CONCLUSIONS AND DISCUSSION

The present study was aimed to develop a technique for remediation of contaminated soil with heavy metals with the help of plants. Studies were carried out into pots filled with the soil mixed with heavy metal Cd and soil amendments. The experiments were carried out to determine the efficiency for the removal of Cd by six plant species viz Raya, Toriya, Rijhka, Bathua, Oat and Barley. The soils were characterized for initial concentration of Cd and different physico-chemical parameters and they are shown in table 3.1 and 3.2. In the same way various types of water which were used for irrigation were also analysed and results are shown in table 3.3 to 3.5.

Thus, the success of phytoextraction, an environmental clean up effort depends to a large degree on the identification of suitable plants that not only concentrate metals to levels that would not inhibit growth of plants, demonstrate prolific growth with established agronomic practices. The efficacy of phytoextraction as a viable remediation technology is still being explored, though the results are positive. This study provides a promising start for biomass based phytoextraction as it includes high biomass producing species and growing these species is practically easier than growing hyper accumulators. Phytoextraction as well as agronomic practices for sustaining high shoot biomass production should be further explored.

Studies were carried out on soil mixed with amendments like sludge, fly ash and lime. The experiments were also carried out to determine the effects of all these amendments on removal of Cd by all the six plant species. The Raya is widely used for the removal of the contamination from soil and showed better results in the remediation of contaminated soil.
Experiments were carried out using soils rather than solutions are considered as more closely to natural conditions, where the effect of soil buffering capacity influences nutrient availability to plants. The goal was to develop the heavy metal removal technique in natural conditions of the soil. It was observed that Cd affects all the growth parameters of the plants. In present experiments biomass was greatly reduced with external cadmium levels.

The dry matter yield and accumulation of Cd by six plant species grown in sandy loam soil have been determined. Plant species showed reduced biomass when grown in high Cd concentration contaminated soil. The accumulation of cadmium increased with the increase in Cd concentration in soil.

Being an environmental clean up effort phytoextraction depends to a large degree on the identification of suitable plants those are not only able to concentrate metals but demonstrate high biomass yield with established agronomic practices. The results in present study are also positive. This study provides a promising start for biomass based phytoextraction as it includes some high biomass producing species also. Moreover growing of these species is practically easier than producing hyper accumulators.

The data of dry matter yield of different species as affected by Cd treatments are presented in table 4.1, 4.5, 4.9, 4.13, 4.17, 4.21, 4.25, 4.29, 4.33, 4.37, 4.41 and 4.45. It was observed that the application of Cd decreased the dry matter yield in all the species. Application of the 20, 40, 60 and 80 mg kg\(^{-1}\) soil, decrease the yield percentage in a gradual manner as compared to control. The decrease in stem dry matter yield was also reported in the same way as compared to control in 20, 40, 60 and 80 mg kg\(^{-1}\) soil, treatments. However, the magnitude of decrease in stem yield varied with different species. The overall dry matter yield of stem was highest in Raya, where as it was lowest in Rijhka.
The data on the leaf dry matter yield of different species as affected by Cd treatments are presented in table 4.2, 4.6, 4.10, 4.14, 4.18, 4.22, 4.26, 4.30, 4.34, 4.38, 4.42, and 4.46 which shows that the application of different levels of Cd has not much effect up to 40 mg kg\(^{-1}\) soil, but further increasing the dose of Cd resulted in the reduction of dry matter yield. Further, increase in Cd amount (after Cd 40 mg kg\(^{-1}\)) showed much adverse effect on dry matter yield of leaves. There was a gradual decrease in percent in dry matter yield of leaf with the application of 20, 40, 60 and 80 mg Cd kg\(^{-1}\) soil, respectively.

The data in table 4.1, 4.5, 4.9, 4.13, 4.17, 4.21, 4.25, 4.29, 4.33, 4.37, 4.41 and 4.45 revealed that there was a little seed yield decreases in all the plant species upto 40 mg Cd kg\(^{-1}\) soil, whereas the seed yield decreased much at the 60 and 80 mg Cd kg\(^{-1}\) soil than control. The impact of the cadmium concentration and soil amendments on dry matter yield of above ground parts (stem, leaf and seed) was due to transportation of Cd with sap flow. It is the only reason behind the impact of cadmium toxicity to the plants that results in the decrease in biomass of shoot also.

