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Integrated Weed Management in *Bt*-Cotton Under Semi Arid Conditions – A Review

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Abstract

Cotton is one the major *Kharif* cash crop of India and is also known as '*White Gold*' or '*King of fibres*'. Being a rainy season, long duration, wide spaced and slow growing crop at initial stage, it is highly sensitive to weed competition. The critical period of crop-weed competition is 15 to 60 days after sowing and during this period the crop suffers from heavy losses in seed cotton yield. Weeds are the major constraints that reduce the crop yields since they compete for the nutrients, moisture, light and space. The losses caused by weeds in cotton ranges from 50 to 85 percent depending upon the nature and intensity of weeds in the field. The most common practices adopted by the farmers are manual weeding and inter-culture operation. But during critical period of crop-weed competition, the non-availability of labour, high wages of labour and wet field conditions, leads to ambiguous conditions for cotton growers. Due to delay in inter-culture operations in the crop, ineffectual results produced are clearly reflected in final yield. Thus, timely management of weeds through physical, mechanical, biological and chemical means needs to be ensured for achieving the higher cotton productivity. Physical and mechanical methods are widely used but in case of biological weed control, limited options are available. Chemical weed management is the better choice of the farmer being economical, quick responsive and suitable to the prevailing conditions. Chemical weed control in cotton by using suitable pre and post emergence herbicides during critical period of crop-weed competition gives a way out to handle the situation and to realise higher productivity. Further, the integration of all the weed management practices in the form of IWM needs to be explored more and more being economically viable, ecologically sustainable and locally available and user friendly techniques. Realization of higher cotton yield and fetching better remunerations mainly depends on an integrated weed management approach that also recognizes the adoption of location specific cultivar.

Key words : Bt-cotton, weeds flora, crop-weed competition, seed cotton yield, weed management

Bt-Cotton (*Gossypium* sp.) is the most important commercial crop in India known as "White Gold" or "King of fibres". Cotton crop is grown in about 70 countries across the world and grown in an area of 33.2 m ha. India ranks first in global occupying about 36% of the world cotton area but in production it ranks second, next to China. In India, cotton cultivation provides livelihood for over 4 million farming families. It occupies 12.95 m ha area with production 371 lakh bales and productivity 487 kg ha^{-1} (Anonymous, 2020-21). Gujarat, Maharashtra and Telangana were the leading cotton growing states covering around 71% (86.4 lakh ha) in area under cotton cultivation and 65% (246 lakh bales) of cotton production in India (Anonymous, 2019-20). It is major kharif cash crop of Haryana grown in area of 7.36 lakh ha with production 24 lakh bales and productivity 580 kg ha^{-1} (Anonymous, 2019-20). Cotton is essentially produced for its high quality fibre, which is commonly used in textile industry. It is the back bone of textile industry contributing nearly 80% of raw material. Hence, cotton is an important commodity in the world economy.

Weeds are major biological constraints that reduce the crop productivity since them highly competition with crop for the resources;

moisture, space, minerals nutrients and solar radiation. Weeds also tend to exhibit allelopathy, competition and parasitism. Cotton being long duration, wide spaced, slow growing habit initial stage which is turn invites multiple weed species infestation. Weed management in cotton concentrated on scientific manner to provide weed free environment to the crop. Brar and Brar (1992) reported that weed infestation in cotton offer severe competition for basic resources and causing yield reduction up to 74 percent in the crop. The infestation of weeds in cotton has to severe competition during its initial growth stages and causing yield reduction extended 40 to 85% (Sreenivas, 2000; and similar results found by Gnanavel and Babu, 2008). Weeds remove about 30-50% of applied fertilizers and 20-40% moisture (Jayakumar *et al.*, 2008). Due to the competition of weeds for nutrients, light, moisture and space the cotton yield was adversely affected. Raskar and Bhoi (2002) reported that competition with weeds caused 79.1% reduction in cotton yield. Productivity loss caused by weeds in cotton ranged from 50 to 85 percent mainly depending upon the nature, associated weeds flora and intensity of weeds in cotton field (Venugopalan *et al.*, 2009 and Prabhu *et al.*, 2012). Uncontrolled weed growth during crop growing season resulted in yield loss of up to 86 percent (Leela *et al.*, 2016). The suitable combination of different weed management practices would be a better option for controlling broad spectrum weeds, increasing the cotton productivity and bring to more sustainability in crop ecosystem. Thus, integrated weed management strategy has several aspects such as physical, mechanical, chemical and biologically methods. Integrated weed management approach totally based upon the critical period of crop weed competition, involving different direct and indirect control methods has been developed which has been commonly adopted by farmers to reducing the weed infestations in cotton field in a sustainable manner.

Keeping all these facts above view, the current review provides, extended overview of weeds associated with of *Bt* cotton and their cost effective suitable weeds management practices as well as future outcomes, needs to developments of weed science importance in Indian agriculture. It also includes weeds associated with *Bt* cotton in Haryana under irrigated conditions, their critical weed competition periods, productivity losses, cost benefit ratios and properly weeds management practices. The present scenarios, weed research findings, their adoptions, challenges and more opportunities for weed management.

Weed spectrum in *Bt*-cotton : To evolve a successful weed management programme, the proper knowledge about identification of weed species in the field, weed life cycle, detail of associated weeds, weed community and seed prolification ability of weeds, critical period of crop-weed completion, and characteristics of the variety along with the cross and multiple resistances to herbicides is essential. However, the weed community also depends upon climatic conditions and soil characteristics. Wide spectrums weeds have greater adaptability, to extreme climatic conditions and edaphic factors and cropping system advocated by Marnotte *et al.*, (1997). Cheema *et al.*, (2008) reported that *Bt* cotton fields were mainly infested with grassy weeds, broad leaf weeds (BLW) and sedges. Broad leaf weeds category mainly present six species viz., *Trianthema portulacastrum, Digera arvensis, Amaranthus viridis, Cucumis prophetarum, Portulaca oleracea* and *Tribulus terrestris*. Broad leaf weeds was the dominant group with 54% mean population followed by grassy weeds such as *Cynodon dactylon, Dactyloctenum aegyptium, Echinochloa colonum* occupying 31% area. Least infestation in cotton field was reported w.r.t. single species of sedges, i.e. *Cyperus rotundus* occupying the 15% area. In cotton experimental field, *Trianthema portulacastrum* was higher with

