WEED MANAGEMENT IN RAPESEED-MUSTARD - A REVIEW

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ABSTRACT

Rapeseed-mustard is an important group of edible oilseed crops in India. Technological advancement in rapeseed-mustard production has resulted in increased productivity. But many biotic stresses such as weeds cause severe yield losses up to 45% in rapeseed-mustard. They reduce crop productivity and quality by competing with crop plants for available nutrients, water, land and light resources and also influence the agro-ecosystem. A variety of weeds affects these crops but the extent of damage in terms of yield and resources is location specific. Many of the weeds are specific to crop and/or location. Orobanche aegyptica is becoming great menace in rainfed areas of Rajasthan, Madhya Pradesh and Haryana, whereas, Chenopodium, Asphodelus, Melilotus and Trianthemus spp. cause serious yield losses in other areas. Unlike other oilseed crops, mustard suffers more from weed competition in early growth stages especially between 20-40 days after sowing. The weed management in mustard is done by both cultural and herbicidal approaches. Different dinitroaniline herbicides are commonly used to eliminate weed species and most of these are effective against only narrow range of weed species. Thus, integration of herbicide at critical growth stages with one or two hand weeding at proper time for improving the weed suppressing effect of crop gives significant improvement in crop yield. Economic analysis revealed that fluchloralin and pendimethalin alone or in combination with hand weeding at 30 days after sowing was the most economical.

Key words: Herbicides, Mustard, Weed management, Weeds.

Rapeseed-mustard is an important group of oilseed crops occupying premier position in oilseed economy of India. It ranks second after soybean and contributed 22.4% and 22.6% to oilseed acreage and production, respectively, in India during 2011-12. For an estimated Indian population of about 1.32 billion, 21.12 million tonnes (mt) of edible oil will be required by the end of 12th five year plan in 2017 at an estimated per capita consumption of 16 kg edible oil/person/day. This demand has to be met by producing about 63.4 mt of total oilseeds, of which, about 20 per cent has to be met by rapeseed-mustard equivalent to 12.7 mt. An all out effort is to be made to achieve this target for rapeseed-mustard production from the present level of 7.3 mt (DRMR, 2011). This target could be achieved through area expansion and or increase in productivity of rapeseed-mustard. Scope for area expansion is limited so production would be increased only through increase in productivity per unit of land. The per hectare productivity of the crop is quite low in the country (1179 kg/ha) against the world average of about 1400 kg/ha in world (FAO, 2011). As this crop is grown in poor soil with poor management practices, weed infestation is one of the major causes of low productivity and causes 25-45 per cent yield reduction, depending on the type of weed flora and their intensity, stage, nature and duration of crop-weed competition (Singh et al., 2001). Due to severe weed competition, the yield reduction in Indian mustard may go as high as 70 per cent (Tiwari and Kurchania, 1993). Weed competition in mustard crop is more serious in early stages because crop grows slowly during the first 4-8 weeks after sowing. However, during later stages crop grows vigorously and exerts a strong suppressing effect on weeds. The traditional practice of hand or mechanical weeding once during early stages of crop growth i.e. 25-30 days after sowing (DAS) is not sufficient as new flushes of weeds appears after every mechanical weeding, irrigation
and winter rainfall, and reinfest the crop and most importantly they take away major portion of the nutrients and moisture from the soil. In general, for producing equal dry matter, weeds deplete more nutrients and moisture than do most crop plants (Gupta, 1998). However, farmers can not afford repeated manual weeding to keep weeds under control during early stage of crop growth. Human labour is often costly and many times not available due to coincidence of sowing operation of other winter season crops when mustard is due for weeding which further accentuates the problem. Selective herbicides provide effective as well as economic alternative to hand weeding (Yadav et al., 1997). But at present no herbicide is available which alone can provide desired degree of control of divergent weed flora. Thus, weed management has tremendous scope for increasing mustard production.

**Losses caused by weeds in mustard:** Loss in mustard seed yield due to weed infestation depends on weed population, their composition, growth habit etc. Various workers reported loss in seed yield of mustard of different degrees viz. upto 30 per cent by Tomar and Namdeo (1991) and 19-42 per cent in mustard (Singh et al., 1992a). Singh (1992) also found yield loss of 20-30 per cent in mustard which under severe competition increased to 62 per cent. Losses in crop yield upto 34 per cent (Ali, 1993), upto 44.5 per cent (Kaneria and Patil, 1995) and up to 56 per cent in mustard (Patil et al., 1997) has been also reported. It is also heavily parasitized by the *Orobanche aegyptiaca* Pers, causing 15–49 per cent seed yield loss (Khattri, 1997). In canola, control of weed species such as annual ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*) is critical to achieving a viable canola harvest because both weeds are a major and extensive problem in Australia, almost all of the canola grown in western Australia are triazine resistant varieties due to a gene (selected by traditional breeding methods) endowing resistance to triazine herbicides (e.g. atrazine and simazine). Thus, the presence of the triazine resistance gene results in a 10–20% crop yield penalty (and 2–3% lower oil content) relative to equivalent varieties that lack triazine resistance (Holt and Thill, 1994; Moore and Carmody, 1997). In India, weed infestation particularly of *Asphodelus tenuifolius* in one of the important reasons of low productivity of mustard and is known to reduce its yield to the extent of 56 per cent (Yaduraju et al., 2000). Purna et al. (2006) reported that presence of weeds throughout growing period resulted in 36-42 per cent reduction in seed yield of mustard. Under All India Coordinated Project on Rapeseed-Mustard, from various locations 18.1% (Ludhiana) to 41.7% (Varanasi) mustard yield loss has been reported (Anonymous, 2011).

