Weed Management in Cotton: A Review

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ABSTRACT

Cotton is one of the most important commercial crops in India. Cotton growth is very slow in the initial stages of its life cycle and row spacing is wider which provides ample space for the growth of different categories of weeds and thus become a source of competition for water as well as nutrients, thereby impeding its growth. Weeds are major constraints that reduce the crop yields since they compete with crop for the nutrients, moisture, light and space. The integration of different weed management practices would be a viable option for broad spectrum weed control and enhancement of cotton productivity. Thus, weed management has several aspects such as physical, mechanical, cultural, chemical and integrated weed management methods. A brief review of research accomplishment made at various places on different fields related to this investigation is reviewed in this paper.

Key words: Cotton, Productivity, Weeds, Weed management.

INTRODUCTION

Cotton is an important cash crop of India owing to its pivotal role in agriculture, industrial development and employment generation. Cotton is essentially produced for its fibre, which is commonly used as a textile raw material. Cotton is an important commodity in the world economy. The losses caused by weeds in agricultural production environments include decrease in crop yield, reduced crop quality, increased irrigation costs, increased harvesting costs and decreased land value, injury to livestock and crop damage from insects and diseases harboured by these weeds. In Tamil Nadu, severe weed competition caused yield reduction to the extent up to 74 per cent in the cotton crop (Shelke and Bhosle, 1990). Weed infestation in cotton has been reported to offer severe competition and causing yield reduction to the extent up to 74 per cent in the cotton crop (Brar and Brar, 1992). Pagar et al. (1995) at Nagpur reported 9.87 quintal per hectare (q ha⁻¹) seed cotton yield from weed free plot while 2.26 q ha⁻¹ seed cotton yield from unweeded condition causing yield reduction to the extent of 77 per cent. Sandhu et al. (1996) revealed that losses caused by weeds in cotton ranged from 40 to 75 per cent depending on nature and intensity of weeds. Giri and Bhosale (1997) at Parbhani reported 71 to 98 per cent yield reduction in cotton by weedy check.

Deshmukh and Mudholkar (1998) observed that yield losses due to weed growth were more than 42 per cent depending on weed intensity. Cotton being a wide spaced and relatively slow growing crop during its initial growth stages suffered from severe weed competition and causing substantial reduction in seed cotton yields up to an extent of 69 per cent (Srinivasulu and Rao, 2000). Vivek et al. (2002) reported that uncontrolled weeds reduced cotton yield by 30 per cent. Yadav et al. (2003) reported that weeds growing throughout the crop season reduced the seed yield of cotton to the extent of 38-79 per cent during both the years. Trianthema portulacastrum density at 5 plants per metre square (m²) or beyond was critical and resulted in considerable reduction in seed cotton yield (17-37 per cent) over weed free treatment (Anjum et al., 2007). Initial slow growth, wide row spacing and high dose of chemical fertilizers permit early and severe crop-weed competition resulting in loss of yield to the tune of 45 to 85 per cent (Das, 2008). Losses caused by weeds in cotton ranged from 50 to 85 per cent depending upon the nature and intensity of weeds (Prabhu et al., 2012).

Weed infestation in cotton has been reported to offer severe competition and causing yield reduction to an extent of 40 to 85 per cent. Weeds which emerge with cotton plants offer a severe competition and bring about considerable reduction in seed cotton yield. Reduction in seed cotton yield under irrigated conditions is primarily due to nutrient depletion caused by weeds and may vary over from 10-90 per cent. Weed infestation in cotton has been reported to offer severe competition and caused yield reduction to the extent of 74 per cent (Nalini et al., 2015). Uncontrolled weed growth during crop growing season resulted in yield loss of up to 86 per cent (Leela et al., 2016).

Critical period of crop-weed competition in cotton

Weeds that germinate along with crop are more damaging than the later emerging weeds. There is a period (time span)
before and after which presence of weeds does not cause any appreciable reduction in crop yield, as irrecoverable loss has been done. Hence, establishing the critical period of crop weed competition is essential to develop effective and economical weed control measures. The critical period of crop-weed competition is defined as shortest time span in the ontogeny of crop when weeding will result in the highest economic return. The critical period of weed control is defined as the period after which growth of the weed will no longer affect the crop yield (Nieto et al., 1968). Several workers have established the critical period of crop-weed competition in cotton. Balasubramanian and Sankaran (1976) reported that the early growth period (first 60 days) of cotton was the critical period for crop weed competition. Similarly, Rethinam and Sankaran (1978) observed first 50 days after sowing as critical period of crop weed competition. Baiyan et al. (1983) reported that the initial 40 to 60 days after sowing as critical period of crop weed competition beyond which keeping the crop free of weeds did not bring any improvement in yield.