40 percent density among all weeds species and poses serious weed infestation problem throughout the crop season. Manikandan (2009) advocated that the predominant broad leaved weeds occurrence in the trial field of irrigated cotton grasses was *Chloris barbata* and *Cynodon dactylon* (L.) in sedges *Cyperus rotundus* (L.) and presence of broad leaved weeds were *Trianthema portulacastrum* (L.), *Digera arvensis* and *Parthenium hysterophorus* (L.). Bharathi *et al*., (2011) reveals that *Cyprus rotundus, Commalina bengalensis, Corchorus acutangulus, Amaranthus viridis, Abutilon indicum, Phyllanthus niruri, Celosia argentia, Parthenium hysterophorus* (L.) were the dominant weeds in experimental field of *Bt* cotton. Prabhu (2012) highlighted that predominant monocots weeds in the experiment field were *Cyperus rotundus* (L.), *Cynodon dactylon* (L.), *Dinebra retroflexa, Echinochloa colonum* (L.), *Echinochloa crusgalli* (L.). Beauv and Tragus Bifloris Schult (2012) reported that common dicotyledonous weeds were *Abutilon indicum* (L.), *Ageratum conyzoides* (L.), *Aristolochia bracteata* Retz, *Commelina benghalensis* L., *Cynaotis dactylon* (L.), *Digeria arvensis Forsk, Merremia emarginata* (L.). Cufod., *Mimosa pudica* (L.), *Parthenium hysterophorus* (L.), *Phyllanthus maderaspetensis, Phyllanthus fraternus, Tribulus terrestris* (L.), *Xanthium strumarium* (L.), *Coccinia indica* and *Sesbania aculeata* Pers. Similar weed population was also reported by Khan and Khan (2003) and Shahzad *et al*., (2012). Duraisamy *et al*., (2013) resulted that in transgenic maize and cotton crops experiment field in both season 2009 and 2010 the population broad leaved weeds were dominated over grasses and sedge. Among the weed community, *Trianthema portulacastrum, Cleome gynandra, Digera arvensis, Datura stramonium, Cynodon dactylon, Dactyloctenium aegyptium, Commelina bengalinsis* and *Cyperus rotundus* were predominant in maize field during both the seasons. Among broad leaved weeds, *Trianthema portulacastrum* was the dominant one during both the season. Werth *et al*., (2013) noted that in cotton based cropping systems a major species shift towards *Conyza bonariensis* and minor increase in *Sonchus oleraceus* at the end of the season is a major concern. Several species including *C. bonariensis, S. oleraceus, Hibiscus verdcourtii* and *Hibiscus tridactylites, Echinochloa colona, Convolvulus species, Ipomea lonchophylla, Chamaesyce drummondii, Cullen* sp., Amaranthus *macrocarpus* and *Chloris virgata* were still present full season. Ray *et al*., (2014) highlighted that south-western, Nimar region of Madhya Pradesh some exotic weeds species were early established as dominant in the *Bt* cotton. The 55 species of weeds were belonging to 21 families and 47 genera have been severing infestation in *Bt* cotton fields. Among them

Table 1. Major weeds of cotton in Haryana

Broad leaf weeds	**Grassy weeds**
Amaranthus viridis	*Cenchrus catharticus*
Cleome viscosa	*Digitaria sanguinalis*
Celosia argentia	*Dactyloctenium aegyptium*
Corchorus spp.	*Echinochloa colona*
Commelina spp.	*Echinochloa crusgalli*
Conaza canadhalensis	*Eragrostis tenella*
Digeria arvense	*Imperata cylindrical*
Eliptica alba	
Ipomoea pestigridis	
Portulaca spp.	
Phyllanthus niruri	
Trianthema portulacastrum	
Tribulus terrestris	
Xanthium strumarium	
Perennial weeds	
Convolvulus arvensis	
Cyperus iria	
Cyperus rotundus	
Cynodon dactylon	
Sorghum halepense	
Saccharum spontaneum	

eleven weed species have been observed to be changeable threatened of *Bt* cotton cultivation in this region.

Weed flora in different soil types

A. Sandy loam soils : Balasubramanian (1985) reported that predominant weed species of cotton fields in sandy loam soils of Coimbatore were Trianthema portulacastrum, Dactyloctenium aegyptium, Echinochloa colonum and Cyperus rotundus the weed ratio of broad leaved 60%, grasses 29% and sedges 11% respectively. Balasubramanian (1992) found that the mainly 14 common BLW namely; 1. *Digera arvensis* 2. *Trianthema portulacastrum* 3. *Amaranthus viridis* 4. *Amaranthus spinosus* 5. *Abutilon indicum* 6. *Cleome viscosa* 7. *Commelina benghalensis* 8. *Corchorus olitorius* 9. *Datura fastuosa* 10. *Euphorbia prostrata* 11. *Flaveria australasica* 12. *Parthenium hysterophorus* 13. *Portulaca oleracea* 14. *Boerhaavia diffusa*, five grass species *viz*., 1. *Cynodon dactylon* 2. *Echinochloa colonum* 3. *Dactyloctenium aegyptium* 4. *Panicum repens* 5. *Chloris barbata* and sedge weed *Cyperus rotundus* were very closely related with cotton crop. Brar *et al*. (1998) found that in Punjab, the dominate weeds in sandy loam soil cotton fields were *Cyperus rotundus, Trianthema portulacastrum, Tribulus terrestris, Eleusine indica, Xanthium strumarium* and *Cenchrus* species. But in Haryana conditions, *Trianthema portulacastrum* (L.) and *Echinochloa crusgalli* (L.) were the most dominant weeds in cotton under sandy-loam type soils (Panwar *et al*., 1998). Panwar *et al*. (2001) observed weeds in the sandy loam soils of Haryana, *Trianthema portulacastrum* (L.), *Cyperus rotundus* (L.), *Digera arvensis* and *Celosia argentia* (L.), were the dominant weeds in cotton field in Hisar condition.