**Weed flora in rapeseed-mustard fields:** A broad spectrum of weed flora infests mustard crop. The composition and competition by weeds is dynamic and is dependent on soil, climate, cropping and management factors. Several studies were conducted on weed flora in India (Table 1).

There is urgent need to continuously monitor the weed flora in all agro-ecological regions of India, to assess the emerging weed problems and to plan weed management strategies for the present and future weed problems across agro-ecological zones.

**Crop weed competition:** Productivity of crop depends upon the nature and extent of competition due to weeds. Chakhaiyar and Ambasht (1990) reported that removal of weeds 20-100 days after the emergence of Indian mustard cv. Type 59 caused reduction in above ground weeds dry weight at harvest from unweeded values of 110.5 to 8.5-88.4 g/m² under Varanasi, U.P. condition. Weed dry weight increased progressively as the weeding date was delayed. Conversely, the treatments increased crop dry weight from 1141.4 g/m² (unweeded control) to 1210.1-1758.6 g/m². Grain dry weight was also increased in the line with plant dry weight from unweeded values of 419.1 to a maximum of 650.9 g/m² (98 per cent of the yield of a continuously weeded crop) in plots weeded 20 days after emergence. Dashora et al. (1990) opined that the period upto 30 DAS was more critical for weed crop competition in mustard. Hence, it is necessary to remove weeds either manually or by using herbicides during that period. Ali (1993) found that maintaining weed free condition beyond 40 DAS did not prove beneficial and the critical period of crop-weed competition was first 8 weeks after sowing and allowing competition till crop maturity reduced seed yield by 34 percent. Chauhan et al. (2005) reported that weed competition in mustard is more serious in
### TABLE 1: Major weed flora of rapeseed-mustard fields in different regions

<table>
<thead>
<tr>
<th>Major Weed flora</th>
<th>Place</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chenopodium album, Cyperus rotundus, Cynodon dactylon, Phalaris minor and Rumex dentatus</td>
<td>Varanasi, U.P.</td>
<td>Chakaiyar and Ambasht (1990)</td>
</tr>
<tr>
<td>Acrachne terebrose, Eragrostis tenella, Trianthema monogyna and Chenopodium album</td>
<td>Ludhiana, Punjab</td>
<td>Brar et al. (1991)</td>
</tr>
<tr>
<td>Chenopodium album, Avena ludoviciana, Anagallis arvensis, Fumaria parviflora, Chenopodium album and Avena ludoviciana</td>
<td>IARI, New Delhi</td>
<td>Ahuja and Yaduraju (1992)</td>
</tr>
<tr>
<td>Asphodelus tenuifolius, Chenopodium spp. and Convolvulus arvensis</td>
<td>Rajasthan</td>
<td>Singh et al. (1992b)</td>
</tr>
<tr>
<td>Boerhavia diffusa, Cyperus rotundus, Chenopodium album, Trianthema monogyna, Asphodelus tenuifolius, Melilotus indica and Convolvulus arvensis</td>
<td>Rajasthan</td>
<td>Rajput et al. (1993)</td>
</tr>
<tr>
<td>Chenopodium album, Melilotus indica, Avena fatua and Phalaris minor</td>
<td>Bulandshahar, U.P.</td>
<td>Singh et al. (1993)</td>
</tr>
<tr>
<td>Broad leaved weeds as strawberry clover (Trifolium flagelatum), chicory (Chicorium intybus), common purslane (Portulaca oleracea), white sweet clover (Melilotus albus), toothed bur clover (Medicago hispida), common lambsquarters (Chenopodium album), corn spurry (Spergula arvensis), sorrel (Rumex dentatus) and sanet pimpernel (Anagallis arvensis), Small canary grass (Phalaris minor), crab grass (Digitaria adscendens), bermuda grass (Cynodon dactylon) and joint grass (Paspalum distichum) as grasses and purple nutsedge (Cyperus rotundus) as sedge</td>
<td>M.P.</td>
<td>Tiwari and Kurcharia (1993)</td>
</tr>
<tr>
<td>Echinochloa colomum, Digena arvensis, Convolvulus arvensis, Eragrostis major, Trianthema monogyna, Physalis minimia and Cynodon dactylon</td>
<td>Navasari, Gujarat</td>
<td>Kaneria and Patel (1994)</td>
</tr>
<tr>
<td>Chenopodium album, Asphodelus tenuifolius, Euphorbia dracunculoides and Trigonella polycerata</td>
<td>Haryana</td>
<td>Malik and Singh (1994)</td>
</tr>
<tr>
<td>Cynodon dactylon, Phalaris minor, Chenopodium album, Melilotus indica and Fumaria parviflora</td>
<td>IARI, New Delhi</td>
<td>Dixit and Gautam (1996)</td>
</tr>
<tr>
<td>Chenopodium album, Polygonum hydropiper, Amaranthus viridis, Phyllanthus niruri, Borneria hispida and Ageratum conyzoides among broad leaved and Cyperus iria, Setaria glauca and Echinochloa indica among narrow leaved weeds</td>
<td>Assam</td>
<td>Gogoi and Kalita (1995)</td>
</tr>
<tr>
<td>Cyperus rotundus as the most important one among weeds</td>
<td>Navasari, Gujarat</td>
<td>Kaneria and Patel (1995)</td>
</tr>
</tbody>
</table>
Asphodelus tenuifolius (31.15 per cent), Cyperus rotundus (23.30 per cent), Cynodon dactylon (22.10 per cent), Chenopodium album (14.22 per cent) and Melilotus indica (7.03 per cent).

