GENERAL DISCUSSION

*Parthenium hysterophorus* is an aggressive exotic weed that has invaded almost every part of India. It is commonly found in vacant spaces, farms, disturbed sites, plantations, cultivated fields, roadsides, railway tracks etc. It reduces the crop productivity, deteriorate human and animal health, environment and natural biodiversity through its prolific growth, large number of seed production, rapid growth in adverse environmental conditions and its strong allelopathic properties (Evans, 1997). The water-soluble allelochemicals such as phenolic acids and sesquiterpene lactone parthenin are involved in allelopathic responses (Kanchan, 1975; Picman and Picman, 1984). Although, allelopathic phenomenon in *P. hysterophorus* has been well documented, but the effect of its residues is yet to be explored. Thus in the present investigation, phytotoxic nature of different types of residues (above ground, below ground (roots), burnt and decomposing) and their effect on soil characteristics have been studied. The results of the study in the light of available literature can be generalized and discussed as under:

1. **Invasive nature of *P. hysterophorus* in relation to its growth parameters**

*P. hysterophorus* is fast growing weed that completes two major flushes of its life cycle in a year. Its presence throughout the year in Chandigarh and surrounding areas is indicative of its naturalization. However, its incidence and dominance is maximum during the rainy season. Its invasive nature can be judged from its morphological and ecological parameters. In the present study, it can be seen that growth parameters of weed such as average length of above ground and below ground parts, number of leaves/plant, secondary roots/root and fresh and dry biomass of different parts both at pre- as well as post-flowering stage favours its fast spread. Further, the rhizosphere area increases nearly three times from pre- to post-flowering stage. The results are in
conformity with the earlier reports on the growth parameters of the weed that favours its quick spread (Kohli and Rani, 1994; Arora, 1999; Batish et al., 2002a).

The weed also possesses a strong reproductive potential, as number of seeds produced per plant is quite high. Navie et al. (1996) reported 25,000 seeds per plant. Its seed bank is estimated to be 2,00,000 seeds/m² in abandoned fields in India (Joshi, 1991). Seeds being extremely small in size get easily disseminated by various agencies like air, water, animals etc. and remain viable for a long period and grow under a wide range of ecological conditions (Williams and Groves, 1980). However, moisture is the only limiting factor for its germination (Haseler, 1976; Hedge and Patil, 1980). Vegetative propagation through cut or clipped stems still attached to the roots is also very common.

Whitish hairs i.e. trichomes covering the whole body of the plant, are also more at pre-flowering compared to post-flowering stage. They are more on the abaxial surface than the adaxial surface of the leaf. Reduction in their number from pre- to post-flowering stage can be attributed to their falling off with the age of the plant. Trichomes have been reported to be storehouse of parthenin – a major sesquiterpene lactone found in the weed (Sahu, 1982).

2. Phytotoxic nature of rhizosphere soil of *P. hysterophorus*

In the present study, rhizosphere soil of *P. hysterophorus* was found to be phytotoxic in nature. The growth of other plants grown in the soil was reduced. To explore this, growth studies were conducted in the rhizosphere soil of *P. hysterophorus*. Maximum growth retardatory effect was observed in *Cicer arietinum* followed by *Brassica campestris* and *Raphanus sativus* and *Brassica rapa* were least affected. This may be due to release of allelochemicals from the plant through various means like leachation, root exudation, volatilization, death and decomposition of the plant parts (Rice, 1984; Einhellig, 1985; Reigosa et al., 1999; Kobayashi, 2004). Leachation is, however, the most common and well-known method of release of chemicals from the plant. Allelochemicals identified in *P. hysterophorus* are phenolic acids and sesquiterpene lactone parthenin that are responsible for bringing growth retardatory effects (Kanchan and Jayachandra, 1980b; Kohli and Batish, 1994).
Kanchan and Jayachandra (1979a) found that root exudates of *P. hysterophorus* contain inhibitors that adversely affect the growth of wheat. Kohli and Batish (1994) have also reported the similar results. Schumacher *et al.* (1983) reported that wheat leaf and root dry weight were significantly reduced by root exudates released from *Avena fatua* plants at 2- and 4-leaf stages of development, respectively. Further, Ambika *et al.* (2003) found that the germination and growth of associated plants were reduced in *Lantana camara* infested soil, suggesting that plant produces phytotoxic root exudates. Similar results were also found with rhizosphere soil of *Ageratum conyzoides* (Singh *et al.*, 2003b), *Agropyron repens* (Friebe *et al.*, 1995), *Bidens pilosa* (Stevens and Tang, 1985), *Euphorbia prostrata* (Alsaadawi *et al.*, 1990), *Helianthus annuus* (Batish *et al.*, 2002b), *Medicago sativa* (Hedge and Miller, 1990) and *Tephrosia purpurea* (Sundaramoorthy and Sen, 1990).