The weed free condition up to three to five weeks after sowing was required to get desirable yield (Mohamed Ali and Bhanumurthy, 1985). Common cocklebur (Xanthium strumarium) adversely affected the cotton (Gossypium hirsutum) between 8-10 weeks after the cotton emergence in fine sandy soils of Mississippi, USA (Snipes et al., 1987). Initial period of 30 to 50 days to be the most critical period for crop weed competition in cotton in Tamil Nadu situation (Jayakumar et al., 1990). Panwar and Malik (1991) observed 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. In American cotton, weed competition during the first 30 days after sowing resulted in an average yield loss of 10.5 per cent in Punjab. Vencill et al. (1993) also reported that the critical period of crop-weed competition for Cynodon dactylon in cotton as four to seven weeks period after sowing. Seed cotton yield increased from 1890 to 3021 kg ha⁻¹ as the initial weed free period was extended from 30 days to full growing season (Third et al., 1995). Mishra (1997) revealed that critical period of crop weed competition was 15-60 days and if weeds were not controlled within this period it caused yield losses from 40- 50 per cent.

The yield levels obtained by managing the weeds during this period should provide yield sufficiently close to those obtained by the full season freedom from weeds (Gupta, 1998). WnJianRong et al. (1999) found that the period of weed interference, crop damage and the critical time of crop-weed competition were 30 to 90 days which occupied 50 per cent of the whole cotton growing period. In cotton plant establishment, plant height, biomass, square and boll number were significantly affected by weed competition (Mushqaq and Cheema, 2008). The critical period of weed competition in cotton was found to be 15 to 60 days (Rajiv Sharma, 2009). Critical period of weed competition occurred between planting and the 3-leaf stage of cotton minimized yield loss to five per cent (Webster, 2009).

Competition for light may commence very early in cropping season if a dense weed growth smothers the crop seedlings. Hence, cotton is prone to heavy weed growth at seedlings stage and finally suffered due to shading effect of weeds. The above studies indicated that the first 60 days of crop growth period is considered to be more critical for crop-weed competition.

**Effect of weeds on cotton**

**Effect of weeds on growth components of cotton**

Cotton growth is always influenced by the presence of weeds in the field. According to Sankaran and Rethinam (1974), the dry matter production of cotton crop per unit area was lower under unveeded condition. Plant height and stem diameter of cotton was reduced by weed competition (Snipes et al., 1982). Decrease in plant height of cotton due to weed competition was reported by Singh (1983) and Rushing et al. (1984). Lesser weed infestation led to increased plant height and number of bolls plant⁻¹ Hussain et al. (1989). Lesser weed competition led to vigorous growth which ultimately resulted in increased dry matter production of crop. Holt and Orcutt (1991) observed that yellow (Cyperus esculentus) and purple (Cyperus rotundus) nutedge competed with cotton for resources and assimilated biomass faster than cotton. Balasubramanian (1992) reported that weed free condition in cotton increased the plant height, dry matter production, number of bolls plant⁻¹, boll weight and kapas yield.

The tallest plant height was observed by reduced weed growth (Khan et al., 2001). Leaf area index (LAI) is the important growth parameter which decides the dry matter production of crop. In cotton, Nandanassababady (2001) reported that weed free period throughout the crop period recorded highest LAI at all stages of crop growth. LAI of cotton crop was significantly influenced by weed free condition up to the critical period. Due to the presence of weeds, reduction in plant height was reported by Bukun (2004) as result of delayed weed management practices.