Chenopodium album, Asphodelus tenuifolius, Convolvulus arvensis, Avena fatua and Phalaris minor.

Cyperus rotundus, Cynodon dactylon among monocots and Parthenium hysterophorus, Amaranthus viridis, Dicanthium calycinum, Euphorbia hirta, Cleome viscosa, Portulaca oleracea, Tridax procumbens and Melilotus indica among dicot weeds.

Anagallis arvensis, Chenopodium album, Phalaris minor, Melilotus alba, Melilotus indica, Cyperus rotundus and Cynodon dactylon

Asphodelus tenuifolius (49.9 per cent), Convolvulus arvensis (14.6 per cent), Anagallis arvensis (11.6 per cent), Chenopodium album (9.3 per cent), Avena fatua (8.3 per cent) and Euphorbia hirta (6.3 per cent)


Medicago denticulata, Melilotus parviflora, Euphorbia helioscopia, Sanchus arvense, Vicia sativa, Coronopus didymus, Sinapis arvensis, Cyperus rotundus, Leptochloa spp., Setaria viridis, Convolvulus arvensis, Chenopodium album, Cynodon dactylon, Bromus tectorum, Anagallis arvensis and Lepidium spp

Medicago denticulata (23.3 per cent), Anagallis arvensis (22.5 per cent), Fumaria parviflora (18.9 per cent), Lathyrus aphaca (9.6 per cent) and Vicia sativa (7.2 per cent)

Asphodelus tenuifolius (Cav.) as the most dominant weed

Chenopodium album, Convolvulus arvensis, Asphodelus tenuifolius, Melilotus indica, Anagallis arvensis, Avena fatua, Cynodon dactylon and Phalaris minor

Chenopodium album, Chenopodium murale, Portulaca oleracea, Melilotus indica, Asphodelus tenuifolius and Rumex dentatus

early stage because crop growth during winter (rabi) season remains slow during the first 4-6 weeks after sowing and during later stage it grows vigorously and suppressing effect on weeds.

**Weed management practices:** Weed management in crop is the process of limiting weed infestations so that crops could be grown profitably. In order to increase production in mustard, effective weed control measures must be taken.

**Cultural method of weed control:** Limited numbers of studies were reported on cultural methods of weed management in rapeseed-mustard. Prior to the introduction of herbicides, cultural practices played an important role in this regard. Enhancing crop competitiveness against weeds could provide a low cost and safe tool for weed management. Differences in weed suppression among crops or cultivars have long been established. Aggressive cultivars growing in association with weeds leave smothering effect over weeds. Crop varieties differ significantly for competition with weeds. Kumar and Kondap (1992) reported that Durgamani variety of mustard showed mild resistance to a major parasitic weed, *Orobanche* sp. of mustard. During 2010-11 examination of competitive behaviour of rapeseed-mustard varieties against weeds and their effect on yield of mustard under All India Coordinated Research Project on Rapeseed-Mustard revealed that different varieties showed differential response to weed competitive ability in terms of yield. At Varanasi, U.P., Ashirwad variety of mustard recorded maximum seed yield with lower weed density and weed dry weight at 60 DAS, whereas at Pantnagar, Uttarakand, Kranti variety recorded maximum weed competitive ability with higher seed yield and lower weed density and weed dry weight than other selected varieties of the respective region (Anonymous, 2011).

Placement of fertilizer in the crop row gives the crop a competitive advantage over weeds in the inter-crops gain more from the fertilizer than the weeds between the rows. Singh *et al.* (2009) reported that deep placement of fertilizer recorded significantly lowest value of weed density and dry matter production and gave the highest value of yield attributing parameters and yield of rainfed mustard followed by side placement which proved its district superiority over broadcasting method of fertilizer application.

Mustard should be grown as apart of rotation in which crops and cultivation are selected to minimize the weed problems progressively. Rotation of crops with different production requirements keeps down weed growth by preventing a build up of weeds ecologically adapted to one crop. Mustard/Gobhi sarson if adopted in sequence after rice during winter season, *Phalaris minor* problem could be reduced to a great extent in north-western wheat belt of India (Singh and Singh, 2006). Intercropping also suppresses weeds better than sole cropping and provides an opportunity to utilize crop themselves as a tool of weed management (Rao and Shetty, 1976). Rana (2006) reported that intercropping of *Brassica carinata* and *Brassica juncea* significantly reduced the weed population and weeds dry matter accumulation compared to their sole stand.

Plant densities also have an effect on weeds. Increasing crop canopy per unit area by manipulating plant density has significant impact on suppressing weed growth (Bhan, 1992). Singh (2006) reported that increasing seed rate has reduced the weed population and weeds dry matter production which has impact in increasing seed yield of mustard. He observed that the lowest seed rate of 4 kg/ha recorded significantly higher weed density and dry matter accumulation than higher seed rates of 5 and 6 kg/ha, respectively. This decrease in weed density and weeds dry matter under higher seed rates could be attributed to suppression of weeds due to increasing crop canopy by higher plant population per unit area.

