2. REVIEW OF LITERATURE

In this chapter, the available literature pertaining to crop-weed competition, their management by chemical means, mechanical means and consequent effects on crops in soybean-wheat sequence have been reviewed. For the sake of comprehension, the limited literature on these aspects has been reviewed under the following subheads:

2.1 Crop-weed competition
   2.1.1 Crop weed association
   2.1.2 Losses due to weeds
   2.1.3 Critical period of crop-weed competition

2.2 Weed management
   2.2.1 Soybean
   2.2.2 Wheat
   2.2.3 Soybean-wheat

2.3 Residual effects of herbicides

2.4 Economics

2.1 Crop-weed competition

2.1.1 Crop-weed association

Soybean

Soybean being a rainy season crop, suffers severely due to competitive stress of weeds. Weeds predominantly associated with soybean were Commelina benghalensis, Echinochloa colona, Panicum dichotomiflorum, Polygonum alatum, Aeschynomene indica and Digitaria sanguinalis, however, Eleusine aegyptium and Cyperus sp. were also observed in experimental fields.
The conventional methods of weed control are time consuming, expensive and laborious. Also, weeding during critical growth stages is sometimes not possible due to continuous heavy downpours.

Various workers throughout the globe have studied the weed association in soybean and their work has been reviewed. At Palampur, the major weeds found growing in association with soybean crop were *Echinochloa colona, Setaria glauca, Digitaria sanguinalis, Cyperus rotundus* and *Cynodon dactylon* among grass weeds and *Gallinsoga parviflora, Commelina benghalensis* and *Euphorbia* sp. among broadleaf weeds (Singh *et al.* 1992).

At Rajgarh (Madhya Pradesh), Rajput and Kushwah (2004) observed *Cyperus rotundus, Echinochloa crus-galli, Cynodon dactylon, Commelina benghalensis, Parthenium hysterophorus, Euphorbia* sp. and *Corchorus* sp. the major weeds in association with soybean crop. However, *Dactyloctenium aegyptium, Panicum repens, Echinochloa colonum, Chloris barbata, Dinebra retroflesea, Cynodon dactylon* and *Perotis indica* were the major weeds in soybean at Coimbatore conditions (Sankaranaryan *et al.* 2002). Priya *et al.* (2009) reported *Cynodon dactylon* and *Echinochloa colona* among grasses, *Cyperus rotundus* among sedges and *Parthenium hysterophorus* and *Digera arvensis* among broadleaf are the predominant weeds in soybean crop at Coimbatore. Ganesaraja and Kanchanarani (2003) reported *Echinochloa colonum, Cynodon dactylon, Cyperus rotundus, Cyperus difformis, Trianthema portulacastrum, Phylanthus niruri* and *Eclipta alba* the major weed flora associated with soybean at Killikulam in Tamilnadu. Rani *et al.* (2004) reported *Abutilon indicum, Celosia argentea, Trianthema portulacastrum, Digera arvensis, Amaranthus tricolor, Cenchrus ciliaris* and *Cyanotis cuculata* the most dominant weed species in soybean crop in Andhra Pradesh. *Digera muricata, Acalypha ciliata, Parthenium hysterophorus, Cyperus rotundus* and *Commelina benghalensis* were found to be the important weed species associated with soybean crop at Pune (Halvankar *et al.* 2005).
Echinochloa crus-galli and Sorghum halepense of the monocotyledon type and Amaranthus powellii, Chenopodium album and Chenopodium hybridum of dicotyledons type were the most dominant weeds in soybean in the untreated control (Bilandzic et al. 2003). Sedegi et al. (2002) observed that Amaranthus retroflexus, Abutilon theopharasti, Echinochloa crus-galli, Chenopodium album were the major weeds of soybean in Iran. From Yugoslavia, Jovanovic et al. (1999) reported Amaranthus retroflexus, Chenopodium album, Datura stramonium, Hibiscus trionum, Polygonum lapthifolium, Solanum nigrum, Stachys annua, Echinochloa crus-galli, Setaria glauca, Sinapis arvensis and Sorghum halepense the prominent weed species associated with soybean.

At Palampur, in the present investigation Echinochloa colona, Cyperus rotundus, Digitaria sanguinalis, Polygonum sp., Aeschynomene indica and Commelina benghalensis were found to be the predominant weed species associated with soybean. Thus, it can be concluded that the weeds found associated with soybean crop in the present investigation were similar to those reported by various workers at different locations in India as well as in other countries of the world. However, their composition and intensity varied with soil, climatic conditions and other ecological factors.

