Optimizing Weed Control: A Review of Integrated Weed Management in Mustard (*Brassica juncea* L.)
Suggested Title: Integrated Weed Management in Mustard (*Brassica juncea* L.)

ABSTRACT

Mustard (*Brassica juncea* L.), a species of the cruciferous family, is the world's third most significant oilseed crop, following soybean and palm. Mustard seeds range in oil content from 37 to 49%. India is the fourth-largest producer of mustard and rapeseed in the world. The most significant issue causing mustard's low yield is weed control. Crop yields are significantly reduced by weeds; in the case of mustard, this can mean a complete failure rate of 15–30%. Crop plants compete with weeds for nutrients, sunlight, space, and water. In addition to lowering crop quality, weeds pose a number of nutritional and environmental hazards. In mustard crops, weed competition is particularly important in the early stages since the crop grows slowly in the first 4–8 weeks after sowing. .. On the other hand, 15–40 days are the critical window for crop–weed competition. Weed control must be carried out appropriately and on time in order to maximize mustard growth and production. During the early stages of crop growth, 25–30 days after sowing, the traditional practice of hand weeding once is insufficient because weeds always reappear after manual weeding, irrigation, or winter rainfall. More importantly, though, is that these weeds drain a large amount of the soil's moisture and nutrients. Though hand weeding mustard is simple, the expense of doing so is significant due to the scarcity of labor at the appropriate time and the uncontrolled growth of various intrarow weeds. Weeds may become tolerant of herbicides despite their regular and high dosage application. Therefore, combined approaches could bethe best option to control the complex weed flora in mustard.

Key words: Herbicides, Manual weeding, Mustard, Weed competition and Weed flora.

INTRODUCTION

In India, oilseeds are the second most important agricultural commodity after grains. The most effective way to manage the diverse weed flora in mustard may be through approaches, which make up over 10% of all agricultural goods and roughly 5% of the country's gross domestic product.(Rai *et al.,* 2014). One of the most significant oilseed crops in terms of worldwide economic significance is mustard. It is a member of the Cruciferae family. It is the second most important oilseed crop in India, after groundnut, out of the seven edible oilseeds that are grown there. Rapeseed-mustard comprising eight different species are cultivated viz. Indian mustard (*Brassica juncea*), brown sarson (*Brassica campestris* var. brown sarson), yellow sarson (*Brassica campestris* var. yellow sarson), toria (*Brassica campestris* var. toria), gobhi sarson (*Brassica* *napus*), black mustard (*Brassica nigra*), karan rai (*Brassica carinata*) and rocket salad or taramira (*Eruca sativa*) are being cultivated in 53 countries spreading all over the globe. Indian mustard (*Brassica juncea*) alone occupies 75 per cent of the total area among brassicas grown in India.

The oil content in mustard varies from 37-49 per cent (Bhowmik *et al*., 2014). In northern India, people use the oil for cooking and food consumption. It is also utilized in the manufacturing of medications and hair oils. Grease production is one usage for it. The seed is added as a flavoring. Young plants' leaves are used as green vegetables because they provide minerals and sulfur to the diet. Oil cake is utilized as manure and feed. Cattle can get plenty of green fodder from green stems and leaves. The oil-cake has glucosinolate, which restricts its usage as a protein supplement, and sinigrin, which has a bitter flavor and impairs palatability. Mustard oil is used in the tanning industry to soften leather.

Despite being one of the top producers of oilseeds and having a sizable population, India cannot supply the world's demand for edible oils. In order to meet demand, India is importing edible oils at a cost in valuable foreign exchange. Productivity has to be increased in order to close the gap between supply and demand. The main biotic stressor in mustard production is weeds. Because crop growth in mustard is modest during the first 4-6 weeks after sowing, weed competition is particularly severe in the early stages. Nevertheless, at later phases, it grows quickly and suppresses weeds. Weeds impede crop growth and development by competing with it for nutrients, light, and water. Hence, there is need to remove weeds in the early stage of crop growth to avoid competition. The most common weeds that grow in rapeseed mustard are *Avena ludoviciana,Phalaris minor*, *Chenopodium album*, *Rumex dentatus*, *Anagallis arvensis, Convolvulus arvensis*, *Melilotus indica* and *Cirsium arvensis* (Singh and Kumar, 2020). The critical period of crop weed competition in mustard is 15-40 DAS and weeds cause about 25-50 % of yield loss (Yadav *et al.*, 2017) depending on weed flora, intensity and stage of the crop. In mustard hand weeding is the traditional practice. But increasing wages, scarcity of labour at peak periods and high-cost involvement compels to depend on other alternatives which are technically feasible and economically viable weed management to get optimum yield. [redacted]

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YIELD LOSSES CAUSED BY WEEDS

Singh et al. (2000) found that infestations of *Asphodelus tenuifolius*, *Chenopodium album*, and *Chenopodium murale* reduced mustard crop output by 30%. According to Gupta (2000), *Chenopodium album* (45.34%) had the greatest impact on mustard seed yield, followed by *Fumaria parviflora* (43.32%) and *Convolvulus arvensis* (40.60%). *Bhoyar and Yaduraju* (2000) showed that *Asphodelus tenuifolius* is one of the main causes of mustard's low productivity, reducing yield by up to 56%. According to Banga and Yadav (2001), crop-weed competition in rapeseed and mustard caused 58% losses in yield. A yield drop of 25-45% was observed in mustard depending on the kind of weed flora and the intensity, stage, character, and duration of crop-weed competition (Singh *et al.,* 2001). Banga *et al.* (2004) found that weed growth throughout the crop season reduced mustard seed produce by 24.7%. Similarly, Purna *et al*. (2006) discovered that the presence of weeds during the growing period resulted in a 36-42% drop in mustard seed output.

O.Donovan *et al*. (2007) estimated that weed infestation reduced yield in rapeseed mustard about 20-70%, depending on the character and density of weed flora and the time of occurrence. Similarly, Chopra and Saini (2007) found that yield loss in gobhi sarson ranged between 23 and 70% depending on the kind, intensity, and length of competition. Weed infestation in rape seed crops reduces output by 20-30% (Punia *et al*., 2010). Mustard yield decreased by 68% when unweeded compared to weed-free conditions (Degra *et al*., 2011).

Singh *et al.* (2012) observed that weed infestation reduced the average production of Indian mustard by 25.8 percent. Many biotic stresses, including weeds, cause severe yield losses of up to 45% in rapeseed-mustard (Singh *et al.*, 2013). Kour *et al.* (2013) observed that weed infestation diminished mustard yields by 20-40% on average. The presence of weeds during the growing season reduced crop yield by 24-50% as compared to weed-free mustard crops (Yadav *et al.*, 2017).

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Weed Flora

The major weeds found in experimental field were *Chenopodium album, Chenopodium murale, Melilotus indica, Cichorium intybus, Coronopus didymus, Spergula arvensis, Anagallis arvensis, Parthenium hysterophorus* and *Phalaris minor* (Nepalia and Jain, 2000). Mishra and Kurchania (2001) noticed similar weed flora *i.e.,Phalaris minor, Anagallis arvensis, Chenopodium album, Cichorium intybus, Medicagohispida,Melilotusindica,Melilotusalba,Viciasativa,Convolvulusarvensis*and*Cyperus* *rotundus*.Themostprominentweedsofrapeseedwere*Chenopodiumalbum*,*Chenopodium murale, Anagallis arvensis, Convolvulus arvensis, Euphorbia heliscopia, Medicago polymorpha, Cynodon dactylon* and *Phalaris minor* (Bhowmik,2003).

