.77	48.89	60.36
	1.0	79.85	76.35	73.17	66.97	61.37	56.72	69.07
	Mean	69.03	66.48	63.15	57.17	53.31	48.13	59.54
Clay loam	0	71.20	70.37	67.78	62.35	60.01	54.78	64.41
	0.5	80.05	79.17	74.61	71.25	68.21	62.79	72.68
	1.0	84.63	83.27	78.28	75.05	71.30	66.96	76.58
	Mean	78.62	77.60	73.55	69.55	66.51	61.51	71.22
Overall Mean		73.82	72.04	68.35	63.36	59.91	54.82	65.38

C.D. (P = 0.05)

Pb	= 1.1	Pb x Manure	= NS
Manure	= 0.8	Pb x Soil	= 1.6
Soil	= 0.6	Manure x Soil	= 1.1
		Pb x Manure x Soil	= NS

(b) Straw

The overall Fe concentration in straw repressed from $323.2 \mu\text{g g}^{-1}$ in control to $272.5 \mu\text{g g}^{-1}$ in 80 mg Pb kg^{-1} soil treatment irrespective of the soil (Table 55). The Pb x soil interaction was significant, Fe concentration being significantly higher in clay loam soil than sandy soil. The mean Fe concentration in straw was reduced from $301.1 \mu\text{g g}^{-1}$ in control to $262.0 \mu\text{g g}^{-1}$ straw at 80 mg Pb kg^{-1} soil in sandy soil and the corresponding reduction in clay loam soil was 345.4 to $283.0 \mu\text{g g}^{-1}$ straw.

Application of manure increased straw Fe significantly and magnitude of increase due to manure application varied with soil texture. The straw Fe increased by 6.7 and 10.3 per cent in sandy soil and 4.6 and 8.0 per cent in clay loam soil due to 0.5 and 1.0% manure over no manure treatment, respectively. The Pb and manure interaction was significant and varied with soil texture. The effect of manure in augmenting straw Fe concentration was also similar in both the soil tested. The manure x soil and Pb x manure x soil were statisitcally non significant.

(c) Root

Overall Fe concentration in root increased with increasing level of Pb, but significant increase started after 5 mg Pb kg^{-1} soil application (Table 56). Soil texture also influenced the Fe concentration of root which was significantly higher ($2856 \mu\text{g g}^{-1}$) in sandy soil than clay loam soil ($2651 \mu\text{g g}^{-1}$). Iron concentration increased by 9.1 per cent in sandy soil and 7.3 per cent in clay loam soil due to 80 mg Pb kg^{-1} soil over control, respectively.

Table 55. Effect of Pb, cattle manure and soil texture on Fe concentration of wheat straw

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Fe concentration (µg g ⁻¹)								
Sand	0	281.3	281.1	279.5	276.3	256.3	241.9	269.4
	0.5	308.3	298.1	290.5	286.0	276.2	266.0	287.5
	1.0	313.9	306.9	301.2	296.7	287.3	278.2	297.3
	Mean	301.1	295.3	290.4	286.3	273.3	262.0	284.7
Clay loam	0	330.3	339.1	310.3	290.1	280.4	268.6	303.1
	0.5	347.9	343.1	325.7	304.1	298.4	284.9	317.3
	1.0	358.1	352.7	336.1	315.2	307.9	295.7	327.6
	Mean	345.4	344.9	324.0	303.1	295.5	283.0	316.0
Overall Mean		323.2	320.1	307.2	294.7	284.4	272.5	300.3

C.D. (P = 0.05)

Pb	= 2.7	Pb x Manure	= 4.8
Manure	= 1.9	Pb x Soil	3.9
Soil	= 1.6	Manure x Soil	= NS
		Pb x Manure x Soil	= NS

Table 56. Effect of Pb, cattle manure and soil texture on Fe concentration of wheat root

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Fe concentration (µg g ⁻¹)								
Sand	0	2490	2521	2557	2597	2660	2729	2592
	0.5	2765	2800	2858	2900	2974	3025	2887
	1.0	2985	2999	3035	3085	3195	3240	3089
	Mean	2747	2773	2816	2861	2943	2998	2856
Clay loam	0	2392	2404	2430	2446	2490	2555	2453
	0.5	2612	2632	2662	2695	2720	2785	2684
	1.0	2687	2700	2805	2885	2900	2917	2816
	Mean	2563	2579	2632	2675	2703	2752	2651
Overall Mean		2655	2676	2724	2768	2823	2875	2753

C.D. (P = 0.05)

Pb	= 32	Pb x Manure	= NS
Manure	= 22	Pb x Soil	= NS
Soil	= 18	Manure x Soil	= 32
		Pb x Manure x Soil	= NS

Application of manure enhanced Fe concentration in root significantly. The increase in Fe concentration due to 0.5 and 1.0% application of manure was 11.3 and 19.1 per cent in sandy soil compared with 9.4 and 14.8 per cent in clay loam soil over control, respectively. The differences among increasing manure levels were also significant. The Pb x manure, Pb x soil and Pb x manure x soil interacted non significantly. When 80 mg Pb kg⁻¹ applied with 1.0% manure enhanced Fe concentration in root by 18.7 and 14.1 per cent in sandy and clay loam soil over 80 mg Pb kg⁻¹ a soil alone, respectively.

The results indicated that Fe concentration decreased in wheat grain and straw and increased in roots due to increase in Pb application. It may be ascribed to antagonistic effect of Pb on Fe which inhibited the translocation of Fe from roots to grain and straw. The antagonistic effect of Pb on Fe seems to have occurred in the roots. The present findings are in agreement with those of Khan and Khan (1983) who observed that Pb application to soil decreased Fe content of egg plant. Significantly higher Fe concentration was observed in grain and straw grown in clay loam soil than sandy soil, which is attributed to higher available Fe status of clay loam soil.

The increase in the Fe concentration of wheat plant could be due to the fact that some of the native Fe might have been chelated by the humic acid, released during the decomposition of organic manure and thus its availability also increased. Moreover, manure itself also contributed to some Fe to plants. The findings are in conformity with the results of Dahiya and Singh (1980) in oats and Raj (1984) in wheat. The reduction in Fe concentration of wheat grain and straw due to Pb application and an increase due to manure, showed that in Pb polluted light textured soil, the adverse

effect of Pb on Fe absorption could be alleviated with the application of FYM.

4.2.3.4 Cu concentration

(a) Grain

The overall mean Cu concentration decreased in grain (Table 57). In sandy soil grain Cu concentration was decreased significantly from $2.53 \mu\text{g g}^{-1}$ to $2.26 \mu\text{g g}^{-1}$ grain due to 80 mg Pb kg^{-1} soil over control, while in clay loam soil it increased upto 10 mg Pb kg^{-1} soil and decreased significantly thereafter. The Pb x soil interaction was non significant. The effect of soil texture on Cu concentration in grain significantly was higher ($2.81 \mu\text{g g}^{-1}$) in clay loam soil than in sandy soil ($2.42 \mu\text{g g}^{-1}$).

Addition of manure, either alone or in combination with Pb levels repressed grain Cu. The mean concentration in grain decreased significantly from $2.68 \mu\text{g g}^{-1}$ in no manure treatment to 2.39 and $2.19 \mu\text{g g}^{-1}$ grain in sandy soil due to application of 0.5 and 1.0% manure. A similar trend was observed in clay loam soil. The effect of manure on Cu concentration in grain varied significantly with soil texture. Application of 80 mg Pb kg^{-1} soil in the absence of manure resulted in 27.8 per cent reduction in grain Cu content over no Pb and no manure treatment, respectively, in sandy soil while the corresponding reduction in clay loam soil was 28.6 per cent.

(b) Straw

It is evident from the data (Table 58) that Cu concentration in straw marginally increased due to 5 mg Pb kg^{-1} soil, while further increase in Pb levels decreased Cu concentration. The effect of Pb in reducing Cu concentration in straw varied with soil texture.