Increasing densities of Trianthema portulacastrum weed up to 10 plants m⁻² significantly reduced the LAI and crop growth rate (CGR) of cotton (Anjum et al., 2007). According to Mahar et al. (2007), plant height of cotton was significantly reduced under unveeded check. Mushqaq and Cheema (2008) concluded that plant establishment, plant height and biomass of cotton were significantly affected by the weed growth and competition. LAI and CGR were decreased in unveeded check (Prabhu et al., 2012). Muhammad et al. (2013) reported that minimum plant population per unit area, reduced plant height and number of monopodial branches plant⁻¹ was recorded in weedy check. No weeding in the cotton significantly reduced the plant length (Soliman et al., 2013). Weedy check significantly decreased the plant height and dry matter production of cotton (Leela et al., 2016).
Effect of weeds on yield components of cotton

Weed control greatly influences the yield components of cotton. The season long weed control resulted in better crop growth and enhanced source capacity which resulted in increased number of yield components of cotton. Significant reduction in number of sympodial branches due to weed infestation was reported by Balasubramanian and Sankaran (1976). Mohamed Ali and Bhanumurthy (1985) reported significant reduction in fruiting points due to uncontrolled weed growth in the field. Sreenivas (2000) observed higher number of bolls plant$^{-1}$ with lesser weed incidence. Khan et al. (2001) recorded the heaviest bolls (2.55 g) with reduced weed interference in cotton crop. Maqbool et al. (2001) revealed that no weeding in cotton significantly reduced the number of sympodial branches plant$^{-1}$, number of matured bolls plant$^{-1}$ and seed cotton weight boll$^{-1}$.

Velayutham et al. (2002) reported that uncontrolled weed growth reduced the number of bolls plant$^{-1}$ and boll weight of cotton. Kalaisundareson and Sundari (2004) reported that the highest number of bolls plant$^{-1}$ (17.4) was recorded when weeds were efficiently controlled. With increased incidence of weeds, less no of sympodial branches, number of bolls plant$^{-1}$ and boll weight in cotton was recorded by Sadangi et al. (2006). According to Anjum et al. (2007), increasing densities of Trianthema portulacastrum weed up to 10 plants m$^{-2}$ significantly reduced the number of sympodial branches plant$^{-1}$, number of bolls plant$^{-1}$ and seed cotton weight boll$^{-1}$. The number of sympodial branches plant$^{-1}$ and productive bolls plant$^{-1}$ were significantly reduced under untreated check (Mahar et al., 2007). The square and boll number of cotton (Mushtaq and Cheema, 2008) were significantly affected by weed competition. Prabhu et al. (2012) opined that total number of bolls harvested and boll weight were decreased in unweeded check compared to other treatments. Muhammad et al. (2013) reported lesser number of sympodial branches plant$^{-1}$ and number of bolls plant$^{-1}$ under weedy check. No weeding in the cotton significantly reduced the number of fruiting branches, number of bolls plant$^{-1}$ and boll weight (Soliman et al., 2013). Leela et al. (2016) reported that number of bolls plant$^{-1}$ was decreased under weedy check.

Effect of weeds on yield and quality characters of cotton

Luxuriant growth of weeds is one of the major causes for low crop yield throughout the world. Weeds cause two types of yield losses. The most important one is the direct yield loss resulting from competition, followed by the indirect loss from reduced crop quality.

The quality characters of cotton were not much affected by associated weeds. The quality parameters of cotton were not affected by weed infestation (Rushing et al., 1984). Singh and Nagwekar (1989) stated that herbicides had no effect on ginning percentage, maturity co efficient and fibre strength. According to Keeley and Thullen (1991) losses of 16 and 26 per cent of yield occurred when Bermuda grass was permitted to compete with cotton for 12 and 20 weeks, respectively. Bishnoi et al. (1993) reported that higher seed cotton yield of 2798 kg ha$^{-1}$ was recorded with lesser weed competition up to 20 days after sowing. Seed weight and fibre per cent were also not affected by herbicide application (Nobrega et al., 1997). However, Dimitrova and Gueorgieva (1997) found that infestation of field bind weed (Convolvulus arvensis) adversely affected the quality of cotton fibre.