**Mechanical method of weed control:** Proper tillage system is the first operational prerequisite in reducing weed problem. Primary tillage operations which bury as great a proportion of weeds at lower depths in the soil as possible can reduce the total weed population which will germinate. Before sowing of mustard seed deep tillage practices become more significant to control most of annual weeds such as *Anagallis arvensis* and *Medicago denticula* and perennial weed such as *Convolvolus arvensis* (Ali and Kumar, 2000). Hand weeding is being practiced by farmers in India since they initiated agriculture. Effectiveness of mechanical means of weed control was advocated by Makowsi (1990) in a trial in East Germany and found weed cover reduced, especially of volunteer cereals in
oilseed rape stands. Hoeing twice a year in early spring and early autumn proved particularly successful. In addition to the positive effect on weed cover, hoeing also resulted in increased yield due to the improved soil structure and plant growth. Rajput et al. (1993) obtained highest seed yield of 23.20 q/ha with hand weeding twice in comparison to control (4.84 q/ha) and other treatments e.g. hand weeding or hoeing once, pendimethalin and isoproturon at 0.75-1.0 kg for weed control in mustard cv. Pusa Bold. Bhadoria and Chauhan (1994) recorded higher seed yield (1.44 t/ha) with hand weeding at 25 DAS in mustard than fluchloralin or hand weeding at 45 DAS. Kaneria and Patel (1994 and 1995) also reported that continuously weeded plots and twice hand weeding at 25 and 45 DAS produced lower weed dry weight and higher weed control efficiency followed by herbicidal treatments. Gogoi and Kalita (1995) observed that hand weeding twice at 20 and 40 DAS resulted in 51.7 per cent weed control efficiency and the lowest weed dry weight of 23.88 g/m² and twice wheel hoeing or hand hoeing or grubbing were equally effective. However, all these methods when used once at 25 DAS failed to attain higher level of weed control efficiency. Weeding by mechanical methods also include the use of hand hoe and wheel hoe etc. Hand or wheel hoeing is a post-planting intercultural operation, faster and require less manpower than hand weeding. However, line sowing is a prerequisite for it. Gogoi and Kalita (1995) reported that wheel hoeing twice at 20 and 40 DAS resulted in highest seed yield (9.07 q/ha) and this was at par with two hand weedings. Patil et al. (1997) obtained the highest mustard yield of 11.6 q/ha with hoeing + hand weeding at 30 DAS followed by oxyfluorfen 0.2 kg (11.3 q/ha), metolachlor 1.0 kg (10.1 q/ha) and weedy check (5.1 q/ha) respectively. Sharma and Mishra (1997) while studying efficacy of various herbicides at Varanasi, U.P. concluded that though hoeing twice at 20 and 40 DAS produced maximum seed yield (9.62 q/ha) and yield traits of mustard, pre-emergence alachlor was at par (9.02 q/ha) and gave highest return per rupee invested (1.48) than other weed control mustard.

Conservation tillage with mulching on surface also helps in controlling the weeds effectively. Bazaya et al. (2006) found that polythene mulch was effective in controlling the weeds by increasing the soil temperature and acting as a physical barrier for emergence of weeds.

Soil solarization for a minimum period of 2 weeks during hot summer months (May and June in India) is also sufficient to control weeds, but it may be continued to several weeks together for prolonged effect. It may control weeds in crops in the wet-season (kharif) as well as subsequently in the winter (rabi). A reduction of 90 percent Orobanche infestation in mustard due to soil solarization in Israel has been reported by Singh (2011).

**Chemical method of weed control:** Herbicides are effective tools in man’s eternal struggle with weeds. When properly used, herbicides can safely and effectively accomplish their objective. Selective herbicides can control all weeds. Therefore, a farmer must know predominant weed species in his field so as to make choice of the herbicides he will use.