Banga *et al*. (2004)identified*Asphodelus tenuifolius, Chenopodium album, Avena ludoviciana* and *Phalaris minor*as major weeds in mustard crop.The predominant weeds *Medicago denticulata, Anagallis arvensis, Fumaria parviflora, Lathyrus aphaca* and *Vicia sativa* were noticed in mustard crop byBazaya *et al*. (2004). According to Chauhan *et al*. (2005), prevalent weeds in mustard crops include*Chenopodium album, Convolvulus arvensis, Asphodelus tenuifolius, Melilotus indica, Anagallis arvensis, Avena fatua, Cynodon dactylon* and *Phalaris minor*as dominant weeds in mustard crop.*Polygonum persicaria, Polygonum pensylvanicum, Polygonum orientale, Stellaria media* and *Vicia sativa* were the dominant weeds in mustard experimental field reported by Sarkar *et al*. (2005).Singh (2006) noticed *Digera muricata, Amaranthus blitum, Celosia argentea, Heliotropium subulatum, Glinus lotoides* and *Cynodon dactylon* as major weeds in mustard crop during *kharif* season.

Khan *et al*. (2008) noticed *Avena fatua, Sorghum halepense, Phalaris minor, Convolvulus arvensis, Cyperus rotundus, Fumaria indica, Vicia sativa, Medicago denticulata, Rumex crispus* and *Anagallis arvensis*weeds on large scale.Hugh *et al* (2008) noted the weed flora *i.e.*,*Avenafatua*,*Setariaviridis*,*Sinapisarvensis*,*Thlaspiarvense*,*Chenopodiumalbum*and *Vaccaria hispanica*in mustard. Punia *et al*.(2010) noticed that mustard crop was seriously infested with *Asphodelus tenuifolis, Chenopodium album, Melilotus indica, Trigonella polycerata, Cynodon dactylon, Orobanche aegyptia, Carthamus oxycantha* and *Convolvulus arvensis*.The experimental field consisted of mixed flora *viz*., *Cynodon dactylon, Phalaris minor, Anagallis arvensis, Cichorium intybus, Convolvulus arvensis, Coronopus didymus, Fumaria parviflora, Melilotus indica, Parthenium hysterophorus* and *Spergula arvensis* (Degra *et al*., 2011). Kumar*et al*.(2012)found that the mustard field was mostly infested with *Phalaris minor, Avena ludoviciana* and *Lolium temulentum*. The broadleaved weeds like *Vicia sativa, Coronopus didymus* and *Anagallis arvensis* as a whole constituted 26.7% of total weedflora.The weed flora observed in mustard field was *Medicago sativa, Anagallis arvensis, Trachyspermum ammi*,similarly, grassy weeds included *Cynodon dactylon*and*Poaannua*andtheprotuberantweedamongsedgeswasfoundtobe*Cyperus rotundus* (Kour *et al*.,2013).

Mukherjee(2014) revealed that*Anagallis arvensis, Chenopodium album, Convolvulus arvensis, Centella asiatica, Melilotus indica, Medicago polymorpha, Coronopus didymus, Oxalis latifolia* and *Vicia sativa*were the predominant weed species in mustard.The major weed flora examined in experimental site of mustard were *Cyperus rotundus, Anagallis arvensis, Chenopodium album, Polygonum plebejum* and *Phalaris minor* asreported by Kumar *et al*. (2015).Das(2016)surveyedand foundthatthe mustard field was infested with broad leaved weedslike *Anagallis arvensis, Chenopodium album, Convolvulus arvensis, Fumaria parviflora, Melilotus alba, Lathyrus aphaca, Euphorbia hirta, Parthenium hysterophorus, Spergula arvensis, Gnaphalium leuteoalbum, Commelina benghalensis, Asphodelus tenuifolius, Cleome viscosa* and grasses like *Echinochloa colona, Cynodon dactylon, Paspalum scrobiculatum, Digitaria sanguinalis* and sedges like *Cyperusrotundus.*

Mustard crop was mainly infested with*Cynodon dactylon, Cyperus rotundus, Phalaris minor, Asphodelus tenuifolius, Anagallis arvensis, Chenopodium murale, Chenopodium album, Convolvulus arvensis, Fumaria parviflora* and *Melilotus indica* during *rabi* season as noticed byKalita*et al*. (2017). The dominant weeds distinguished in the experimental field were *Phalaris minor, Cynodon dactylon, Chenopodium album, Anagallis arvensis, Melilotus alba, Vicia hirsuta, Lathyrus asphaca* and *Cyperus rotundus* (Yadav *et al*., 2017).Jangir *et al.* (2018) noticed from Navsari, Gujarat that the experimental field was mainly infested with monocot weeds *viz., Echinochloa crusgalli, Digitaria sanguinalis, Eragrostis barbinodis* and *Cynodon dactylon.* dicot weeds *viz*., *Convolvulus arvensis, Digera arvensis, Achyranthes aspera, Achyranthes sessilis, Corchorus triflorus, Abutilon indicum* and *Boerhavia diffusa.*

Suryavanshi *et al.* (2018) realised that mustard crop was seriously infested with *Medicagosativa,Sonchusarvensis, Cichorium intybus* and *Physalis minima*. The predominant weeds observed were *Chenopodium album, Thithonia diversifolia, Anagallis arvensis, Melilotus alba, Cyperus rotundus* and *Cynodon dactylon*in mustard during the twoyears of study reported by Gupta *et al*.(2018).The most dominant weed species observed was *Anagallis arvensis, Chenopodium album, Convolvulus arvensis, Centella asiatica, Melilotus indica, Melilotus alba, Medicago polymorpha, Coronopus didymus, Oxalis latifolia* and *Vicia sativa* (Chatterjee and Singh, 2018).

The pre-dominant weeds noted in the experimental field was *Phalaris minor,Chenopodium album, Anagallis arvensis, Melilotus alba, Vicia hirsuta, Lathyrus aphaca* and *Cyperus rotundus* (Raj*et al*., 2020). Singh and Kumar (2020) in mustard crop noticed *Avena ludoviciana, Phalaris minor, Chenopodium album, Rumex dentatus, Anagallis arvensis, Convolvulus arvensis, Melilotus indica* and *Cirsium arvense* as important weeds.Sharma *et al.* (2021) reported that crop heavily infested with mixed flora of monocot and dicot weeds, *viz.Cynodon dactylon* and *Cyperus rotundus* among monocot weeds and *Coronopus didymus* and *Chenopodium album* among dicot weeds.

Critical Crop Weed Competition

Kondap and Upadhyay (1985) detailed that critical period of crop weed competition existed up to 5 to 6 weeks after sowing the rapeseed and mustard crops under Hyderabad condition.Dashora *et* *al.* (1990) reported 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) discovered that sustaining weed-free conditions beyond 40 DAS was inefficient and that the crucial time of crop-weed competition occurred within the first 8 weeks of seeding. Chauhan *et al.* (2005) found that weed competition in mustard is more significant in the early stages because crop development during the rabi season is modest for the first 4-6 weeks after sowing, but then it grows aggressively and eliminates efficiently. Shekhawat *et al*. (2012) revealed that the significant phase of crop weed competition in mustard occurs during the early growth stages, especially between 15 and 40 days after sowing. Similarly, Singh *et al.* (2013) found that crop weed competition is severe during early growth stages particularly between 15-40 DAS in mustard.

Weed Density and Weed DryWeight

The lowest dry matter was attainedwith two hand weeding and which was on par with stale seed bed (SSB) + fluchloralin 1.0 kg ha^{-1}followedbyonehandweedingat4WAS(Singh*etal.*, 2000). Similarly, Chandel and Saxena (2001)recorded lower weed dry matter and weed density was observed with handweedingtwiceat30and45DAS.Chauhan *et al.* (2002) realized the lowest weed population and weed dry weight in mustard with weed free treatment which was on par with application of oxyfluorfen 0.25 kg ha^{-1}.The lowest weed density was observed with pendimethalin 1.32 kg ha^{-1}(PE) as relatedto other weed management treatments(Marwat*etal*., 2003).Bazaya*etal*.(2004)observed that significant reduction in population and dry matter of weeds with fluchloralin 0.70 kg a.i. ha^{-1} followed by two hand weedings at 30 and 60 DAS.