Yield reduction in cotton 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). Seed cotton yield was reduced upto 34 per cent due to yellow nutsedge (Cyperus rotundus) infestation (Molett and Mcclosky, 1998). Maqbool et al. (2001) revealed that no weeding in cotton significantly reduced the seed cotton yield. Bhan and Mishra (2002) opined that the yield loss due to weeds varied from 40-85 per cent due to weed competition for resources. Khan and Khan (2003) reported that grassy weeds caused 15 to 40 per cent and broad leaved weeds caused 15 to 30 per cent yield losses in cotton. Mukhtar et al. (2006) found that seed cotton yield was adversely affected by untreated check compared to other treatments. Anjum et al. (2007) stated that increasing densities of Trianthema portulacastrum weed up to 10 plants m$^{-2}$ significantly reduced the seed cotton yield and lint yield. Seed cotton yield was significantly reduced under untreated check (Mahar et al., 2007).

According to Prabhu (2010), weed infestation had no effect on quality characters of cotton but affected the yield of cotton. Muhammad et al. (2013) revealed that weedy check decreased the seed cotton weight bolt$^{-1}$, seed index, seed cotton yield and ginning out turn of cotton compared to other treatments. Nithya and Chinnusamy (2013) concluded that, if the field left uncontrolled with weeds not only reduced crop yield but also increased the weed seed bank in soil which created problems for succeeding crop. Hence, weeds play a significant role in reducing the seed cotton yield. No weeding in the cotton significantly reduced the seed index seed cotton yield, lint per cent, micronaire, uniformity ratio, pressely index and fibre length (Soliman et al., 2013). Leela Rani et al. (2016) reported that kapas yield plant$^{-1}$ and kapas yield kg ha$^{-1}$ were decreased under weedy check.

From the above literatures, it is obvious that weed competition in cotton drastically reduced the seed cotton yield with the negligible effect on quality characters viz., lint index, seed index and ginning percentage.

Effect of weeds on nutrient removal by weeds

Fast growing weeds remove considerable amount of nutrients from soil. Results from Delhi (Mani, 1975) revealed that on average, weeds siphoned off 46.6 kg N ha$^{-1}$, 12.1 kg P$_2$O$_5$ ha$^{-1}$ and 73.3 kg K$_2$O ha$^{-1}$. Subramaniam and Sankaran (1976) reported a yield reduction of 11.92 kg ha$^{-1}$ of cotton for every kg of N removed by weeds. Under weedy conditions, every
quintal of weed dry matter removed 0.81, 0.32 and 2.11 kg of N, P₂O₅ and K₂O, respectively, caused drastic reduction (77 per cent) of cotton yield from 6.3 to 1.47 q ha⁻¹ (Shanthamugam and Meenakshisundaram, 1977). Weeds usurped 20.1 kg N ha⁻¹, 16.4 kg P₂O₅ ha⁻¹ and 13.2 kg K₂O ha⁻¹ at 45 DAS (Rethinam, 1978).

Weeds removed 5-6 times nitrogen, 5-12 times phosphorus and 2-5 times potassium compared to uptake by cotton under upland situation (Jain et al., 1981). Weeds were found to deplete nutrients from 10-90 per cent resulting in a loss of crop yield by 67-75 per cent in northern India (Singh et al., 1988). Uptake of nutrients by crop was also reduced from 43 to 14, 10 to 4 and 58 to 17 kg ha⁻¹, respectively of N, P₂O₅ and K₂O and reduced seed cotton yield from 11 to 6 q ha⁻¹ (Singh and Malik, 1992). Detroja et al. (1992) observed lower uptake of N, P and K in cotton and higher uptake of N, P and K by weeds. Nadanassababady and Kandasamy (2002b) reported that weeds in cotton removed 86.3, 16.7 and 88.6 kg NPK ha⁻¹, respectively.

Weeds removed majority of plant nutrients from soil and caused maximum damage to the crops. Weeds reduced the availability of both macro and micro nutrients to the crop (Shobana, 2002). Baldev et al. (2004) recorded maximum nutrient depletion of 61.8 kg N, 5.6 kg P and 57.6 kg K ha⁻¹ by weeds were recorded in cotton at 60 days after sowing. Deshpande et al. (2006b) reported that grassy weeds were tapping the nutrients from soil more efficiently than cotton. Kumar et al. (2007) reported that higher nutrient removal by weeds was observed in cotton resulting in luxurious weed growth.

The nutrient removal by weeds showed a significant impact on the availability of nutrients to the crop and thus affecting its dry matter accumulation.

