How can we increase the coping capacity of farmers to meet the challenges of global warming, in addition to common natural calamities including disease pest, epidemics and weed problems? (Swaminathan, 2010b). The change in climatic pattern and crop production are two different entities, which determine the national economic growth. The weather changes directly influence both soil and crop factors, associated with the ultimate yield. Among climatic changes, the occurrence of drought is not a new phenomenon and it is mainly due to less rainfall (Rajagopal, 2010) in such situations, disaster management will be taken to save the people from hardships. For major food production, the country like India mainly depends on Kharif and Rabi sown crops, including cereals, millets, pulses, and oilseeds, to great extent, besides nutritionally rich vegetables.

Since, the pulses are grown under rained conditions, both the area sown and the yield mainly depends upon the available rainfall and any shortage in rains has direct adverse effect in the production (Nadarajan et al., 2010). Although, pulses or legumes as a whole are relatively tolerant to drought as compared to cereals and another crops. On the other hand, pulses are also facing the downfall due to Root Knot Nematodes (RKN), which leads to very high damage to pulse production. Simultaneously, the cost of protein in the diet is going up and only the pulses will help to end the protein hunger (Swaminathan, 2011). There are outstanding varieties of pulses available now. What is important is to multiply the good strains and cultivate them with the needed soil health and plant protection measures. We should take advantage of the growing
interest among farmers in the cultivation of pulses, both due to the prevailing high prices and these crops requiring less

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irrigation water. Such high value, but low water requiring crops also fix-nitrogen in the soil. Thus, an effective crop management system should be incorporated, which on one hand provide solution to water management and on the other hand can develop a defense mechanism in the plant itself to overcome RKN problem. This piece of work is an effort to provide answer to overcome above said problems, simultaneously suggest the use of potentiality of obnoxious weed (*Parthenium hysterophorus* L.)

**Section A**

The present investigations revealed that the different extracts of Parthenium plant invariably affected the germination parameters and seedling growth. The lower concentrations upto 80% of RE and SE, upto 60% of LE and FE initiate early germination as well as more G%, as compared to control. These findings are partially supported by the studies of Srivastava *et al.* (1985), who observed the aqueous extracts of leaves and inflorescence were more inhibitory than extracts of root and stem for germination and seedling growth of barley. The present results with promotory lower concentrations are in accordance with the findings of Oudhia (2000), Tefera (2002) and Tamado *et al.* (2002). Earlier findings made on different seed germination parameters of different crops suggested that the concentrations lower than 10% were effective or promotory, but higher concentrations reduced them (Pandey, 1994, 1996; Oudhia *et al.*, 1997 a, b; Marwat *et al.*, 2008; Rashid *et al.*, 2008). Tefera (2002) also reported that higher concentrations of Parthenium extracts reduced the seed germination and seedling growth of *Eragrostis*. 
The findings also indicated the reduction in water absorption by growing seedlings under the treatment of Parthenium extracts (PE) and it is associated with increase in G% value.

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The maximum reduction was observed with lower concentrations 20 to 60% RE (50%), 20% of SE (53.84%), 60% of LE (61.53%) and 20% of FE (38.46%), over control (Table-A and B). These findings suggest that the allelochemicals present in different parts of Parthenium are able to develop water restoration capacity in the growing seedlings and may develop the capability to withstand water scarcity in plants. Other seed germination parameters, like GRI, SpG, CVG, EI and RSG also showed an increase with lower concentrations and effective were 20 to 60% of PE. The higher concentrations of PE showed significant reduction in all these parameters. The increased GRI suggests that allelochemicals present in different parts of PE, initiated early and more G% than control. Similarly, SpG with increased values clearly indicated that the maximum germination (100%), which was reached on 3rd day with different treatments, as compared to control (9th day), also support that lower concentrations are promotory for seed germination. For CVG different concentrations of PE were promotory and only higher concentrations i.e. 160 and 200% were inhibitory, which supports that germination was induced early under the PE treatment.

Similarly, the observations on EI suggest that different extracts of Parthenium were effective with lower concentrations and the optimum was 40% of RE, SE, LE and FE, which promote the emergence of radicle and plumule. The RSG, was also enhanced with very lower concentrations (20 to 60%) and 40% proved to be optimum for seed germination. Earlier studies for promoting different seed germination parameters with very low concentrations support the present findings.
Other seedling growth parameters, like SG (cm), VI, seedling root length, shoot length, fresh and dry weights also followed the same pattern of enhancement. The root length was increased significantly with lower concentrations of RE and SE, while LE and FE showed different pattern for root length. Under LE, upto 100% concentrations were non-significant, but higher concentrations (120 and 140%) increased the length. On the other hand, all the concentrations of FE significantly enhanced the root length and only 160 and 200% were inhibitory. Similarly, the observations on seedling shoot length also showed the increasing pattern with the treatment upto 140% and it was decreased above 140%. Contrary to these findings, earlier reports showed inhibitory effect, even with lower concentrations, especially LE and FE (Kohli et al., 1985; Srivastava et al., 1985; Nath, 1988; Patil and Hedge, 1988; Swaminathan et al., 1989; Narwal, 1994; Murthy et al., 1995; Bernet et al., 2004; Kumar et al, 2006; Oyun, 2006; Ahmed et al., 2007; Kumar and Kumar, 2010; Srivastava et al., 2011).