B. Clayey loam soil : Jadhav *et al*., (1995) advocated that in clay loam soil of Maharashtra kharif season weed flora in cotton field were flashes *Digera arvensis, Abutilon indicum, Cynodon dactylon, Parthenium hysterphorus* and *Cyperus rotundus*. In clayey loam soil, cultivated irrigated hybrid cotton the predominant weeds were observed *Cyperus rotundus, Cynodon dactylon, Trianthema portulacastrum, Echinochloa colonum, Eclipta alba, Panicum repens* and *Cleome viscosa* (Gnanavel and Babu, 2008).

C. Black soil : Giri and Bhosle (1997) highlighted that cultivation of rainfed condition cotton in deep black soil of cotton research farm Parbhani (Maharashtra), the main dominant weeds in cotton field were *Trianthema portulacastrum, Digera arvensis, Eclipta alba, Euphorbia hirta, Abutilon indicum, Acalypha indica, Ischeemum pilosum, Cyperus rotundus, Cynodon dactylon, Vicoa indica, Amischophacelous cucullata, Phyllanthus medraspatensis, Corchrous acutangulus, Alleteropsis cimicina*.

Cotton (*kharif*) season - Dominate weed flora : The major weeds infesting the in crop season such as *Trianthema portulacastrum* (58.9%), *Echinochloa crusgalli* (16.9%), *Cyperus rotundus* (16.6%) and *Digera arvensis* (5.6%) were predominately weed species of cotton fields. The ratio of broad leaved weeds 58% grasses 16% and sedges 16% respectively as observed by Chander *et al*., (1997). Ali *et al*., (2005) reported *Euphorbia prostrata, Convolvulus arvensis, Cynodon dactylon, Cyperus rotundus, Portulaca oleracea, Sorghum halepense, Trianthema monogyna, Amaranthus viridis, Echinochloa colonum, Setaria viridis, Euphorbia helioscopia, Corchorus tridens, Digeria muricata* and *Tribulus terrestris* as the predominant weed flora in *kharif* season. Vivek *et al*., (2002) observed that the major weed flora occurrences in cotton-wheat cropping system

Bulandshar region of UP were *Cyperus rotundus, Cynodon dactylon, Cyperus iria, Panicum* spp. and *Trianthema monogyna.* According to Patil *et al*., (2003) major weed flora found in cotton fields of Akola area in Maharashtra such as *Cynodon dactylon, Cyperus rotundus, Poa annua, Parthenium hysterophorus, Digera arvensis* and *Euphorbia* sp. were dominate weeds community. The predominant broad leaved weed species were identified; *Trianthema portulacastrum, Acalypha indica, Cleome viscosa* and in grasses; *Dactyloctenium aegyptium, Echniochloa colona, Digitaria sanguinalis and in sedges Cyperus rotundus, Cyperus iria* weeds in Tamil Nadu noticed by Srinivasan (2003).

Critical period of crop-weed competition : The critical period crop weed competition is the period between early growth stage during which weeds can grow without affecting crop yield and the point after which weed growth does not affect the yield. The critical crop weed competition occurs in crop, when growth and development of crop and weeds are in the same growing period. The critical period of crop-weed competition is approximately 1/3rd of the duration of the crop. Weeds that germinate along with crop are more damaging than the later emerging weeds. This weed competition period in cotton crop varies from 3 to 9 weeks after sowing time and it's totally depends on climatic condition and edaphic factors that crop area.

The weed free condition up to three to five weeks after sowing was required to get desirable yield (Mohamed Ali and Bhanumurthy, 1985). Initial period of 30 to 50 days the most critical period for crop weed competition in cotton in Tamil Nadu condition Jayakumar *et al*., (1990). Panwar and Malik (1991) reported that competition of carpet weed (*Trianthema portulacastrum*) was more during initial 50 days after sowing, whereas the competition of barnyard grass (*Echinochloa crusgalli*) was during 50 and 100 days after sowing. They opined that initial 60 days were most critical for crop weed competition in cotton under sandy loam soils of Hisar condition. In American cotton, weed competition during the first 30 days after sowing resulted in an average yield loss of 10.5 percent in Punjab. Thind *et al*., (1995) observed that seed cotton yield increased from 1890 to 3021 kg ha^{-1} when the initial stage weed free period extended from 30 days to full growing season. Mishra (1997) revealed that critical period of crop-weed competition was 15-60 days and during this period weeds were not controlled caused yield losses from 40-50 percent. Papamichail *et al*., (2002) reported that cotton is very sensitive to weed competition in the first 60 days of crop growth. The occurrence of weeds for more than three weeks after crop emergence caused significant losses in crop growth and yields. Sivakumar and Subbian, (2002) observed 33-40% reduction in yield have been noted due to severe infestation of weed population field. They also found higher weed biomass per square meter than that recorded in weed free treatments. In cotton plant establishment, plant height, square

Table 2. Critical period of crop-weed competition in some major crops

Crop	Critical period of crop-weed competition (DAS)
Black gram	30-45
Bt-Cotton	30-60
Green gram	20-45
Groundnut	30-50
Maize	15-45
Paddy	15-45
Pearl-millet	25-45
Sorghum	15-45
Soyabean	30-45
Sugarcane	30-120
Sunflower	30-45
Wheat	30-45