Wheat

Weeds are ever associated with crops. Some weeds adapt the mechanism of phenotypic mimicry e.g. Phalaris minor in wheat, whereas others contaminate crop seeds due to same height and time of maturity as the crop has and get easily mixed with crop seeds at harvest time.

Weed flora associated with wheat crop was Phalaris minor, Avena ludoviciana, Anagallis arvensis, Lolium temulentum and Vicia sativa. Besides these weeds, Bisen et al. (2006) also noticed Cynodon dactylon, Cyperus rotundus, Rumex dentatus and Chenopodium album in the wheat crop. Shukla and Misra (2006) have reported the dominance of Coronopus didymus, Melilotus indica along with Chenopodium album and Phalaris minor in wheat crop under
Pantnagar conditions. Singh et al. (2005) have reported the association of broad leaf weeds like *Medicago denticulata*, *Rumex dentatus*, *Melilotus indica* and *Anagallis arvensis* at a small scale while *Phalaris minor* dominated the field. Almost all above mentioned weeds were also reported by Sinha and Singh (2005) in association with wheat at Varanasi. Yadav et al. (2009) have also reported the association of *Phalaris minor*, *Coronopus didymus*, *Anagallis arvensis*, *Melilotus indica*, *Medicago denticulata*, *Rumex dentatus*, *Vicia sativa* and *Lathyrus aphaca* with wheat crop.

Sharma and Singh (2010) recorded grassy, broad-leaf and sedges associated with wheat crop under Uttar Pradesh conditions. *Phalaris minor* (19.8%) among grasses, *Rumex* sp. (34.3%), *Anagallis arvensis* (21.9%) and *Chenopodium album* (34.3%) among broadleaved weeds and *Cyperus rotundus* (7.2%) among sedges were the major weeds invading wheat. Brar and Walia (2009) reported the presence of *Trigonella polycerata*, *Lepidium sativa* and *Malva neglecta* alongwith other broad-leaf and grassy weeds under Ludhiana conditions.

### 2.1.2 Losses due to weeds

Weeds are the major constraints in realizing optimum yield potential. They may cause a drastic reduction in yield to a level of one-third to almost total failure of crop. Weeds not only deplete nutrients and moisture from the soil but also act as alternate hosts of insect-pests and diseases. It is well established that losses caused by weeds exceeds the losses from any other category of agricultural pests like insects, diseases or rodents. Unlike insect-pest and disease outbreak, losses due to weeds do not show any clear visual symptom especially at the early stages of growth. Therefore, farmers pay little attention to weed control practices. But now weeds have been considered most important pests of crops as they lower yields, increase cost of production and impair the quality of produce in various ways. The magnitude of effect depends upon weed species, their intensity, duration of infestation, stages of critical competition and other management factors.
Soybean

Soybean crop is often infested with grassy, broadleaf weeds and sedges which compete with crop, resulting in drastic reduction in yield to the tune of 26 to 71 per cent depending upon type and intensity of weeds and their occurrence (Rathore et al. 2006). Hazra et al. (2009) reported that weeds including Trianthema portulacastrum (67% weed density) offered severe competition to soybean crop and resulted in significantly lower seed yield than weed free check. Uptake of nutrients (N, P and K) by soybean was also reduced due to the competition exerted by weeds.

Infestation of soybean crop with weeds like Echinochloa, Cyperus, Digitaria, Commelina etc. had reduced seed yield upto 31.2 per cent when compared to imazethapyr at 75 g ha⁻¹ applied as post-emergence (Kushwah and Vyas, 2006). Malik et al. (2006) have reported that field of soybean infested with broad-leaf weeds (80%) and grasses and sedges (20%) throughout the crop season resulted in soybean yield reduction by 55 per cent. Singh (2005) reported that weeds if not controlled may cause reduction in the soybean yield upto 33 per cent. Singh et al. (2004) at Pantnagar, reported more than 84 per cent reduction in grain yields of soybean in the weedy plots when compared with weed free plots. At Dharwad, weed competition reduced the yield of soybean by 63.4 per cent as compared to the weed free control (Bandiwaddar and Itnal 1998). Singh et al. (2003) reported that soybean crop infested with weeds like Echinochloa colona, Trianthema portulacastrum and Celosia argentea resulted in 82 per cent reduction in soybean grain yield when compared with season long weed free treatment.