Present studies revealed that the VI of seedlings also increased with lower concentrations upto 60% of different extracts, while 80% or above it, were either non-significant or inhibitory. These findings are contrary to the findings of different workers on different crops like okra, clover, chilli, peppers, and some pulses, etc. (Dhawan and Dhawan, 1995; Mehta et al., 1995; Murthy
et al., 1995; Oudhia and Tripathi, 1998; Wu et al., 1999; Inderjit and Duke, 2003; Weston and Duke, 2003; Sharma et al., 2009).

The results on fresh weight of seedlings showed that upto 140% of PE, it was increased and only 160 and 200% showed reduction or non-significant change, except LE, where lower concentrations (20 to 60%) reduced the fresh weight. The increasing fresh weight suggests that effect of different extracts develop the capability of seedlings to restore water. On the other hand, dry weight of seedlings showed variable pattern of increase i.e. upto 80 or 100% of RE and LE, were promotory, while all the concentrations of SE were inhibitory and only 60 % of FE was promotory. This dry matter accumulation in seedlings showed that allelochemicals present in RE were less toxic and more promotory, as compared to LE, FE and SE. The allelochemicals present in SE were initiated water restoration more as compared to other extracts, while inhibited dry matter accumulation. Other reports also suggest that positive effect of different parts of PE, but only with lower concentrations in different crop plants (Swaminathan et al., 1989, 1990; Singh and Sangeeta, 1991; Agarwal and Anand, 1992; Singh et al., 1992, Madhu et al., 1995).

Contrary to these findings many allelopathic plants showed reduction in seedling growth and biomass (Jefferson and Pennacchio, 2003; Ashrafi et al., 2007; Mutlu and Atici, 2009).

Overall, 20 to 60% of different extracts were promotory, while only 20% of FE showed the enhancement in different seed germination parameters. These concentrations were prepared from 1.4g/L basis. Contrary to these findings, earlier reports suggest even 2 to 10% concentrations prepared from 100g/L stock solution, were inhibitory for seed germination%, root and shoot length of seedlings in different crop species (Maharajan et al., 2007).
Section B

The present investigations on the effect of different extracts under lab conditions on seed germination and seedling growth parameters showed slight variations, as compared to the

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pot experiment, in which the extracts were used as foliar spray. The observations taken on growth and productivity, at three stages of plant growth and development revealed that the lower concentrations (20 to 40%) were more effective, as compared to other concentrations. The RE upto 120% showed enhancement in growth and productivity parameters, while the optimum concentration was 40% for some parameters or 80% for other parameters. SE treatment showed increase in growth and productivity parameters, upto 80% and optimum was either 40% or 80%. On the other hand, LE showed significant increase upto 80% for some parameters, while for other parameters only 20% showed the enhancement and other concentrations (40 to 140%) either showed non-significant change or reduction. Similarly, 20 to 120% of FE showed enhancement in many parameters while, 20 or 40% proved to be optimum and for other parameters only 20 or 40% showed the enhancement.

Overall, the root length and shoot length showed maximum enhancement with 40% of SE while, other extracts showed different pattern i.e. for root length the increasing pattern was 40% SE > 80% FE > 40% RE > 20% LE. For shoot length, the increasing pattern showed slight variations i.e. 40% SE > 80% RE > 80% FE > 20% LE. On the whole, the increasing pattern showed that higher concentrations (120 and 140%) were either non-significant or inhibitory for increasing the height of the plant. Earlier reports also showed similarities with the present findings for
increasing the length of the plant with lower concentrations (Mersie and Singh, 1987; Swaminathan et al., 1990; Oudhia, 1998, 1999, 2000 a, b; Tefera, 2002; Singh et al., 2002; Maharajan et al., 2007; Singh et al., 2008, 2009; Singh, 2010). Contrary to the findings, the Parthenium had inhibited the growth in many cereals, vegetables and other plant species (Singh and Sangeeta, 1991; Agarwal and

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Anand, 1992; Singh et al., 1992; Ayala et al., 1994; Madhu et al., 1995; Navie et al., 1996; Evans, 1997; Ramaswami, 1997; Khalid, 2000; Belz et al., 2007; Rashid et al., 2008).

The observations also revealed the increase in number of laterals, with lower concentrations and 40% of FE increased the maximum. The increasing pattern showed variability with increase in height of the plant, as 40% FE > 80% LE > 80% RE > 40% SE. This is almost the reversed pattern as that of other parameters of growth at different stages. The increasing number of laterals coincides with the increase in length of shoot, which ultimately provides the better growth of the plant. The earlier reports don’t support this data because of higher concentrations of extracts taken in those studies (Rajan, 1973; Kanchan 1975; Maharajan et al., 2007).

The Present investigations also revealed better leaf growth with lower concentrations of different extracts, although, RE and SE were reported to be more enhancing than LE and FE. As the number of leaves/plant showed an increase, simultaneously the fresh and dry weights were increased. The increasing pattern of number of leaves/plant, with the optimum concentrations showed 80% SE > 40% RE > 80% FE > 20% LE, but fresh and dry weights showed different pattern. The increasing pattern of weight of leaves revealed that all the concentrations of SE significantly enhanced the fresh and dry weights and the optimum was 80% for fresh weight and
40% for dry weight. Both fresh and dry weights of leaves, under RE treatment showed 80% to be optimum. Similarly, 40% of LE is optimum for increasing fresh and dry weights, but FE showed optimum 20% for fresh weight, while 40% of dry weight. This variation in fresh and dry weights of leaves showed the pattern as

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80% SE > 80% RE > 40% LE > 20% FE and 40% SE > 80% RE > 40% FE > 40% LE, respectively. The earlier studies revealed the inhibitory effect of PE on leaf growth (Pandey, 1994; Barkosky and Einhellig, 2003; Yu et al., 2003; Bajaj et al., 2004).