Table 57. Effect of Pb and cattle manure on Cu concentration of wheat grain grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Cu concentration (µg g ⁻¹)								
Sand	0	2.77	2.78	2.73	2.71	2.64	2.50	2.68
	0.5	2.51	2.41	2.40	2.40	2.35	2.28	2.39
	1.0	2.30	2.30	2.29	2.17	2.10	2.00	2.19
	Mean	2.53	2.49	2.47	2.42	2.36	2.26	2.42
Clay loam	0	3.25	3.30	3.40	3.31	3.21	2.98	3.24
	0.5	2.86	2.86	2.84	2.72	2.69	2.63	2.76
	1.0	2.52	2.51	2.49	2.40	2.38	2.32	2.43
	Mean	2.87	2.89	2.91	2.81	2.76	2.64	2.81
Overall Mean		2.70	2.69	2.69	2.61	2.56	2.45	2.61

C.D. (P = 0.05)

Pb = 0.03

Manure = 0.02

Soil = 0.01

Pb x Manure = 0.05

Pb x Soil = NS

Manure x Soil = 0.03

Pb x Manure x Soil = 0.07

Table 58. Effect of Pb and cattle manure on Cu concentration of wheat straw grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Cu concentration (µg g ⁻¹)								
Sand	0	3.70	3.69	3.68	3.69	3.52	3.27	3.59
	0.5	2.88	2.86	2.87	2.83	2.62	2.56	2.77
	1.0	2.52	2.54	2.54	2.46	2.38	2.26	2.45
	Mean	3.03	3.03	3.03	2.99	2.84	2.70	2.93
Clay loam	0	4.40	4.50	4.40	4.45	4.37	4.09	4.36
	0.5	3.70	3.65	3.69	3.62	3.51	3.46	3.60
	1.0	3.30	3.30	3.19	3.16	3.12	3.08	3.19
	Mean	3.80	3.81	3.76	3.74	3.66	3.54	3.72
Overall Mean		3.41	3.42	3.39	3.36	3.25	3.12	3.32

C.D. (P = 0.05)

Pb = 0.08

Manure = 0.06

Soil = 0.05

Pb x Manure = NS

Pb x Soil = NS

Manure x Soil = NS

Pb x Manure x Soil = NS

Application of manure, either alone or in combination with Pb levels repressed straw Cu significantly. The mean concentration in straw decreased from $3.59 \mu\text{g g}^{-1}$ in no manure treatment to 2.77 and $2.45 \mu\text{g g}^{-1}$ straw due to application of 0.5 and 1.0% manure, corresponding in clay loam soil it was varied from 4.36 to $3.19 \mu\text{g g}^{-1}$ straw, respectively. The various interaction between Pb, manure and soil texture were non significant.

(c) Root

The overall mean Cu concentration in root (Table 59) decreased from $21.68 \mu\text{g g}^{-1}$ in control to 20.96, 20.08 and $19.26 \mu\text{g g}^{-1}$ due to 10, 40 and 80 mg Pb kg^{-1} soil, respectively. In sandy soil Cu content in root decreased significantly at 10 mg Pb kg^{-1} soil and the difference between 10 mg Pb kg^{-1} soil and higher levels was significant. Copper concentration in root due to mean effect of soil texture was significantly higher in clay loam soil than in sandy soil.

Application of manure significantly reduced root Cu from $22.64 \mu\text{g g}^{-1}$ in control to 18.80 and $15.59 \mu\text{g g}^{-1}$ at 0.5 and 1.0% manure in sandy soil and from 25.14 to 22.18 and $19.61 \mu\text{g g}^{-1}$ root in clay loam soil, respectively. The effect of manure on Cu concentration in root vary with soil texture. The Pb x manure, Pb x soil and Pb x manure x soil interactions were non significant.

The results indicated that Pb application reduced Cu concentration significantly at 10 mg Pb kg^{-1} soil in wheat tissue. The lower levels of Pb had some what additive effect on Cu concentration while higher level of Pb had antagonistic effect. Khan and Khan (1983) also observed that Pb application depressed Cu content of egg plant. The depression in Cu content of wheat

Table 59. Effect of Pb and cattle manure on Cu concentration of wheat root grown in texturally different soils

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
Cu concentration (µg g ⁻¹)								
Sand	0	23.50	23.35	23.00	22.75	22.25	21.00	22.64
	0.5	20.00	19.87	18.65	18.35	18.03	17.95	18.80
	1.0	16.10	16.30	15.85	15.35	15.00	14.95	15.59
	Mean	19.86	19.84	19.16	18.81	18.42	17.96	19.01
Clay loam	0	27.33	25.80	25.65	25.05	24.10	22.95	25.14
	0.5	22.87	22.85	22.65	22.35	21.85	20.55	22.18
	1.0	20.30	20.18	20.00	19.70	19.30	18.20	19.61
	Mean	23.50	22.94	22.76	22.37	21.75	20.56	22.31
Overall Mean		21.68	21.39	20.96	20.59	20.08	19.26	20.66

C.D. (P = 0.05)

Pb = 0.38

Manure = 0.27

Soil = 0.22

Pb x Manure = NS

Pb x Soil = NS

Manure x Soil = 0.38

Pb x Manure x Soil = NS

might be due to antagonistic effect of Pb on Cu absorption, since both Pb^{2+} and Cu^{2+} are absorbed at same carrier site.

Reduction in Cu concentration due to manure is in agreement with the finding of Singh (1990) who reported that humic acid may have more affinity for Cu which indicates that organic manure producing humic acid would act better 'sink' for copper. Gupta *et al.* (1989) reported that application of FYM on highly contaminated soil, resulted in decreased Cu concentration in wheat grain and straw.

4.2.4 Effect of Pb, cattle manure and soil texture on DTPA extractable Pb in soil

4.2.4.1 DTPA-extractable Pb in pre-sowing soil samples

The data (Table 60) showed that extractable Pb increased significantly and consistently with graded rates of Pb in pre-sowing soil samples. The overall mean values of DTPA - Pb obtained were 0.48, 2.09, 3.25, 5.58, 10.34 and 22.65 $\mu\text{g g}^{-1}$ soil in 0, 5, 10, 20, 40 and 80 mg Pb kg^{-1} soil treatment, respectively.

The amount of extractable Pb varied with soil texture. The amount of extractable Pb was low in clay loam soil and high in sandy soil. Application of manure in conjunction with Pb caused reduction in extractable Pb in both the soils and was significant. Application of 0.5 and 1.0% manure with Pb levels reduced the Pb extractability by 1.28 and 2.07 $\mu\text{g g}^{-1}$ in sandy soil and 0.69 and 1.43 $\mu\text{g g}^{-1}$ in clay loam soil, respectively over no manure treatment.

The extractability of Pb was affected significantly due to Pb x manure interaction in both the soils. The various interactions between Pb, manure

Table 60. Effect of Pb, cattle manure and soil texture on DTPA-extractable Pb in soils before seeding

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
DTPA-Pb (µg g ⁻¹)								
Sand	0	0.55	2.92	3.00	6.43	13.60	27.20	8.95
	0.5	0.38	2.56	2.89	5.44	11.33	23.44	7.67
	1.0	0.22	2.01	2.44	5.00	10.78	20.87	6.88
	Mean	0.38	2.49	2.78	5.62	11.90	23.83	7.83
Clay loam	0	0.87	1.87	4.30	6.30	9.21	23.50	7.67
	0.5	0.55	1.78	3.87	5.77	8.68	21.25	6.98
	1.0	0.31	1.44	3.00	4.56	8.44	19.69	6.24
	Mean	0.58	1.69	3.72	5.54	8.78	21.48	6.96
Overall Mean		0.48	2.09	3.25	5.58	10.34	22.65	7.39

C.D. (P = 0.05)

Pb	= 0.11	Pb x Manure	= 0.19
Manure	= 0.08	Pb x Soil	= 0.16
Soil	= 0.06	Manure x Soil	= 0.11
		Pb x Manure x Soil	= 0.28

and soil were significant. Application of Pb without manure, increased DTPA- Pb significantly, while manure alone showed significant depression in both the soils. The results showed that application of manure has antagonistic effect on DTPA extractable Pb in soil.