At Columbia and Novelty, Setaria faberi, Amaranthus viridis, Xanthium strumarium, Ambrosia artemisiifolea and Ipomoea hederacea infesting soybean reduced its grain yield by 53 per cent in the weedy plots when compared with treated plots (Dirk et al. 2000). In Brazil, daily yield loss of 5.15 kg ha⁻¹ in soybean had been reported due to the presence of weeds, whereas, their absence provided a daily grain yield of 7.27 kg ha⁻¹ (Merchede et al. 2002). In
Pakistan, Khan et al. (2004) estimated more than 30 per cent reduction in soybean grain yield each year due to weeds. Cowan et al. (1998) reported that yield losses in soybean ranged from 32 to 99 per cent in the presence of *Amaranthus* spp. and *Echinochloa crus-galli*.

Mosier and Oliver (1995) reported that interference from entire leaf morning glory (*Ipomoea* spp.), common cocklebur (*Xanthium strumarium*) or both species reduced the soybean yield by 64 per cent. Whereas, Jones et al. (1997) observed that due to interference of *Senna obtusifolia* and *Xanthium strumarium*, the yield of soybean was reduced by 49 and 39 per cent, respectively. Similarly, Fellows and Roeth (1992) reported that when height of *Sorghum bicolor* exceeded with that of soybean, the yield of latter reduced by 25 per cent. Avav et al. (1995) in Southern Nigeria reported 51 per cent reduction in soybean grain yield in the fields where uncontrolled growth of weeds was allowed.

**Wheat**

Wheat occupies prime position among the food crops of the world. In India it contributes 30-35 per cent to total food grain basket of the country (Bisen et al. 2006). It is infested by multifarious weed flora comprising both grassy as well as broad-leaf weeds causing yield reduction of 15 to 40 per cent depending upon type and intensity of their infestation (Jat et al. 2003). *Phalaris minor* is the most dominant weed in wheat crop and it alone affects grain yield upto 40 per cent (Saini et al. 2009). However, Walia and Brar (2006) have reported yield reduction in wheat to the level of 30-80% per cent due to *Phalaris minor* alone.

Wheat crop infested with weeds like *Avena ludoviciana, Phalaris minor, Chenopodium album, Melilotus indica* and *Coronopus didymus* throughout the growing season caused 44.6 per cent reduction in grain yield (Punia et al. 2006). Jain et al. (2006) reported the presence of *Avena ludoviciana* (73%), *Phalaris minor* (0.62%), *Medicago hispida* (23.15%), *Chenopodium album* (2.61%), *Vicia sativa* (0.14%) and *Lathyrus aphaca* (0.41%) as major weeds which caused 65
per cent reduction in grain yield of wheat under Jabalpur (M.P.) conditions. Punia et al. (2005) reported that presence of weeds throughout the growing period reduced grain yield of wheat by 49 per cent. However, under Pantnagar conditions 65.2 per cent loss in wheat grain was recorded due to uncontrolled weeds (Singh et al. 2005b). At Karnal (Haryana) a field infested with Rumex dentatus, Anagallis arvensis, Melilotus indica and Medicago denticulata besides Phalaris minor had 29 per cent lower yield than weed free plots (Singh et al. 2005a).

Chopra and Chopra (2005) reported 70.0 and 65.6 per cent yield reduction under uncontrolled weedy check compared to clodinafop + carfentrazone and fenoxaprop + carfentrazone, respectively under Karnal conditions. The reduced grain yield of wheat to the extent of 51.9 to 57.6 per cent due to presence of grassy (65%) as well as broadleaf weeds (35%) throughout the crop season may be attributed to the production of significantly less number of spikes under Hisar conditions (Malik et al. 2005). Similarly, more than 68.8 per cent reduction in the grain yield of wheat was reported by Singh et al. (2004a) due to presence of Phalaris minor, Chenopodium album, Melilotus sp., Melilotus denticulata etc. under Pantnagar conditions. Chopra et al. (2001) reported 37.8 per cent reduction in wheat yield due to higher weed intensity under unchecked weed plots in Baraut (UP). In Pakistan, more than 39 per cent reduction in grain yield (4.6 t ha⁻¹) of wheat was recorded under weed control plots compared to plots where weeds were controlled by application of affinity (carfertrazone ethyl ester) 50 WDG at 0.016 kg a.i. ha⁻¹ (2.8 t ha⁻¹) [Khan et al. 2004a].

2.1.3 Critical period of crop-weed competition

Critical period is the maximum period for which weeds can be tolerated without affecting final crop yields or the point after which, weed growth does not affect final yield (Dawson 1965). The yield loss of a crop depends upon the length of crop-weed competition and stages at which the competition occurs.
Soybean

Hager et al. (2002) concluded that common waterhemp (Amaranthus viridis) interference in soybean should be taken care before 4 weeks (28 days) after soybean unifoliate leaf expansion in order to reduce the potential loss of seed yield. In Iran, 23 days after emergence was reported as the critical time for weed control in soybeans (Hadizadeh and Rahimian 1998). Whereas, Ponnuswamy et al. (1996) concluded the critical period for weed competition in soybean as 15 to 60 days after sowing.