The increase in number of laterals, leaves, fresh and dry weights of leaves showed the ultimate effect of extracts on leaf area / plant, which was drastically increased. The increase in leaf area was more at 25 DAS than 45 and 65 DAS, which showed the effect of initial single dose on the vegetative growth of plant is more as compared to two doses at flowering stage and three doses at post flowering stage. These findings are supported by the studies of Singh (2010), on the effect of PE on leaf area of bottle ground and brinjal. The increase in leaf area ultimately affects the plant growth in terms of fresh and dry weights and total biomass of plant.

The findings indicated the promotory effect on fresh and dry weights of plant (Stem + Root) and the cumulative effect of three doses at post flowering stage is clearly visible with RE and SE, while LE and FE showed inhibitory or non-significant cumulative effect. For both the parameters, LE showed the least effect on increasing the fresh weight or inhibited the dry weight significantly. The trend from most effective extract to increased fresh weight was SE > RE > FE > LE and for dry weight RE > SE > FE > LE, showed that the lower concentrations of FE and LE were more inhibitory than higher concentrations of RE and SE. Similarly, the biomass on dry
weight basis, almost showed the same pattern as that of dry weight of plant and the maximum was observed with 80% RE, followed by 80% SE. The higher concentrations of RE and SE and all the concentrations of LE and FE were non significant or inhibitory. Earlier findings suggested that biomass production was

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suppressed with aqueous extracts of Parthenium in different crop plants ([Hsu et al., 1989; Lawrence et al., 1991; Husain and Abidi, 1991; Afzal et al., 2000]). Some findings also support the present studies partially that very lower concentrations showed stimulatory effect on biomass ([Pandey, 1994; Bajwa, 2004; Kumar and Kumar, 2010]). The above findings indicated the increase in vegetative growth with lower concentrations i.e. 20 and 40% of different extracts and 80 or 120% of RE and SE. These increasing pattern or stimulatory effect on vegetative growth was continued till productive age of the plant (65 DAS), which is clearly visible in the findings on floral initiation, number of flowers and pods, length of pods, number of seed / pod, and seed yield. The data recorded showed that lower concentrations initiated early flowering by two to five days. While, other concentrations neither delay nor showed early flowering. This pattern followed with number of flowers/ plant and showed a significant increase with all the concentrations of RE, 20 to 80% of SE, LE and FE. The similar trend was also observed for number of pods / plant, except that 40% of FE showed more pods, as compared to RE and LE. This increasing pattern on number of pods may be correlated with the leaf area under the treatments. The pattern of increase in leaf area was observed as SE > FE > RE > LE and the similar pattern was observed in number of pods.
The increasing leaf area (Fig.-1) clearly indicates that more area for photosynthesis and sink for photosynthates are developing pods and seeds at post flowering stage. Other correlative data for productivity was clearly observed as the average length of pod was increased significantly with all the treatments of SE, upto 120% of RE, 20 to 80% of PE, while, LE showed non-significant effect on it. This parameter showed the increasing pattern as SE > RE > FE > LE. As the number of pods and length of pods increased with treatments, also showed almost similar trend for number of seeds / pod and weight of 100 seeds. These observations clearly showed the cumulative effect of three spray doses of PE (20, 40 and 60 DAS), which affect the productivity in terms of 100 seeds weight.

The concentrations of different extracts, which proved to be most beneficial were 40% of RE, SE for number of seeds / pod and 100 seeds weight, while, 20% of LE and FE provide better increase in number of seed / pod and 40% of LE and FE were optimum for 100 seed weight. The seed yield / plant also showed the similar trend of increase i.e. maximum increased with 40% of all the extracts and higher concentrations were non-significant, except SE, while all the concentrations of LE, expect 40% showed non-significant increase (Fig-3). When seed yield / plant (g) was converted on per hectare basis (q) showed that upto 120% of RE and SE increased the yield, while all the concentrations of LE and FE, except 40% of FE either showed non-significant effect or significantly reduced the yield/ ha. Earlier experimental work on regulation of productivity was studied by different workers on different crops suggested the reduction in yield upto 30 to 40% (Channappagoudar et al., 1990; Swaminathan et al., 1990; Kohli and Batish, 1994), but the present studies revealed the increase in yield upto 33.42% with 40% of
extracts (0.4 g/L), even 20% of FE showed significant increase i.e. 5.61%, over control. The higher concentrations (120 and 140%) reduced the yield upto 31.0%. The earlier findings also suggest the reduction of grain filling in maize (Towers and Subba Rao, 1992; Mew et al., 1982), while the lower concentrations in present studies increased the number of seeds/pod by 3.27 to 18.62%.

It is well documented that the high densities of Parthenium significantly reduce the yield in the standing crop, even by 97.0% (Tamado et al., 2002). It has also been reported that pollen allelopathy significantly reduced the yield in many Solanaceous crops (Kanchan and Jayachandra, 1976). Few reports suggested the use of flower extract with pollen, increase the yield with lower concentrations (0.2-0.8 g/L), upto six fold increase in brinjal and three fold increase in bottle guard (Singh, 2010). The increase in crop production may be due to the establishment of plant under the treatment of different extracts, which increase the plant growth, leaf area and biomass. These traits develop the ability of plant to withstand allelopathic effect, to compete for nutrient acquisition capacity and nutrient absorption capacity by increasing root growth. The healthier plant are able to photosynthesize better and supply good amount of photosynthates to the developing pods and seeds, in terms the better yield.