**Weed population and growth:** Makowskhi (1990) in East Germany stressed that despite good weed control achieved by mechanical means, it was still necessary to use some form of chemical control with hoeing. In India, Rana and Angiras (1990) revealed that minimum weed density and dry matter was recorded in twice hand weeded plots followed by pendimethalin and isoproturon at each of the phosphorus level. A review on chemical weed control of rape in USSR by Kurtozov and Truzina (1990) revealed that trifluralin 24 per cent EC killed 66-78 per cent weeds when applied pre-plant at 4 l/ha and quickly masked into soil, kept the crop weed free throughout the season and increased yields. Metolachlor 50 EC pre-emergence at 3 l/ha and pendimethalin 35 EC pre-emergence killed 68 per cent and 82-89 per cent weeds, respectively, including once not effectively controlled by trifluralin. Integrated weed management by using chemical herbicides viz. isoproturon, pendimethalin, fluchloralin and oxadiazon along with hoeing produced greatest reduction in weeds at average of 80-390 kg/ha weed dry matter compared to 970-1020 kg/ha in unweeded control, respectively (Brar et al., 1991). EL-Bastawery et al. (1991) concluded from a weed control experiment that the best weed control was achieved with fluometuron or hoeing, and trifluralin and pendimethalin were the least effective control agents. Tomar and Namdeo (1991) emphasized that
the efficacy of fluchloralin at 1.0 kg/ha for weed control in mustard as it was the most efficient in reducing dry matter of weeds and it was 41-73 kg/ha against 112-153 kg/ha under herbicides like pendimethalin, isoproturon and oxadiazon. They also opined that weeding once at 30 DAS in Indian mustard was sufficient to control the weeds as effectively as two weedings. Ahuja and Yaduraju (1992) reported that isoproturon, imazethapyr and pendimethalin when applied pre-emergence, all the three being at par, significantly reduced the population and fresh weight of Chenopodium album at 75 DAS compared to control. Pre-plant application of fluchloralin at 1.0 kg/ha significantly reduced the number of Chenopodium album and its fresh weight which was more effective than its lower dose of 0.5 kg/ha but both the doses were at par. Post-emergence application of isoproturon and imazethapyr, however, was not much effective in controlling weeds. Except isoproturon no other chemical could influence the growth of Avena ludoviciana. Singh (1992) opined that hand weeding at 25 DAS and thiobencarb at 1.0 kg/ha at 2 DAS significantly reduced the weed dry weight at 45 DAS during both years (31.9, 20.5, 29.7 and 19.4 g/m² 1986-87 and 1987-88, respectively). Singh et al. (1992a) reported lowest weed count (6/m²) after treatment with fluchloralin, other than weed free in comparison to other chemical viz. isoproturon, oxadiazon or pendimethalin and manual weeding at 30 DAS. According to Chauhan et al. (1993) pendimethalin and fluchloralin alone or in combination with hand weeding at 30 or 40 DAS decreased the weed dry weight from 249-280 kg/ha under untreated control to 32-77 kg/ha. Pahuja et al. (1993) reported that hand hoeing twice, three and six weeks after sowing, pre and post-emergence application of pendimethalin and isoproturon, respectively reduced the weed dry weight over control. In an experiment at Bulandsahar, U.P., various manual and chemical methods reduced the weed dry weight from unweeded control values of 22.4 g to 9.5-21 g/1000 cm² (Singh et al., 1993). Pradhan (1993) proved the superiority of integrated weed management in comparison to either manual or chemical weed control. Though hand weeding twice resulted in the maximum seed yield, oxadiazon at 0.75 kg/ha pre-emergence and hand weeding or hoeing proved the next best. Tiwari and Kunchania (1993) observed that the perennial weeds i.e. bermuda grass, joint grass and purple nutsedge were not controlled by any herbicides. However, annual weeds effectively controlled (25-73 per cent) by pre and post-emergence application of isoproturon, oxadiazon and metoxuron. Post-emergence application of fluazifop-p-butyl controlled the grass weeds only, whereas fluoroxyprpy + 2,4-D and fluoroxyprpy + MCPA reduced the population of broad leaved weeds by 42.6 and 39.8 per cent, respectively but the latter two treatments proved phytotoxic to mustard crop. In a sandy loam soil at Gwalior, M.P., Tomar (1994) found that pre-emergence and post-emergence application of fluchloralin produced 35.77 to 45.35 per cent weed control efficiency (WCE) compared to WCE of 77.08 per cent under the weed free plot, whereas hand weeding once at 25 DAS resulted in 45.35 per cent weed control. Bhadoria and Chauhan (1995) recorded weed dry weight of 35.32 g/m² in weedy check at 65 DAS compared to 25.87-28.05 g/m² by various weed control treatments e.g. hand weeding at 30 DAS, weeding with wheel-hoe at 30 DAS and fluchloralin, pendimethalin, isoproturon and oxadiazon each at 0.75 kg/ha. While studying the efficacy of different herbicides at different rates, alone or in combination in controlling weeds of mustard crop, Brar and Walia (1995) noticed better control of weed at higher rates of application of pendimethalin and fluchloralin. Combination of isoproturon with pendimethalin or with trifluralin also excelled their weed control potential over individual application of either of these herbicides. Fluchloralin pre-planting application at 0.75 kg/ha (Ahuja and Yaduraju, 1995) in mustard significantly reduced weed density and dry weight and increased seed yield in comparison to other herbicides. Fluchloralin pre-planting application at 0.75 kg/ha (Ahuja and Yaduraju, 1995) in mustard significantly reduced weed density and dry weight and increased seed yield in comparison to other herbicides. Sharma and Chauhan (1995) stated that hand weeding twice at 30 and 45 DAS and fluchloralin at 0.75 kg/ha were next in order to weed free in reducing weed dry matter and density compared with one hand weeding at 30 DAS and pendimethalin at 0.75 kg/ha as pre-emergence application. Evaluating different levels (0.5, 0.75, 1.0 kg/ha) and time of application of isoproturon (pre-plant, pre-emergence and post emergence), Yadav et al. (1995) observed that though all treatments reduced weed population, pre-plant application of 1.0 kg isoproturon was significantly more effective in reducing the weed population (92%) than other
treatments and post-emergence application was inferior to other two methods. Madhavilatha et al. (1997) observed the highest weed dry weight (55.2 g/m²) in unweeded check and butachlor + handweeding (10.1 g/m²), fluchloralin + hand weeding (10.1 g/m²), but hand weeding twice produced least weed dry weight (8.1 g/m²). In an experiment at Akola, Maharashtra, Patil et al. (1997) obtained significantly highest weed dry matter in unweeded check (174.3 g/m²) and hoeing + hand weeding at 30 DAS (28 g/m²). Among herbicides, oxyfluorfen 0.2 kg/ha resulted in lowest weed dry matter (22.8 g/m²) followed by isoproturon 1.0 kg/ha at 30 DAS (28.8 g/m²). Sharma and Mishra (1997) observed that hoeing twice at 20 and 40 DAS reduced weed dry matter and population significantly at all phenophases of mustard crop. Marwat et al. (2003) obtained application of pendimethalin at 1.32 kg/ha proved to be the best in giving lowest weed dry weight of 7.75 weeds/m² followed by trifluralin at 1.2 kg/ha (8/m²) and S-metolachlor at 1.92 kg/ha (12.75/m²) as compared to weedy check (26/m²). Yadav (2004) at Morena, M.P. reported that effective control of weeds in mustard was due to integrated use of isoproturon at 0.75 kg/ha as pre-emergence along with hand weeding at 25 DAS compared with other herbicides alone and in combination with cultural method of weed control. In a sandy loam soil at Gwalior, M.P., Chauhan et al. (2005) noticed the lowest weed population, weeds dry weight and weed control efficiency were recorded in the weed free treatment which was found to be significantly lower than all other treatments except two hand weedings (25 and 40 DAS) and oxyfluorfen 0.25 kg/ha. Degra et al. (2006) found that pre-emergence application of isoproturon at 0.5 kg/ha with one hand weeding at 40 DAS brought the highest reduction in weed growth when compared with other herbicides. In an experiment at Hisar, Haryana, Purna et al. (2006) observed oxadiargyl at 150 and 180 g/ha alone and tank mixture of oxadiargyl + isoproturon at 90 + 150 g/ha proved very effective in minimizing density and dry weight of Chenopodium album, Medicago denticulata and Melilotus indica weeds as compared to other treatments and were at par with two hoeings, pendimethalin at 1.0 and 1.5 kg/ha and trifluralin at 1.0 kg/ha. Singh (2006) obtained two hand weedicings at 25 and 50 DAS and integration of fluchloralin at 0.75 kg/ha as pre-plant incorporation supplemented by one hand weeding at 25 days after sowing found significantly superior in terms of reducing weed density and dry weight of weeds over fluchloralin at 1.0 kg/ha and weedy check.