formation, number of bolls and biomass were significantly affected by weed competition Mushtaq and Cheema (2008). Rajiv Sharma (2008) found that critical period of crop weed competition was 15 to 60 days during its growing period. Webster (2005) reported that the significant reduction in yield and yield attributes due to weed infestation over weed free treatments. Critical period of weed competition occurred between planting and the 3-5 leaf stage of cotton minimized yield loss to five percent (Webster, 2008). Spasova *et al.*, (2008) advocated the duration of weed presence with the crop and the time of weed emergence, generally affect crop-weed competition. Ayyadurai and Poonguzhalan (2013) pointed that critical period of weed competition was found to be 20 to 60 days after sowing. Cotton yield loss increased in during weed competition and maximum loss (96.5%) occurred due to full growing season competition. Seed cotton yield increased significantly with the increase in initial duration of weed free condition up to 80 days after sowing. Beyond 80 DAS, seed cotton yield was reduced considerably due to decrease no. of bolls percentage. Poonguzhalan *et al.*, (2013) found that cotton was very sensitive to weed competition in the first 60 days of crop growth. The period of weed interference, crop damage and the critical period of crop-weed competition were 30 to 60 days which occupied 50 percent of the whole cotton growing period. Seed cotton yield loss increased with the increase in the duration of competition and maximum loss was observed due to full season competition. Tursun *et al.*, (2015) noted that proper knowledge and understating power of crop weed competition period is very important for weed management strategies in any cropping systems. Indiscriminate use of fertiliser, the relative yield of cotton decreased with increasing duration of weed interference. Depending on the nitrogen application rate, weed free conditions need to be established as early as one week after crop emergence and maintained as late as eight weeks after crop emergence to avoid more than 5% loss in cotton yield. These findings could help cotton producers improve the cost effectiveness and efficacy of their weed management programme under different nitrogen application rates.

Weed interference in cotton : Weed infestation in crop field is main hindrance and limiting factors in crop production. Cotton being a long duration, wide spaced and slow growing habits in initial stages that caused severe weed infestation field. Weeds have always drastically competed with crops and pull down the seed cotton yield. Incompetent weed control at appropriate stage is considered as a major constraint for high production. Cotton was very sensitive to weed competition in the first 60 days of crop growth. The period of weed interference, crop damage and the critical period of crop weed competition were 30 to 60 days which occupied 50% of the whole cotton growing period. Seed cotton yield loss increased with the increase in the duration of competition and maximum loss was observed due to full season competition. Weeds also increased the infestations of insects-pest and diseases in cotton such as whitefly, jassid, aphid, thrips, green leaf hoppers and mealy bug (sucking insects) resultants decrease the yield, revealed by Zhang *et al.*, (2014). Weed infestation in cotton has been reported to offer severe competition and causing yield reduction to an extent of 40 to 85 percent. Due to their high competitive ability, weeds compete for resources like as nutrients, light, soil moisture and space thereby affecting productivity of cotton. Hence, the productivity of cotton is largely depends on a weed free condition particularly in their early growth periods. Broad spectrums of weeds with grater adaptability in adverse climatic conditions, edaphic factor and biotic or abiotic stresses are occurs in the cotton fields. So, mention views is presented on the nature of weed spectrum in

cotton, competition between crops and weeds effect the growth, yield attributes, yield and also impaired quality of cotton. Long persistence nature type of weeds has high ability seed production and its proliferation or induced more seed viability (Nadanassababady *et al*., 2001). The crop productivity totally depends upon the severity of weed interference in field. The losses of crop productivity causes by weed interference depends on many factors, such as environmental conditions, edaphic factor, fertility status of soil, nature of weed community and their intensity, density, distribution and duration of emergence of weeds community in relation to cotton crop (Papamichail *et al*., 2002).

Effect of weeds on cotton

A. Growth components : Cotton growth stage plant height, dry matter accumulation and in development phase flowers initiations, square formation and finally bolls developments and yield or yield attributes are significantly influenced the presence of weeds in the cotton field.

According to Sankaran and Rethinam, (1974) the dry matter production of cotton crop per unit area was the lowest under uncontrolled weeds field. Similar result was recorded by Snipes *et al*., (1982). Decrease in plant height was observed due to weed competition by Balasubramanian and Sankaran, 1976; Singh, 1983; Rushing *et al*., 1984. Based on research study Holt and Orcutt (1991), concluded that yellow nut sedge (*Cyperus esculentus*) and purple nut sedge (*Cyperus rotundus*) highly competition for light, soil moisture and space with cotton and takes very faster growth, accumulation more biomass by using resources rather than the cotton crop. Reduction in plant growth & development prolonged delays in weed removal in cotton field was observed by Bukun (2004). Balasubramanian (1992) found that weed free condition in cotton increased the plant height, dry matter production, number of bolls/plant, boll weight and seed cotton yield. The highest plant height was recorded by low weed growth in cotton field (Khan *et al*., 2001). According to Mahar *et al*., (2007) plant height of cotton was significantly decreased in uncontrolled weeds plots. Spasova *et al*., (2008) found that the presence of weeds for more than three weeks after crop emergency caused significant reductions in crop growth and seed cotton yields. However, weeds that emerged 11 weeks after crop emergence they did not much adversely affect cotton yields. A weed free period of eleven weeks after crop emergence was needed to prevent significant reductions in plant height, dry matter production, number of bolls and seed cotton yield. Veeramani *et al*., (2009) opined that the pre-emergence application of chemical herbicide paraquat @ 0.40 kg ha^{-1} fb cultural hoeing to check weed density significantly influenced the plant growth and development parameters like plant height, sympodial and monopodial fruiting branches, number of bolls and accumulation of biomass on per plant basis. Post sowing weed management practices on 20 DAS fb glyphosate @ 1.5 kg/ha (protective cultivation) increased the plant height, physiological parameters and dry matter production per plant over the control treatment. Cotton plant establishment, plant height and accumulation of biomass significantly influenced the presence of number of weeds per unit area, their growth and crop-weed competition in the cotton field (Mushtaq and Cheema, 2008). Leaf area index and crop growth rate were decreased in unweeded check plots (Prabhu *et al*., 2012). Muhammad *et al*. (2013) concluded that decreased plant population per unit area, small plant height and number of monopodial branches per plant was recorded in weedy check field. Scientific application of pre and post-emergence chemical herbicides viz; pendimethalin, pyrithiobac sodium and quizalofop ethyl which are not harmful to cotton

crop. Directed spray of glyphosate caused foliar injuries or leaf scorching may be occurs. All the herbicides application alone or tank mix according to their compatibility were significantly influenced the plant height, biomass accumulation, number of bolls per plant, boll size and weight, seed cotton yield and quality parameters (Hargilas *et al*., 2015). Leela *et al*., (2016) observed that plant establishment, plant height, dry matter production of plant significantly higher in unweeded check cotton field.