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The further studies revealed that effect of different extract of Parthenium on growth parameters showed variation in pot experiment, which inhibit the growth parameters like number, size and colour of nodules, fresh and dry weights of nodules. The lower concentrations significantly increase the number of nodules, while higher concentrations were either inhibitory or
significantly reduced the number. The optimum increase recorded with 20% of RE, 40% of SE, LE and FE. The contrary findings also indicated that allelochemicals released from some weeds, behave as growth inhibitory substance that not only suppress growth, but also inhibit nodules formation, growth and development of other crops (Singh et al., 2001). Such interactions are very common in the rhizosphere (Bais et al., 2004). The residues and allelochemicals released from the weed also affect the nitrogen fixation by the soil microbes (Weston and Putnam, 1985; Wardle et al., 1994; Halsall et al., 1995; Mallik, 1999; Batish et al., 2006, 2007).

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The residues of quack grass (Agropyron repens (L). Beaur), when incorporated into the soil decreased the nodules number, nodule fresh weight and nitrogen fixation in soybean and beans (Weston and Putnam, 1985). While, present studies revealed the spray treatment of different extracts with 20 to 80% (0.2 g to 0.8 g/L) showed an increase in nodulation parameters. These findings indicated that healthy nodules perform better function in fixing the nitrogen, as indicated by the colour of nodules at later stages (Table-14). The allelochemicals of Parthenium might be working in a synergistic way to promote the formation of new nodules, till later stages of growth, as well as reduce the number of senesced nodules (Table 12 and 13).

Recently, Batish et al. (2006) reported that the severely stunted root growth of chickpea with the suppression of nodulation. It has also been reported that allelochemicals also suppress the process of nodule formation and soil nitrogen fixation (Rice and Pancholy, 1973; Mallik and Tesfai, 1988; Mallik, 1999). Parthenium inhibit nodulation and growth of legumes, ragi bean and cowpea (Kanchan and Jayachandra, 1979).
The development of root nodules is also evidenced by the presence of low amount of abscisic acid (Cohen et al., 1978). The high amount of abscisic acid pools in the nodules ceased the meristematic activity (Watts et al., 1983; Wheeler et al., 1983). It might be possible that allelochemicals present in PE, especially root and stem, reduced the level of abscisic acid, thus promoting nodulation with lower concentrations. Although earlier studies suggest that effect of weeds usually decreases the biological nitrogen fixation and produce adverse effect on nodulation (Singh and Wright, 1999, 2006). Different extracts of Parthenium may promote the signaling factor to induced nodulation by communication between compatible rhizobium to the leguminous roots.

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The early interactions for developing the infection threads and curling in the root hairs is largely controlled by the signals released from legume roots in the form of chemicals like flavonoids (Peters and Verma, 1990; Verma, 1992). These signals are often exuded by the portions of root with emerging root hairs region i.e. highly susceptible to infection by rhizobia. These compounds activate the expression of Nod gene in rhizobia, stimulating production of bacterial Nod factors (Long, 1989; de Bruijn and Downie, 1991; Kondorosi, 1992). The initiation of meristematic activity that give rise to the nodule, occur before the infection thread is formed and can occur prior to root hair curling, which is an early host response to rhizobia (Libbenga and Harkes, 1973; Newcomb et al., 1979; Dudley et al., 1987).

The allelochemicals may induce the primary receptors, which through hormonal balance, control the nodule morphogenesis. The allelochemicals present in Parthenium might be possible to regulate the flavonoids synthesis and initiate communication signals for rhizobium to release the
infection thread. As already established that the hormones, which are present in plants play an important role in early nodule development and the degeneration in nodules occur naturally as a result of changes in environmental factors that affect plant growth (Sutton, 1983; Raghava, 1990; Raghava et al., 1993, 1996; Ali and Bano, 2008). The factors that can arrest nodule growth and development resulting progressive deficiency in nitrogen fixing efficiency, mainly due to degradation in nodular proteins or enhance proteolytic activity (Atkins et al., 1984; Wagner and Sarath, 1987; Ali and Bano, 1999). The onset of nodule senescence has been associated with different factors including genetics and/or endogenous level of hormones (Thomas and Stoddart, 1975).

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Allelochemicals can also lead to increased cell membrane permeability. Consequently, cell contents spill and there is increased lipid peroxidation. Finally, there is slow growth or death of plant tissue. In addition, allelochemicals can also inhibit plants from absorbing nutrients from surroundings and affect the normal growth of plants.

A series of physiological and biochemical changes in plants induced by these compounds are shown in the following figure.
Mechanism of allelochemicals (courtesy Wang et al., 2006)

The impact of allelochemicals on the respiration of plants has mainly been shown to involve weakened oxygen absorption capacity, while the impact on photosynthesis has mainly been to reduce the chlorophyll content and photosynthetic rate (Patterson, 1981; Yu et al., 2003). The results showed that leaf transpiration, stomatal conductance, and the intercellular CO$_2$ concentrations were all decreased. The allelochemicals amended the soil by inducing the stress conditions affecting the plant growth in general. These allelochemicals may be phenolics, as ferulic, coumaric or syringic acids (Blum and Shafer, 1988; Blum, 1998; Blum et al., 1999; Mizutani, 1999; Li et al., 2010). These are reported in general to reduce the crop

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growth and yield by affecting the uptake of Ammonium ions by the developing plants (Bergmark et al., 1992; Mizutani, 1999;).