Application of thiazopyr 120 g a.i. ha^{-1} as pre-emergence application followed by one hand weeding reduced the density and dry weight of different weeds was noticed by Banga *et al.* (2004).The highest reduction in weed growth was registered with pre-emergence application of isoproturon 0.5 kg ha^{-1} followed by one HW at 40 DAS and it showed statistical similarity with fluchloralin 1.0 kg ha^{-1} + HW treatments (Degra *et al*., 2006). Kumar *et al. (*2012) investigated an experiment during *rabi* season on silty clay soils and found that, lowest weed density and dry matter accumulation under hand weeding twice at 30 and 60 DAS followed by pendimethalin 0.75 kg ha^{-1} (PE) *fb* isoproturon0.75 kg ha^{-1} (PoE).

Patel *et al.* (2013) understoodthe lowest weed density and weed dry matter accumulation with application of pendimethalin 0.5 kg ha^{-1} (PE)+ 1 HW at 25 DAS followed by oxadiargyl 75 g ha^{-1} (PE) + 1 HW at 25 DAS. Application of pendimethalin 1 kg ha^{-1} as pre-emergence significantly reduced the weed density and dry matter (Kour *et al.*,2013). Mukherjee (2014) detailed that significantly the lowest weed density was recorded under pendimethalin 0.75 kg ha^{-1} + HW at 35 DAS and it was on par with the hand weedingtwiceduringboththeyearsofstudy.Pre emergence application of oxadiargyl *fb* clodinafop as PoE reduced the weed density significantly over the other treatments (Mankar, 2015).The minimum weed density and dry matter accumulation of weeds were registered under manual weeding (117 m^{-2}) followed by quizalofop-p-ethyl 60 g ha^{-1} (288 m^{-2}) as reported by Kumar *et al.* (2015).

The lowest weed density and dry weight were observed with pendimethalin1 kg ha^{-1} as pre-emergence application noticed by Das(2016). Bamboriya *et al.* (2017) reported that the lowest weed density and weed biomass were noticed with fluazifop-p- butyl 0.055 kg ha^{-1}at 10 DAS + 1 hoeing at 40 DAS being at par with fenoxaprop-p- ethyl 0.075 kg ha^{-1} at 10 DAS + 1 hoeing at 40DAS.Kalita *et al.* (2017) found that among weed management practices, one hand weeding treatment resulted in lower density of monocot, dicot and total weeds followed by oxadiargyl 0.09 kg ha^{-1} and pendimethalin 0.75 kg ha^{-1}.Significantly lower weed dry weight was registered with application of pendimethalin 30 EC 0.75 kg ha^{-1} + imazethapyr 2 EC 0.75 kg ha^{-1} (ready to mix) as noticed by Gupta *et al*. (2018).

Suryavanshi *et al*. (2018) found that application pendimethalin and isoproturon drastically decreased weed density and biomass when compared to an unweeded control area. In accordance with Jangir *et al*. (2018), applying pendimethalin 1.0 kg ha^{-1} as PE + quizalofop-p-ethyl 0.04 kg ha^{-1} as PoE + HW and intercultivation (IC) at 40 DAS resulted in lower total weed population and dry weight. Chatterjee and Singh (2018) reported that using pendimethalin 0.75 kg ha^{-1} as PE followed by HW at 30 DAS resulted in decreased weed density and was comparable to hand weeding twice. Weed density and dry matter accumulation were much reduced withPendimethalin 30% + imazethapyr 2% EC (RM) 1 kg ha^{-1} as PE *fb* mechanical weeding at 30 DAS maintained superiority and registered lowest weed density and weed dry weight (Sanketh *et al*., 2021).

Sharma *et al.* (2021) opined that minimum dry matter of weeds noticed with pre-emergence application of pendimethalin 38.7 CS @ 0.75 kg ha-1 + HW 30 DAS followed by pendimethalin 30 EC @ 0.75 kg ha-1 + HW 30 DAS.Tyagi *et al.* (2022) reported that two hand weeding at 25 and 50 DAS exhibited minimum value of weed density and dry weight which was significantly inferior over weedy treatment. It was followed by pendimethalin 30 EC 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE recorded significantly lowest weed density and dry weight in comparison to rest of the herbicide treatments.Pandey *et al*. (2022) lowest weed density and dry weight m^{-2} recorded with metribuzin (PE) @ 175 g ha^{-1} either with hand weeding at 40 DAS. Weedy check till maturity recorded significantly highest density and dry weight of weeds.Singh*et al.* (2023) noticed that lower weed density and dry weight were recorded with pendimethalin (PE) @ 1000 g ha^{-1} + hand weeding at 40 DAS.

Weed Index

The combination of pendimethalin 0.5 kg ha^{-1} (PE) + 1 HW at 25 DAS and oxadiargyl 75 g ha^{-1} (PE) + 1 HW at 25 DAS resulted in the lowest weed index in mustard (Patel *et al*., 2013. In mustard crops, hand weeding provided a lower weed index than quizalofop-p-ethyl 60 g ha^{-1} (Kumar *et al*., 2015). Jangir *et al.* (2018) concluded that the application of pendimethalin 1kg ha^{-1} as PE + quizalofop-p-ethyl 0.04 kg ha^{-1} as PoE + HW and intercultivation (IC) at 40 DAS resulted in the lowest weed index, which was comparable to the application of pendimethalin 1.0 kg ha^{-1} as PE + HW and IC at 40 DAS.Hand weeding twice at 20 and 40DAS recorded lower weed index followed by pendimethalin (PE) 1000 g ha^{-1} + hand weeding at 40DAS in mustard (Pandey *et al*., 2019). The lowest weed index was registered with the application of paddy straw mulching 5 t h^{-1} followed by pendimethalin 1.0 kg ha^{-1}(PE)+ clodinofop 60 g ha^{-1}(PoE) (Singh and Kumar, 2020).

Weed Control Efficiency

The application of pendimethalin 0.5 kg ha^{-1} (PE) + 1 HW at 25 DAS resulted in the highest weed control efficiency in mustard on loamy soils, followed by oxadiargyl 75 g ha^{-1} (PE) + 1 HW at 25 DAS. Patel *et al.* (2013) found that two HW plus two intercultivations at 20 and 40 DAS led to significantly greater weed control efficiency, which was comparable to the pre-emergence application of pendimethalin at 1 kg ha^{-1} in groundnut. According to Kaur *et al.* (2013), the best and most effective weed control method in mustard was two-hand weeding (25 and 45 DAS), followed by pendimethalin 0.75 kg ha^{-1}.

Kumar et al. (2015) revealed that manual weeding had a higher weed control efficiency than quizalofop-ethyl 60 g ha^{-1}. Das (2016) found that hand weeding twice at 20 and 40 DAS had a greater weed control efficacy than pendimethalin 1 kg ha^{-1} (PE) in mustard. Similarly, Kalita *et al.* (2017) realized that the highest weed control efficiency (69.5%) was recorded with one hand weeding and it was on par with oxadiargyl 0.09 kg ha^{-1} (67.01%). A field experiment was conducted in mustard during winter season on sandyloam soils and observed that higher weed control efficiency was with weed free followed by pendimethalin 1 kg ha^{-1} (PE) as noticed by Bijarnia *et al.* (2017). Yadav *et al.* (2017) laid out an experiment during *rabi* season on loamy sand and reported that, maximum weed control efficiency was noticed with oxadiargyl 90 g ha^{-1} (PE) in mustard crop. Pre-emergence application of pendimethalin 38.7 SC 0.75 kg ha^{-1} *fb* hand weeding twice at 30DAS and 45 DASregistered higher weed control efficiency in mustard (Gupta *et al*., 2018).