Suwanagul (1998) reported the critical period in soybean to prevent yield loss was 1 to 12 and 1 to 9 weeks after emergence in early rainy and dry season, respectively. At Hisar (India) Chhokar and Balyan (1999) concluded that weed free maintenance upto 45 days after sowing resulted in 74 per cent increase in grain yield of soybean over the unweeded control, whereas allowing weeds to remain in the crop for less than 30 days resulted in no significant yield loss. At Ranichauri, Arya et al. (1994) reported that maintaining a weed-free period for 0-60 and 0-40 days after sowing resulted in highest soybean grain and straw yields. From Orissa, Mohapatra and Haldar (1998) reported that the most critical period of weed competition in soybean was 4 to 5 weeks after sowing.

Esqueda et al. (1997) from Mexico, reported that soybean can withstand the presence of weeds for the first 20 days without any yield reduction and it requires an initial weed free period from 30 to 40 days. In soybean critical period of weed control was reported to begin at the first or second node developmental stage, whereas the end was at the early flowering (Halford et al. 2001). In Iran, Keramati et al. (2008) concluded that weed control should be carried out between 26 to 63 days after planting of soybean to obtain maximum grain yield. In Beijing, critical period of weed management in soybean was reported from 16 to 29 days after sowing (Zhenguo 1993). Similar results were reported by Abusteit (1993) where he concluded that weed free period for at least first 6 weeks after emergence was required to ensure optimum soybean growth and yields. In southern Ontario, Acker et al. (1993) described critical period of weed
control in two discrete periods i.e. a critical weed free period and a critical time of weed removal. The critical weed free period was reported 30 days after emergence which is consistent across different locations, whereas, the critical time of weed removal was 9 to 38 days after emergence and it was variable across these locations. In Argentina, Eyherabide and Cendoya (2002) reported that critical weed free period required to prevent yield loses in soybean was between 50 and 61 days. Whereas, in Thailand, Reawat (1995) found that soybean requires initial weed free period of four weeks in rainy season.

**Wheat**

At Anand (Gujarat), optimum yield of wheat was obtained with a weed free period between 30 to 45 days after sowing (Barevadia et al. 1993). At Ambikapur (Madhya Pradesh), Singh and Bajpai (1992) reported initial 40 days after sowing of wheat as critical period of weed competition, delaying beyond which 1000-grain yield may be suppressed.

Rahman et al. (1990) in Bangladesh and Villasana et al. (2003) in Cuba reported 30 days after sowing as the critical period of competition from weeds in wheat. In Sudan, Mohamed (1997) concluded that at Finta the critical period was 8 to 10 weeks after sowing while at Elbar it was between 4 and 8 weeks after sowing. Cruz et al. (2004) concluded that in wheat, the critical period of competition under high weed pressure was from 0 to 60 days after emergence while that under low pressure 15 to 70 days after emergence. Whereas, Agostinetto et al. (2008) proposed that the effective weed control measures should be taken between 12 and 24 days after emergence. In Bangladesh, Alam et al. (1994) reported 28 to 42 days after emergence the critical period of weed competition in wheat.

Thus, under the light of literature reviewed above, it can be concluded that every crop requires a maximum initial period during its growth, where interference due to weeds should be least. This critical period for both soybean and wheat is first 60 days and control of weeds during this period may result in considerable increase in grain yield. Managing the weeds beyond this period does not affect the crop yield.
2.2 Weed management

2.2.1 Soybean

Soybean has poor competitive ability with weeds during initial growth stages due to its inherent characteristics such as short stature, shallow root system and a very slow growth. Thus, it is imperative to keep the fields free from weeds during early period of crop growth. Weeds can be controlled manually by hand pulling, mechanically and chemically by application of herbicides or by combination of these methods. Hand weeding is the traditional method of weed control, but, it is time consuming venture. Also, continuous rainfall may not permit this operation to be carried out well in time. Such weather conditions of high temperature coupled with high humidity as sequel of frequent rain showers provide favourable conditions for weed growth in soybean. Moreover, mechanical methods of weed control are intensively used in areas where labour is cheap and easily available whenever required.