As shown in table 4.3, 4.7, 4.11, 4.15, 4.19, 4.23, 4.27, 4.31, 4.35, 4.39, 4.43 and 4.47 the various treatments led to higher Cd concentration in various plant parts. In this study it was observed that plants were not highly affected with 20 mg Cd kg\(^{-1}\) soil but the treatment of 40, 60 and 80 mg Cd kg\(^{-1}\) soil affected the growth in more adverse way. Plants have shown a good potential for phytoextraction of cadmium contaminated soil and so these plants can be used for decontamination for metal contaminated sites like mining and industrial waste affected areas.

Results show that Cd concentration in different plant parts was depending on the concentration of heavy metals in soil. Based on these results, it may be concluded that all these six species can successfully uptake Cd from
the contaminated soil. The concentrations of the Cd in plant parts were affected due to variation of Cd concentrations in the soil. Raja, Toriya, Rijhka, Bathua, Oat and Barley plants were able to accumulate cadmium. These plants actively remove Cd from soil and translocate it from roots to the shoots in a similar way as per the mechanism suggested for heavy metal hyperaccumulator plant species.

In the present work phytoextraction potential and differential tolerance to the Cd stress was studied. Amendments added to soil enhances the mobility of Cd concentration in shoots of all the plant species. But it could be used as a solution to remedy the Cd contaminated soil without the application of any chemical. The soil of the field should be characterized for background concentration in terms of different physico-chemical parameters as shown in table 3.1 and 3.2.

All the amendments enhanced the growth of all the six plant species because it is helpful to develop symbiotic relationship with plants root ligaments. The growth of the plants with amendments treatment showed a better result in phytoremediation. The plant growth was more affected by Cd without any amendment. As all the plant species have shown a good potential for phytoremediation of Cd contaminated soil. So these plants can be used for decontamination of metal contaminated sites like mining and industrial waste affected areas.

As shown in table 4.4, 4.8, 4.12, 4.16, 4.20, 4.24, 4.28, 4.32, 4.36, 4.40, 4.44 and 4.48 the various treatment led to higher Cd plant concentration. In this study it was observed that increase in Cd concentration in various plant parts was not so high upto 20 mg Cd kg\(^{-1}\) soil but the treatment of 40, 60 and 80 mg Cd kg\(^{-1}\) soil results in the increase of Cd concentration in several folds.
Results show that the variation of Cd concentration in different plant parts was depending on the concentration of heavy metals in soil, amendment type and type of irrigation water. Based on these results, it may be concluded that all these six species can successfully uptake Cd from the contaminated soil, if amendments are used in proper ratio. The concentrations of the Cd in plant tissues were affected by the concentrations of the Cd in the soil. Raya, Toriya, Rijhka, Bathua, Oat and Barley plants were able to accumulate cadmium.

The reason behind the increase in Cd concentration in shoot is its transportation from root to shoot. Cadmium concentration in different plant parts varied markedly with plant species and increased with increasing in Cd concentration. The data regarding the concentration of cadmium in various plant parts showed that Cd concentration in root of all the species increased with the highest rate of applied Cd over control. The concentration of cadmium increases in stem, leaf and seed were also in the similar way of roots i.e. it increase with the highest rate of applied Cd over control. So it can be concluded that the cadmium concentration and soil amendments results in higher cadmium concentration in stem, leaf and seed (above ground parts) also.

Cadmium concentration in different plant parts varied markedly with plant species and increased with increase in Cd concentration in respective pots. Generaly highest mean Cd concentration was found in Raya while the lowest was found in roots of Rijhka. The magnitude of Cd concentration increase in roots of all the plant species was varied with the species and Cd concentration in pots.

In Raya and Toriya Cd concentration was almost similar in this study; Raya had higher potential to accumulate Cd than the other plant species. There was less Cd accumulation in roots of Rijhka, Bathua, Oat and Barley as compared to Raya. In case of controlled plants, Barley accumulates highest Cd
concentration in roots whereas at 80 mg Cd kg\(^{-1}\) soil, it was in Raya. The Cd concentration in the root of Oat and Barley was near about same even in all the Cd treatments.

The over all Cd concentration was highest in the stem of Raya followed by Toriya where as it was lowest in Bathua. Rijhka accumulates highest Cd concentration at control among all the species but at level of 20, 40 and 60 mg Cd kg\(^{-1}\) soil, the maximum concentration was recorded in Raya. Higher concentration of Cd in roots with respect to stem, leaves and seed of different species at different Cd levels tried demonstrats that there is limited transport of this element from root to shoot.