The maximum weed control efficiency was observed with the application of pendimethalin 1 kg ha^{-1} as PE + quizalofop-p-ethyl 0.04 kg ha^{-1} as PoE + HW and intercultivation (IC) at 40 DAS, which was comparable to the application of pendimethalin 1.0 kg ha^{-1} as PE + HW and IC at 40 DAS (Jangir *et al*., 2018). Pandey *et al*. (2019) conducted an experiment on silty loamy soils and showed that pendimethalin (PE) 1 kg ha^{-1} + hand weeding at 40 DAS had a greater weed control efficiency. Singh and Kumar (2020) conducted an experiment on clay loamy soils during the rabi season and determined that pendimethalin 1 kg ha^{-1} was the most effective weed control agent, followed by pendimethalin 1 kg ha^{-1} *fb* hand hoeing (35 DAS).

The highest weed control efficiency (WCE) was recorded in pre-emergence application of pendimethalin 38.7 CS @ 0.75 kg ha^{-1} + HW 30 DAS (64.04%) followed by pendimethalin 30 EC @ 0.75 kg ha-1 (65.66%) (Sharma *et al.*, 2021).Yernaidu*et al*. (2021 a) reported that higher weed control efficiency was noticed with intercultivation and hand weeding at 15 and 30 DAS and it was followed by oxadiargyl 6% EC 0.09 kg ha^{-1} PE *fb* intercultivation at 30 DAS.Bharat*et al.* (2022) reported that the higher weed control efficiency was recorded in weed free plots followed by pre -emergence application of oxyfluorfen @ 0.15 kg/ha (PE) though being at par with pendimethalin @ 1.0 kg/ha.Tyagi *et al.* (2022) revealed that application of pendimethalin 30 EC @ 1.0 kg a.i. ha^{-1} PE *fb* quizalofop 5 EC @ 60 g a.i. ha^{-1} PoE along with 125% RDF exhibited significantly highest weed control efficiency. Which was found statistically at par with pendimethalin 1.0 kg a.i. ha^{-1} PE *fb* clodinafop 60 a.i. ha^{-1} PoE.

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The maximum plant height in mustard was observed with a stale seed bed, followed by fluchloralin 1.0 kg ha^{-1}, which was comparable to manual weeding twice at 4 and 7 WAS (Singh *et al*., 2000). Similarly, Sharma and Jain (2002) found that weed-free plots had increased leaf area, plant height, and dry matter buildup, which was followed by two hand weedings. The application of isoproturon 0.75 kg ha^{-1} as a pre-emergence treatment, along with hand weeding at 25 DAS, resulted in maximum plant height and leaf area (Yadav, 2004). Sewak *et al.* (2004) recorded maximum plant height and dry weight of mustard with metribuzin 0.175 kg ha^{-1}(PE) followed by hand weeding at 30 DAS compared to weedy check.Significantly higher leaf area and dry matter accumulation in mustard were recorded with two hand weedings at 25 and 50 DAS and it was on par with integration of one HW at 25 DAS with fluchloralin 1.0 kg ha^{-1}(Singh, 2006).Chaitanya(2010) noted that pre-emergence application of pendimethalin 1.0 kg ha^{-1} incombinationwithquizalofop-p-ethyl50gha^{-1}at20DASrecordedsignificantlyhigher total dry matter production in groundnut as compared to other treatments.

Degra *et al*. (2011) revealed that two hand weedings at 25 and 45 DAS was at par with fluchloralin 1.0kgha^{-1}+HWat45DASin recordingsignificantlyhigherthelеafareaofmustard.Shaheenuzzamn *et al*. (2010) identified that application of s-metolachlor 960EC 1.0 l ha^{-1} registered higher plant height in groundnut.Sah *et al*. (2013) reported that maximum plant height, numberoffunctionalleaves,LAIanddrymatterwas observedwith one HW at 30 DAS in mustard and it was on par with pendimethalin0.75kgha^{-1}(PE) andoxyfluorfen0.125 kg ha^{-1}.Patel *et al.* (2013) stated that maximum plant height and dry matter accumulation was with pendimethalin 0.5 kg ha^{-1} (PE)+ 1 HW at 25 DAS followed by oxadiargyl 75 g ha$^{–1}$ (PE) + 1 HW at 25 DAS. Maximum plant height, leaf area and dry matter accumulation were registered with oxadiargyl75 g ha$^{–1}$ (PE) and it was followed by oxyflurofen (PE) (Mankar, 2015). Among the chemical weed control measures,applicationofpendimethalin1kgha^{-1}(PE)recordedhigherplantheight of yellow sarson, which was at par with application of pendimethalin 1.5 kgha^{-1} (PE),fluchloralin1.5kgha^{-1}(PPI)andclodinafop0.06kgha^{-1}(25-30DAS) as noticed by Das(2016).

Yadav *et al*. (2017) conducted an experiment during *rabi* season on silty loamy soils and concluded that maximum plant heightand dry matter accumulationwas registered underoxadiargyl90gha^{-1}(PE).The highest plant height and dry matter accumulation were noticed with application of fluazifop-p-butyl 0.055 kg ha^{-1} at 10 DAS + one hoeing at 40 DAS and followed by two hand-weedings at 20 and 40 DAS (Bamboriya*et al.*, 2017). Significantly higher plant height and dry matter accumulation were registered with weed free by pendimethalin 1 kg ha^{-1} (PE) (Bijarnia *et al.*, 2017). Gupta *et al.* (2018) concluded that two hand weedings recorded maximum plant height over other treatments. Similarly, Kumar *et al.* (2018) noticed that the highest plant height and dry matter accumulation were observed with two hand weedingsat 25 and 45 DAS followed by pendimethalin at 0.75 kg ha^{-1} (PE) over the weedy check.

Singh and Kumar (2020) conducted an experiment during *rabi* season on clay loamy soils and realized higher plant height and leaf area index with application of pendimethalin 1 kg ha^{-1} *fb*hand hoeing at 35 DAS.Chishi*et al.*(2021) noticed that pendimethalin 750 g/ha PE *fb* one hand weeding was superior than other treatments in recording highest plant height, plant population, and dry matter.Hadke*et al.* (2021) reported that hand weeding produced significantly higher plant height, dry weight it was followed by pendimethalin 30 EC (PE) + propaquizafop 10 EC (PoE) + WH (40 DAS). Unweeded check had the lowest plant height and dry weight.Sharma *et al.* (2021) noticed that weed free treatment resulted in the highest yield attributes like number of siliquae plant^{-1}, number of seeds siliquae^{-1} and number of secondary branches plant^{-1} significantly which was followed by pendimethalin 38.7 CS @ 0.75 kg ha-1 + HW 30 DAS and pendimethalin 30 EC @ 0.75 kg ha^{-1} + HW 30 DAS respectively.

Raj *et al.* (2021) revealed that two hand weeding at 20 and 40 DAS gave higher plant height, dry matter accumulation in g/plant, leaf area index and number of primary and secondary branches/plant. It was at par with pendimethalin (PE) 1.0 kg/ha + straw mulch 5 t/ha.Dipak and Kumar (2022). observed that among the weed management treatments, the growth and yield parameters of indian mustard viz. plant height, number of primary and secondary branches per plant, dry matter weight per plant, and leaf area were obtained under three hand weeding (30 DAS, 45 DAS and 60 DAS) which was followed by pendimethalin @ 0.5 kg/ha (pre-emergence) + isoproturon @ 1.0 kg/ha (45 DAS).Ananthapadmanabhan*et al*. (2022) revealed that higher plant height, number of branches plant^{-1}, and dry matter per plant were recorded under pendimethalin 30% EC (PE) @ 1.0 kg a.i. ha^{-1} + Hand hoeing (20 DAS) + Hand weeding (30-35 DAS).

EFFECT OF WEED MANAGEMENT PRACTICES ON YIELD ATTRIBUTES

Higher yield attributes of mustard like number of primary branches plant^{-1}, number of siliqua plant^{-1} and number of seeds silqua^{-1} were observed with stale seed bed followed by fluchloralin 1.0 kg ha^{-1}. However, it was on par with hand weeding twice at 4 and 7WASandoneHWat4WAS(Singh*etal*., 2000).Pre-emergenceapplication of pendimethalin 1.0 kg ha^{-1} recorded higher number of primary branches plant^{-1}, number of siliqua plant^{-1} and number of seeds silqua^{-1} and found best substitute for manual weeding where the labour costs are too high (Singh *et al*.,2001).