**Mustard growth and yield:** Increase in seed yield of mustard due to various weed control method namely, manual, mechanical, chemical or combination of these depends on the extent of weed control and their resultant effect on various growth and yield deciding parameters. Tomar and Namdeo (1991) advocated the efficiency of fluchloralin in mustard and Yan (1990) supported the efficacy of trifluralin for weed control in spring rape. Brar et al. (1991) obtained highest seed yield (19.29 kg/ha) by oxadiazon compared to 16.2 and 13.39 in twice weeded and unweeded control, respectively. In a weed control trial of mustard cv. Pusa Bold, Tomar and Namdeo (1991) observed no significant effect of weed control practices on yield and yield traits, but fluchloralin proved the best with maximum number of primary branches, siliqua/plant and seed yields. Andersson and Bengtsson (1992) while evaluating results of 41 trials carried out in South Sweden found hoeing and alachlor at 5 l/ha reduced weed number and dry weight and increased seed yield of rapeseed by 15 per cent. Singh (1992) reported significant increase in primary branches, siliqua/plant, seeds/siliqua and 1000-seed weight due to hand weeding at 25 DAS and thiobencarb at 1.0 kg pre-emergence over control during 2 years of experimentation, but difference between thiobencarb and hand weeding was not significant. Singh et al. (1992a) recorded seed yield of 25.6, 24.1 and 22.7 q/ha with weed free, fluchloralin and oxadiazon, respectively. At Sumerpur, Rajasthan in a trial on mustard cv. Pusa Bold, Singh et al. (1992b) obtained seed yields of 1.53 t in weedy check, 2.56 t in weed free, 1.8 t by hoeing 30 DAS, 1.83 t with 0.75 kg/ha isoproturon at 30 DAS, 2.27 t with 0.75 kg/ha pre-emergence oxadiazon, 2.13 t with 1.0 kg/ha pre-emergence pendimethalin and 2.41 t with 1 kg/ha pre-plant fluchloralin/ha. Ghosh et al. (1993) on sandy clay loam soil at Kharagpur, West Bengal observed that among various manual and mechanical weedicings 20 and 40 DAS or 40 DAS alone or in combination with mulching with black polythene or post-emergence application of isoproturon at 1.0 kg/ha, isoproturon + mulching
resulted in the highest mustard seed yield (1030 kg/ha) against control value of 210 kg/ha. Khan et al. (1993) at Islamabad, observed manual weeding effective for mustard but appeared time consuming and costly, however, trifluralin at 1.0-2.0 l/ha in rapeseed and 1.0-1.5 l/ha in mustard proved optimum for satisfactory weed control in both the crops. Pradhan (1993) proved the superiority of integrated weed management in comparison to either manual or chemical weed control. Though hand weeding twice resulted in the maximum seed yield, oxadiaxon at 0.75 kg pre-emergence + hand weeding or hoeing proved the next best. Pahuja et al. (1993) concluded that among weed control treatment viz. hoeing twice 3 and 6 weeks after sowing, pendimethalin pre-emergence at 1.0 kg and 1.5 kg/ha post-emergence (30 DAS) isoproturon at 0.5 and 0.75 kg/ha in Indian mustard, isoproturon at 0.75 kg/ha resulted in the maximum yield. Singh and Singh (1993) during a two years trial on weed control in mustard found that total biological yield was almost similar to each other with thiobencarb, isoproturon and one hand weeding + hoeing. Singh et al. (1993) at Bulandshahar, U.P. realised seed yields of 12.0 to 17.5 q/ha with hand weeding once 30 DAS, pendimethalin 1.0 kg and isoproturon at 0.75 kg in mustard compared to untreated control (7.0-9.7 q/ha). Weed control treatments also affected oil content in mustard. Tiwari and Kurcharia (1993) in an extensive weed control trial in mustard observed that pre and post-emergence application of isoproturon, oxadiazon and metoxuron produced seed yields of 15.5, 15.2, 14.6 and 14.7 q/ha respectively. All these treatments and butachlor, oxyfluorfen, metolachlor and pendimethalin were at par with hand weeding (14.0 q/ha) and significantly superior to the weedy control (8.2 q/ha). However, fluoroxyphyrr + 2, 4 -D and fluoroxyphyrr + MCPA proved phytotoxic to the crop. At Navasari, Gujrat, Kaneria and Patel (1994) evaluated different weed control methods viz. manual at 25 or 45 DAS, pendimethalin or alachlor and their all possible combination in Indian mustard and observed that all weed control treatments increased seed yield from 830 to 985-1400 kg/ha. Ahuja and Yaduraju (1995) reported that there was no significant difference in seed yield in the unweeded to weed free or treated with various herbicides (fluchloralin, pendamethalin, isoproturon etc.). Pre-emergence application of imazethapyr proved phytotoxic to emerging crop there by reduced the seed yield. However, Bhadoria and Chouhan (1995) observed enhancement in seed yield from 1.45 t/ha to 1.67-.84 t/ha, primary and secondary branches, siliqua/plant, 1000-seed weight and oil per cent with various treatment viz. hand weeding, wheel hoeing at 30 DAS, fluchloralin, pendimethalin, isoproturon and oxadiazon. Fluchloralin recorded the maximum yield and yield parameters (except oil content) while oxadiazon resulted maximum oil content. Brar and Walia (1995) while evaluating tank-mix application of trifluralin + isoproturon (0.3 + 0.5 kg) obtained 14.1 and 41.7 per cent more seed yield than hand hoeing and unweeded control, respectively followed by pre-plant trifluralin and pendimethalin. Sharma and Chauhan (1995) realised seed yields in decreasing order of weed free, twice hand weeding (30 and 55 DAS), fluchloralin 0.75 kg/ha in mustard. At Morena, M.P. Yadav et al. (1995) reported the highest mustard seed yield with 1.0 kg/ha isoproturon pre-plant (1.78 t/ha).
ha) followed by same rate as pre-emergence (1.77 t). Similar trend was also noticed for siliqua/plant and seed weight/plant. Madhavilatha et al. (1997) at Rajendranagar, Hyderabad revealed that hand weeding twice produced the highest seed yield and yield traits followed by fluchloralin + hand weeding (14.2 q/ha), butachlor + hand weeding (14.2 q/ha), metolachlor + hand weeding (13.6 q/ha), the later three treatments remained at par with one another. Singh et al. (2001) reported pre-emergence application of pendimethalin at 1.0 kg/ha recorded higher seed yield and found best substitute of repeated manual weeding where the labour costs are too high. Marwat et al. (2003) realised the maximum seed yield (2291 kg/ha), 1000-seeds weight (4.04 g) and number of seeds/siliqua (25.75) in pendimethalin treated plots followed by trifluralin (2141 kg/ha, 3.99 g and 25.50) and S-metolachlor (1950 kg/ha, 3.88 g and 25.06), respectively. Chauhan et al. (2005) observed that application of oxyfluorfen at 0.25 kg/ha as pre-emergence, fluchloralin 1.0 kg/ha as pre-plant application and two hand weedicings (25 and 40 DAS) in Indian mustard drastically reduced weed density, weed biomass and increased the seed yield over other weed control treatments.