Other reports suggest that an important enzyme of bacterial origin, chitinase play an important role in the root nodule development and senescence (Collinge et al., 1993; Goormachtig et al., 1998; Regalado et al., 2000; Kasprzewska, 2003; Santos et al., 2008). During legume nodule induction, plant roots secretes flavonoids as a response to nitrogen deprivation. These flavonoids induce the transcription of rhizobial Nod genes. The protein encoded by these genes catalyze the synthesis of specific lipochito-oligosaccharide, the so called Nod factor which induced the early step of nodule formation and are the main determinants of host specificity in rhizobial symbiosis. Due to their chitin backbone, several chitinases have been found to be capable to differentially hydrolyse Nod factors (Minic, 1998; Perret et al., 2000). The allelochemicals, like flavonoids present in PE may activate the synthesis of Nod factors, in turn activate the nodule induction. As early reported the role of flavonoids to activate the synthesis of Frankia Nod factors (Prin and Rougier, 1987; Van Ghelue et al., 1997; Laplaze et al., 1999).

The role of chitinases in the defense against pathogens is undisputed (Kasprzewska, 2003). Plant chitinases evolve rapidly, suggesting that they are critical in the co-evolution of plant and pathogen (Bishop et al., 2000). It has long been suggesting that chitinases may

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regulate plant growth and development by modifying polysaccharides attached to the proteins or by generating or degrading signal molecule (D’Haeze and Holsters, 2002; Kasprzewska, 2003). Thus, rhizobial Nod factors might represent imitations of endogenous plant signal molecules and acidic class III endochitinase (glucoside hydrolase) from cowpea was found to
represent a protein (yieldin) i.e. required for cell wall loosening during acid growth (Okamoto - Nakazato et al., 2000 a, b). The chitinase defense system against pathogen may be correlated with the development of RKN in cowpea plants. Hirsch et al., (2009) worked out some of the key components of DNA binding complex that plays an important role in Nod factor signaling in *Medicago truncatula*. They investigated the function of domain proteins ‘Nodulation Signaling Pathways’ (i.e. NSP 1 and NSP 2) and found that these two proteins interact to form a complex that binds directly to a specific promoter region of Nod factor inducible genes. They also showed that the interaction between NSP 1 and NSP 2 is enhanced by Nod-factor perception (flavonoids) and is necessary for proper development of nodules.

These findings also indicated that when PE directly added to the isolated nematodes in aqueous solution and sprayed on plants, differently affect the nematode growth. The activity of nematodes at J2 stage and eggs was effectively checked with all the concentrations, except 20% of RE and SE after 24 hrs of treatment (Plate No.-11a and 12a). Overall, LE and FE with all the concentrations showed significant reduction in the number of eggs and active nematode J2 stage. After 48 hrs, the effect of PE continued, but after 72 hrs, the effect of lower concentrations was reduced active eggs and J2 stages were observed (Plate No.-11b and 12b, Table 17).

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**Discussion**

This shows that the different extracts of Parthenium, if directly added to the nematode aqueous solution, try to check the multiplication or egg hatching, as well as the activity of J2, J3 and adult stages. When the extracts were sprayed on the plants at different stages of growth, the development of root knots (galls) was also checked and reduced with lower as well as higher
concentrations (Table 17c). The lower concentrations showed reduction in number of galls on one hand and increase the number of nodules on the other hand (Plate No.-9 and 10; Table-12 and 17c). These observations indicate the compatibility of nematode to form galls is reduced, while of rhizobium to form nodules is increased.

The similar observations were made by Tiyagi et al., (1988) by the addition of crude form of some weeds of Compositae members to the soil, retarded the final population of Meloidogyne incognita and improving the plant growth. Datta and Saxena (2001) also reported the nematicidal activity of the allelochemicals from Parthenium, which check the J2 stage of root-knot nematodes. Other members of family Asteraceae contains the allelochemicals known to reduce the population of RKN (Oostenbrink et al., 1957; Uhlenbroek and Bijloo, 1958; Winoto, 1969; Varma et al., 1978; Kanagy and Kaya, 1996; Buena et al., 2008; Khan et.al., 2008; Gommers and Bakker, 1988; Rangaswami and Reddy, 1993).

Besides this, other plant extracts were also used to reduce the nematode population and checked the loss to yield (Siddiqui and Alam, 1987 a, b, 1988; Kashem, 1992; Deborah, 1999; Musabyimana and Saxena, 1999; Hassan et al., 2000). The herbal nematicides were also added to the soil have been reported to check the RKN (Goswami and Vijayalakshmi, 1986; Goswami, 1993; Goswami et al., 2006).

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The allelochemicals like phenolic acids, terpenes, terpenoids, flavonoids, etc. were directly used to see the effect on root galling intensity, egg mortality and juveniles and reported that these allelochemicals effectively control RKN (Blum, 1996; Ali et al., 2001; Shaukat and Siddiqui,
Section D

The parameters recorded on stomatal studies at three different stages at plant growth indicated that stomatal frequency, as well as stomatal index (SI) increased with lower concentrations while, above 80% either reduced or non-significantly changed the parameters. The reduction in stomatal frequency followed the pattern FE < LE < RE < SE. This indicates that FE is more inhibitory than other extracts and SE least inhibitory (Table-18 a, b, c). The allelochemicals present in Parthenium enhanced the stomatal frequency with lower concentrations and reduced with higher concentrations, as reported earlier by Singh, (2010) in brinjal and bottle gourd. The reduction in stomatal frequency suggests the negative allelopathy, which in turn may reduce stomatal conductance by inhibiting stomatal opening.