4.2.4.2 DTPA-extractable Pb in post-harvest soil samples

The DTPA-extractable Pb increased significantly with increasing levels of Pb in the soil (Table 61). The overall DTPA extractable Pb increased from 0.39 to 19.04 $\mu\text{g g}^{-1}$ soil with an increase in Pb levels from 0 to 80 mg kg^{-1} soil, respectively. However, DTPA extractability of Pb was significantly lower in clay loam soil as compared to sandy soil.

Application of manure significantly lowered the DTPA extractable Pb in both the soils. In sandy soil it decreased from 7.63 to 5.88 $\mu\text{g g}^{-1}$, while in clay loam it decreased from 7.01 to 5.47 $\mu\text{g g}^{-1}$ with an increase in manure levels from 0 to 1.0%, respectively.

The Pb and manure increased significantly in affecting the Pb extractability. Application of Pb without manure, increased DTPA extractable Pb, while manure alone showed significant depression in both the soils. The various interaction of Pb, manure and soil interacted significantly for affecting Pb extractability.

DTPA extractable Pb increased with increasing rates of Pb and was higher in sandy soil than clay loam soil. This may be ascribed to strong binding of Pb with colloidal particles and organic matter in clay loam soil.

The reduction in Pb extractability with the application of manure might be attributed to its complexation or chelation with organic matter. Lagerwerff (1972) had observed that soil organic matter strongly adsorbed Pb.

Table 61. Post-harvest DTPA-extractable Pb in soils as influenced by Pb, cattle manure and soil texture

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)						Mean
		0	5	10	20	40	80	
DTPA-Pb (µg g ⁻¹)								
Sand	0	0.48	2.70	2.77	6.07	11.89	21.90	7.63
	0.5	0.30	2.31	2.60	5.00	9.59	18.95	6.45
	1.0	0.17	1.97	2.00	4.87	9.00	17.27	5.88
	Mean	0.31	2.32	2.45	5.31	10.16	19.37	6.65
Clay loam	0	0.77	1.77	4.11	5.92	8.49	21.00	7.01
	0.5	0.39	1.51	3.46	5.29	7.59	18.00	6.04
	1.0	0.26	1.37	2.95	4.06	7.05	17.13	5.47
	Mean	0.47	1.55	3.51	5.09	7.71	18.71	6.17
Overall Mean		0.39	1.93	2.98	5.20	8.93	19.04	6.41

C.D. (P = 0.05)

Pb	= 0.06	Pb x Manure	= 0.10
Manure	= 0.04	Pb x Soil	= 0.08
Soil	= 0.03	Manure x Soil	= 0.06
		Pb x Manure x Soil	= 0.15

4.3 Effect of Pb, P and cattle manure on Pb distribution among fraction in texturally different soil

4.3.1 Effect of Pb, P and soil texture on the distribution of applied Pb among soil fractions (before seeding)

4.3.1.1 Exchangeable + Water soluble lead (EX+ W - Pb)

The amount of exchangeable and water soluble fraction of Pb increased with increasing rate of Pb in both the soils (Table 62). Application of P decreased EX + W - Pb fraction in both the soils. In sandy soil without Pb application EX + W - Pb fraction was decreased by 20.0, 40.0 and 48.0 per cent, while, at 80 mg Pb kg⁻¹ soil it decreased by 10.4, 15.4 and 21.6 per cent, due to application of 25, 50 and 100 mg P kg⁻¹ soil, respectively, over no P. In clay loam soil EX + W - Pb fraction was decreased by 12.0, 36.2 and 43.0 per cent without Pb, but at 80 mg Pb kg⁻¹ soil decreased it by 7.1, 21.1 and 25.0 per cent due to 25, 50 and 100 mg kg⁻¹ soil over no P, respectively. The magnitude of decrease in EX + W soluble Pb fraction was more in coarse texture soil than fine texture soil. The effect of P in reducing the solubility of Pb was anticipated, since phosphate of this metal tend to relatively insoluble.

4.3.1.2 Carbonate bound lead (CARB - Pb)

Lead in carbonate fraction increased with increasing rate of Pb as well as P application in both the soils (Table 62). This fraction was increased from 1.50 to 25.20, 1.67 to 26.90, 1.72 to 27.60 and 1.77 to 28.35 µg g⁻¹ in 0, 25, 50 and 100 mg P kg⁻¹ soil, respectively, with change in Pb application from 0 to 80 mg kg⁻¹ soil in sandy soil, while corresponding values in clay loam soil was 1.56 to 21.86, 1.60 to 22.90, 1.95 to 23.15 and 2.15 to

23.20 $\mu\text{g g}^{-1}$ soil, respectively. A drastic increase in CARB-Pb fraction was observed in clay loam soil with 50 and 100 mg P kg^{-1} soil as compared to sandy soil. The presence of Pb in the carbonate fraction might indicate a pH suitable for metal precipitation. Calcium carbonate may act as a strong absorbent for heavy metals and could complex as a double salts like $\text{CaCO}_3 \cdot \text{PbCO}_3$.

4.3.1.3 Organically bound lead (OM-Pb)

The amount of organically bound lead increased with increasing rate of Pb, but decreased by P levels in both the soils (Table 62). It decreased by 25.7 per cent due to $\text{Pb}_0\text{P}_{100}$ and 24.5 per cent due to $\text{Pb}_{80}\text{P}_{100}$ over Pb_0P_0 , respectively in sandy soil compared with 30.7 and 19.8 per cent in clay loam soil, respectively. The effect of P in the reduction of this fraction was more pronounced in fine textured soil than coarse textured one. This could be attributed to higher content of organic matter in clay loam soil.

4.3.1.4 Manganese oxide bound lead (MnOX - Pb)

Lead in this fraction was increased with increasing rate of Pb but slight increase was recorded with increase in P levels. The increase was 4.0, 6.0 and 5.0 per cent in sandy and 4.0, 12.5 and 15.0 per cent due to 25, 50 and 100 mg P kg^{-1} soil over control at 0 Pb application in sandy and clay loam, respectively. This showed that Pb was more increased in clay loam soil than sandy soil with increase in P application.

4.3.1.5 Amorphous Fe - oxide bound lead (AFeOX - Pb)

Amorphous FeOx bound Pb (Table 62) increased with increase in P and Pb levels, irrespective of the soils. With the application of 100 mg P kg^{-1} soil, Pb in this fraction increased by 24.1 and 13.0 per cent at 0 Pb over

Table 62. Effect of Pb, P and soil texture on the distribution of applied Pb among soil fractions (before seeding)

Treatments		Fractions ($\mu\text{g g}^{-1}$)						
P-levels	Pb-levels	EX+W	CARB	OM	MnOX	AFeOX	CFeOX	RES
(mg kg ⁻¹ soil)								
SAND								
0	0	0.50	1.50	0.35	1.00	1.45	2.50	5.00
	5	1.55	2.90	0.70	1.80	2.55	2.90	5.10
	10	2.70	4.35	0.90	2.50	3.60	3.25	5.20
	20	5.10	7.20	1.25	4.02	5.60	3.78	5.55
	40	10.10	13.00	2.06	7.58	9.50	4.66	5.60
	80	20.10	25.20	3.58	14.62	16.70	5.80	6.50
25	0	0.40	1.67	0.36	1.04	1.55	2.48	5.00
	5	1.30	3.06	0.65	1.84	2.68	2.88	5.09
	10	2.30	4.64	0.80	2.66	3.80	3.20	5.10
	20	4.40	7.90	1.00	4.10	5.90	3.70	5.48
	40	8.80	14.00	1.80	7.70	10.02	4.58	5.50
	80	18.00	26.90	3.00	14.72	18.00	5.60	6.00
50	0	0.30	1.72	0.30	1.06	1.70	2.40	5.02
	5	1.25	3.20	0.60	1.88	2.80	2.68	5.08
	10	2.15	4.78	0.72	2.70	4.00	3.10	5.05
	20	4.10	8.20	0.90	4.25	6.00	3.55	5.40
	40	8.65	14.35	1.65	7.80	10.20	4.40	5.45
	80	17.00	27.60	2.85	14.80	18.95	5.25	5.95
100	0	0.26	1.77	0.26	1.05	1.80	2.36	5.00
	5	1.00	3.28	0.55	1.99	2.95	2.50	5.12
	10	2.08	4.80	0.65	2.80	4.20	2.90	5.00
	20	3.90	8.25	0.75	4.35	6.40	3.35	5.45
	40	8.20	14.40	1.50	8.00	10.55	4.30	5.35
	80	15.75	28.35	2.70	15.25	19.20	5.00	5.85

Contd.....