Marwat *et al*. (2003) found that higher yield attributes *i.e.*, 1000-seed weight and number of seeds siliqua^{-1} were registered with pendimethalinpendimethalin (PE) 1 kg ha^{-1}followedbytrifluralin.Sewak*etal*.(2004) recorded significant improvement in number of siliquae plant^{-1}, seeds siliqua^{-1} and test weightofmustardwithmetribuzinat0.175kgha^{-1}followedbyhandweedingat30DAS compared to weedycheck.Fluchloralin 0.70 kg ha^{-1} alone or in combination with hand weeding reduced weed growth significantly and increased the yield attributes of mustard compared to control(Bazaya *et al.*, 2004). Sarkar *et al.* (2005) reported that pre-plant incorporation of fluchloralin 1.25 kg ha^{-1} registered highest number of siliquae plant^{-1} (72.67) over weedy check on clay loam soils of West Bengal.

Significantly higher number of branches plant^{-1}, number of siliquae plant^{-1}, seeds siliqua^{-1} and test weight in mustard were recorded with two hand weedings at 25 and 50 DASand it was on par with oneHWat25DASwithfluchloralin 1.0 kgha^{-1}(PPI) (Singh, 2006).Higher number of siliquae plant^{-1}, seeds siliquae $^{-1}$ and test weight were reported with hand weeding and followed by s-metolachlor 1 l ha^{-1}(Shaheenuzzamn *et al.*, 2010).Degra *et al.* (2011) found that two hand weedings at 25 and 45 DAS resulted in a larger number of siliquae plant^{-1}, seeds siliqua^{-1}, and 1000 seed weight in mustard as compared to weedy check treatment, and were comparable to fluchloralin 1.0 kg ha^{-1} (PPI) + HW at 45 DAS. Kumar *et al.* (2012) observed a larger number of siliquae plant^{-1}, seeds siliqua^{-1}, and test weight in mustard following using pendimethalin 0.75 kg ha^{-1} (PE) and isoproturon 0.75 kg ha^{-1} (PoE). The highest number of branches plant^{-1} and siliquae plant^{-1} were found after two hand weedings (25 and 45 DAS), followed by pendimethalin 0.75 kg ha^{-1} (PE) (Kaur *et al.*, 2013).

Higher numberofbranchesplant^{-1}andnumberofsiliquaplant^{-1}wereobserved with oxadiargyl 90 gha^{-1}(PE) and it was followed by oxyflurofen150 g ha^{-1} (PE) (Mankar,2015). Yadav*et al*. (2017) noticed significantly higher number of siliquae plant^{-1} andseedssiliqua^{-1}with oxadiargyl90 gha^{-1}. Bijarnia *et al.* (2017) conducted field experiment during the winter season on loamy sand soils and confirmed that, higher number of branches plant^{-1}, siliquae plant^{-1} and seeds siliqua^{-1} were registered with weed free treatments compared to others.Among different weed management treatments, oxadiargyl 0.09 kg ha^{-1}(PE) recorded higher yield attributes such as siliquae plant^{-1}, seeds siliqua^{-1}and weight of 1000 seeds in mustard and it was on par with one hand weeding at 25 DAS as reported by Kalita *et al.* (2017).Bamboriya*et al.* (2017) stated that the highest yield attributes, *viz*. siliquae plant^{-1} (297.0), seeds siliqua^{-1} (15.5) and 1000-seed weight (4.89 g) were recorded in mustard with fluazifop-p-butyl 0.055 kg ha^{-1} at 10 DAS + 1 hoeing at 40 DAS. Gupta *et al.* (2018) stated that among weed management practices hand weedings recorded significantly higher number of branches plant $^{-1}$, siliquae plant^{-1} and seeds siliquae $^{-1}$ over weedy check in mustard.

Kumar *et al.* (2018) carried out an experiment on loamy sand soils during winter and concluded that higher number of branches plant $^{-1}$, siliquae plant^{-1} and seeds siliquae $^{-1}$ were noticed with application of pendimethalin 0.75 kg ha^{-1} (PE) and it was on par with two hand weedings at 25 and 45 DAS. Pandey *et al.* (2019) reported that the highest number of branches plant^{-1} and number of siliquae plant^{-1} were observed with pendimethalin (PE) 1000 g ha^{-1} + paddy straw mulch 5 t ha^{-1} at 2-3DAS.Higher number of branches plant $^{-1}$, siliquae plant^{-1} and seeds siliquae $^{-1}$ were recorded under two hand weedings at 20 and 40 DAS followed by pendimethalin (PE) 1kg ha^{-1} + hand weeding at 30 DAS as reported by Singh *et al*. (2020). Singh and Kumar (2020) conducted an experiment during *rabi* season on clay loamy soils and noticed higher number of primary and secondary branches plant $^{-1}$ under weed free situation.

Higher number of yield attributes *viz,* number of siliquae plant^{-1}, length of siliquae, seeds siliquae $^{-1}$ and 1000 seed weight were noted with application of pendimethalin (PE) 1 kg ha^{-1} + straw mulch 5 t ha^{-1} followed by two hand weedings at 20 and 40 DAS (Raj *et al.*, 2021). Chishi*et al.*(2021) reported that Seed/siliqua, siliqua/plant, length of siliqua, and seed weight were recorded under pendimethalin 750 g/ha PE *fb* one hand weeding. The treatment hand weeding produced maximum length of siliquae, number of siliquae per plant, number of seeds per siliquae and test weight and which was followed by pendimethalin 30 EC (PE) + propaquizafop 10 EC (PoE) + WH (40 DAS). Unweeded check was noticed minimum yield attributes (Hadke*et al.*, 2021). Maximum number of siliquae per plant, number of seeds per siliqua, 1000 seed weight, and seed weight per plant were recorded with three hand weeding (30 DAS, 45 DAS and 60 DAS) which was followed by pendimethalin @ 0.5 kg/ha (pre-emergence) + isoproturon @ 1.0 kg/ha (45 DAS)(Dipakand Kumar, 2022).

Bharat*et al.* (2022) noticed that the maximum yield attributes *viz.*, siliquae per plant, seeds per siliquae, and 1000-Seed weight were recorded in weed free plots and followed by pre - emergence application of oxyfluorfen @ 0.15 kg/ha (PE) though being at par with pendimethalin @ 1.0 kg/ha.Yernaidu*et al.* (2022) higher number of siliquae/ plant and number of seeds/siliquae were recorded under inter-cultivation and hand weeding at 15 and 30 DAS and it was statistically on par with oxadiargyl 0.09 kg/ha *fb* inter-cultivation at 30 DAS.Singh*et al.* (2023) reported that the number of siliquae per plants, number of seeds per siliquaea and length of silique were recoded higher under pendimethalin (PE) @ 1000 g ha^{-1} + hand weeding at 40 DAS.

YIELD

Bazaya *et al*. (2004) conducted a *rabi* experiment on clay loamy soils and reported that the highest seed yield was obtained under polythene mulch, followed by fluchloralin *fb* manual weedings at 30 and 60 DAS. According to Chauhan *et al*. (2005), using oxyfluorfen 0.25 kg ha^{-1} as a pre-emergence treatment followed by two manual weedings (25 and 40 DAS) in Indian mustard enhanced seed yield more than other weed control treatments. Singh (2006) conducted a *rabi* experiment on sandy loamy soils and found that two hand weedings at 25 and 50 DAS, followed by fluchloralin 0.75 kg ha^{-1} (PPI), resulted in greater seed output. Khan *et al*. (2008) studied an experiment on sandy loamy soils and revealed that, application of trifluralin 1.20 kg ha^{-1}recorded maximum seed yield of mustard and it was on par with fluazifop-p-butyl 0.26 kg ha^{-1}.