Changes in the nutrient status and chemistry of *P. hysterophorus* infested soil were also studied. Increased electrical conductivity due to enriched ionic strength and increase in organic matter and macro- and micro-nutrients in the rhizosphere soil suggest that the soil was not deficient in nutrients and hence, ruled out the possibility of any resource depletion. On the other hand, phenolic content in the rhizosphere soil was quite high compared to control soil. These may be responsible for causing growth retardatory effects as they are well known plant growth inhibitors (Sequiera *et al.*, 1991; Blum *et al.*, 1999; Chou, 1999).

3. **Residue of *P. hysterophorus* is phytotoxic in nature**

*P. hysterophorus* grows quickly and completes its life cycle within a short period under favourable conditions. After the completion of its life cycle, large amount of its residue is left in the fields. Most of the allelopathic studies in the past were conducted with the fresh parts and none of these have reported the effect of naturally dried residues of the weed. Thus, the naturally dried residues (formed after the completion of its life cycle) were collected from the fields infested with *P. hysterophorus* and growth studies were undertaken to check their phytotoxicity under both laboratory and green house conditions. Aqueous extracts prepared from the residues were found to
be inhibitory towards early growth and establishment of crop plants viz. *Cicer arietinum, Raphanus sativus, Brassica campestris*, *B. rapa* and *B. oleracea*. *C. arietinum* was most sensitive crop followed by *B. rapa* and *B. campestris*. The early growth of test crops was also inhibited or suppressed when residues or their extracts were amended in soils.

Several other workers have also reported the phytotoxicity of residues formed from other plants. The residues of different *Vulpia* species (*V. bromoides* and *V. myuros*) and their plant parts exert phytotoxic effect towards the germination and growth of *Triticum aestivum* under greenhouse and laboratory conditions (Pratley, 1989; Pratley and Ingrey, 1990; An et al., 1996b, 1997, 2000a). Likewise, above ground residue of other weeds like *Ageratum conyzoides* (Singh et al., 2003b; Xuan et al., 2004), *Avena sativa* (Kato-Noguchi et al., 1994), *Cardaria draba* and *Salvia syriaca* (Qasem, 2001), *Evolvulus alsinoides* (Kato-Noguchi, 1999), *Fagopyrum esculentum* (Tsuzuki and Dong, 2003), *Lantana camara* (Ambika et al., 2003)) are also reported to be allelopathic in nature.