Treatments		Fractions ($\mu\text{g g}^{-1}$)						
P-levels	Pb-levels	EX+W	CARB	OM	MnOX	AFeOX	CFeOX	RES
(mg kg ⁻¹ soil)								
CLAY LOAM								
0	0	1.16	1.56	1.30	2.00	2.76	4.40	6.82
	5	2.06	2.53	1.90	2.85	3.46	5.20	6.99
	10	2.98	3.66	2.40	3.69	4.26	5.79	7.22
	20	4.88	5.96	3.40	5.20	6.26	6.88	7.62
	40	8.76	10.76	5.30	7.92	10.92	8.16	8.08
	80	16.80	21.86	8.30	14.50	20.76	9.00	8.50
25	0	1.02	1.60	1.28	2.08	2.86	4.25	6.90
	5	1.86	2.80	1.70	2.95	3.56	5.15	6.95
	10	2.70	3.92	2.20	3.70	4.86	5.27	7.25
	20	4.25	6.35	3.00	5.35	6.95	6.40	7.65
	40	8.00	11.25	5.05	8.25	11.25	7.85	8.18
	80	15.60	22.90	7.75	15.90	21.00	8.30	8.50
50	0	0.74	1.95	1.00	2.25	3.05	4.00	6.95
	5	1.65	3.10	1.50	3.05	3.75	4.95	6.95
	10	2.50	4.10	1.95	3.95	4.95	5.00	7.30
	20	3.80	7.00	2.65	5.55	7.60	5.53	7.70
	40	7.25	11.90	4.60	8.30	12.00	7.40	8.25
	80	13.25	23.15	6.75	16.00	24.30	7.95	8.55
100	0	0.66	2.15	0.90	2.30	3.12	3.90	6.95
	5	1.25	3.50	1.25	3.30	3.90	4.75	7.00
	10	2.40	4.35	1.75	3.95	5.25	4.85	7.25
	20	3.80	7.30	2.25	5.80	7.85	5.05	7.80
	40	6.90	12.10	4.40	8.55	12.20	7.15	8.30
	80	12.60	23.20	6.65	16.25	24.90	7.60	8.60

control and 16.1 and 9.1 per cent over 25 mg P kg⁻¹ in sandy and clay soil, respectively. Mostly, this fraction contributed highest Pb, with higher level of Pb followed by carbonate bound fraction in clay loam soil but reverse was true in case of sandy soil. Amorphous sesquioxides have greater ability to retain the trace metals due to their high specific surface area.

4.3.1.6 Crystalline Fe-oxide bound lead (CFeOX - Pb)

The crystalline Fe oxide bound Pb (Table 62) decreased as a consequent of P application, regardless of soil texture. There was 5.6 and 11.3 per cent reduction of CFeOX fraction of Pb at 0 Pb 0 P over 0 Pb 100 P in sandy and clay loam soil, respectively.

4.3.1.7 Residual lead (RES-Pb)

The residual Pb was higher in clay loam soil than sandy soil (Table 62). There was very less change in this fraction due to increase in Pb levels in both the soils. Lead associated with this fraction slight increased from 5.00 to 6.50, 5.00 to 6.00, 5.02 to 5.95 and 5.00 to 5.85 µg g⁻¹ in sandy soil and 6.82 to 8.50, 6.90 to 8.50, 6.95 to 8.55 and 6.95 to 8.60 µg g⁻¹ in clay loam soil with 0, 25, 50 and 100 mg P kg⁻¹ soil, with change in Pb level from 0 to 80 mg kg⁻¹ soil, respectively.

4.3.2 Effect of Pb, P and soil texture on the distribution of applied Pb among soil fractions (after harvesting)

4.3.2.1 Exchangeable + Water soluble bound Pb (EX + W - Pb)

Exchangeable + water soluble fraction of Pb decreased as a result of P application in sandy and clay loam soil (Table 63). After harvesting of the crop the Pb fraction of EX+ W was consumed by the wheat plants. This fraction

was decreased from 0.20 to 0.12 $\mu\text{g g}^{-1}$ at 0 Pb and due to increased in P levels from 0 to 100 mg kg^{-1} soil in sandy soil and 0.72 to 0.48 $\mu\text{g g}^{-1}$ at similar level in clay loam soil. While with the increase in Pb at 80 mg kg^{-1} soil it was decreased from 9.05 to 7.85 $\mu\text{g Pb g}^{-1}$ soil in sandy and 11.76 to 8.95 $\mu\text{g Pb g}^{-1}$ soil in clay loam soil due to increase in P from 0 to 100 mg kg^{-1} soil, respectively. The decrease in EX + W soluble was more at lower level of Pb but at higher level the decrease was less as compared to clay loam soil.

4.3.2.2 Carbonate bound lead (CARB - Pb)

Carbonate bounded-Pb fraction increased with increasing rate of Pb and P in both the soils (Table 63). In sandy soil CARB-Pb increased from 1.50 to 1.77 $\mu\text{g g}^{-1}$ and 1.56 to 2.15 $\mu\text{g g}^{-1}$ at 0 mg Pb kg^{-1} soil due to increase in P from 0 to 100 mg kg^{-1} soil, respectively. While at 80 mg Pb kg^{-1} soil it was 25.20 to 28.35 $\mu\text{g g}^{-1}$ in sandy and 21.86 to 23.20 $\mu\text{g g}^{-1}$ in clay loam soil with increase in P level from 0 to 100 mg kg^{-1} soil. In general, this form was consumed by the plants parts. The exchangeable and carbonate fractions had very small amount of Pb suggesting that the solubility and mobility of the element was low in the soil.

4.3.2.3 Organically bound lead (OM-Pb)

This form of Pb also decreased with increasing level of phosphorus in the soil. The organically bound-Pb was higher in clay loam soil as compared to sandy soil due to higher organic carbon in former soil (Table 63). The utilization of OM - Pb was more in sandy soil as compared to clay loam soil. At 80 mg Pb kg^{-1} soil OM - Pb decreased from 3.15 to 2.45 $\mu\text{g g}^{-1}$ in sandy soil and 7.40 to 6.26 $\mu\text{g g}^{-1}$ in clay loam soil due to increase in P level from 0 to 100 mg kg^{-1} soil.