**Methods of weed control in cotton**

Successful weed control is essential for economic cultivation of cotton. The greatest competition of weeds usually occurs early in the growing season. Weed control methods adopted by the farmers are time consuming and expensive. Also, herbicide applied at the time of sowing will not give season long control of weeds. Pre-plant or pre-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. Thus, weed management has several aspects such as physical, mechanical, cultural, chemical and integrated weed management methods (Zimdahl, 1999).

**Physical methods**

**Manual methods of weed control in cotton**

Manual weed control is the oldest, most practical, physical method of weed control that utilizes manual energy and simple hand tools to control weeds and is followed widely. Hand weeding is still a traditional and effective method of weed control to eliminate annual weeds which could not recover again. It reduced perennial weed population in cotton by removing rhizomes and stolons of weeds and suppressed annual weed species (Wilcut et al., 1995).

**Hand weeding and Hand hoeing**

Dry matter production and nutrient uptake by cotton were maximum in conventional method of manual weed control (Singh and Verma, 1988). Two hoeing provided the best weed control and the highest seed cotton yield (Tiwana and Brar, 1991). According to Nehra et al. (1992), higher yield parameters and kapas yield were recorded in hand weeding twice than chemical weed control methods. Detroja et al. (1992) reported that three interculturing with three hand weeding at 20, 40 and 60 DAS increased yield significantly as well as nutrient uptake by cotton crop. Gogai et al. (1992) reported that the highest weed control efficiency (WCE), better crop growth and maximum fibre yield under hand weeding done at 21 and 42 DAS.

Two hand weeding carried out at 30 and 60 DAS significantly influenced the weed dynamics and increased the yield of cotton (Singh et al., 1992). Waugh et al. (1992) found that the removal of nitrogen and phosphorus by weeds was lowest with weeding twice (25 and 45 DAS) coupled with two hoeing. Weed free check registered the highest WCE and seed cotton yield (Pagar et al., 1995). Yadav et al. (1995) reported that hoeing and weeding twice gave the highest yield compared to control. Higher kapas yield was recorded with two hoeing at 30 and 60 DAS compared to chemical weed control methods (Panwar et al. (1995). Hoeing and hand weeding three times at 20, 40 and 60 DAS gave the best weed control in cotton at Vidarbha region (Patil et al., 1997). The farmer’s practice (three hoeing + tree weeding) gave 50.8 per cent increase in seed cotton yield over weedy check (Kakade et al., 1999) because of significant increase in number of bolls, boll weight and seed cotton yield plant⁻¹.

According to Nalayiniet al. (2001a) among the weed control methods hand weeding twice recorded significantly higher dry matter and N uptake, which ultimately resulted in higher seed cotton yield, lint yield and N-use efficiency. Nalayani et al. (2001b) found that hand weeding in cotton recorded the highest CGR at all stages. The highest seed cotton yield of 1148 kg ha⁻¹ was recorded with two hand weeding at 30 and 60 DAS (Vivek et al., 2002). Maximum WCE and B:C ratio were recorded with two hand weeding and two hoeing (Deshpande et al., 2006a).

Nagalakshmi et al. (2006) noticed that hand weeding twice showed significant effect in reducing weeds and also increased the yield. Mahar et al. (2007) reported that hand weeding for full season in cotton significantly reduced the weed density (92.4 per cent) and increased the plant height, sympodial branches plant⁻¹, productive bolls plant⁻¹ and seed cotton yield. Verma et al. (2009) reported that hand weeding twice recorded 87.55 per cent WCE and one weeding followed by earthing up treatment recorded maximum of 93.88 per cent WCE. Nithya and Chinnusamy (2013) reported that hand weeding at 25 and 45 DAS significantly decreased the number of total weed density m⁻² and total
dry weight in cotton. Mechanical weeding at 20, 40 and 60 DAS extensively increased the plant height, crop dry matter, number of bolls plan−1, kapas yield plant−1 and kapas yield kg ha−1 of cotton (Leela et al., 2016).

Mechanical methods of weed control in cotton

Weed morphology and stage of growth would influence the selection and efficacy of weeding implement. It is found that physical damage by burial to one cm depth is effective for controlling weeds followed by cutting at the soil surface. Mechanical weed control is comparatively faster and requires less labour than hand weeding (Chivinge, 1990).

