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Integrated Weed Management in Turmeric- A Review

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Abstract Weeds constitute a major component among the bottlenecks for successful crop production. Weeds are generally hardy species having vigorous, deep root system and compete very efficiently with cultivated crops for the nutrients available in the soil and for the much needed moisture and sunlight. Weeding is one of the important farm operations for agricultural crops. Different types of weeders are used in different parts of a country. Since, a major portion of labor input is spent on weeding operations; it was felt that the technology of weeding should be improved for the benefit of the farmers. For proper implementation of this, a few selected existing methods are needed to be evaluated to formulate an efficient and economically viable integrated weed management practice. In this connection, the literature on various aspects related to the proposed study was collected and summarized in this chapter.
Keywords Integrated Weed Management; Turmeric; *kharif* season

Weed Spectrum in Turmeric

The degree of damage caused by weeds is related to the type, species and density of weeds growing in a crop community. Weed species are known to vary with season and type of cultivation. Persistence of weeds in a location is largely influenced by climatic, edaphic (soil) and biotic factors which affect their occurrence, abundance, range and distribution.

Singh and Mahey (1991) reported that the major weed flora composition in the turmeric field included *Trianthema monogyna*, *Euphorbia hirta*, *Amaranthus viridis*, *Eleusina indica*, *Acrachene racemose*, *Cyperus rotundus* and *Digitaria sanguinalis.*

Avilkumar and Reddy (2000) observed the weed species like *Amaranthus viridis*, *Commelina benghalensis*, *Cyperus rotundus*, *Cynodon dactylon*, *Celosia argentia*, *Digitaria marginata*, *Digitaria muricata*, *Euphorbia hirta*, *Eleusine indica* and *Panicum repens* in turmeric and maize intercropping system. According to Gill *et al*. (2000), *Digitaria ischamum*, *Cynodon dactylon*, *Cyperus rotundus*, *Eluesine aegypticum*, *Euphorbia hirta*, *Commelina benghalensis* and *Eragrostis pilosa* were the predominant weeds in turmeric.

In Dharwad, major weed species present in the turmeric field were *Cynodon dactylon*, *Digitaria marginata*, *Panicum repens*, *Parthenium hysterophorus*, *Amaranthus viridis*, *Mimosa pudica*, *Euphorbia hirta*, *Tridax procumbens*, *Cynodon dactylon* and *Cyperus rotundus* (Mannikeri, 2006).

Kaur *et al*. (2008) observed that predominant weed species like *Cyperus rotundus*, *Arachne racemosa*, *Digitaria sanguinalis*, *Eleusine aegyptiacum*, *Echinochloa crusgalli*, *Eragrastis pilosa*, *Commelina bengalensis*, *Eleusine indica*, *Euphorbia hirta*, *Phyllanthus niruri*, *Trianthema portulacastrum* and *Amaranthus viridis* in turmeric field.

According to Tahira *et al*. (2010), *Sonchus aspera*, *Chenopodium album*, *Rumex dentatus*, *Ageratum conyzoides*, *Convolvulus arvensis*, *Cynodon dactylon*, *Oxalis corniculata*, *Malva parviflora*, *Malvastrum coromandelianum*, *Trifolium resupinatum*, *Euphorbia prostarta* and *Phalaris minor* were found to be the most prevalent weed species in turmeric at Kasur district of Pakistan. *Cyperus rotundus*, *Cynodon dactylon*, *Eleusine aegyptiacum* and *Euphorbia hirta* were the dominant weed species in turmeric at Punjab (Manhas *et al*., 2011).

Ratnam *et al.* (2012) observed that grasses like *Echinochloa colona* (L.), *Dinebra retroflexa* (L.), *Cynodon dactylon* (L.), and *Panicum repens* (L.), sedges like *Cyperus rotundus* (L.), and broad leaved weeds like *Phyllanthus niruri* (L.), *Celosia argentea* (L.), *Chrozophora rotteleri* (L.), *Cleome viscose* (L.), *Parthenium hysterophorus* (4%), *Abutilon indicum* (L.), *Digera arvensis* (L.), *Trianthema portulacastrum* (L.), *Euphorbia hirta* (L.), *Corchorus acutangulus* (L.), *Portulaca oleracea* (L.), *Acalypha indica* (L.), *Eclipta alba* (L.) and *Commelina bengalensis* (L.) dominated in turmeric at Guntur, Andhra Pradesh.

According to Suresh Kumar *et al.* (2014), *Echinochloa colona*, *Digitaria sanguinalis*, *Panicum dichotomiflorum*, *Commelina bengalensis*, *Cyperus iria*, *Ageratum conyzoides*, *Polygonum sp*., *Physallis minima*, *Eragrotis spp* and *Aeschynomene indica* were the predominant weeds in turmeric field of Himachal Pradesh.

Crop-Weed Competition

The degree of crop-weed competition is determined by the weed species and their density, duration of infestation, associated crops in the field, growth habit of crop plants and environmental conditions. Weeds that grow with crop depleted considerable amount of costly fertilizer, limited moisture, light and space, thereby leading to poor growth and development of crops resulting in lower yields.

Critical period of crop-weed competition

Establishing the critical period of competition is the most essential to develop effective and economical weed control measures.

The critical period of weed competition is an important consideration in the development of alternative weed management strategies (Swanton and Weise, 1991). The critical period indicates the appropriate timing for weed management and it assists in understanding the impact of weed density on the crop (Hall *et al*., 1992).