Table 63. Effect of Pb, P and soil texture on the distribution of applied Pb among soil fractions (after harvesting)

Treatments		Fractions ($\mu\text{g g}^{-1}$)						
P-levels	Pb-levels	EX+W	CARB	OM	MnOX	AFeOX	CFeOX	RES
(mg kg ⁻¹ soil)								
SAND								
0	0	0.20	1.42	0.33	1.00	1.58	2.48	5.02
	5	0.60	2.58	0.60	1.78	2.68	2.90	5.12
	10	1.05	3.85	0.75	2.46	3.76	3.22	5.25
	20	2.14	6.45	1.08	3.98	5.85	3.75	5.60
	40	4.35	11.70	1.80	7.50	9.88	4.62	5.62
	80	9.05	22.65	3.15	14.45	17.36	5.75	6.55
25	0	0.17	1.50	0.32	1.02	1.64	2.45	5.00
	5	0.57	2.75	0.56	1.82	2.82	2.85	5.10
	10	1.00	4.15	0.70	2.62	4.00	3.18	5.12
	20	1.98	7.18	0.88	4.06	6.18	3.65	5.50
	40	4.15	12.74	1.60	7.60	10.46	4.55	5.50
	80	8.46	24.46	2.67	14.50	18.80	5.55	6.00
50	0	0.14	1.55	0.26	1.05	1.80	2.35	5.05
	5	0.57	2.88	0.52	1.85	2.98	2.55	5.05
	10	1.01	4.35	0.63	2.67	4.26	3.00	5.08
	20	1.98	7.54	0.80	4.20	6.36	3.45	5.45
	40	4.18	13.20	1.48	7.72	10.80	4.40	5.50
	80	8.33	25.35	2.55	14.65	20.00	5.20	6.00
100	0	0.12	1.60	0.22	1.05	1.92	2.35	5.05
	5	0.47	2.98	0.48	1.96	3.16	2.48	5.15
	10	0.99	4.37	0.56	2.70	4.46	2.98	5.12
	20	2.00	7.59	0.65	4.28	6.80	3.35	5.50
	40	4.08	13.38	1.35	7.95	11.16	4.30	5.40
	80	7.85	26.05	2.45	15.00	20.25	4.95	5.85

Contd.....

Treatments		Fractions ($\mu\text{g g}^{-1}$)						
P-levels	Pb-levels	EX+W	CARB	OM	MnOX	AFeOX	CFeOX	RES
(mg kg ⁻¹ soil)								
CLAY LOAM								
0	0	0.72	1.25	1.15	2.00	3.00	4.35	6.70
	5	1.25	2.03	1.60	2.80	3.84	5.20	6.88
	10	2.00	3.06	2.09	3.65	4.68	5.80	7.16
	20	3.32	5.00	2.99	5.15	6.88	6.70	7.53
	40	6.05	9.25	4.75	7.85	11.70	8.10	8.00
	80	11.76	19.24	7.40	14.35	22.00	8.95	8.55
25	0	0.66	1.30	1.12	2.00	3.17	4.20	6.77
	5	1.18	2.25	1.49	2.90	3.95	5.15	6.90
	10	1.85	3.14	1.98	3.65	5.40	5.25	7.20
	20	2.98	5.05	2.70	5.25	7.70	6.35	7.60
	40	5.70	9.20	4.58	8.00	12.37	7.75	8.05
	80	11.25	18.80	6.98	14.95	22.89	8.20	8.50
50	0	0.58	1.52	0.90	2.18	3.35	4.00	6.85
	5	1.17	2.50	1.32	3.00	4.20	4.90	6.85
	10	1.82	3.50	1.75	3.75	5.55	4.90	7.25
	20	2.68	5.75	2.38	5.35	8.50	5.50	7.60
	40	5.18	9.52	4.23	8.10	13.35	7.35	8.00
	80	9.31	19.82	6.18	15.00	26.24	7.85	8.55
100	0	0.48	1.75	0.85	2.25	3.50	3.82	6.85
	5	0.89	3.00	1.10	3.05	4.39	4.72	6.85
	10	1.68	3.58	1.60	3.90	5.80	4.80	7.10
	20	2.70	6.00	2.10	5.70	8.59	5.00	7.80
	40	4.90	9.84	4.09	8.20	13.45	7.05	8.25
	80	8.95	19.40	6.26	15.50	27.35	7.60	8.30

4.3.2.4 Manganese oxide bound lead (MnOX - Pb)

The MnOX-Pb fraction was increased with Pb levels but slightly increased with increase in P levels in both the soils (Table 63). In sandy soil this form was slightly decreased after harvesting but in clay loam soil it increased slightly. This showed that application of P did have a marked effect on this fraction of Pb.

4.3.2.5 Amorphous Fe - oxide bound lead (AFeOX-Pb)

This fraction also increased with increasing level of P in the soil (Table 63). In clay loam soil at 0 and 80 mg Pb kg⁻¹ soil it increased from 1.58 and 17.36 to 1.92 and 20.25 µg g⁻¹ but in clay loam soil increased from 3.00 and 22.00 to 3.50 and 27.35 µg g⁻¹ due to increase in P level from 0 to 100 mg kg⁻¹ soil. With increase in period of sampling this form was increased may be due to shifting of more Pb in this form.

4.3.2.6 Crystalline Fe-oxide bound lead (FeOX - Pb)

The CFeOX-Pb decreased slightly with increase in P level, irrespective of soil texture (Table 63). This form almost remained unaffected with time and also not absorbed by the plant. Crystalline FeOX bound was higher in clay loam soil as compared to sandy soil.

4.3.2.7 Residual lead (RES-Pb)

This form of Pb was not much affected from before seeding to after harvest of the crop (Table 63). RES-Pb was higher in clay loam soil as compared to sandy soil. It was increased from 6.82 to 8.50 µg Pb g⁻¹ soil in clay loam soil and 5.0 to 6.50 µg g⁻¹ in sandy soil due to increase in Pb from 0 to 80 mg kg⁻¹ soil in 0-P treatment.

4.3.3 Effect of Pb, cattle manure and soil texture on the distribution of applied Pb among soil fraction (before seeding)

4.3.3.1 Exchangeable + Water soluble bound lead (EX + W - Pb)

Amount of Pb in this fraction decreased regardless of soil texture as a result of application of cattle manure (Table 64). It was decreased by 20.0 and 46.7 per cent due to 0 Pb and 0.5 % manure and 0 Pb and 1.0% manure over 0 Pb 0% manure, at similar level due to 80 mg Pb kg⁻¹ soil it was 1.5 and 11.7 per cent in sandy soil. In clay loam soil it decreased by 12.16 and 25.6 per cent due to 0 Pb and 0.5% and 0 Pb 1.0% manure over control and at 80 mg Pb kg⁻¹ soil 0.5% manure and 80 mg Pb kg⁻¹ soil it was 3.4 and 7.9 per cent over 80 mg Pb kg⁻¹ soil 0% manure in clay loam soil. The reduction in EX + W - Pb was higher in sandy soil as compared to clay loam soil. Lead extractability suppressed due to manure application might be attributed to its complexation or chelation with organic matter. Lagerwerff (1972) studied that soil organic matter strongly adsorbed Pb, when O.M. increased the Pb decreased this is that, because Pb¹² has strong affinity to humic acid (Takenaga and Aso, 1975), usually combines with organic matter to form stable Pb-organic complex.

4.3.3.2 Carbonate bound lead (CARB - Pb)

Lead in carbonate fraction increased as a result of cattle manure application. Applied Pb was shifted toward carbonate bound fraction in both the soils. In sandy soil CARB-Pb increased from 1.72 to 1.78 and 1.90 µg g⁻¹ from 0 Pb 0 manure to 0 Pb .5% manure and 0 Pb 1.0% manure levels, while in clay loam soil at similar levels it increased from 1.95 to 2.10 and 2.25 µg g⁻¹, respectively.

4.3.3.3 Organically bound lead (OM - Pb)

Organically bound fraction was largely associated with clay loam soil than sandy soil. It increased from 0.30 to 0.45 and 0.75 due to 0, 0.5 and 1.0% manure in the absence of added Pb, however, in the presence of 80 mg Pb kg⁻¹ soil, the increase was from 2.85 to 3.15 and 3.55 µg g⁻¹ in sandy soil, respectively. In clay loam soil it increased from 1.00 to 1.20 and 1.25 µg g⁻¹ at 0 Pb and from 6.75 to 7.20 µg g⁻¹ at 80 mg Pb kg⁻¹ soil, respectively.