In Pakistan, Akhtar et al. (1990) obtained highest seed yield with mechanical weed control (1235 kg ha\(^{-1}\)). In Bangladesh, seed yield of soybean was highest in hand weeded plots followed by pendimethalin treated plots (Rahman et al., 1995). Similarly, Reddy et al. (1998) reported significantly higher seed yield and weed control efficiency owing to two hand weedings at 25 and 40 days after sowing. Yield of soybean was highest in weed free plots, which received two hand weedings at 20 and 40 DAS, but the control of weeds through hand weeding is more expensive than the use of pendimethalin (Bhan and Kewat, 2002). Sankarnarayanan et al. (2002) and Kankal et al. (1999) reported that hand weeding at 15 and 30 days after sowing was the most effective to control weeds and increase yield attributes and yield of soybean. At 20 and 40 days after sowing also, hand weeding gave significantly highest yield (Singh et al. 1990; Veeramani et al. 2001) and net return (Padmavathi et al. 1995) in different parts of the country.
At Ludhiana, Singh et al. (1994) obtained lowest weed dry matter accumulation at 60 and 90 DAS and highest soybean seed yield due to manual weeding at 30 and 60 DAS. At Rajgarh, Rajput and Kushwah (2004) recorded highest seed yield and net return by following hand weeding twice at 20 and 30 days after sowing. At Ludhiana, none of the herbicides were superior to hand weeding twice in influencing the grain yield of soybean (Singh and Jolly 2004). Mandloi et al. (2000) and Vyas and Jain (2003) reported highest weed control efficiency with two hand weedings at 30 and 45 days after sowing.

Soybean is both a legume and an oil seed crop. One of the major reasons for the poor performance of soybean is inadequate weed control. Since ages, the conventional methods of weed control is hand weeding but, it is time consuming and labour intensive. Also, soybean roots are spreading type and tillage is likely to injure the roots and hence decrease the yield. Thus, it is more favourable to use chemicals due to scarcity of human labour during peak season (Jain et al. 2000) and to obtain higher weed control efficiency and economic returns against hand weeding (Joshi 1997). Moreover, the chemicals provide weed control at early growth stage of soybean. Baric and Ostojic (2000) advocated the use of selective pre-sowing, pre-emergence and post-emergence herbicides to control annual and perennial weeds in soybean in Croatia. Herbicides, carfentrazone and carfentrazone-ester in combination with chlorimuron-ethyl had broader activity spectrum and control broadleaf weeds like Commelina benghalensis, Ipomoea grandifolia and Acanthospermum hispidum satisfactorily in soybean (Foloni and Christoffoleti, 1999). In Michigan, USA, Nelson et. al. (1998) obtained poor control of Chenopodium album (common lambs-quaters) with post-emergence imazethapyr with 0.25% (v/v) non-ionic surfactant. Reynolds et.al. (1995) reported considerable improvement in weed control and soybean yield with PPI trifluralin followed by post emergence chlorimuron over soil applied herbicides alone.

Nayak et al. (2000) recorded highest seed yield of soybean with pendimethalin 30 EC 1.0 kg ha$^{-1}$, which was statistically similar with two hand weedings. Jain et. al. (2000) reported pendimethalin (1.5 kg ha$^{-1}$) was equal to
hand weeding twice in influencing weed control efficiency and in increasing the weight and number of pods. Application of imazethapyr 75 g ha\(^{-1}\) was more effective in reducing weed biomass resulting in higher weed control efficiency over other pre and post-emergence herbicides. However, among post emergence herbicides quizalofop ethyl 50 g ha\(^{-1}\) gave higher grain yield as compared to weedy check (Kushwah and Vyas 2005). The combined application of chlorimuron ethyl and metolachlor 0.009 kg and 1.0 kg ha\(^{-1}\), respectively, resulted in highest (95%) weed control efficiency (Behera \textit{et al.} 2005). Early post emergent application of imazethapyr 100-200 g/ha significantly reduced weed density and dry weight and increased soybean seed yield in Western Maharashtra (Deore \textit{et al.} (2007). Highest grain yield of soybean was reported with post-emergence sethoxydim + imazethapyr (0.37 + 0.10 kg ha\(^{-1}\), respectively) in Nigeria (Avav \textit{et al.}, 1995). Increased grain yield was due to reduced weed biomass. These yields were comparable to those from plots weeded with a hoe 2 and 3 times. Uncontrolled growth of weeds in the unweeded control reduced the grain and stover yields by 51%. Maintaining a weed-free period until 23 DAE reduced weed dry weight by 85% and the weed count by 70%, compared to the weedy control.