Power weeding in cotton

Pagar et al. (1995) suggested that the weed free situation through mechanical weeding resulted in maximum WCE and seed cotton yield as compared to all other treatments. Mechanical ridge moulding and hand hoe-weeding at six weeks after sowing reduced the weed dry weight in cotton at harvest (Dodari and Kuchinda, 2004). Power weeder was found useful for weeding in between crop rows in cotton, tapioca and grape. Oguntunde and Olukunle (2006) reported that introduction of effective mechanical weeder would encourage small farmers leading to increased production and reducing the poverty. Prasad (2006) revealed that at Central Research Institute for Dry Land Agriculture (CRIDA) by using power weeder the saving in labour was up to 80 to 87.5 per cent. In addition to cost saving timeliness in weeding was ensured through mechanization. This technology gave more relief to the farmers who are facing acute labour shortage and higher cost of labour during the peak season. The weeder could cover an area of one ha day−1 of 8 hr. The cost of weeding by this machine was only one-third of the weeding cost by manual labourers (Tajuddin, 2006).

Mechanical weed control not only uprooted the weeds between the crop rows but also kept the soil surface loose, ensuring better soil aeration and water intake capacity (Yadav and Pond, 2007). According to Verma et al. (2009), manual weeding followed by earthing up operation done by mechanical weeder at 20 DAS prevented weed competition (86.0 per cent WCE) resulting in higher values of growth attributes viz., plant height, culm girth and leaf area index than weedy check.

Chemical method

A proper technical know-how is pre-requisite for successful adoption of chemical method of weed control. Pre-emergence herbicides control weeds right from the beginning of their germination and thus prove to be more efficient than many other methods of weed control. Most herbicides prove to be more economical than mechanical and manual methods where manual labour costs are high. Herbicides as an alternative to mechanical control reduce mechanical damage to crops.

Pre emergence herbicides for cotton

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

Pendimethalin is pre-emergence herbidce used to control grasses and broad leaved weeds in many field crops including cotton. It is a selective herbicide chemically called N-(1-ethylpropyl) -2,6- dinitro 3,4 - Xyldine (Dinitroaniline group), absorbed by roots and leaves, inhibits cell division and cell elongation and the affected plants die shortly after germination or following emergence from soil (Tomlin, 1997).

Balasubramanian (1992) reported that application of pendimethalin at 1.25 kg ha−1 increased the plant height, dry matter production, number of bolls plant−1, bollweight and kapas yield of cotton. Pre-plant application of pendimethalin 1.0 kg ha−1 and trifluralin 1.5 kg ha−1 and followed by one hoeing controlled weeds and increased yield by 47 to 92 per cent, respectively (Brar et al., 1998; Panwar et al., 1998). Kakade et al. (1999) described that pre-emergence herbicides (Pendimethalin at 1.0 kg ha−1 + diuron 0.5 kg ha−1) realized maximum yield like that of hoeing and weeding at 40 DAS.

Pendimethalin applied as pre-emergence at 1.5 kg ha−1 provided excellent control of weeds including Digeraanvensis (Panwar et al., 1999). Khan et al. (2001) reported that application of pendimethalin and oxadiazon significantly reduced the weed density and increased the number of bolls plant−1 and seed cotton yield.

Application of pendimethalin at 690 g ha−1 as pre-emergence herbicide controlled annual grassy weed species and improved control of Amaranthus hybridus and Chenopodium album over the control (Richardson et al., 2007). Pendimethalin was applied as pre-emergence herbicide in cotton for the control of grasses and small seeded dicot weeds (Grey et al., 2008). According to Gnanavel and Babu (2008) application of pendimethalin at lower dose in combination with one hand weeding provided significantly higher seed cotton yields than application of these herbicides alone at higher doses. Pre-emergence application of pendimethalin (1.0 kg ha−1) was very effective for controlling broad leaved weeds as well as narrow leaved weed as observed by Mushtaq and Cheema (2008). PE application of pendimethalin at 2.5 L ha−1 significantly reduced the weed dry biomass and increased the seed cotton yield (Ali et al., 2013). Application of pendimethalin significantly decreased the weed density as reported by (Rajanand et al., 2013).