4. Phenolic allelochemicals present in residues are responsible for inhibitory effects

From the above discussion it is clear that residue of *P. hysterophorus* exert inhibitory effects on the crops through the release of allelochemicals in soil environment. Allelochemicals present in the residue were also found to be mainly phenolic acids besides sesquiterpene lactone parthenin (Kanchan and Jayachandra, 1980b; Kohli and Rani, 1994). Phenolic acids were present in quite high amount in aqueous extracts that are responsible for growth inhibition in the test crops. Phenolic acids identified in the residue were chlorogenic acid, ferulic acid, *p*-coumaric acid, gallic acid, syringic acid, caffeic acid, vanillic acid and *p*-hydroxybenzoic acid. Kanchan and Jayachandra (1980b) also reported a variety of phenolic acids such as ferulic acid, caffeic acid, syringic acid, gallic acid, vanillic acid and *p*-hydroxybenzoic acid besides sesquiterpene lactone parthenin present in *P. hysterophorus*. It has also been reported that parthenin is a major inhibitor for the germination and growth of plants and may be used for the management of weeds (Batish et al., 2001a,b).
In the amended soils, phenolics were found to be more in comparison to unamended control. However, their amount was less as compared to aqueous extracts. Lesser amount of phenolics in the soil could be due to the fact that upon entering the soil, these phenolics undergo a number of transformations such as adsorption to soil particles, detoxification or toxification depending upon environmental conditions (both biotic and abiotic) (Blum et al., 1999). Therefore, only a fraction of phenolics may be available in the soil (Elliot and Cheng. 1987). In the changed edaphic conditions, the inhibitory effect of test species was further increased. The studies conducted with available nutrients of amended soils reveal that pH and electrical conductivity were within the optimum range and a sharp increase was observed in various macro- and micro-nutrients in the amended soils as compared to unamended control soil. These may affect plant growth either directly or indirectly through their interference with nutrients.

5. Burning of residues exert a significant influence on allelopathic potential of the weed

As *P. hysterophorus* grows in pure and huge patches, the heaps of residues are commonly seen in the cultivated fields and other disturbed sites. To get rid of these heaps, farmers generally burn these residues. In the present study also, the residue of *P. hysterophorus* was burnt and its impact on the allelopathic potential and physico-chemical properties of the amended soils was studied. Under both laboratory and greenhouse conditions, the growth of *C. arietinum*, *R. sativus*, *B. campestris*, *B. rapa* and *B. oleracea* was significantly reduced. Mallik and Gimingham (1983) reported that burning of plants in forest systems leads to considerable reduction in species diversity with loss of grasses, forbs and lichen species and also slower recovery of bare ground. Keeley et al. (1985) reported that crop residue burning reduces the yield of succeeding crops. Other studies have also indicated the phytotoxicity of burnt residues (Giovannini *et al.*, 1990; Ball-Coelho *et al.*, 1993; Kennard and Gholz, 2001).

The pH of the aqueous extracts and amended soils prepared from burnt residues was found to be quite high and caused ash accretion. The organic matter was also decreased in amended soils compared to unamended control soil.
retarding the growth of other plants. Cationic elements (Ca, Mg, Na, K, etc.), especially K, were measured to be significantly high in the amended soils, and may likely to affect the plant. Some other workers also reported that plant growth in the burnt areas may be slowed or impaired due to high pH, depletion of organic matter and toxic levels of minerals (Raison, 1979; Giovannini et al., 1990; Garcia-Oliva et al., 1999; Kennard and Gholz, 2001) that are unavailable to the plants through the combined effects of reduced soil moisture, soil porosity, water infiltration rates and water holding capacity (Wells et al., 1979).

Burning not only caused phytotoxicity but also affected soil chemistry. At high pH, many of micro-nutrients became unavailable. Perhaps these got combined with hydroxyls and carbonates and formed insoluble precipitates. Phenolics present in the amended soils were significantly high in aqueous extracts and amended soils compared to control but quite less compared to unburnt residue. Parthenin was also identified in the burnt residue. The allelochemicals present in burnt residue were also responsible for bringing growth retardatory effects on the plants. Singh et al. (2003a) also reported similar observations.