Application of imazethapyr 75 g ha\(^{-1}\) was most effective in controlling weeds over other pre and post-emergence herbicides in clayey loam soils of Madhya Pradesh (Kushwah and Vyas, 2005). Shete \textit{et al.}, (2008) reported that the yield contributing characters of soybean under mechanical weed control (one hoeing 20 days after sowing + 2 hand weedings 30 and 60 DAS) were comparable to the application of imazethapyr at 87.5 g ha\(^{-1}\). Among the post-emergence herbicides, quizalofop ethyl and quizalofop-p-tefuril significantly reduced the growth of monocots while imazamox and imazamox + imazethapyr paralysed the dicot weeds. The seed and straw yields under imazamox + imazethapyr (800 ml ha\(^{-1}\)) and quizalofop ethyl (50 g ha\(^{-1}\)) were comparable to hand-weeding twice in Madhya Pradesh (Pandey \textit{et al.} 2007). At Hisar, among the post emergence herbicides, chlorimuron ethyl at 12 g ha\(^{-1}\) provided 50 per
cent control of non-grassy weeds, whereas, alongwith haloxyfop (at 6 + 150 g or 9 + 150 g ha\(^{-1}\)), it provided 85 to 90 per cent control of broadleaf and 70 to 85 per cent of grassy weeds (Balyan and Malik 2003). Angiras and Rana (1995) obtained higher soybean seed and straw yields with pre and early post-emergence application of imazethapyr at 200 g and hand weeding twice. Kumar et. al., (2008) reported that haloxyfop at 0.100 kg ha\(^{-1}\) and acetachlor 1.50 kg ha\(^{-1}\) resulted in highest weed control efficiency. Former controlled grassy weeds like *Panicum*, *Echinochloa* and *Digitaria* effectively while latter was most effective against grassy as well as broad leaved weeds like *Ageratum*, *Polygonum* and *Commellina*.

### 2.2.2 Wheat

The irrigated wheat is infested with several weeds which create competitive stress, resulting in severe yield losses. Therefore, proper management of weeds is essential to get higher yield. Khan et. al. (2003) reported higher wheat grain yields in the plots treated with different post emergence herbicides as compared to weedy control. Marwat et. al. (2005) reported similar results in rainfed situations in Pakistan. Rapparini and Geminiani (2007) reported that a new mixture (Hussar Marx) as post-emergence spray completely controlled *Lolium* and *Phalaris* whereas, it performed well against *Avena*. In Bulgaria, use of combinations of any two herbicides were found economically viable for the control of broad-leaved and grass weeds in wheat (Aleksiev et.al. 2003). Similar results were reported in Pakistan by Cheema and Akhtar (2005). Post emergence application of isoproturon 500 g ha\(^{-1}\) significantly reduced weed density and dry weight (*Avena fatua, Chenopodium album, Fumaria parviflora* and *Cyperus rotundus*) and increased grain yield of wheat (Sharif et. al. 2005).

Several herbicides have been found effective and among them isoproturon is being used for last two decades for controlling weeds especially grasses in wheat (Mishra et al. 2005), although it has not been found excellent against all broad leaved weeds (Kushwaha and Singh 2000). The broad-leaved
weeds can, however, be controlled effectively with 2,4-D. At Hisar, sequential application of 2,4-D one week after spray of fenoxaprop and clodinafop-propargyl did not reduce efficacy of these herbicides and gave grain yield of wheat at par with weed free check (Punia et al. 2006). From Baraut (UP), Chopra et al. (2001) reported lowest competition due to weeds in wheat in plots with 0.75 kg isoproturon. It also showed highest weed control efficiency against *Phalaris minor*. Similar results were also reported by Sharma and Pahuja (2001) with 1.0 kg isoproturon. Whereas, isoproturon applied alone at 0.75 kg could not control wild oats (Panwar et al. 2000). Kushwaha and Singh (2000) in Uttar Pradesh studied comparative efficacy of mechanical and chemical weed control in wheat and reported that pre-emergence application of isoproturon at either 0.52 or 0.75 kg ha\(^{-1}\) reduced both grassy and non-grassy weeds.