Pre-emergence application of pendimethalin 1.0 kg ha^{-1} in combination with quizalofop-p-ethyl 50 kg ha^{-1} PoE recorded significantly higher pod yield as compared to hand weeding in groundnut (Chaitanya, 2010). Significantly higher seed, stover yield and harvest index of mustard were recorded under hand weeding on clay loamy soils(Shaheenuzzamn *et al*., 2010).The application of pendimethalin 0.75 kg ha^{-1} (PE) *fb* isoproturon 0.75 kg ha^{-1} (PoE) on mustard resulted in increased seed, stover yield, and harvest index (Kumar *et al*., 2012). Kour *et al.* (2013) found that applying pendimethalin 1 kg ha^{-1} (PE) to mustard increased seed and stover yields, followed by fluchloralin 1 kg ha^{-1} (PPI).Mukherjee (2014) noticed that during first year, maximum seed yield was registered with pendimethalin 1.25 kg ha^{-1}, and it was significantly superior over fluchloralin 0.75 kg ha^{-1}. In second year, highest seed yield wasrecordedwiththehandweedingtwice,andwasatparwithpendimethalin1.25kg ha^{-1}.

Among the chemical weed control measures, application of pendimethalin 1 kg ha^{-1}(PE) recorded higher seed yield of yellow sarson, which was on par with application of clodinafop0.06kgha^{-1}(Das,2016). Kalita *et al.* (2017) noticed that one hand weeding at 25 DAS recorded maximum seed, stover and biological yields of 2.24, 5.59 and 7.83 t ha^{-1} respectively, and it was found statistically at par with pre-emergence application of oxadiargyl 0.09 kg ha^{-1} (2.23, 5.46 and7.70 t ha^{-1}, respectively).Maximum seed and stover yields of mustard were noticed with application of fluazifop-p-butyl 0.055 kg ha^{-1} at 10 DAS + one hoeing at 40 DAS followed by two hand-weedings at 20 and 40 DAS as reported by Bamboriya*et al.* (2017). Higher harvest index was noticed with application of pendimethalin 1 kg ha^{-1} (PE) followed by weed free check (Bijarnia *et al.*, 2017). Gupta *et al*. (2018) conducted an experiment and concluded that, maximum seed and stover yield of mustard were recorded under one or two hand weedings followed by pre-emergence application of pendimethalin 38.7 SC 0.75 kg ha^{-1}. Kumar *et al.* (2018) conducted an experiment on loamy sand soils during winter and stated that maximum seed and straw yield of mustard were observed with two hand weedings at 25 and 45 DAS followed by pendimethalin at 0.75 kg ha^{-1} (PE).

Jangir *et al*. (2018) opined that the highest grain and stover yield of mustard was noticed with application of pendimethalin 1.0 kg ha^{-1} (PE)+ quizalofop-p-ethyl 0.04 kg ha^{-1} (PoE)+ HW and intercultivation (IC) at 40 DAS. The highest seed and stover yield of mustard were recorded with pendimethalin *fb* HW under conventional tillage (maize)-zero tillage (mustard residues)-zero tillage (green gram) system(Suryavanshi *et al.*, 2018).Oxadiargyl application at 0.1 kg ha^{-1}, followed by hand weeding twice at 20 and 40 DAS, resulted in better seed and straw yield than other mustard treatments (Chatterjee and Singh, 2018). Pandey *et al.* (2019) found that the maximum seed and straw yield of mustard was attained with pendimethalin (PE) 1000 g ha^{-1} + manual weeding at 40 DAS, followed by pendimethalin (PE) 1000 g ha^{-1} + paddy straw mulch 5 t ha^{-1} at 2-3 DAS on silty loamy soils during the *rabi* season. Maximum seed and stover yieldand harvest index of mustard were noticed under two hand weeding at 20 and 40 DAS followed by pendimethalin (PE) 1kg ha^{-1} +hand weeding at 30 DAS (Singh *et al.*, 2020). Raj *et al.* (2021) reported that, maximum seed,stover yield and harvest indexwere observed with application of pendimethalin (PE) 1 kg ha^{-1} +straw mulch 5t ha^{-1} followed by two hand weedings at 20 and 40 DAS in mustard.

Sharma *et al.* (2021) observed that among the treatments, pre-emergence application of pendimethalin 38.7 CS @ 0.75 kg ha-1 + HW 30 DAS recorded higher seed yield, straw yield and biological yield (1220, 5549 and 6769 kg ha^{-1}) next to weed free treatment (1297, 5888 and 7185 kg ha^{-1}). The highest seed yield, straw yield, biological yield and harvest index was obtained in the treatment of pendimethalin 30% EC (PE) @ 1.0 kg a.i ha^{-1} + hand hoeing + hand weeding (30-35 DAS). This was followed by hand hoeing (20-25 DAS) + hand weeding @ (40-45 DAS) (Ananthapadmanabhan*et al*., 2022). Dhruw *et al*. opined (2023) thatthe highest biological, seed, straw yield and harvest index of mustard were recorded under the weed free conditions which was followed by isoproturon @ 1 kg a.i ha^{-1} (PE)+ fenoxaprop-p-ethyl @ 0.75 kg a.i ha^{-1} at 25 to 30 DAS (PoE). Lower of these values were found under weedy check.

QUALITY PARAMETERS

The higher oil content and oil yield in mustard seed was realized with metribuzin 0.175 kg ha^{-1} (PE) over othertreatments (Sewak *et al*., 2007). Degra *et al.* (2011) conducted an experiment and found thatmaximum oil content and oil yield were recorded under two hand weedingsat 25 and 45 DAS followed by fluchloralin 1.0 kgha^{-1} + HW 45 DAS on clay loamy soils. Kumar *et al.* (2012) reported that, maximum oil content and oil yield were registered with applicationof pendimethalin 0.75 kg ha^{-1} (PE) *fb* isoproturon0.75 kg ha $^{-1}$(PoE). Sah *et al*. (2013) recorded the maximum oil content in mustard seed in one hand weeding which was at par withoxyfluorfen0.125kgha^{-1}. Application of pendimethalin 0.5 kg ha^{-1} (PE)+ 1 HW at 25 DAS realized significantly higher oil content (38.68 %) and it was statistically on par with oxadiargyl 75 kg ha^{-1} (PE) + 1 HW at 25 DAS (Patel *et al*., 2013).

Bamboriya *et al.* (2017) conducted an experiment on clay loamy soils during winter and concluded that maximum oil content was observed with application of fluazifop-p-butyl 0.055 kg ha^{-1} at 10 DAS + one hoeing at 40 DAS. Singh *et al.* (2020) conducted an experiment and noticed maximum oil content with two hand weedings at 20 and 40 DAS followed by pendimethalin (PE) 1 kg ha^{-1} + hand weeding at 30 DAS.Kumar *et al*. (2021) reported that the maximum oil content (41.07%) and oil yield (1029 kg ha^{-1}) was recorded in two HWs at 25 and 45 DAS treatment. Being at par with two HW at 25 and 45 DAS and pendimethalin @ 0.75 kg ha^{-1}.Oil content and oil yield was found higher in two hand weeding at 20 and 40 DAS and it was at par with pendimethalin (PE) 1.0 kg/ha + straw mulch 5 t/ ha (Raj *et al.*, 2021).Dipak and Kumar (2022)reported that quality parameters *i.e.*, oil content, and protein content were recorded highest with three hand weeding (30 DAS, 45 DAS and 60 DAS) which was followed by pendimethalin @ 0.5 kg/ha (pre-emergence) + isoproturon @ 1.0 kg/ha (45 DAS).