Post emergence herbicides for cotton

Post emergence chemical control involves application of foliage active herbicide after the emergence of both crops and the weeds. They are absorbed by the plant foliage and in many cases, these are translocated to other plant parts.
Post emergence directed spray is the application of herbicides to chiefly weeds growing in the inter rows of the crops, avoiding the crop foliage as much as possible. Early post emergence application of trifloxysulfuron at 20 ha⁻¹ + adjuvants in cotton reduced the total weed dry weight with higher WCE at 60 DAS (Kumar et al., 2007). Post emergence application of trifloxysulfuron at 7.5 g ha⁻¹ without a pre-emergence herbicide controlled annual grass species and improved control of smooth pigweed and common lambsquarters (Richardson et al., 2007).

**Glyphosate**

Weed intensity observed in glyphosate at 2.05 kg ha⁻¹ applied plot was lower than plot applied with glyphosate at 1.025 kg ha⁻¹ (Detroja et al., 1992). Patil et al. (2003) reported that directed post emergence application of glyphosate at 8 to 10 leaf stage of cotton (35 DAS) caused phytotoxicity on crop due to drift. Application of glyphosate twice controlled all the species of weeds up to 93 per cent and glyphosate applied three times was no advantage over glyphosate applied twice. Higher yield was obtained when glyphosate was applied as early post emergence (3-4 weeks) as compared with mid post emergence (5-7 weeks). The highest WCE was recorded by post emergence application of glyphosate with two hand weeding and two hoeing at 20 and 40 days (Deshpande et al., 2006a). Application of metolachlor and glyphosate increased the cotton lint yield (Clewis and Wilcut, 2008).

According to Singh and Kakate (2010), best weed control of 96.8 per cent was recorded in the integration of pre and post emergence treatment of glyphosate at 1.0 kg ha⁻¹. This was followed by glyphosate alone with 90.2 per cent weed control. Application of glyphosate (2700 g a.i. ha⁻¹) twice (25 and 45 DAS) resulted in complete control of broad spectrum weeds with higher seed cotton yield and net income in transgenic cotton during winter season (Chinnusamy et al., 2011). Lower dry weight of weeds was recorded with direct spray of glyphosate 1 kg a.i. ha⁻¹. Higher WCE (83.3 per cent) was recorded with direct spray of glyphosate 45 per cent SL at 1.0 kg a.i. ha⁻¹ (Kumar et al., 2016).

**Pyriothiobac sodium**

Pyriothiobac sodium (sodium 2-chloro-6-[(4, 6-dimethoxypyrimidin-2-yl) thio] benzoate, is one of the new herbicides used in cotton. As a post emergence weed control herbicide it has shown promise in controlling broad leaved weeds in cotton at low application rates with no adverse effect on seed cotton yield. According to Allen et al. (1997), there was no yield reduction with post emergence application of pyriothiobac at 105 g ha⁻¹. Post emergence cotton herbicides, such as pyriothiobac sodium and trifloxysulfuron, can be mixed with glyphosate to increase the control of troublesome weeds (Branson et al., 2005). According to Rao (2011), the highest seed cotton yield was obtained with post emergence tank mix application of pyriothiobac sodium and quizalofop-ethyl over herbicides applied singly and it was comparable with other tank mixtures of pyriothiobac sodium with fenoxaprop-ethyl and clodinafoppropargyl. This treatment recorded 98 per cent higher seed cotton yield than weedy check.

**Integrated weed management**

Integrated weed management is a system approach whereby whole land use planning is done in advance to minimize the very invasion of weeds in aggressive forms give crop plants a strongly competitive advantage over the weeds (Gupta, 1998). Further, importance is given to involve more than one weed control methods in tackling the weeds so that broad spectrum of weeds is kept under check for longer period.

A pre-emergence herbicide takes care of weeds only for a limited period and do not give long term weed control in long duration crop like cotton where the problem of late emerging weeds arises. So to attain a season long weed control, integration of chemical, mechanical and cultural methods holds a great promise in crop production.