The stomatal differentiation was also studied analyzing variations in SI i.e. stomata / 100 epidermal cells, showed that different concentrations of PE invariably affect it (Table -19 a, b, c). Overall, lower concentrations slightly increased the SI, while other concentrations either showed no effect or slightly reduced it. This suggested that as the number of epidermal cells was increased, the number of stomata didn’t increased. It is quite possible that allelochemicals showed stimulatory effect on cell division in epidermal cells, while

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differentiation of epidermal cells into stomata was checked. The earlier reports showed that the stomatal variations occur under the effect of different growth regulators (Zeiger, 1983; Blatt, 1991; Kun et al., 2000; Wolf et al., 2006).

The stomatal frequency and SI vary with the structure of leaf surface among different plants, under different growing conditions, developing leaves adjust, their leaf areas based stomatal frequency and SI (Salisbury, 1927), in response to changing environmental factors and chemical regulators (Willmer and Fricker, 1996; Furukawa, 1997; Brownlee, 2001).

As generally observed in cowpea, the stomata are paracytic type with two bean shaped guard cells (GCs) and five subsidiary cells (SCs). The aperture is slit like, but appear to be eye shaped, when open (Plate No. 13-48). Under the effect of PE, several variations were observed like different sizes of GCs, number of SCs, shape and size of stomatal aperture. The unequal size of GCs, which was observed after I treatment (20 DAS), continued to II treatment (40 DAS) then to III treatment (60 DAS). Usually higher concentrations, above 80% showed many variations in the size of GCs. The RE treatment showed unequal GCs just after the I Treatment (on 21 DAS), both on adaxial and abaxial surfaces with different concentrations (Plate No.-13 A3, A4, A6, B2, B3, B4, B6). This effect was overcome on 22 and 23 DAS and only few concentrations showed the effect i.e. 20% and 140% (Plate No.- 15 A2, A6, B2, B6). Similarly, II treatment (40 DAS) and III treatment (60 DAS) showed the same effect with 20 and 140% of RE (Plate No.-18 A2, A6, B2, B6). This effect was continued as cumulative effect, but with 80 to 140% of RE (Plate No.-21 A5, A6, B4, B6).

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Almost similar observations on structural variations of stomata were observed with SE, where after I treatment (20 DAS), the higher concentrations showed variations as unequal GC (Plate No.-22 A4 to A6, B5, B6), this variation continued to 3rd day (23 DAS) and wavy GCs also observed (Plate No.-22 to 24, A5, A6, B5, B6). After II treatment of SE (40 DAS), the similar variations with higher concentrations were observed (Plate No.-25 A4, A5, B2, B4, B6; 26 A2, A3, A6, B5, B6; 27 A2, A5, A6, B6). After the 3rd treatment of SE (60 DAS), all the concentrations showed unequal GCs (Plate No.-28, 29, 30), against control.

LE showed more variations in the size of GCs, with higher concentrations on adaxial surface and almost all the concentrations on abaxial surface, just after the I treatment (Plate No.-31 A4, A6, B2, B3, B4, B6). The effect continues upto the 3rd day after I treatment (23 DAS; Plate No.-33 A2-A4, A6, B6). After II treatment, all the concentrations, except 20% on both the surfaces showed either unequal GCs (Plate No.-34 to 36 A3, A6, B3 to B6) or wavy GCs (Plate No.-34, A4, B3, B5; 35 and 36, A4, B4). After the III treatment, more variations occur in the GCs, almost all the concentrations either showed unequal, wavy or wing like GCs (Plate No.-37 to 39).

Similarly, FE affects the GCs with higher concentrations, just after I treatment (20 DAS), followed by II treatment (40 DAS) and III treatment (60 DAS). The effects of FE was more visible on the adaxial surface than abaxial surface, where unequal GCs were observed after I treatment (Plate No.-40 A3, A4, A6, B2, B6). The effect continued till 3rd day after I treatment, with all the concentrations, except 20%. After II treatment unequal GCs observed, except 20% on abaxial surface and almost all the concentrations showed one of the GCs invariably larger than control (Plate No.-43 to 45). The same effect continued

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after the III treatment and unequal GCs were observed, except few treatments. The maximum effect of 20% of FE was observed on 63 DAS, as invariably large one of the GC (Plate No.-46 to 48 A2).

These observations revealed that the variations in GCs directly affect the regulations of GCs movement to open and close the stomata for gaseous exchange (Furukawa, 1997; Visser, et al., 1997; Granados and Korner, 2002; Reid et al., 2003). There is a significant positive correlation between stomatal frequency and subsidiary cells (Epidermal cells) in the present studies, which shows the enhanced photosynthetic efficiency correlated with increase leaf area. These studies are supported by the earlier findings on the significant positive correlation between stomatal density and epidermal cell increased with leaf area (Poole et al., 2000; Gray et al., 2000; Bergmann, 2003; Bird and Gray, 2003; Taye and Furukawa, 2008).