B. Yield components : Weeds have always harmful impact on yield and quality of cotton. Efficient weed management practices significantly influences the cotton yield. The growing season of crop weed control resulted in better crop growth and increased source availability which resulted in increased number of yield components of cotton. Balasubramanian and Sankaran (1976) reveal that significant reduction in number of sympodial branches, fruiting bodies and seed yield due to weeds infestation in cotton field. Similar result was found by Mohamed Ali and Bhanumurthy (1985). Loss in seed cotton yield varied from 40-85 percent due to crop weed competition (Jain *et al*., 1981; Bhan and Mishra, 1993). Bishnoi *et al*., (1993) reported that effective weed control at initial stage 20 days after sowing significantly higher seed cotton yield (2798 kg ha^{-1}) as compared to weedy check plots (1614 kg ha^{-1}). Mofett and Mcclosky, (1998) recorded that severe infestation of weeds yellow nut sedge (*Cyperus rotundus*) seed cotton yield was reduction upto 34 percent in field. Seed cotton yield reduction is mainly due to severe weed competition in the initial stages. Weeds accumulated higher concentration of mineral nutrients than crops, thereby depleting soil nutrients quickly and reducing the yield (Gupta, 1998). According to Srinivasulu and Rao, (2000) Being a long duration, wide spaced, very slow growth in early stages crop permitted more weed competition that causing seed cotton yields reductions extended upto 69 percent in unweeded check. Sreenivas (2000) observed higher number of bolls plant per plant with lower weed incidence. Khan *et al*., (2001) recorded the big size bolls with lesser weed interference in cotton crop. Maqbool *et al*. (2001) revealed that no control the weeds in cotton field significantly reduction in the seed cotton yield. According to Velayutham *et al*., (2002) uncontrolled weed growth reduced the number of bolls plant per plant and boll size and weight and ultimately yield of cotton. Significant reduction in no. of bolls plant and boll weight in unweeded check was similar result found by Srinivasan (2003). Khan and Khan (2003) reported that yield losses in cotton from broad leaved weeds infestations was nearly 15 to 30 percent and infestations of grassy weeds nearly15 to 40 percent. Kalaisundareson and Sundari (2004) concluded that the highest number of bolls plant per plant was observed when weeds were efficiently controlled. Sadangi *et al*., (2006) observed that lesser no. of sympodial branches, no. of bolls per plant and boll weight in unwed control treatments. Higher intensity per unit area of broad leaf weeds Trianthema portulacastrum significantly decrease the number of fruiting branches, number of bolls per plant and seed cotton yield reported Anjum *et al*. (2007). According to (Mahar *et al*., 2007) in cotton number of sympodial branches, no. of bolls per plant and yield were significantly reduction under untreated check plots. Mushtaq and Cheema, (2008) reveal that significant reduction in square formation, number of fruiting bodies and seed yield due to higher weeds infestation in cotton field. Prabhu *et al*., (2012) recorded that total number of bolls at harvested and boll weight were significantly affected in unweeded check compared to other treatments. In weedy check plots lesser number of sympodial branches and

number of bolls plant per plant assumed by Muhammad *et al*., (2013). Weeds can utilise more water than cotton plants and compete for sun light, space and nutrients with cotton plants and ultimately, significantly reduction in the cotton yields observed by Nalini *et al*., 2015). Leela *et al*., (2016) observed that number of bolls per plant, boll weight and seed cotton yield was significantly affected weedy check cotton field.

Cotton quality characteristics : Cotton yield is decreased due to severe weed competition in the initial stages. Often, noticeable that weeds causes mainly two types losses the in crop. The most important one is the direct yield loss due to competition of resources; second one is the indirect loss by destroyed crop productive quality. Nobrega *et al*., (1997) reported that chemical herbicide application not affected the seed weight, quality, fiber percentage and staple length of fiber. Dimitrova and Gueorgieva (1997) found that infestation of field bind weed (*Convolvulus arvensis*) by sticking or mixing with fiber impairs the quality of cotton. Weeds exhaust more mineral and nutrients from soil than crops and depleting soil nutrients quickly or decrease the soil fertility that causes significantly reduction in the seed cotton yield (Gupta, 1998). Sandhu *et al*., (1996) advocated that yield losses caused by weeds in cotton ranged from 45-75 percent depending upon weed flora and intensity of weeds. Prabhu (2010) state that weed infestation was no affected the quality parameter of cotton, but weeds were significantly reduction the yield of cotton. Highest weed control efficacy approximately 96% and seed cotton yield of kg ha^{-1} were recorded by Singh and Kokate (2010) from pre and post emergence application of pendimethalin @1.00 kg ha^{-1} fb by glyphosate @ 1.00 kg ha^{-1} with nearly 90% weed control and higher seed cotton yield as compared to unweeded check plots. Similar trend was noted in respect of physiological parameters such as growth and development, yield attributes and fibre quality characteristics. According to Soliman *et al*., (2013), unweeded check significantly reduced the seed cotton yield and quality parameters i.e. lint percent, staple length, micronaire value, fibre length and ginning percentage. Crop season competence uncontrolled weeds also reduced the crop yield and along with enhanced weed seed bank of soil which serious problem for cultivation. Hence, weeds play a significant greater role in decreasing the cotton yield and quality characteristics (Nithya and Chinnusamy, 2013). Highest dry matter accumulations of weeds were recorded at harvest time in the weedy check plots. Pre and post emergence herbicides application and cultural practices significantly reduced the weed density than in weedy check (Patel *et al*., 2013). From the above mentioned views, it is obvious that crop weed association and crop weed competition drastically pull down the seed cotton yield with the significantly affected the quality characters viz., lint percentage, ginning percentage, staple length and micronaire value.