EFFECT OF INTEGRATED WEED MANAGEMENT PRACTICES ON NUTRIENT REMOVAL BY WEEDS

Dashora *et al.* (1990) identified that uncontrolled weed growth in mustard throughout the crop season caused loss of 14.6 kg N ha^{-1}. The nutrient depletion was higher under unweeded treatment (18.5, 4.7 and82.2 kg ha^{-1} NPK, respectively) and lowest under thiobencarb 1 kg ha^{-1}as pre -emergence application*fb*at 25 DAS in mustard (Singh 1992). Minimum N and S uptake by weeds was noticed with pendimethalin + isoproturon and hand weeding twice reported by Kumar *et al.* (2012). Kour *et al.* (2013) found that, the lowest uptake of N, P and K by weeds was noticed with application pendimethalin 1 kg ha^{-1} (PE) and followed by fluchloralin 1 kg ha^{-1} (PPI) on sandy loamy soils.

Mukherjee (2014) realized lower depletion of N, P and K by weeds with hand weeding twice during twoyearsof his study. However, it was found at par with pendimethalin 0.75 kg ha^{-1} + HW at 35 DAS. Lowest N removal by weeds in mustard was observed with oxadiargyl 90 g ha^{-1} as pre-emergence application (Yadav*etal.,* 2017).The application of pendimethalin 1 kg ha^{-1} as PE + quizalofop - p - ethyl 0.04 kg ha^{-1} as PoE + HW and intercultivation (IC) at 40 DAS resulted in the least amount of N, P, and K removal by weeds, which was comparable to the application of pendimethalin 1.0 kg ha^{-1} as PE + HW and IC at 40 DAS observed by Jangir *et al.* (2018). Similarly, pendimethalin (PE) 1.0 kg ha^{-1} + straw mulch 5 t ha^{-1} and pendimethalin (PE) 1.0kg ha^{-1} + manual weeding at 45 DAS resulted in the lowest nutrient loss by weeds (Raj *et al*., 2021).

EFFECT OF INTEGRATED WEED MANAGEMENT PRACTICES ONNUTRIENT UPTAKE BY CROP

Singh*etal.*(1993)opined that significantlyhigherN,PandKuptakebymustard crop was recorded in hand weeded and herbicides treated plots than unweeded plots.KaneriaandPatel(1995)concluded that the highestN,PandKuptakeinIndianmustard (122.7, 43.0 and 144.9 kg N, P and K ha^{-1}, respectively) was recorded under twohandweedingsat25and45DASincomparisontoweedycheckplots(51.3,15.6and 85.4 kg ha^{-1} respectively).HigheruptakeofN,P and Kbymustardcropwasrecordedwithhandweedingtwice at 25 DAS and 45 DAS which was at par with pendimethalin as pre-emergence application (Dixit and Gautam, 1996). Nepalia and Jain (2000) at Udaipur found that oxadiargyl 0.5 kg ha^{-1} treated plots registered the maximum uptake of N, P, K and S by mustard crop and lowest in weedy check.

Chandoliya *et al.* (2010) conducted an experiment at MPUAT, Udaipur on sandy loamy soiland found thatpendimethalinandoxyfluorfenincombination withonehandweedingwere the most effective in enhancing total N and P uptake except weed freecheck in groundnut. The maximum N uptake was observed with pendimethalin0.75 kg ha^{-1}*fb* isoproturon 0.75kgha^{-}

^{1}beingatparwithoxadiargyl0.90kgha^{-1}*fb*isoproturon0.75 kg ha^{-1}as noticed by Kumar *et al*. (2012). Application of pendimethalin 1 kg ha^{-1} (PE) followed by fluchloralin 1 kg ha^{-1} (PPI) registered higher nutrient uptake (N, P and K) by crop (Kour *et al*., 2013).Uptake of N, P and K nutrients by mustard crop was maximum under two hand weedings at 20 and 40 DAS followed by paddy straw mulch 10 t ha^{-1} at 2-3 DAS (Pandey *et al*.,2019).Raj *et al.* (2021) reported that significantly higher nutrient uptake by crop recorded under two hand weedings at 20 and 40 DAS and it was at par with pendimethalin (PE) 1.0 kg/ha + straw mulch 5 t/ha. Yernaidu*et al.* (2023 c) revealed that among different weed management practices, higher nutrients uptake (59.57, 24.51, 52.46 kg ha^{-1} N, P_2O_5, and, K_2O, respectively) by crop were observed under intercultivation and hand weeding at 15 and 30 DAS and it was on par with oxadiargyl 6% EC 0.09 kg ha^{-1} PE *fb* intercultivation at 30 DAS.

EFFECT OF INTEGRATED WEED MANAGEMENT PRACTICES ON ECONOMICS OF MUSTARD

Singh (2006) recorded maximum net profit and B:C ratio with pre-plant incorporation of flucholaralin 0.75 kg ha^{-1} along with one hand weeding at 25 DAS. The highest B:C ratio in groundnut (3.06) was obtained with application of oxyfluorfen 0.1 kg ha^{-1} as pre-emergence in combination with one HW at 30 DAS, followed by pendimethalin + one HW at 30 DAS (2.98) as compared to hand weeding alone (1.63) (Chandolia *et al*., 2010).Pre-emergence application of pendimethalin 1.0 kg ha^{-1} in combination with quizalofop-p-ethyl 50 g ha^{-1} PoE recorded significantly higher benefit:cost ratio (2.43) as compared to hand weeding (2.21) in groundnut (Chaitanya, 2010). Degra *et al*. (2011) stated that, higher net returns and benefit cost ratio were recorded with application of fluchloralin 1.0 kg ha^{-1} followed by two hand weedings at 25 and 45 DAS.Maximum gross returns and net returns were observed with application of trifluralin 0.75 kg ha^{-1} (PPI) + HW at 30 DAS (Kumar *et al.,* 2012). Application pendimethalin 0.5 kg ha^{-1} (PE)+ HW at 25 DAS and followed by oxadiargyl 75 g ha^{-1}(PE) + 1 HW at 25 DAS resulted in higher net returns (Patel *et al*., 2013).

Yadav *et al*. (2014) conducted a field experiment on groundnut and concluded that higher B:C ratio was obtained with the application of alachlor 1.25 kg ha^{-1} with one HW at 6 WAS that was followed by oxyfluorfen 200 g ha^{-1} with one HW at 6 WAS. The highest net returns (Rs19,950) were obtained with two HW treatment and was followedbypendimethalin0.75kgha^{-1}+HWat35DAS(Mukherjee, 2014).In mustard crop higher net returns and benefit cost ratio were noticed under manual weeding followed by quizalofop-p-ethyl 60 g ha^{-1}as reported by Kumar *et al*. (2015). MaximumnetreturnswereobtainedwithoxadiargylPE(Rs21909ha^{-1})followed by oxyflurofen as PE (Rs 17248 ha^{-1}) (Mankar, 2015). The highest net returns and benefit:cost ratio (2.69) were recorded with fluazifop-p-butyl 0.055 kg ha^{-1} at 10 DAS+ 1 hoeing at 40 DAS being at par with fenoxaprop-p-ethyl 0.075 kg ha^{-1} at 10 DAS + 1 hoeing at 40 DAS (Bamboriya*et al.*, 2017). Kalita *et al*. (2017) realized higher net returns and B:C ratio with pre-emergence application of oxadiargyl 0.09 kg ha^{-1} followed by one hand weeding at 25 DAS.

Suryavanshi *et al.* (2018) found that the highest gross and net returns were registered with pendimethalin 1kg ha^{-1}*fb* HW and isoproturon 0.75 kg ha^{-1}under conventional tillage (maize)-zero tillage (mustard residues).The highest B:C ratio (3.51) was obtained with the application of pendimethalin 1 kg ha^{-1} as PE + quizalofop-p-ethyl 0.04 kg ha^{-1} as PoE + HW and intercultivation (IC) at 40 DAS, which was comparable to the application of pendimethalin 1.0 kg ha^{-1} as PE + HW and IC at 40 DAS, as observed by Jangir *et al.* (2018).The highest net returns and benefit-cost ratio were observed with the application of pendimethalin 0.75 kg ha-1 (PE), which was comparable to two hand weedings at 25 and 45 DAS (Kumar *et al*., 2018). Chatterjee and Singh (2018) noticed maximum net returns and benefit-cost ratio with application of oxadiargyl 0.1 kg ha^{-1} followed by hand weedings twice at 20DAS and 40 DAS. Application of pendimethalin (PE) 1.0kg ha^{-1} + hand weeding at 30 DAS obtained higher gross returns, net returns and benefit-cost ratio (Singh *et al*., 2020).