Chandi et al. (1993) observed that pre-emergence application of pendimethalin at 1.0 to 1.5 kg a.i. ha⁻¹ with one hand weeding at 6 weeks after sowing resulted in the highest seed cotton yield. Pendimethalin at 1.0 kg ha⁻¹ as pre-emergence herbicide followed by hand weeding on 30 DAS reduced the weed density and nutrient uptake by weeds (Chander et al., 1994). According to Panwar et al. (1995), one hoeing before or after spraying pendimethalin would assist through improved soil moisture conservation and removal of weed population in cotton. Brar et al. (1995) stated that pre-emergence application of pendimethalin at 1.5 kg ha⁻¹ followed by one hand hoeing at 30 DAS was effective for the control of annual broad leaved and grassy weeds like *Trianthema portulacastrum* and *Elusine indica*. The dry weight of total weeds was significantly reduced in plots where pendimethalin at 1.05 kg a.i. ha⁻¹ was applied as pre-emergence spray supplemented with 1 or 2 hoeing. The glyphosate at 1.0 kg ha⁻¹ + hand weeding stood next only to pendimethalin + hand weeding (Panwar et al., 1995).

Velayutham (1996) reported that PE application of pendimethalin at 0.75 kg ha⁻¹ followed by one hand weeding resulted in the enhanced kapas yield which was comparable with hand weeding twice. The highest seed cotton yield was recorded with pre-emergence application of pendimethalin at 1.50 kg ha⁻¹ followed by one hoeing and was 72 per cent higher than the unweeded control (Brar et al., 1999). According to Nadanassabababy and Kandasamy (2002b), glyphosate at 2.05 kg ha⁻¹ + hand weeding recorded the lowest weed density followed by glyphosate at 1.025 kg ha⁻¹ + hand weeding and glufosinate at 0.45 kg ha⁻¹ + hand weeding.

Higher seed cotton yield under integrated method of herbicide with manual weeding was comparable with manual weeding twice (Rajavel et al., 2002). The total weed density was reduced by 60-70 per cent with application of pendimethalin at 1.0 kg ha⁻¹ followed by hand weeding on 30 DAS (Vivek et al., 2002).

Ali et al. (2005) reported that maximum increase in seed cotton yield was obtained with PE application of pendimethalin at 2.5 kg ha⁻¹ in combination with inter-culturing with hand weeding. The higher seed cotton yield and benefit: cost ratio...
(Deshpande et al., 2006a) were recorded with three hand weeding and three hoeing followed by pre and post emergence application of pendimethalin and glyphosate with two hand weeding and two hoeing. Muktar et al. (2006) revealed that pre-emergence application of pendimethalin at 1.875 L ha\(^{-1}\) + one hand weeding at 45 DAS significantly increased the seed cotton yield compared to untreated check (1932 kg ha\(^{-1}\)). The highest seed cotton yield was obtained from application of pendimethalin at 1.5 kg ha\(^{-1}\) followed by hoeing (Shaikh et al., 2006). According to Nikam et al. (2007), application of glyphosate at 1200 g ha\(^{-1}\) with hand weeding at 45 DAS recorded lower weed populations with higher yield and yield attributes of cotton.

Pre-emergence application of pendimethalin at 0.68 kg a.i. ha\(^{-1}\) as + post emergence application of quizalofop ethyl at 0.05 kg a.i. ha\(^{-1}\) at 35 DAS + intercultivation and hand weeding at 60 DAS drastically reduced the dry weight of weeds and increased the WCE, CGR, total number of bolls harvested, boll weight, seed cotton yield and uptake of nutrients (Prabhu et al., 2012). Higher WCE was recorded under pre-emergence application of pendimethalin at 1.0 kg ha\(^{-1}\) on 3 DAS + hand weeding on 45 DAS (Nithya and Chinnusamy, 2013). PE application of pendimethalin at 1.0 kg a.i. ha\(^{-1}\) + quizalofopethyl at 50 g a.i. ha\(^{-1}\) at 30 DAS + one hoeing 50 DAS improved significantly all the growth and yield attributing characters over weedy check (Kumar et al., 2016).

**CONCLUSION**

From this review it can be concluded that, successful weed control is essential for economic cultivation of cotton. The greatest competition of weeds usually occurs early in the growing season. Weed control methods adopted by the farmers are time consuming and expensive. Also, herbicide applied at the time of sowing will not give season long control of weeds. Pre-plant or PE 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 management of weeds and enhancement of cotton productivity.

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