Nutrient depletion by weeds : The nutrient removal by weeds showed a significant impact on the availability of nutrients to the crop and thus affecting its dry matter accumulation. Jain *et al*., (1981) reveals that the nutrients uptakes by cotton very slow as compare to weeds. Weeds 5-6 time more nitrogen uptake, phosphorus 5-12 times and potassium 2-5 times than the cotton crop. Singh *et al*., (1988) found that nutrients depletion by weeds range 10-90 percent that causes significantly losses of crop yield up to 67 to 78 percent particularly in northern India. Weeds absorbed present major plant nutrients from soil and caused significantly losses in crop production. Weeds reduced the availability of both major and micro nutrients to the crop (Shobana, 2002). Maximum nutrient depletion was recorded in cotton at early growth stages i.e. 60 days after sowing. The depletion

rate of major nutrients NPK was 61.8 kg, 5.6 kg and 57.6 kg per ha respectively reported Baldev *et al*. (2004). Excessive absorption of nutrient's by weeds resulting luxurious growth of weeds in cotton crop reported by Kumar *et al*., (2007).

Integrated weed management in *Bt*-cotton : Proper time and successful way weed control is essential for economic cultivation of cotton. Cotton being a wide spaced, slow growth habit crop at initial stages suffers severe weed competition that resulting more depleting of mineral & nutrients turn to substantial decreased soil fertility, reduction in seed cotton yields and quality parameters. Often it's seen that, weed control practices adopted in the field are time consuming and more expensive. Among the agronomic constraints of cotton production, weed infestations have been a major issue. Innovation of many advances technology in weed management, despite cotton farmers still faces significant challenges from weeds. Chemical herbicide applications at the time of sowing will not give season long control of weeds. Pre and post emergence application has the initial advantage to cotton over the weeds. Hence, the integration of different weed management practices would be a viable option for broad spectrum weed control and enhancement of cotton productivity and balancing crop ecosystems. Thus, weed management has several aspects such as physical, cultural, mechanical, chemical and biological integrated weed management methods.

Why IWM? : Integrated weed management approach is the simultaneous application of different strategies on successful weed control in a sustainable way. Integrative methods is based on critical period of crop weed competition, including different direct and indirect weeds control method has been developed time to time and adopted by farmers to reduced weed infestations in cotton in a best suitable manners. An integrated weed management approach to land management practices combined use of complementary weed control methods such as animals grazing, herbicide application, land fallowing, crop rotation, crop diversification and biological control. IWM is a method whereby all economically, ecologically and toxicologically justifiable methods are employed to keep the harmful organisms below the threshold level of economic damage, keeping in the foreground the conscious employment of natural limiting factors. Thus, use of IWM has been shown to be the most economical and sustainable way to weeds management. In this review to include the present scenario of weed research findings or researcher's outcomes and their adoptability among farmers, challenges, opportunities and future perspectives for weed management study.

- Highly sustainable in crop ecosystem
- Cost effectiveness
- Long term approach
- Broad spectrum weed control
- Prevent development of herbicide resistant
- Weed management practices may be flexible to accommodate
- Optimum utilization of natural resources & environmental safety
- Appropriate integration of synthetics organic & inorganic herbicides

Principles of weed management

1. Prevention
2. Eradication
3. Control

Types of Integrated Weed Management

A). Indirect Methods

1. Preventive Methods
2. Cultural Methods & Ecological Methods

B). Direct Methods

1. Physical/Manual Methods
2. Mechanical Methods
3. Biological control
4. Chemical control

A. Indirect Methods

1. Preventive Methods

- Use of clean seed
- Use of clean farm equipments
- Clean leaves, watercourses and irrigation canals
- Control grazing of livestock
- Ensure that farmyard manure and other soil materials are free of weed
- Prevent the formation of weed seeds or vegetative progules
- Legislation

2. Cultural Methods : Cultural practices are important after preventive measure as eco-friendly techniques. All over the globe several cultural practices are available for weed control in cotton crop. These practices are strong reliable, cheap or even costless and are easily adjustable in the weed management strategy for cotton. The most important of these may include crop rotation, intercropping, smoother crops, stale seedbed method, soil solarization, suitable sowing time, sowing method, use of appropriate variety, plant geometry (spacing), plant density, flooding and drainage, irrigation scheduling, cover crop, mulching and managerial skill or judicious uses of farm management practices for weed control in cotton.

B). Direct Methods

Physical/manual method of weed control : Manual weed control is the oldest, most practical, physical method of weed control that utilizes manual power and simple hand tools to control weeds and is followed by farmers widely. Hand weeding, hand pulling, hand hoeing (kasola, khurpa etc.) wheel hand hoeing, bullock drawn plough, bullock operated trifali is still a traditional and effective method of weed control to eliminate weeds which could not recover again. It's very effectiveness to control annual and perennial weed population in cotton by removing rhizhomes and stolons of weeds and suppressed weed species.

Hand weeding/hand hoeing : Singh and Varma (1988) reported that nutrient uptake and dry matter production in cotton was significantly highest by manual weed control. Tiwana and Brar (1991) state that two hoeing provided the best weed control and the highest seed cotton yield. According to Detroja *et al*., (1992) three hand weeding at 20, 40 and 60 days after sowing significantly increased seed cotton yield and nutrient uptake capacity of cotton crop. Two hand weeding carried out at 21 and 42 DAS significantly higher weed control efficiency, crop growth and higher seed cotton yield recorded by Gogai *et al*., (1992). Two hand weeding carried out at 30 and 60 DAS, similar result was observed by Singh *et al*., (1992). Patil *et al*., (1997) advocated that Vidarbha region in cotton crop 20, 40 and 60 DAS time interval hand hoeing and hand weeding showed significantly effect in reducing weed density. Growing full season of hand weeding in cotton significantly decreased the weed density (92%) and increased the plant height, sympodial branches and no. of bolls per plant or seed

cotton yield Mahar *et al*., (2007). Hand weeding at time interval 25 and 45 DAS significantly reduction number of total weed density and total dry weight in cotton highlighted Nithya and Chinnusamy (2013).