Sharma (1991) reported that isoproturon at 1.50 kg ha\(^{-1}\) as post emergence application was the most effective herbicide treatment in controlling grassy weeds in wheat. At Meerut (UP), Tomar et al. (2004) reported significantly highest growth parameters, yield contributing characters and yield of wheat with 2,4-D + isoproturon (0.50 + 1.0 kg ha\(^{-1}\)). Kanojia and Nepalia (2004) from Udaipur (Rajasthan) reported that application of 2,4-D + isoproturon (0.40 kg ha\(^{-1}\) + 0.75 kg ha\(^{-1}\)) resulted in significant reduction in total weed density and dry matter at 40 and 80 DAS. Pre-emergence application of pendimethalin 1.00 kg ha\(^{-1}\) produced lower dry matter content of weeds (Sonawane and Sabale, 2003). In wheat crop pendimethalin (1.0 kg ha\(^{-1}\)) was most effective in controlling *Chenopodium album* whereas, isoproturon (0.75 kg ha\(^{-1}\)) showed the highest control efficiency for *Phalaris minor* (Chopra et al., 2001). Similar crop yield was obtained with two hand weedicings at 30 and 60 DAS and by keeping the crop free of weeds for the entire growing season of wheat (Kushwaha and Singh, 2000). Panwar *et.al.* (1995) found that isoproturon + 2,4-D at 1.20 + 0.30 kg also gave good control of mixed weed flora (87-95%). The highest grain yield of wheat was achieved with 0.75 kg isoproturon WP sprayed 20 DAP (Balyan *et. al.*, 1994). Thakur and Singh (1988) reported that isoproturon at 1.25 kg ha\(^{-1}\) gave effective
control of weeds when applied as post emergence at 2-3 leaf stage of weeds.
Saini and Angiras (1991) obtained better control of weeds (*Lolium temulentum*, *Phalaris minor*, *Vicia sativa* and *Avena fatua*) in silty clay loam soils of Palampur with isoproturon 1.5 kg ha\(^{-1}\) when applied at pre emergence and seedling stages of the wheat crop than the maximum tillering stage.

### 2.2.3 Soybean-wheat crop sequence

At Jabalpur, studies with different herbicides applied in soybean showed that metolachlor was quite effective in controlling all weeds except *Commellina communis* which was effectively controlled by trifluralin. Significantly higher yield was obtained with metolachlor which was statistically at par to hand weeding. The herbicides applied to soybean did not show any effect on weeds in wheat whereas, the direct effect of herbicides applied to wheat was significant on weed control (Anonymous 1991). Similar results were also reported by Tiwari *et al.* (1990) and Anonymous (1990). At Indore, pre-plant incorporation of fluchloralin 1.0 kg ha\(^{-1}\) in soybean and post-emergence application of 2,4-D sodium salt at 1.0 kg ha\(^{-1}\) in wheat or two hand weedings in soybean and application of 2,4-D sodium salt in wheat were quite promising and produced 40 and 20 per cent higher yields than untreated check in soybean and wheat, respectively (Raghuvanshi *et al.* 1990). At Pantnagar, Singh and Tiwari (1992) reported that pre-emergence application of pendimethalin at 1.0 and 2.0 kg ha\(^{-1}\) in soybean was more effective for weed control than imazethapyr. However, the weed control efficiency of imazethapyr was increased when tank mixed with pendimethalin. None of the treatments had any residual effect on the subsequent crop of lentil and its associated weeds.

Raskar and Bhoi (2002) at Rahuri, Maharashtra reported significant increase in grain and biological yields of soybean with all the herbicidal treatments including pursuit and pendimethalin over weedy check. They observed no carryover effect of herbicide applied in soybean on yield of successive *rabi* crop. This was supported by the findings of the Kewat (1998) which revealed that nearly 75 per cent pendimethalin was dissipated within 45 days after its application, thus produces no adverse effect on succeeding crop.
Very scanty literature is available on effect of herbicides applied in wheat on weeds and their effect on succeeding crop and weeds associated with that crop. Studies conducted by Randhawa and Sandhu (1989) reported that isoproturon applied for the weed control in wheat is degraded to non-detectable level by the time wheat crop is harvested and pose no residue problem to succeeding crops. However, application of sulfosulfuron and mesosulfuron + iodosulfuron in wheat showed no residual toxicity in succeeding cotton, summer moong, okra, dhaincha and muskmelon crops. On the contrary, residual toxicity of these two herbicides has been observed on succeeding maize, bajra, sorghum and bottle gourd crops (Saini et al. 2010). Rana (1992) studied the residual effects of imazethapyr and found it 5 per cent more efficient to control the weeds with isoproturon and hand weeding twice in succeeding crop of wheat-pea.

From their studies at Hisar, Malik et al. (2007) concluded that herbicidal combinations including isoproturon have been proved very effective against weeds in wheat and resulted in grain yield higher than weedy check, yet no adverse effect on the fodder yield of succeeding sorghum crop was detected. Also, application of 2,4-D sodium salt and isoproturon did not exhibit any adverse effect on succeeding Kharif crops like mungbean, maize, cowpea, pigeonpea, pearlmillet and cotton (Yadav et al. 2004). Similar results were also reported by Malik et al. (2008) with the same herbicides. No adverse effects of these herbicides were detected in succeeding sorghum crop.