Similarly, it is very much clear from the observations that, all the treatments of PE also affect the number and shape of subsidiary cells (SCs) and stomatal aperture. Specifically under RE treatment, the higher concentrations (120 and 140%) on both the surfaces showed four SCs, as well as the shape of SC was irregular after I treatment and continued till the III treatment (Plate No.-13 to 21). Three SCs were also observed with 20% of RE, on 61 DAS (Plate No.-19 B2) and 80% of RE on 63 DAS (Plate No.-21 A4). Under SE treatment, the lower concentrations (20 and 40%) didn’t vary the number of SCs, but the size was slightly enlarged, while higher concentrations (80 to 140%) showed four SCs on adaxial surface and three/four SCs on abaxial surface, other variations in SCs were unequal sizes or abnormally enlarged. With 120% of SE, on abaxial surface showed unequal division and six SCs were observed (Plate No.-25 B5) after II treatment.
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Under LE treatment, the numbers of SCs were generally reduced to four, but with larger and variable sizes, after I treatment. The effect was continued after the II treatment and followed by III treatment (Plate No.-31 to 39). Similarly, FE treatment also showed variations in SCs, on both the surfaces, but with some specific shapes like winged, flattened or wavy (Plate No. 40 to 42), after I treatment and followed by II and III treatment (Plate No.- 43 to 48.).

Usually, water treated leaves showed slit like open aperture (eye shaped), while under the PE treatments, stomatal aperture appeared to be small, as the size of GCs reduced, Although 20% of PE didn’t show much variations, while in higher concentration the stomatal aperture was widely opened. Some of the treatments showed very narrow slit like aperture or small rounded pore under LE treatment (Plate 31-33).

Stomatal regulation of gaseous exchange has been studied for well over a century, yet these time pores connecting the outer world, with the interior of the plants remain poorly understood. Although, GCs responds to number of factors, it is remarkable that no single response can clarify the mechanistic model of stomatal behavior. A true model of stomatal response can consider at least three levels, the first level of individual GCs, second signaling pathway and the third at the level of total GCs (including number of stomata) on the single leaf. There is hardly any standard technique in cell biology to suggest a single mechanistic model to describe stomatal behavior under variable environmental conditions (Fan et al., 2004, 2008; Mott and Peak, 2007).

Many studies have been made to study the stomatal behavior considering a number of factors, such as blue light, red light, CO₂ conditions, humidity, abscisic acid, osmotic and turgor pressure of GCs and epidermal subsidiary cells, etc., to understood the signaling
processes and to accurately predict changes in GCs and effect on stomatal aperture (Edwards et al., 1976; Spence et al., 1983; Meidner, 1990; Franks et al., 1995, 1998; Buckley and Mott, 2002; Buckley, 2005; Israelsson et al., 2006; Pandey et al., 2007; Acharya and Assmann, 2009) to understand the stomatal behavior, one should understand, how individual stomatal aperture determine leaf level stomatal conductance (a measure of average stomatal aperture over a defined area) and variability among stomatal aperture as well as interactions among adjacent stomata (Laisk et al., 1980; Spence, 1987; Mott et al., 1997; Buckley and Mott, 2002; Buckley et al., 2003).

Earlier studies were made to correlate the effect of stomatal frequency, size and number of stomata / unit leaf area on transpiration, photosynthesis and yield. It has been shown that high stomatal frequency is directly correlated with transpiration and CO₂ uptake, but inversely with yield (Teare et al., 1971; Koy et al., 1972; Ciha and Brown, 1975; Shimshi and Ephrat, 1975; Farquhar et al., 2002; Gaskell and Pearce, 1983; Maghsoudi and Maghsoudi moud, 2008).

The leaf shape, including leaf area is an important factor that determines both the processes of photosynthesis and transpiration. It also plays a major role in the recognition of plants by pollinators and herbivores (Givinish, 1979; Wien, 1982; Brown and Lewton, 1991; Qin and Xiang, 1994; Yamada and Suzuki, 1996). Although, leaf shape is assumed as heritable trait (Wu, et al, 1999) and it can be highly variable one among the individuals of same population as well as ontogeny of certain plants (Wyatt and Antonovics, 1981; Sawada, 1992; Tsukaya, 1995; Jones, 1995). The leaf shape also determines the diffusion reaction through the leaf
surface. Different experiments have shown that the number of lobes a leaf will grow is determined very early in its development,

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but the final size and shape of leaf depends on number of cell divisions in different directions and the expansion of individual cells (Fuchs, 1975; Lyndon, 1990; Howell, 1998). It seems reasonable to consider the prepattern of morphogens that might later influence cell division and cell expansion within leaf primordia.

The small size of leaf primordia is such that they are an ideal size of pre-patterns of a particular plant, to be laid down by reaction diffusion system, controlled by growth promoting and growth inhibiting substances. The impact of allelochemicals from Parthenium plant, relatively in smaller quantities have been shown to regulate the plant growth and altered the leaf size in terms of leaf area, might be during primordial stage. This might be due to influencing the cell division and cell expansion within the leaf primordia. The lower concentrations of allelochemicals (20 to 80% or 0.2 to 0.8 mg/L) increased the leaf area as well as changed the morphology of stomata, may suggest that the plants could tolerate allelochemicals upto a certain extent. Orcutt and Nilsen (2000) has suggested that plants can tolerate and withstand allelochemicals due to developing some abilities, like to reduce uptake of allelochemical at plant surface, by compartmentalization of allelochemical away from molecular target sites and detoxification of allelochemicals by the receiver plant. The above studies are also supported by the changes in some biochemicals parameters of cowpea plant, under the effect of allelochemicals from different parts of PE.
Section-E