Mechanical methods of weed control in cotton : Mechanical weed control starts with the primary and secondary tillage practices. In this method included mowing, mulching different tillage operation such as dry hoeing, deep ploughing and disk harrowing etc. uprooting and shredding of weeds in a field during the early spring season in cotton. They also bury the weed seeds deep layer with in the soil where they will not be able to emerge. Mechanical weed control after the planting of cotton is more successful when the weeds are relatively small. Therefore, cultivating a cotton field early in the season when the weeds are young will give better results than waiting until later. Mechanical weed control is comparatively faster and requires less labour than hand weeding (Chivinge, 1990). Pagar *et al*., (1995) observed that weed free environment through mechanical weeding resulted in high weed control efficacy (WCE) and seed cotton yield as compared to all other treatments. Central Research Institute for Dry Land Agriculture (CRIDA) use the power weeder for control the weeds and saving in labour up to 80 to 87 percent reported Prasad (2006). By applying these techniques they save time and cost remove weeding. This technology gave more relief to the farmers who are facing labour shortage and higher cost of labour during the peak season. Yadav and Pond, (2007) state that mechanical weed control can be applied as an intervention within the crop rows kept the soil surface loose resultant more soil aeration and increased water holding capacity. Leela *et al*., (2016) noticed that mechanical weeding at 20, 40 and 60 days after sowing significantly increased the plant height, crop dry matter, number of bolls, seed yield per plant and of cotton seed yield.

Chemical method : Chemicals that are used to kill plants or weeds are called herbicides. Herbicides have an important role in management of weeds in cotton. Herbicides make the weed control in cotton easy, efficient and economical. Herbicides as an alternative to mechanical control reduce mechanical damage to crops. The sequential application of pre-emergence and post-emergence application of herbicides with kept the weeds under control and favoured to plant growth and development and also improvement in quality characteristics. Their use has been increasing rapidly since 1944 when 2; 4-D was first use as herbicide. In many instance, they offer most practical, effective and economic means for controlling weeds. Successfully weed management by the chemical method always applied recommended dose of herbicides with uniform application in correct way over the target area. Proper calibrations of sprayers with adequate precision tools are very important to increase the herbicides efficacy. Over dose application of herbicides injurious the crops and too low may not be adequate amount weed control in crop field. Hence, it is very important to use the herbicides applications timely and with suitable calibrations for better management of weeds. Most common application of chemical herbicide in agro ecosystem as under;

a) Pre plant incorpation (PPI) e.g. Fluchloralin 45 EC, Trifluralin 48 EC, Metham sodium

b) Pre-emergence application e.g. Pendimethalin 30 EC

c) Post-emergence application e.g. Glyphosate 41 SL, Paraquat Dichloride 24 SL, Pyrithiobac sodium 10 EC, Quizalofop Ethyl 5 EC, Fenoxaprop-p-ethyl 9 EC, Quizalofop Ethyl 4 EC + Pyrithiobac sodium 6 EC (Hitweed maxx)

Today's chemical weed control: Become first choice of farmers

- Due to increase agriculture wages
- Scarcity of labours
- Short duration - effective control
- Easy to handling
- Availability in market

Pre-emergence herbicides for cotton : Pre-emergence herbicides are usually applied before germination or immediately after the sowing the crop but generally prior to crop sowing. Pre-emergence application of soil active herbicides are commonly applied to surface of the soil and these herbicides should be able to move into upper 3.5 to 4 cm of soil under the influence of irrigation to kill the germinating weeds (Gupta, 1998). Their use would be appropriate not only for minimizing early weed competition, but also for reducing the labour requirement and control weeds in the inter row as well as within the row (Nadanasababady, 2001).

Pendimethalin : Nalini *et al*. (2019) observed that new formulation of pre-emergence herbicide pendimethalin 38.7% resulted on growth and development of cotton with effective weed management in a cost effective manner, under irrigated condition. Pendimethalin and trifluralin are the most common herbicides that are applied for a pre-emergence weed control in cotton (Keeling *et al*., 1996). Pendimethalin is pre emergence herbicide used to control grasses and broad leaved weeds in many field crops including cotton. It is selective herbicides belong to dinitroaniline group. Mode of action in plant from absorption by roots and leaves and inhibits cell division, cell elongation and that caused plants die shortly after germination (Tomlin, 1997). Vencill, W. K. (2002) reported that application of pendimethalin (38.7%) @ 2-4 kg ha^{-1} fb one hand weeding at time of 45 days after sowing resulted in effectively control of all broad leaved weeds, grasses weeds and sedges weeds due to its broad spectrum action. Pendimethalin applied at pre-emergence @ 690 g ha^{-1} significantly controlled annual grassy weed species and effective control of broad leaves weed particularly on Amaranthus hybridus and Chenopodium album weed species reported Richardson *et al*., (2007). According to Grey *et al*., (2008) pre-emergence application pendimethalin was applied gave the significantly result in cotton for the control of grasses and broad leaves weeds. Application of pendimethalin at lower dose fb one hand weeding provided significantly higher seed cotton yields than application of pendimethalin herbicides alone at higher doses Gnanavel and Babu (2008). Kumar *et al*. (2020) reported that among the weed management practices, lower weed density was recorded with pre-emergence application of pendimethalin at 1.0 kg/ha and hand weeding twice at 40 and 60 DAS during studied periods of cotton. Mushtaq and Cheema (2008) reported that pre emergence application of pendimethalin @ 1.0 kg ha^{-1} was very effective controlling of broad leaved weeds as well as narrow leaved weed in cotton. The combined practices of pendimethalin + mechanical weeding observed maximum crop growth, higher yield and yield attribute over sole application of chemical weed control reported by Muhammad *et al*., (2009). Rajanand *et al*., (2013) revealed that pre-emergence application of pendimethalin significantly decreased the weed density in cotton field. Pre-emergence application of pendimethalin @ 2.5 letters ha^{-1} significantly reduced weed dry biomass and higher the seed cotton yield (Ali *et al*., 2013).

Post-emergence herbicides for cotton : Post-emergence herbicides work to control weeds after they have already germinated. They work by travelling down the plant stalk and into

the root system to kill the weed. As a post-emergence weed control herbicide it has shown promise in controlling broad spectrum weeds in cotton at low application rates with no adverse effect on seed cotton yield.