4.3.3.4 Manganese oxide bound lead (MnOX-Pb)

This fraction increased with Pb levels and decreased with increased in manure levels in both the soils (Table 64). This fraction was decreased from 1.06 to 0.92 µg g⁻¹ at 0 mg Pb kg⁻¹ soil and 14.80 to 13.60 µg g⁻¹ at 80 mg Pb kg⁻¹ soil due to increase in manure level from 0 to 1.0 per cent in sandy soil, in clay loam soil it decreased from 2.25 to 2.00 µg g⁻¹ and 16.00 to 14.75 µg g⁻¹ at similar levels of Pb and manure, respectively.

4.3.3.5 Amorphous Fe - oxide bound lead (AFeOX-Pb)

Amorphous Fe oxide bound Pb (Table 64) increased with increase in manure and lead levels, irrespective of the soil. The increase in this fraction due to manure was more pronounced in sandy soil compared to clay loam soil. AFeOX-Pb fraction increased by 15.3 per cent due to 1% manure without added Pb in sandy soil, while in clay loam soil, it increased by 4.9 per cent. Applied Pb was also shifted towards this fraction of Pb.

4.3.3.6 Crystalline Fe - oxide bound lead (CFeOX-Pb)

Lead in this fraction decreased in both the soils with increasing rates of applied organic matter. Depression in CFeOX-Pb due to 1.0% manure at

Table 64. Effect of Pb, cattle manure and soil texture on the distribution of applied Pb among soil fractions (before seeding)

Fractions ($\mu\text{g g}^{-1}$)	Manure (%)																										
	0									0.5									1.0								
	Pb levels (mg kg^{-1} soil)																										
	0	5	10	20	40	80	0	5	10	20	40	80	0	5	10	20	40	80									
SAND																											
EX+W	0.30	1.25	2.15	4.10	8.65	17.00	0.24	1.04	2.08	4.00	8.09	16.75	0.16	0.94	1.90	3.78	7.75	15.00									
CARB	1.72	3.20	4.78	8.20	14.35	27.60	1.78	3.30	4.92	8.80	14.95	28.50	1.90	3.45	5.15	9.00	15.45	30.00									
OM	0.30	0.60	0.72	0.90	1.65	2.85	0.45	0.80	0.90	1.10	1.95	3.15	0.75	0.90	1.10	1.25	2.15	3.55									
MnOX	1.06	1.88	2.70	4.25	7.80	14.80	1.00	1.82	2.48	4.00	7.45	14.20	0.92	1.70	2.25	3.80	7.20	13.60									
AFeOX	1.70	2.80	4.00	6.00	10.20	18.95	1.76	2.94	4.25	6.45	10.75	19.30	1.96	3.15	4.65	6.90	11.05	20.35									
CFeOX	2.40	2.68	3.10	3.55	4.40	5.25	2.10	2.58	2.80	2.95	4.00	4.85	1.90	2.40	2.55	2.75	3.75	4.35									
RES	5.02	5.08	5.05	5.40	5.45	5.95	5.00	5.02	5.00	5.17	5.25	5.75	4.90	4.95	4.90	5.00	5.15	5.65									
CLAY LOAM																											
EX+W	0.74	1.65	2.50	3.80	7.25	13.25	0.65	1.45	2.20	3.35	6.85	12.80	0.55	1.25	1.95	3.00	6.55	12.20									
CARB	1.95	3.10	4.10	7.00	11.90	23.15	2.10	3.20	4.45	7.30	12.00	23.70	2.25	3.40	4.90	7.55	12.30	24.20									
OM	1.00	1.50	1.95	2.65	4.60	6.75	1.20	1.70	2.10	2.90	4.90	6.95	1.25	1.95	2.35	3.25	5.15	7.20									
MnOX	2.25	3.05	3.95	5.55	8.30	16.00	2.05	2.88	3.75	5.35	8.00	15.30	2.00	2.65	3.50	5.00	7.75	14.75									
AFeOX	3.05	3.75	4.95	7.60	12.00	24.30	3.20	3.97	5.20	7.90	12.75	25.00	3.20	4.25	5.42	8.15	12.95	25.70									
CFeOX	4.00	4.95	5.00	5.53	7.40	7.95	3.75	4.75	4.85	5.35	7.10	7.55	3.50	4.35	4.45	5.20	6.85	7.25									
RES	6.95	6.95	7.30	7.70	8.25	8.55	7.00	7.00	7.35	7.75	8.30	8.60	7.05	7.10	7.40	7.82	8.35	8.60									

0 mg Pb kg⁻¹ soil was 20.8 and 12.5 per cent over 0 Pb 0 manure level in sandy and clay loam soil, respectively. Lead in this form was not increased more due to Pb application.

4.3.3.7 Residual lead (RES - Pb)

The residual form of Pb slightly decreased due to manure application in sandy soil but reverse was true in case of clay loam soil. This fraction was slightly changed with the addition of Pb in the soil, it increased from 5.02 to 5.95 µg g⁻¹ in sandy soil and 6.95 to 8.55 µg g⁻¹ in clay loam soil due to increase in Pb from 0 to 80 mg kg⁻¹ soil with 0% manure, respectively.

4.3.4 Effect of Pb, cattle manure and soil texture on the distribution of applied Pb among soil fraction (after harvesting)

4.3.4.1 Exchangeable + Water soluble lead (EX + W - Pb)

The EX+W-Pb fraction decreased with increasing level of manure, irrespective of the soil (Table 65). This form was more available to plant and it also decreased more after harvesting of the crop as compared to before seeding. It decreased from 0.14 and 8.33 µg g⁻¹ to 0.08 and 7.52 µg g⁻¹ at 0 mg Pb kg⁻¹ and 80 mg Pb kg⁻¹ soil due to increase in manure level from 0 to 1.0%, respectively, in sandy soil, in clay loam soil it decreased from 0.58 and 9.31 µg g⁻¹ to 0.39 and 8.88 µg g⁻¹ soil, respectively. The reduction in EX+W-Pb fraction was higher in sandy soil as compared to clay loam soil.

4.3.4.2 Carbonate bound lead (CARB-Pb)

Lead in this fraction increased as a result of application of manure. This form was also available for plant uptake, so this was reduced after harvesting as compared to before seeding samples. Added Pb to soil also

shifted in carbonate bounded fraction in both the soils. Lead in sandy soil was increased from 1.55 to 1.76 $\mu\text{g g}^{-1}$ at 0 Pb due to increase in manure level from 0 to 1.0%, similarly in clay loam soil increased from 1.52 to 1.90 $\mu\text{g Pb g}^{-1}$ at similar levels, respectively.

4.3.4.3 Organically bound lead (OM-Pb)

This form of Pb was higher in clay loam soil than sandy soil. This fraction of Pb increased with increasing rate of Pb and manure in both the soil. This form was also associated with plant availability. The increase in Pb fraction was more in sandy soil due to increase in Pb and manure level as compared to clay loam soil.

4.3.4.4 Manganese oxide bound lead (MnOX-Pb)

Lead fraction in this form was increased with Pb levels and decreased due to manure application (Table 65). This fraction was not much changed as compared to pre-seeding soil samples. MnOX-Pb fraction was decreased from 1.06 to 0.92 at 0 mg Pb kg^{-1} soil with increase in manure level from 0 to 1% in sandy and at similar level it decreased from 2.25 to 2.00 $\mu\text{g g}^{-1}$ in clay loam soil.

4.3.4.5 Amorphous Fe - oxide bound lead (AFcOX - Pb)

This fraction of Pb increased with increasing levels of Pb and manure, higher amount of carbonate bound added Pb was shifted in this form in both the soils (Table 65). This fraction increased from 1.80 to 2.10 $\mu\text{g g}^{-1}$ in sandy and from 3.35 to 3.54 $\mu\text{g g}^{-1}$ in clay loam soil at 0 mg Pb kg^{-1} soil with increase in manure level from 0 to 1%. With increase in time the fraction increased in both the soils.