The present studies revealed that as the leaf area is increased for providing more photosynthetic surface, simultaneously the total chlorophyll content has also been increased. After I treatment of PE, all the concentrations significantly increased the total chlorophyll, except 140% of SE and LE. All the concentrations of FE, except 40% were either non-significant or inhibitory at initial stage. As the age was growing, 20 to 80% of RE, SE and LE were promotory for total chlorophyll, while only 20 and 40% of FE showed the enhancement. Among all the treatments, RE was more promitory and less inhibitory than other extracts, while FE showed more inhibition and least enhancement. Out of total chlorophyll, Chl ‘a’ and Chl ‘b’ showed different pattern of increase, over control. At vegetative stage (25 DAS), RE and LE showed more increase in Chl ‘b’, as compared to Chl ‘a’, while SE and FE showed the reverse pattern and also Chl ‘a’ reduced significantly with LE. Chl ‘b’ reduced significantly with FE. The increasing age at flowering (45 DAS), showed all the treatments of PE enhanced Chl ‘a’, more than Chl ‘b’, while at post flowering stage (65 DAS) with III treatment, Chl ‘b’ was more than Chl ‘a’. Overall, the increasing amount of chlorophyll is supported by the increased leaf area and total chlorophyll content, in turn enhanced the photosynthetic area, as well as photosynthesis. This might be correlated for the functioning of increased number of stomata in the present studies (Lawson et al., 2008). Many authors suggested that stomatal response with the movement of GCs and SCs, as well as the chloroplastic pigments directly correlated with the efficient photosynthesis (Zeiger, 2002; Vavasseur and Raghvendra, 2005).
The biochemical changes in nodules also depict that the lower concentrations (20 to 80%), significantly enhanced the total proteins in nodules, at almost all the three stages of growth, except 80% FE at post flowering stage (Fig.-8). On the other hand, Lb content is more sensitive to higher concentrations i.e. 80% and above it, while at initial stages i.e. pre-flowering and flowering, LE and FE were inhibitory, over control. As Lb is a part of protein, the ratio of protein to Lb was maximum with 40% of RE and FE, 20% of SE and

140% of LE, even at post-flowering stage. The increasing total protein, Lb and their ratio suggest that more healthy nodules, which might be correlated with more number of healthy nodules, increasing fresh and dry weight of nodules. There is a direct correlation between Lb and nitrogen fixation by the leguminous root nodules, more healthy nodules, higher Lb content, higher the nitrogen fixation (Virtanen et al., 1947; Brisson et al., 1981; Appleby, 1992). Contrary to these findings, Lb content was reduced significantly with 5g/kg residue from Chenopodium (Batish et al., 2007).

As we know, nitrogen fixation is catalyzed by the enzyme nitrogenase that is highly sensitive to oxygen (O₂) and can only function in an O₂ free environment. For aerobic bacteria, like Rhizobia, this leads to the so-called O₂-dilemma for the process of nitrogen fixation. A high O₂ flux to respiratory chain is required adjacent to vanishingly low O₂ concentration at the site of nitrogen fixation. The rhizobia rely on the plant host to provide O₂ protection for nitrogenase, to participate in the active nitrogen fixation. The nodule endodermis, a part of the nodule cortex forms O₂ diffusion barrier protecting the rhizobia containing tissue, while leaving the vascular system well aerated. The O₂ concentration remains to be very low in the inner tissue (Bergersen,
In order to provide higher amount of O\textsubscript{2} for respiration, an O\textsubscript{2}-binding protein i.e. Lb is formed in the infected cells forming the nodule (Appleby, 1984; Hargrove \textit{et al.}, 1997). Lb facilitates O\textsubscript{2}-diffusion to the nitrogen fixing bacteria, as well as plant mitochondria (Wittenberg \textit{et al.}, 1974).

The symbiotic Lb of legumes is important for modulating the levels of nitric oxide (NO), an inhibitor of mitochondrial electron transport i.e. also an important II messenger in plants, involved in a broad range of developmental processes and in pathogen defense signaling (Trevaskis \textit{et al.}, 1997). The sequence of reactions required for NO-scavanging under hypoxic conditions has been defined as Hb/ NO cycle (Igamberdiev and Hill, 2004; Igamberdiev \textit{et al.}, 2004, 2006; Pawlowski, 2008).

The observations on total protein and Lb contents in the nodules, which leads to efficient and higher nitrogen fixation, may be directly correlated with the protein storage in the dry seeds. The data on total protein content and TSS also showed an increase with lower concentrations of PE. The optimum concentrations, which increased both the parameters, were 40\% of RE and SE for protein and 20\% of SE for TSS, 20\% of LE and FE for both. The maximum increase in both total protein content and TSS was recorded with 40\% of RE (26.50\% and 23.35\%, respectively), over control.

Cowpea is a starch-protein legume and the results suggest both the parameters i.e. TSS and the protein increased in the seeds, in turn we can say the productivity is increased which is very much clear from the observations by the increase in 100 seed weight, seed yield plant (g) and yield in q/ha. Obviously, the improvements in the capture and conversion of Light energy have
been a central part of crop improvement during the last century. The increase in growth parameters, specifically, the leaf area with chlorophyll content allowing the crop to be extremely efficient at absorbing the solar radiations. The application of allelochemicals (no doubt toxic nature) increased leaf area and also the rate of photosynthesis/unit leaf area. Additionally, this enhancement with the nematode pest management, enhanced nodulation have resulted in the higher yield. Thus, incorporating the mechanism of active variety of allelochemicals and using the dual nature of allelochemicals as growth regulating and nematicidal properties, these can be utilized for promoting the crop yield.