Hadke*et al.* (2021) reported that pendimethalin 30 EC + propaquizafop 10 EC + WH (40DAS) has a B:C ratio of 2.28, which was higher than all other treatments, followed by oxyfluorfen 23.5 EC (PE) + propaquizafop 10 EC (PoE) + WH (40 DAS).The maximum economical gain of gross returns, net retunes and BCR were obtained under weed free condition which was significantly followed by isoproturon @ 1 kg a.i ha^{-1} (PE)+ fenoxaprop-p-ethyl @ 0.75 kg a.i ha^{-1} at 25 to 30 DAS (PoE). Lower of these values were found under weedy check (Dhruw *et al*., 2023). Maximum net returns and B:C ratio were recorded under pendimethalin (PE) @ 1000 g ha^{-1} + hand weeding at 40 DAS (Singh*et al.*, 2023).

EFFECT OF INTEGRATED WEED MANAGEMENT ONSOIL ENZYMES ACTIVITY

An experiment was conducted in rice crop and urease activity and dehydrogenase activity in butachlor treated soil showed an increasing trend from 7th day to 28th day of incubation. Similar trend was exhibited in paraquat and glyphosate treated soil. It was evident from the data that the soil treated with pyrazosulfuron had the lowest set of dehydrogenase activities as compared to other herbicides treated soil reported by (Baboo *et al.*, 2013). Panda and Raha (2016) conducted a laboratory study and observed that glyphosate at field application dose (0.90 µg g^{-1}) and double the field application dose (1.80 µg g^{-1}) inhibited the Fe and Mn reduction from 5.18 to 14.35% and stimulated the soil dehydrogenase activity from 11.64 to 43.12%. However, both inhibition and stimulation effect on Fe and Mn reduction and soil dehydrogenase activity was resulted from the application of herbicides paraquat and pendimethalin at their field (0.45µ g g^{-1}) and double the field application dose (1.41 μg g^{-1}).Lal *etal.*(2017) observed that weed free check recorded significantly higher dehydrogenase, urease and phosphatase activity at 7 and 15 days after spraying compared to all other treatments and lower dehydrogenase, urease and phosphatase activity under imazethapyr (75 g ha^{-1} with adjuvant) application at 7 and 15 days after spraying in green gram.Significant increase in dehydrogenase activity of all the treatments at 50 days after herbicide spray *i.e.*, peak period of crop growth was observed indicating that microbial activity was increased in maize(Varshitha *et al*., 2019).

EFFECT OF WEED MANAGEMENT ON ENERGETICS

Firouzi and Aminpanah (2012) observed that the total energy input and total energy output recorded was found to be 20,164.36 MJ ha^{-1} and 79,252.02 MJ ha^{-1} respectively for groundnut production. Energy usage ratio of 3.93 indicates the affective use of energy in groundnut production. Energy productivity was computed to be 0.212. This shows that 0.212 kg of groundnut obtained per unit energy input (MJ).Energy use efficiency, energy productivity, specific energy and net energyof dry land barley production were 5.3, 0.28 kg MJ^{-1}, 3.58 MJ kg^{-1}, 33,833.67 MJ ha^{-1}, respectively. Results of this study showed that human labour as well as machinery energy inputs were the most important inputs influencing the dry land and irrigated barley production systems (Azizi and Heidari, 2013).

In their four-year study, Alper *et al.* (2015) revealed that tillage methods had a substantial impact on energy indices, with no till requiring the least energy for wheat production (8.20 MJ/kg) and CT consuming the highest (11.74 MJ/kg). NT (normal tillage) has been shown to be the most efficient all tillage system during his study. However, conservation tillage of winter wheat can be used to increase productivity with only a minimum energy input. In a study conducted at PJTSAU, Rajendranagar, the results depicted that the total energy input and output energy under different weed management practices were about 16051 to 18550 and 2360 to 16838 MJ ha^{-1}respectively. The highest energy use efficiency (0.9), energy intensiveness (0.7 MJ ₹ $^{-1}$), specific energy (12.9MJ kg^{-1}), energy productivity (0.9 kg MJ^{-1}), net energy (-1712 MJ ha^{-1}) of *Bt* cotton production system were reported in mechanical weeding thrice at 20, 40 and 60 DAS (Rani *et al.*, 2016).

Hanumanth (2017) showed that kapas energy output, total energy output, kapas energy use efficiency, total energy use efficiency, kapas energy productivity, and total energy productivity were considerably greater after three mechanical weedings at 20, 40, and 60 DAS. Zero tillage + crop residues 4 t ha^{-1} (ZT+CR) yielded much more energy and had a greater energy-use efficiency than ZT+CR 2 t ha^{-1} + hydrogel. Devi *et al.* (2018) conducted an experiment in wheat crops during the rabi season and concluded that tank mix application of pinoxaden (50 g ha^{-1}) followed by carfentrazone + metsulfuron-methyl (25 g ha^{-1}) 35 days after sowing optimized energy use efficiency, profitability, productivity, and intensity.

Significantly maximum energy output:input ratio, energy use efficiency and energy productivity were recorded under oxadiargyl 90 g ha^{-1} (PE) *fb* penoxsulam 22.5 g ha^{-1} (PoE) followed by pyrazosulfuron + pretilachlor 10 kg (G) ha^{-1} (PE) *fb* bispyribac sodium 25 g ha^{-1}(PoE) in rice crop. The lowest output energy was recorded under unweeded control reported by Bajaj *et al*. (2019).In black soil, significantly higher energy use efficiency and energy productivity of kapas and total output was recorded with diuron 0.75 kg ha^{-1} PE *fb* pyrithiobac sodium + quizalofop-p-ethyl PoE and mechanical weeding thrice in cotton(Varsha *et al*.,2020). Maximum energy output to input ratio, energy use efficiency and energy productivity were noticed in rice under oxadiargyl 70 g ha^{-1} (PE) *fb* bispyribac sodium 20 g ha^{-1} at 25 DAS (Jha *et al*., 2020).

Kumar *et al*. (2021) opined that higher output energy (151500 MJ ha^{-1}), output input energy ratio (13.65), energy use efficiency (0.225) and energy balance (140430 MJ ha^{-1}) were obtained with two hand weeding at 25 and 45 DAS.Yernaidu*et al.* (2023 a) noticed that maximum energy output, net energy, energy use efficiency and energy productivity were noticed under intercultivation and hand weeding at 15 and 30 DAS and it was statistically on par with Raft 6 % EC as PE *fb* intercultivation at 30 DAS, Goal 23.5 % EC as PE *fb* intercultivation at 30 DAS and Stomp 30 % EC as PE *fb* intercultivation at 30 DAS.

CONCLUSION

Weed interference in mustard causes significant yield loss. Weed duration in the field affects yield, as do damage thresholds, which differ according on the weed. To avoid economic losses, weed control should be implemented early in the growth cycle, especially during the first four to six weeks of competition in mustard. Weed management is a system approach in which all land use planning is done advance of time to limit aggressive weed invasions and offer crop plants a competitive advantage over weeds. Weeds in mustard can be effectively controlled with pre-plant herbicides such as fluchloralin and trifluralin. Among pre-emergence herbicides, alachlor, butachlor, isoproturon, metolachlor, metribuzin, nitrofen, oxadiargyl, oxadiazon, oxyfluorfen, pendimethalin, terbutryn, and thiobencarb show potential. However, in the modern era, integrated weed management approaches are becoming increasingly significant due to their environmental benefits. An adequate level of weed control in mustard crops can be achieved using integrated management strategies that incorporate preventive, cultural, and herbicidal measures. The most efficient and practical way to manage weeds in mustard is to combine chemical weed control with mechanical weeding.

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