Thus, it can be concluded that various herbicides can be used to control weeds in soybean and wheat crops separately. However, continuous use of some of them may lead to build up of their residues in the soil which may harm the succeeding crops. The impact of herbicide residues on succeeding crops is of great concern as very low concentrations can cause crop damage and increase chance of leaching in soil profile (Sondhia 2008). Therefore, it is pertinent to select only those herbicides for weed control in the crop which provide satisfactory results during the crop period and should not exhibit phytotoxicity to next crop in sequence.
2.3 Residual effect of herbicides

Ideally, an herbicide should remain biologically active long enough to provide satisfactory weed control at least upto critical period of crop-weed competition and after that period, it must degrade into non-toxic components both in soil and plant biomass. Studies on residual effect of any herbicide are important before it is finally recommended for field applications to the farmers. The residual effect of herbicides depend upon soil texture, soil reaction, organic matter content and climatic conditions of a place. Herbicides with higher residual effect may cause phytotoxicity to the succeeding crop in the rotation, whereas, an ideal herbicide not only controls the weeds in the crop in which it is applied but also in the succeeding crop without phytotoxicity to the crop in the rotation.

Among various herbicides, most commonly used for weed control in soybean are pendimethalin, imazethapyr, chlorimuron ethyl etc. whereas isoproturon and 2,4-D are recommended herbicides for weed control in wheat crop. Very scanty information is available regarding residual effects of these herbicides on weeds and crops in rotation.

Saini et al. (2010) at Ludhiana reported that the application of sulfosulfuron, mesosulfuron + iodosulfuron to wheat resulted in significant reduction in plant height of succeeding maize, bajra, sorghum and bottle gourd crops indicating residual effects of these herbicides. Similar results were reported by other workers who recorded significantly higher plant height of succeeding bajra crop (Kaur et al. 2007), sorghum crop (Brar et al. 2007) and bottle gourd (Singh and Walia, 2005) in unsprayed plots as compared to the crop sown in the plots where sulfosulfuron and mesosulfuron + iodosulfuron were applied to wheat.

From New Delhi Kewat et al. (2000), reported that application of metribuzin as pre-emergence in soybean appreciably lowered the weed population and biomass. Also, about 50 per cent of the metribuzin was lost within 45 day, thus, no residual effect was detected in succeeding crops. Raskar and
Bhoi (2002) studied the bioefficacy of different herbicides applied in soybean i.e. pendimethalin, pursuit plus (imazethapyr + pendimethalin) and alachlor. They reported no carry over effect of soybean herbicides on succeeding *rabi* season potato.

At Hisar, Sharma *et al.* (2002) found residual effect of chlorsulfuron on growth and quality of succeeding forage sorghum crop, when applied in wheat at 30 g ha\(^{-1}\). Application of pinoxaden at 40 g ha\(^{-1}\) significantly reduced weed count and biomass in wheat crop. Following crop tolerated the application of pinoxaden in the preceeding wheat crop and observations on weed control and yield were comparable with untreated one, showing no residual effect of this chemical on the succeeding crop (Dixit *et al.* 2011).

Thus, it can be concluded that application of herbicides in a crop, not only control the weeds throughout the crop period but sometimes take care of weeds in succeeding crops. It is due to their residual effect. However, most of herbicides applied in soybean and wheat have least residual properties and degraded in soil within crop period, thus produce no adverse effect on succeeding crops except few at higher doses.

### 2.4 Economics

Weeds should be controlled by least expensive available technology that does not interfere with other phases of crop production or other human activities. Any weed control measures should be used only when its results are expected to be more economically beneficial than without using any control measure (Moody, 1993). Farmers compare time and cost of weed control at the lowest cost. Therefore, choice of weed control inputs depends not only on its efficacy but also on its cost (De-Dutta and Foster, 1977).

Marginal benefits cost ratio and net returns are the best way to assess the economic viability of a particular weed control treatment. However, Padmavati *et al.* (1995) reported highest seed yield and net returns with hand weeding twice (1910 kg and Rs. 9533 ha\(^{-1}\), respectively). Kankal *et al.* (1999) also reported highest net profit and benefit: cost ratio by following mechanical weed control at Rahuri.
Singh and Singh (2004) reported highest grain yield of wheat (3980 kg ha\(^{-1}\)) with two hand weedings, but additional investment with two hand weedings decreased the net returns (Rs. 7480) over pendimethalin plus one hand weeding (Rs. 8063).