Biological method of weed control: It involves the use of living organisms as insects, fungus, bacteria, virus and competitive plants to limit the infestation of the weeds. In rapeseed-mustard the various bioagents for weed control has been identified. Sharma et al. (2011) reported that Fusarium solani infection on Orobanche increased the number of dead spikes of broom rape. Bioagents insects such as Phytomyza orobanchia and fungi such as Fusarium oxysporum sp. orthoceras are natural enemies of Orobanche. Seed production in Orobanche was found to be reduced significantly in many countries (Kroschel and Klein, 2003).

Integrated method of weed management: No single method, e.g. cultural, mechanical or chemical and biological could reach to the desired level of weed control efficiency in certain location or across locations mainly because of the vast diversity of weeds in crop fields. These have led to the evolution of integrated weed management (IWM), which means maintaining or managing a population below a threshold level, which may not cause substantial economic damage to crops. Thus, integrated weed management system is defined as a science-based decision-making process that coordinates the use of macro and micro-environment information, weed biology and ecology, and all available technologies to control weeds by the most economical and ecologically viable methods (Sanyal, 2008). Many advances have been made in recent years in India on integrated weed management in mustard. Several research publications (Chauhan et al., 1993; Singh et al., 1999; Yadav, 2004; Degra et al., 2006; Singh, 2006; Singh et al., 2009) have proved that integration of herbicides with hand weeding is the most effective and economical method of weed management in rapeseed-mustard (Table 2).