6. Roots of *P. hysterophorus* are allelopathic too

As already discussed, *P. hysterophorus* possesses a well developed root system. It is reported that allelochemicals (mainly water-soluble phenolics) from the roots may either be released through root exudates or upon their death and decay i.e. from the root residue (Kanchan and Jayachandra, 1979a). Root residue of *P. hysterophorus* significantly reduced the growth of all the above said crops under laboratory as well as green-house conditions. The effect was concentration dependent and chemical based. Batish et al. (2003) also reported similar results. An appreciable amount of phenolics was found to be present not only in the root residue extracts but also in the amended soils that may be responsible for bringing growth retardatory effects. A variety of phenolic acids namely chlorogenic acid, ferulic acid, *p*-coumaric acid, gallic acid, vanillic acid, *p*-hydroxybenzoic acid etc. were identified. However, parthenin – a major sesquiterpene lactone in the plant was found to be absent in the root residue extracts. Root residue of
other weeds such as Ageratum conyzoides (Jha and Dhakal, 1990), Amaranthus retroflex and A. bilitoides (Qasem. 1995b,c), Avena fatua (Qureshi et al., 1987), Cardaria draba and Salvia syriaca (Qasem, 2001), Helianthus annuus (Azania et al., 2003) and Lantana camara (Ambika et al., 2003) has also been reported to be phytotoxic in nature.

7. Allelopathic potential of P. hysterophorus changes during decomposition

Decomposing residues of P. hysterophorus collected after different time periods were found to be phytotoxic in nature against test plants namely R. sativus and B. campestris. The root, shoot lengths and dry biomass were greatly reduced when grown in aqueous extracts and soils amended with decomposing residues and their extracts. The effects were concentration dependent showing a dose response relationship. The growth inhibitory effect was observed to decrease with increasing period of decomposition and at later stages, it showed growth stimulatory effects. The growth inhibitory effects were correlated to the amount of phenolics in the decomposing residues at different stages of decomposition. As decomposing rate proceeds, the amount of phenolic acids was found to decrease and was minimum after four weeks period of decomposition. Kanchan and Jayachandra (1979b) reported that leaves of P. hysterophorus mixed in soil lose their inhibitors almost completely within 30 days and the soil lacks significant inhibition after this period. Similar observations were also made by Mersie and Singh (1987b). In case of Vulpia residue, the phytotoxic activity was same to increase with increasing period of decomposition upto 60 days, and thereafter, it declined (An et al., 1996a, 2000b). Concentration of allelochemicals from decomposing plant residues has been shown to be related to phytotoxicity dynamics (Chou and Patrick, 1976; Tang and Weiss, 1978).

Not only the quantity but also the composition of the phenolic acids got changed with the passage of time during decomposition. In the six weeks old plant material, ferulic acid, p-coumaric acid and caffeic acid were found to be in negligible amounts where as, the amount of p-hydroxybenzoic acid and vanillic acid were in appreciable amounts. This indicates that complex phenolic acids get breakdown into simpler forms by microbial activity. Blum (1998) also reported that phenolic acids are readily converted from one form to another with different phytotoxicities (e.g. ferulic acid into vanillic
acid) by soil borne microbes. Phytotoxic dynamics during residue decomposition has been well documented (Shindo and Kuwatsuka, 1975a,b, 1976; Mason-Sedun and Jessop, 1988; Wojcik-Wojtkowiak et al., 1990). The amount of parthenin – a major sesquiterpene lactone of the weed also diminished after six weeks of decomposition.

Further, the amounts of macro-and micro-nutrients present in amended soils were also quite large in the residues decomposed for shorter period. It was so, especially, for those left to decomposition for one and two weeks. However, if residue was allowed to decompose for longer period, nutrients declined indicating that these leach out to lower depths of the soil. Several workers have been reported that mass and nutrient loss occurs during the period of decomposition (Douglas et al., 1980; Christensen, 1985b; Schomberg and Steiner, 1999; Collins et al., 1990a,b; Luna-Orea et al., 1996).

From the above discussion, it could be concluded that for managing the weed *P. hysterophorus* invasion and/or to remove large heaps of residues that remain in the cultivated and uncultivated fields, the burning of the weed residue is not the practical solution as it deteriorates the physico-chemical properties of the soil by making it alkaline or deficient in organic matter. On the other hand, decomposing the residue on/in the soil improves the soil quality by releasing the nutrients into the soil, reduces water run-off and soil erosion. Thus, phytotoxicity decreased with increasing the period of decomposition and it got diminished after 4 or 6 weeks.