Glyphosate : Direct application of glyphosate at 8-10 leaf stage of cotton (30-35 DAS) caused phytotoxicity on crop due to drift hazards observed by Patil *et al*., (2003). They concluded that direct two times application of glyphosate controlled 90-95% all types of weeds in cotton, three times was no advantage over glyphosate applied twice. They also recorded early post-emergence (3-4 weeks) application of glyphosate obtained higher seed cotton yield as compared to mid post-emergence (6-7 weeks). According to Deshpande *et al*., (2006) the combination of post-emergence application glyphosate + two hand weeding and two hoeing at 20 and 40 days after sowing recorded maximum weed control efficiency in cotton crop. Protected spray of glyphosate (0.5%) integrated with pendimethalin or paraquat (0.3%) with pyrithiobac sodium fb quizalofop-p-ethyl being at par with three mechanical weeding (at 20, 40 and 60 DAS) helped to significantly reduce the population and dry weight of weeds at 90 DAS over weedy check (Punia *et al*. 2019). Singh and Kakate (2010) reveals that that combined pre-emergence and post-emergence application of non-selective herbicides glyphosate @ 1.0 kg ha^{-1} provides maximum (96%) weeds control as compare this was followed by glyphosate alone with 90 percent weed control.

Pyrithiobac sodium : Pyrithiobac sodium is new herbicides for cotton crop, used as post-emergence in cotton. It has great capacity to control broad leaved weeds in cotton without any harmful effect on seed cotton yield. There was no yield loss in cotton using post-emergence application of pyrithiobac at 105 g ha^{-1} reported Allen *et al*., (1997). Chaudhari *et al*., (2017) observed that pre-emergence application of pendimethalin 1000 g ha^{-1} fb hand weeding twice at 20 and 50 DAS, and pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g ha^{-1}) as post-emergence fb directed spray of glyphosate 2000 g ha^{-1} at 60 DAS recorded significantly lower weed dry biomass as well as higher seed cotton yield and benefit cost ratio as compared to rest of the treatments. The weed control efficiency of these treatments proved to be 90 and 86% during 2014 and 2015 respectively. According to Branson *et al*., (2005) cotton new herbicides pyrithiobac sodium and trifloxysulfuron tank mixed with glyphosate at post-emergence application to significantly increase the control of troublesome weeds in cotton. Herbicide mixture containing pyrithiobac sodium + quizalofop ethyl at @ 100-125 g ha^{-1} can be recommended for broad spectrum weed control in cotton without any phytotoxic effect on cotton and without any residual effect on succeeding crops reported by Madhavi *et al*., (2015).

Quizalofop ethyl : According to Rao (2011) tank mix application of pyrithiobac sodium and quizalofop ethyl gives higher seed cotton yield instead of singly applied in cotton, but in other hand tank mixtures of pyrithiobac sodium + fenoxaprop ethyl and clodinafop propargyl significantly higher controlled broad spectrum weeds and 98% higher seed cotton yield than weedy check treatments. Application of tank mixed post-emergence herbicides pyrithiobac sodium + quizalofop ethyl at rate of 100-125 g ha^{-1} significantly controlled grassy and broadleaf weeds in cotton and no any phytotoxicity effect on the crop or without any residual effect in soil reported by Madhavi and Ramprakash (2015). Punia *et al*. (2019) found that irrigated cotton in Haryana conditions, application of pendimethalin @ 1.0 kg ha^{-1} supplemented with other two hoeing at 20 and 50 DAS or one hoeing and post-emergence

application of quizalofop-p-ethyl at 60 g/ha or one hoeing and post-emergence application of propaquizafop-p-ethyl at 62.5 g ha^{-1} at 60 DAS caused significant reduction in density and dry weight of weeds as compared to weedy check up to harvest in both the (2014 & 15) years.

Biological control : Last several decades, the concept of biological control/bio-herbicides of weeds in cotton has received significant interest. A considerable diversity of biological agents has been used to control weeds, includes the insects, plant pathogens, fungi, snails, mites, intercrops, herbivores fish, birds like geese, duck, rabbits and nematodes etc. However, these biological methods have shown limited successes in effective control of weeds in agronomic crops. Biological control must be implemented with a combination of management practices in order to increase their efficacy.

Challenges faced by IWM in present scenario

- Emergence of feral (wild) crops
- Herbicide resistance
- Effect of climate change
- Evidence of weed developing

	Biological methods
Insects	*Mexican beetle, Crocidosema lantana, Dactylopius tomentosus, Agasicleshygrophyla*
Plant pathogen	*Mycoherbicides (Devine, Collego)*
Herbivores fish	*Carp fish, Chinese grass carp, Fresh water, carp fish, white amur*
Snails	*Merisa cornuoritis & fresh water snails*
Mites	*Teranychus sp. (control prickly pear)*
Fungi	*Rhizoctina blight (control water hyacinth)*
Plants	*Cowpea as intercrop in sorghum*
Rabbit and rodents	*Bio-fauna*

- Shifting in weed flora
- Production of higher yields while conversion environment
- Eco-friendly cotton production
- Biotechnological perspectives
- No available antidote
- Policy perspectives

Conclusion

Based on the critical study of the previous work on weed management in cotton crop, the present review conclude that, suitable time and appropriate weed management strategy is essential for economical cotton cultivation. The famers need to be aware about weed flora in *Bt* cotton their critical stage, productivity losses, impaired fiber quality and appropriate weed management practices. The greatest weed competition usually occurs at the initial stage of growing period of crop 30 to 60 days after sowing. Pre and post-emergence application of chemical herbicides has the initial advantage to cotton over the traditional method. To ensure high crop yield, weed management programme require holistic approach, rely on mechanical, chemical or biological control practices to keep weeds pressure below the threshold levels that reduce yields, qualities and quantities. Hence, successful cotton production depends on the integration of different weed management strategy (IWM) would be a better option for broad spectrum management of weeds and enhancement of cotton productivity with maintaining the sustainability in ecosystems.

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