Table 65. Effect of Pb, cattle manure and soil texture on the distribution of applied Pb among soil fractions (after harvesting)

Fractions ($\mu\text{g g}^{-1}$)	Manure (%)																							
	0								0.5								1.0							
	Pb levels (mg kg^{-1} soil)																							
	0	5	10	20	40	80	0	5	10	20	40	80	0	5	10	20	40	80						
SAND																								
EX+W	0.14	0.57	1.01	1.98	4.18	8.33	0.12	0.48	0.99	1.92	3.92	8.20	0.08	0.45	0.92	1.88	3.80	7.52						
CARB	1.55	2.88	4.35	7.54	13.20	25.35	1.64	3.04	4.52	8.10	13.75	26.50	1.76	3.25	4.76	8.37	14.36	28.05						
OM	0.26	0.52	0.63	0.80	1.48	2.55	0.40	0.72	0.82	0.99	1.76	2.86	0.68	0.82	1.00	1.14	1.96	3.26						
MnOX	1.05	1.85	2.67	4.20	7.72	14.65	1.06	1.90	2.50	4.20	7.50	14.30	0.92	1.95	2.35	3.85	7.25	13.70						
AFeOX	1.80	2.98	4.26	6.36	10.80	20.00	1.88	3.15	4.56	5.98	11.56	20.65	2.10	3.40	4.95	7.35	11.76	21.66						
CFeOX	2.35	2.55	3.00	3.45	4.40	5.20	2.12	2.60	2.84	2.98	4.10	4.90	1.90	2.42	2.58	2.80	3.82	4.45						
RES	5.05	5.05	5.08	5.45	5.50	6.00	5.10	5.12	5.08	5.27	5.25	5.85	4.95	4.95	4.98	5.05	5.20	5.72						
CLAY LOAM																								
EX+W	0.58	1.17	1.82	2.68	5.18	9.31	0.48	1.03	1.55	2.36	4.90	9.15	0.39	0.90	1.42	2.18	4.75	8.88						
CARB	1.52	2.50	3.50	5.75	9.52	19.82	1.72	2.60	3.65	5.96	9.78	20.00	1.90	2.82	4.03	6.18	10.05	20.37						
OM	0.90	1.32	1.75	2.38	4.23	6.18	1.08	1.54	1.92	2.64	4.45	6.28	1.14	1.85	2.11	2.94	4.70	6.58						
MnOX	2.18	3.00	3.75	5.35	8.10	15.00	2.02	2.85	3.70	5.30	8.00	15.30	2.00	2.55	2.45	4.92	7.68	14.65						
AFeOX	3.35	4.20	5.55	8.50	13.35	26.24	3.48	4.37	5.82	8.82	14.08	27.25	3.54	4.68	6.00	8.92	14.18	28.16						
CFeOX	4.00	4.90	4.90	5.50	7.35	7.85	3.75	4.75	4.80	5.28	7.00	7.55	3.48	4.35	4.45	5.10	6.80	7.20						
RES	6.85	6.85	7.25	7.60	8.00	8.55	6.92	6.92	7.30	7.68	8.22	8.55	7.00	7.00	7.35	7.78	8.30	8.50						

4.3.4.6 Crystalline Fe - oxide bound level (CFeOX-Pb)

The crystalline Fe oxide bound lead was not changed much after harvest when compared with before seeding. This fraction decreased in both the soils with increase in manure levels and slightly increased with addition of Pb levels.

4.3.4.7 Residual lead (RES-Pb)

This form was slightly changed due to Pb as well as manure application. With change in time, it almost remained the same in both the soils.

CHAPTER-5

SUMMARY AND CONCLUSION

The beneficial effects of phosphate and organic matter in reducing extractable Pb in the soils and its uptake by plants provide a basis for adopting management practices to lessen the potential hazard of Pb-contaminated soil. Laboratory and screenhouse experiments were, therefore, carried out to study the "Lead bioavailability to wheat as influenced by phosphorus, cattle manure and soil texture".

5.1 Screen house experiments

Screen house experiments were conducted to study the effect of phosphorus (0, 25, 50 and 100 mg P kg⁻¹ soil) and cattle manure (0, 0.5, 1.0%) with different Pb levels (0, 5, 10, 20, 40 and 80 mg kg⁻¹ soil) on yield, chemical composition and nutrient availability to wheat crop. The wheat crop (var. WH-533) was harvested at maturity. The matured wheat crop were partitioned into straw, grain and roots. The results are summarized below :

5.1.1 Effect of Pb, P and soil texture on yield and nutrient availability to wheat

Initial level of Pb 5 mg kg⁻¹ soil in sandy and clay loam soil had beneficial effect on grain, straw and root yield of wheat, however, higher rates of Pb had a significant depressing effect on yield. Relative yield (%) of wheat tissue increased with lower levels of applied Pb and alleviated with increasing rate of Pb in both the soils.

In general, application of P either alone or in combination with Pb augmented yield of wheat grain, straw and root in sandy and clay loam soil.

The differences among various added P levels were found significant in both the soils. The results showed that response to added P was more pronounced in sandy soil and the magnitude of response was higher with 25 mg P kg⁻¹ soil as compared to other P levels, over no P treatment.

Application of Pb, resulted in a significant increase in its concentration and uptake by grain, straw and root of wheat. Lead uptake by different parts of wheat was higher in clay loam soil while, the concentration was higher in sandy soil raised plants. Roots of wheat accumulated more Pb than grain and straw.

Application of P significantly reduced the Pb concentration in wheat tissue, which varied significantly with soil texture. The Pb x P interaction on Pb concentration was significant in both the soils. In general, phosphorus application enhanced Pb uptake by wheat grain, straw and root over control but the effect of P varied with soil texture, however, uptake of Pb decreased at 100 mg P kg⁻¹ soil when compared with 50 mg P kg⁻¹ soil. The results depicted that interaction effect of Pb and P on tissue Pb was more in sandy than clay loam soil.

All the fractions^{of Pb} of the pre-sowing soil samples were significantly correlated with Pb uptake by wheat plant parts, being higher in clay loam soil as compared to sandy soil. In sandy soil amorphous Fe-oxide bound fraction showed the highest ($r = 0.84^{**}$) correlation with Pb uptake by grain and straw. The correlation coefficients of Pb uptake by root with Pb fraction was highest with amorphous Fe-oxide bound in sandy and residual bound in clay loam soil, respectively. The various pools of Pb in the soil are probably in dynamic equilibrium with each other.

Phosphorus concentration and uptake by wheat grain, straw and roots of wheat increased at lower levels of Pb and decreased at higher levels irrespective of soil texture. Application of P significantly elevated its concentration and uptake by wheat plant parts. The effect of P x Pb interaction was significant and Pb had antagonistic effect on P concentration and uptake by wheat grain and straw and synergistic with root.

By and large Pb application restricted the translocation of Zn, Fe and Mn to shoot and grain by enhancing accumulation of these elements in roots. In contrast Cu absorption decreased in all the plant fraction. The reduction in Zn and Mn concentration of wheat tissue due to Pb was higher in clay loam than sandy soils but reverse was true with Fe and Cu.

Application of P alone or in conjunction with Pb alleviated the concentration of Zn, Fe and Cu in wheat grain and straw, but roots, Mn was increased due to P application in all plant parts of wheat.

DTPA-extractable Pb increased significantly with increasing levels of Pb in pre-sowing and post-harvest soil samples. However, their extractability was higher in sandy soil than in clay loam soil. Application of P decreased DTPA-Pb in soil significantly and magnitude of depression due to P application varied with soil texture. Therefore, P had a antagonistic effect on extractable Pb in soil.

Olsen's extractable P in pre-sowing and post-harvest soil samples decreased due to increasing level of Pb. Application of P significantly elevated extractable P in both the soils. The magnitude of increase in available P due to its application was more pronounced in sandy soil.