Cadmium concentration in different plant parts varied markedly with plant species and increased with increase in Cd concentration in different pots. The data presented in tables 4.3, 4.7, 4.11, 4.15, 4.19, 4.23, 4.27, 4.31, 4.35, 4.39, 4.43 and 4.47 showed that Cd concentration in various plant parts of all the species increased upto the highest rate of applied Cd over control. The highest mean Cd concentration was found in Raya while the lowest was found in roots of Rijhka. The magnitude of Cd concentration increase in root was varied with the species.

It was further observed that Cd concentration in stem increased as a consequent of increasing rate of Cd. The increase in Cd concentration was reported in several times at 20, 40, 60 and 80 mg Cd kg\(^{-1}\) soil, respective as compared to control. However the magnitudes of increase in stem concentration varied with different species. The over all Cd concentration was highest in the stem of Raya followed by Toriya where as it was lowest in Bathua. Rijhka accumulates highest Cd concentration at control among all the species but at level of 20, 40 and 60 mg Cd kg\(^{-1}\) soil, the maximum concentration was recorded in Raya. It is interesting to note that root had
higher concentration of Cd than in stem, leaves and seed of different species at different Cd levels, demonstrating that there is limited transport of this element from the root system to the above ground parts.

Cd concentration in leaf was also affected by different levels of cadmium application. Application of 20, 40, 60 and 80 mg Cd kg\(^{-1}\) soil resulted in several fold increase in Cd concentration respectively over control. However, the magnitude of increase varied with in the species. The mean Cd concentration in Raya was greater than the Toriya, Bathua Oat and Barley but less than Rijhka. The mean Cd concentration in seed increased with increasing levels of Cd. However, the magnitude of increase in Cd concentration varied with the species. The increase in Cd concentration in seed was also noticed in several times more at 20, 40, 60 and 80 mg Cd kg\(^{-1}\) soil, respectively as compared to control. Among the species the maximum Cd accumulated in Raya seeds.

The results indicated that there was increase in the biomass yield in the amended soil, over the sandy loam soil. The highest dry matter yield of Raya was also recorded in the amended soil and irrigated with waste water irrigated soil. Similar trend was observed in Toriya, Oat, Bathua, Rijhka and Barley. The reduction in the yield with cadmium application was mainly due to its toxic effects on the plant growth.

In this study, the response of different plant species towards the application of Cd varied considerably in the sandy loam soil. In the sandy loam soil, Cd\(_0\), to Cd\(_{80}\) treatment the mean root dry matter yield decrease with a large variations. The maximum decrease in the mean dry matter yield was at Cd\(_{80}\) treatment as in sandy loam soil. As compared to Cd\(_0\) the overall reduction in the mean stem and leaf dry matter yields was more in Cd\(_{80}\) level. Species
showed variability in their mean dry matter yield, irrespective of soils and Cd levels.

The dry matter yield was the highest in Raya, which was followed by Toriya, Barley, Oat, Bathua and Rijhka. Results from table 4.1 to 4.8 shows that increase in Cd concentration decreases the dry biomass which is also observed by several scientists, so results are similar to the previous researches. Several researchers observed that the low Cd concentration has some beneficial effects on plant growth. Although the decrease in yield at higher level of Cd is mainly due to toxicity. Gradual decrease in crop yield with increasing levels of Cd was also reported by several researchers and the effect was attributed to factors like reduced photosynthesis rate.

Juwarkar and Shendi (1976) reported that reduction (32%) in the grain yield of wheat occurred at a level as high as 400 mg kg$^{-1}$ soil, applied Cd through Cd enriched sewage sludge. The reductions in crop yield due to cadmium application are in agreement with the findings of Gupta et al. (1989). Similarly He and Singh (1994) also found significant yield reduction with soil added Cd in Oats.

The yield of different plant parts (viz., root, stem, leaf and seed) of the six species taken in this study was more in amended soil and waste water irrigated pots at comparable levels of added Cd. The beneficial effect of such combinations may be ascribed to the (i) improvement in the physico-chemical and biological environment of growth medium, (ii) additional supply of essential nutrients, (iii) and possible decrease in toxic effect of added Cd through organo-metallic complexation reactions in soil.

The apparent complexing and slow release of Cd to root system alleviates its toxicity even though the absolute amount may be greater in the
larger and more vigorous plants. This is probably a result of dilution of the absorbed Cd in a larger biomass of plant tissues. Severe stunting of growth and toxicity occurs when the Cd in the rooting medium is readily available in the soil solution or when the concentration exceeds the complexing capacity of the soil.