Nutrient uptake: Dashora et al. (1990) found that uncontrolled weed growth in mustard throughout the crop season caused loss of 14.6 kg N/ha. Singh (1992) obtained that nutrient depletion was the highest under unweeded treatment (18.5, 4.7 and 82.2 kg NPK/ha, respectively) and lowest under hand weeding at 25 DAS and thiobencarb at 1.0 kg pre-emergence owing to lower dry weight of weeds and nutrient depletion was higher at 45 DAS than harvest. Singh and Singh (1993) further observed that significantly higher N, P and K uptake by mustard in hand weeded and herbicides treated plots than unweeded plots. Kaneria and Patel (1995) realised the highest N, P and K uptake in Indian mustard (122.7, 43.0 and 144.9 kg NPK/ha, respectively) with weed free treatment followed by two hand weeding at 25 and 45 DAS in comparison to weedy check plots (51.3, 15.6 and 85.4 kg/ha, respectively). Dixit and Gautam (1996) at IARI, New Delhi found that weedy check resulted in the lowest uptake (79.1, 12.7 and 66.7 kg N, P and K/ha) and though weed control methods enhanced uptake of nutrients by mustard crop no significant difference was found between hand weeding (97.9, 16.1 and 86.5 kg) and pendimethalin (104.8, 17.1 and 88.4 kg) application. Patil et al. (1997) at Akola, Maharashtra found similar trend in nutrient uptake by crops and weeds in proportion to their dry matter production. Nutrient removal by weeds governed the amount of nutrient uptake by crop. Hand weeding hoeing caused higher nutrient uptake followed by herbicidal treatment of oxyfluorfen 0.2 kg/ha as pre-emergence.
Integrated effect of fertilizer and weed management practices: In an experiment on gobhi sarson (Brassica napus), Angiras and Rana (1990) obtained significantly highest yield with combination of hand weeding twice and 60 kg P₂O₅/ha. But at 40 kg P₂O₅/ha, it was statistically at par with combination of pendimethalin 1.5 kg/ha (pre) and hand weeding twice. 20 kg P₂O₅/ha could be economised in medium phosphorus status acidic soils. The highest level of management with higher fertilizer dose, two weedings in irrigated condition produced significantly higher seed yield in mustard than medium and lower levels. Application of fertilizer to Indian mustard under irrigated conditions offered congenial environment for weed infestation, particularly Asphodelus tenuifolius, Chenopodium album and Convolvulus arvensis (Tomar and Namdeo, 1991). Singh (1992) found that though fertilizer application and weed control methods individually increased mustard seed yield and yield traits significantly, the interaction was not significant. Similarly, Bhadoria and Chauhan (1994) revealed that fertility levels increased all growth and yield traits and seed yield of mustard significantly but weed control methods increased all the parameters except primary branches, seeds/siliqua significantly. Kaneria and Patel (1994, 1995) in a study at Navsari, Gujrat on weed and nitrogen management in mustard obtained seed yield in order of weed free > two hand weeding > pendimethalin + one hand weeding at 45 DAS > alachlor + one hand weeding at 45 DAS > alachlor alone. However, last two treatments were found superior to one interculture at 25 DAS or hand weeding at 45 DAS, interculture at 25 DAS + hand weeding at 45 DAS and weedy check in respect of all yield traits, seed yield and nitrogen uptake. Increasing nitrogen from 60 to 90 kg/ha significantly improved all these parameters and N, P and K uptake by weeds also which are associated with higher weed biomass production. Dixit and Gautam (1995) studying interactive effect of management systems and weed control methods in mustard at IARI, New Delhi reported increase in weed population with increase in fertility levels from 50 to 100 per cent of recommended dose. But highest seed yield (21.92 q/ha) was obtained from pendamethalin under 100 per cent fertilizer. Singh et al. (2009) while studying the effect of fertilizer placement and weed management practices in rainfed mustard at Varanasi observed integrated weed management strategy with pre-emergence application of isoproturon at 1.0 kg/ha along with interculture once at 30 DAS under deep fertilizer placement method recorded the highest seed yield which proved its district superiority over other combinations of methods of fertilizer and weed management practices.

Economics

In modern agriculture, feasibility of any method can be judged on the basis of additional return due to that practice over the established one. The fundamental economical principle for weed management is simple that act only if benefits exceed the cost (King et al., 1998). The result of Dixit and Gautam (1995) indicated that pendimethalin fetched more profit (‘ 1083/ha) than one hand weeding (‘ 791/ha) under different weed management system of mustard. Yadav et al. (1999) revealed that economics of different weed management practices was obtained the highest net realization with two hand weedings at 20 and 40 DAS, followed by metribuzin 0.175 kg/ha (pre-emergence) and isoproturon 0.75 kg/ha (pre-plant), but highest benefit: cost (B: C) ratio of 4.8 was observed with isoproturon 0.75 kg/ha (pre-plant) and metribuzin 0.175 kg/ha (pre-emergence). Singh (2000) realised the highest net return (‘ 12423/ha) and B: C ratio (1.96) with isoproturon pre-emergence + interculture once which was ‘ 6302/ha higher than weedy check and the lowest B: C ratio (1.12) was obtained with weedy check. Bazaya et al. (2004) reported that maximum B: C ratio (1.83) was obtained with pre-plant incorporation of flucholaralin at 0.70 kg/ha supplemented with one hand weeding at 30 DAS. Chauhan et al. (2005) conducted field experiment at Gwalior, M.P. observed that weed control with two hand weedings (25 and 40 DAS) recorded higher net return (‘ 10094/ha) and B: C ratio (2.31) over chemical weed control and weedy check in Indian mustard. Singh (2006) observed that maximum net profit and B: C ratio were recorded with pre-plant incorporation of flucholaralin at 0.75 kg/ha along with one hand weeding at 25 DAS.

CONCLUSION

Weed interference in mustard causes significant yield reduction. Duration of weeds in the field also affect yield as do damage thresholds; which vary from one weed to another. To avert economic
losses therefore, weed control should be affected early in the growth period, especially in the first four to six weeks which is the critical period of competition in mustard. Weed management is a system approach whereby whole land use planning is done in advance to minimize the every invasion of weed in aggressive terms and give crop plants a competitive advantage over weeds. Effective control of weeds in mustard has been achieved with pre-plant herbicide use of fluchloralin and trifluralin. Among pre-emergence herbicides, alachlor, butachlor, isoproturon, metolachlor, metribuzin, nitrofen, oxadiargyl, oxadiazon, oxyfluorfen, pendimethalin, terbutryn, thiobencarb hold promise. However, in present context integrated methods of weed management gets paramount important as it is eco-friendly. Integrated management strategies involving preventive, cultural and herbicidal methods can provide an acceptable degree of weed control in mustard crop. Integration of chemical weed control with mechanical weeding is the most effective and economically viable method for weed management in mustard.

REFERENCES