5.1.2 Effect of Pb, cattle manure and soil texture on yield and nutrient availability to wheat

Also, in this experiment, the initial rate of lead (5 mg kg^{-1} soil) escalated yield of all fractions of wheat, while higher levels of Pb had depressing effect on yield. The per cent relative yield of wheat increased with 5 mg Pb kg^{-1} soil and decreased at higher levels in both the soils.

Application of manure markedly improved wheat yield and addition of 1.0% cattle manure almost eliminated adverse effect of 40 mg Pb kg^{-1} soil in both the soils. Combined application of 1.0% manure and 80 mg Pb kg^{-1} soil resulted in higher grain yield over 80 mg Pb kg^{-1} soil. Adverse effect of 80 mg Pb kg^{-1} soil on shoot yield was counteracted by adding 0.5% manure in both the soils. It is deduced that application of manure was more effective in off-setting the harmful effects of Pb on yield, particularly at higher Pb levels.

Similar to previous experiment, Pb concentration and uptake increased by wheat tissue with its increasing levels in soils. Application of manure significantly depressed grain, straw and root Pb, which varied significantly with soil texture. Thus, cattle manure has a antagonistic effect on Pb concentration in wheat tissue. In both the soils, Pb uptake increased as a result of 0.5% manure, but 1.0 per cent manure depressed it. Uptake of Pb by roots increased with manure and Pb application.

Like previous experiments, all corresponding values of correlation coefficients are better correlated in clay loam soil than sandy soils in this experiment also. The highest correlation coefficient of Pb uptake by wheat grain, straw and root with different fraction was CFeOX ($r = 0.90^{**}$), CARB

and AFeOX bound in sandy soil and corresponding it in clay loam soil were residual bound ($r = 0.96^{**}$) with grain and organically bound with straw and root, respectively.

Application of Pb alleviated Zn, Mn and Fe content in wheat grain and straw, and increased their concentration in roots. Generally, Pb application reduced Cu concentration significantly at 10 mg Pb kg^{-1} soil in wheat tissue. The lower levels of Pb had some what additive effect on Cu concentration, while higher level of Pb had antagonistic effect.

Application of manure with or without Pb augmented Zn and Fe concentration in roots, shoot and grains of wheat, in contrast Mn increased in shoot and grain but decreased in roots, irrespective of the soil. Addition of manure either alone or in combination with Pb levels repressed. Cu concentration in wheat plant tissue.

DTPA extractable Pb increased significantly and consistently with graded rate of Pb in pre-sowing and post-harvest soil samples. However, DTPA extractability of Pb was significantly lower in clay loam as compared to sandy soil. The extractability of Pb was affected significantly due to Pb manure interaction in both the soils. Application of Pb without manure increased DTPA-Pb significantly, while, manure alone showed significant depression in both the soils.

5.2 Laboratory experiments

A laboratory study was conducted to assess the effect of phosphorus and cattle manure on various chemical fraction of Pb and their bioavailability to wheat. Soil texture, Pb levels, P levels and cattle manure rates were same as in screen house experiments.

5.2.1 Effect of P, cattle manure and soil texture on various chemical fraction of Pb and their bioavailability to wheat

All fractions in both soils were increased with increasing level of Pb. Lead decreased in exchangeable + water soluble, organically bound and crystalline Fe-oxide fractions, but increased CARB, MnOX, AFeOX fractions due to P application in both the soils. Added Pb in soil mostly shifted toward CARB, MnOX and AFeOX bound fractions in sandy and clay loam soils. While, there was little change in residual bound fraction due to Pb and P application in both the soils. All Pb-fractions were higher in clay loam soil than sandy soil. By and large, analysis after harvest showed that Pb was consumed by the crop from EX + W, CARB and OM bound fraction in both the soils. Application of cattle manure decreased EX + W, MnOX and CFeOX bound fraction and increased CARB, OM and AFeOX bound in both the soils. Added Pb was also shifted towards CARB, AFeOX and MnOX bound forms in both the soils. Organically bound Pb fraction was increased due to manure more in clay loam soil than sandy soil. Residual and crystalline Fe-Oxide bound fraction was less affected due to Pb as well as manure addition. The decrease in EX+W, CARB, OM, MnOX and CFeOX bound forms after harvest of the crop. Mainly exchangeable + water soluble and carbonate bound fraction were used by the crop.

In conclusion, heavy texture soil can be used as a sink to reduced Pb absorption by plants. The finding, signify that increased use of phosphorus and application of organic waste (manure) are capable of detoxifying the adverse effect of Pb on plant growth.

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ANNEXURE - 1

Relative yield (%) of different plant parts of wheat as affected by Pb, P and soil texture

Soil	P applied (mg kg ⁻¹ soil)	Rate of Pb application (mg kg ⁻¹ soil)					
		0	5	10	20	40	80
Grain							
Sand	0	100.00	108.64	93.48	87.42	86.36	85.30
	25	100.00	107.16	100.27	94.27	93.37	91.58
	50	100.00	102.44	90.35	89.03	85.92	75.35
	100	100.00	88.04	83.88	82.64	77.93	73.59
Clay loam	0	100.00	108.00	104.75	101.69	92.19	86.73
	25	100.00	107.03	99.85	96.83	94.32	87.94
	50	100.00	107.18	100.14	92.97	90.09	85.79
	100	100.00	102.06	93.72	88.21	87.58	83.86
Straw							
Sand	0	100.00	111.27	108.78	106.88	99.67	96.35
	25	100.00	105.42	102.93	99.29	98.21	87.52
	50	100.00	110.30	108.94	103.18	101.68	92.92
	100	100.00	97.37	86.48	84.60	81.75	78.97
Clay loam	0	100.00	109.31	100.14	97.95	91.43	84.77
	25	100.00	105.73	100.40	96.18	95.10	94.59
	50	100.00	103.29	101.51	100.00	98.86	97.61
	100	100.00	102.12	101.80	99.45	95.59	93.88
Root							
Sand	0	100.00	125.80	100.00	87.09	83.87	80.64
	25	100.00	103.77	94.34	92.45	83.01	79.24
	50	100.00	101.51	92.42	84.84	77.27	69.69
	100	100.00	98.59	91.55	83.09	78.03	70.98
Clay loam	0	100.00	106.55	98.36	89.50	74.42	63.93
	25	100.00	103.07	96.92	87.69	81.23	77.84
	50	100.00	110.14	106.66	104.05	101.45	93.91
	100	100.00	98.70	96.10	94.80	92.98	88.31

ANNEXURE - 2

Relative yield (%) of different plant parts of wheat as affected by Pb, cattle manure and soil texture

Soil	Manure applied (%)	Rate of Pb application (mg kg ⁻¹ soil)					
		0	5	10	20	40	80
Grain							
Sand	0	100.00	102.44	90.35	89.03	85.92	75.35
	0.5	100.00	100.75	96.70	91.33	84.97	78.61
	1.0	100.00	98.56	93.18	90.57	86.69	80.03
Clay loam	0	100.00	107.18	99.66	92.97	90.09	85.79
	0.5	100.00	105.95	102.67	93.15	92.69	90.48
	1.0	100.00	103.86	99.01	95.58	87.44	86.88
Straw							
Sand	0	100.00	110.30	108.94	103.18	101.68	92.87
	0.5	100.00	100.40	99.32	98.29	95.22	91.63
	1.0	100.00	100.00	97.61	96.75	96.26	94.62
Clay loam	0	100.00	103.29	101.51	100.00	98.86	97.61
	0.5	100.00	103.00	101.91	99.02	97.69	96.02
	1.0	100.00	102.45	101.05	96.15	94.05	93.70
Root							
Sand	0	100.00	101.51	92.42	84.85	77.27	69.70
	0.5	100.00	100.53	97.87	86.13	84.80	78.40
	1.0	100.00	100.00	96.07	92.93	85.34	80.63
Clay loam	0	100.00	110.14	106.67	104.06	101.45	93.91
	0.5	100.00	100.52	98.17	96.60	95.04	90.60
	1.0	100.00	101.51	99.50	95.97	93.20	91.18