The successive additions of Cd in soils resulted in a decrease in the yield of different plant parts (viz., root, stem, leaf and seed) of different species. Cadmium being toxic to plant, its increased concentration in soil reduces growth and impairs metabolism. The toxicity symptoms were observed in plants at higher Cd levels. It is, however, not certain whether the toxicity symptoms exhibited by the plants were solely due to the excessive levels of Cd in the plant tissue or due to ionic imbalances involving other essential elements. The beneficial effect of sewage waste water irrigation and adverse effect of Cd on different crops have also been reported by several workers.

Several Brassica species moderately enhance Cd accumulation and are most effective in removing Cd from the contaminated soil and suggested for phytoremediation of polluted soil. Data in present study shows that Cd accumulated largely in roots than in shoots. The increase in Cd concentration due to cadmium application has also been reported by several workers. Hyper accumulation of potentially phytotoxic metallic elements is a phenomenon which has been found in a wide range of plant families for Cd and several other heavy metals. The phenomenon has presented possibilities for exploitation in the remediation of metal polluted soils. Many of the metal accumulating plants are member of the Brassicaceae family.

Whereas contradictory results have been reported by Lambrecht et al. (1999) stating that extraction of Cd by Indian mustard and B. rapa was low in contaminated soil. The effect of chelator application was very limited and
indicated that heavy metal binding forms in contaminated soils were different. Therefore, it is necessary to find means to improve the metal uptake from contaminated soils or to modify plants genetically to improve metal extraction and biomass production. Results suggest that Brassicaceae (e.g. Turnip, Indian mustard or white mustard) could be the most effective in Cd phytoextraction in contaminated soils.

The relative concentration of Cd in different plant parts varied markedly with plant species and increased with increasing rates of cadmium application. The data presented in tables showed that Cd concentration in root, stem, leaf and seed of all the species increased over control. However, the Cd concentration significantly varied between species and application Cd concentration. Raya was having higher concentration than all other plant species.

It is evident from the data that Raya performed better as compared to Toriya. These findings are in agreement with those of suggestions that Brassica may be more effective species such as B. juncea, B. napas and B. rapa which have been shown to accumulate moderate levels of heavy metals. In the present study plant biomass decreased with Cd treatments which coincides with earlier studies obtained by Cd, Cu and Al treatments. Cd supply markedly increased the Cd concentration of all plant parts. Roots of all the plant species shows the highest Cd-concentrations at all Cd levels.

A perusal of data in table 4.3, 4.7, 4.11, 4.15, 4.19, 4.23, 4.27, 4.31, 4.35, 4.39, 4.43 and 4.47 revealed that Cd concentration in different plant parts of all the species increased significantly with increasing levels of cadmium application. The Cd concentration in different plant parts was about many times higher at different higher concentration of Cd kg^-1 soil, as compared to control; however, the magnitude of increase in Cd concentration varies between
species. Higher concentration of Cd was found in Raya as compared to other species.

Table 4.3, 4.7, 4.11, 4.15, 4.19, 4.23, 4.27, 4.31, 4.35, 4.39, 4.43 and 4.47 revealed the Cd concentration in different plant parts depends on the concentration of heavy metals in soil, soil type and presence of chelator. Based on these results, it may be concluded that all these six species can successfully uptake Cd from the contaminated soil. The concentrations of the Cd in plant tissues were affected by the concentrations of the Cd in the soil and the use of chelator. Therefore, the Raya, Toriya, Rijhka, Bathua, Oat and Barley plants actively removes Cd from soil and translocate it from roots to the shoots in a similar fashion to the mechanism suggested for heavy metal hyper accumulator species.

The Cd concentration in shoots of Raya increased dramatically as the soil Cd concentration increased. Quite a number of studies claimed that EDTA assisted heavy metal phytoextraction might provide a cost effective soil decontamination strategy. These findings corroborate with those of who indicated that heavy metals usually accumulate more in root than aerial parts, most of Cd was retained in roots and little was translocated to shoot.

Plants commonly employed for phytoremediation combine a high biomass plant, rapid growth, and high hyper accumulation, such as Oat (Avena sativa), Barley (Hordeum vulgare), and Indian mustard (Brassica). Most plants that survive in toxic soils do so by either, avoiding heavy metals or hyper accumulating them in their tissues. Such plants are in common and to date, approximately 400 hyper accumulator species have been identified. Phytoremediation using Indian mustard (Brassica juncea) has been used to reduce Pb levels under field conditions.
Metal hyper accumulator plants have great potential as phytoextraction of Cd and Pb from contaminated soil. According to the observation of a scientist, *Cadaminopsis hallari* is a hyper accumulator of Cd. The current approaches for the phytoremediation of metals contaminated environmental contaminated areas for the extraction of metal for recycling or less expensive disposal.