Knezevic *et al*. (2002) described the critical period of weed competition as a window in the crop growth cycle in which weeds must be controlled to prevent unacceptable yield losses. Weed competition throughout the crop period, on an average caused 82.2 per cent reduction in bulb yield. According to Hossian *et al*. (2008), for higher yield of turmeric the weeds need to be removed during 70 to 160 days after planting, indicating that it needs a longer period of weed free condition than other crops.

Effect of competition on growth and yield components

Reduction in crop yield has a direct correlation with competition in drought situation and weeds thrive better than crop plants, when left uncontrolled. Weeds can grow taller than crop plants and suppress the growth.

Many workers have emphasized that the effect of weeds on growth and yield components ultimately decide the yield. The reduction may occur as a result of competition between the crop and weed for nutrients, space, light and water (Klingman, 1961).

Growth components: The plant growth parameters in onion such as height, leaves plant^{-1}, fresh and dry weight of plants were measured significantly higher under weed free situation. Manjunath *et al*. (1989) found that weeds affected plant height, leaf area index (LAI), leaf area duration (LAD), net assimilation rate (NAR) and crop growth rate (CGR) of onion. According to Singh and Singh (1994), plant height and number of leaves increased significantly with treatments which were kept weed free till harvest due to least crop weed competition for nutrients, moisture, space and sunlight between crop and weeds in onion. Similarly, Verma and Singh (1997) observed that plant height, leaves plant^{-1}, fresh and dry weight of plant were significantly higher under weed free condition in onion. In onion, Dandge and Satao (1999) found that weed free treatment recorded maximum plant height and number of leaves plant^{-1}. Vora and Mehta (1999) indicated that maximum number of leaves plant^{-1} and neck thickness was recorded under weed free check in garlic. In turmeric, the maximum number of plant height, number of leaves plant^{-1}, number of tillers plant^{-1}, dry matter production, leaf area and LAI were observed in weed free check plots due to reduction in weed population as noticed by Mannikeri (2006) and Babu (2008). According to Kaur *et al*. (2008), unweeded control recorded lesser leaf area index than all other herbicide treatments in turmeric. Pre-emergence application of pendimethalin 1.0 kg ha^{-1} recorded higher LAI, LAD, CGR and NAR in turmeric (Channappagoudar *et al*., 2013).

Yield and yield components

Yield attributes like bulb diameter, number of cloves plant^{-1}, 100 cloves weight, bulb yield plant^{-1} and total bulb yield of garlic were most favourable under weed free check (Vora and Mehta, 1999). According to Ramachandra Prasad (2000), uncontrolled weeds reduced the bulb yield by 75 per cent due to severe weed competition, particularly due to the presence of grasses and broad leaved weeds as weed competition could lower the bulb diameter and bulb weight considerably in onion. Kaur *et al*. (2008) found that uncontrolled weed growth resulted in 63.9 per cent reduction in average rhizome yield of turmeric. Kavaliauskaite (2009) noticed that weed competition throughout the crop period caused 82.2 per cent reduction in bulb yield of onion.

Unweeded check reduced the rhizome yield by 80 per cent due to severe weed competition, particularly due to the presence of grasses and broad leaved weeds as weed competition could lower the number of rhizome plant^{-1} and rhizome weight considerably in turmeric (Ratnam *et al*., 2012).

Nutrient depletion by weeds

The minimum N, P and K removal (7.45, 0.62, 8.00 kg ha^{-1}, respectively) by weeds was observed when oxyfluorfen at 0.25 kg ha^{-1} was supplemented with hand weeding at 40 DAT followed with the application of oxyfluorfen at 0.37 kg ha^{-1} in onion (Nandal and Ravinder Singh, 2002). Unweeded check registered higher nutrient removal of weeds when compared to herbicide applied plots as reported by Kumar *et al*. (2004) in groundnut. Kaur *et al*. (2008) suggested that unweeded control removed 103.5, 19.7 and 170.4 kg N, P K ha^{-1} in turmeric. Tuti and Das (2011) observed that weedy check resulted in higher removal of N, P and K by weeds. The lowest N, P and K removal by weeds was observed with pre-emergence application of metribuzin at 0.5 kg ha^{-1} in soybean.

Weed Management Methods

Weed control aims at limiting the growing of unwanted plants both in space and time, without any attempt to eliminate the same from the field environment. Minimizing the weed infestation for attaining the remunerative crop yield forms the primary component of weed management.

Cultural Method

Weed control is one of the most important objectives of cultural operations. Following proper cultural operations is more than half the weed control method envisaged on a farm, which directly includes a healthy growth of crops and indirectly it maintains a crop environment that is detrimental to weeds.

Vedprakash *et al*. (2000) observed that bulb yield of onion showed better performance under herbicides combined with hand weeding treatment over herbicides alone owing to effective control of weed through herbicides during initial stage and later on by hand weeding. Higher weed control was obtained with manual weeding throughout the crop season in onion (Marwat *et al*., 2005, Ghadage *et al*., 2006 and Zubiar *et al*., 2009).

Babu (2008) reported that weed free check treatments registered higher cured rhizome yield (7.08 t ha^{-1}) than all other treatments and was followed by pendimethalin at 1.5 kg ha^{-1} (6.03 t ha^{-1}) and 1.0 kg ha^{-1} (5.74 t ha^{-1}) in turmeric. Maximum bulb size and yield of onion were recorded in hand weeded plots followed by pendimethalin as compared to weedy check as noticed by Hussain *et al*. (2008). Rahman *et al*. (2011) reported that hand weeding throughout the growing season controlled all weeds and resulted in higher bulb yield in onion.

Mechanical Method

Mechanical weeding is one of the oldest, but the most common methods of weed control in upland crops. Hand weeding with simple weeders is common. These simple weeders are cheap, more efficient and suitable for farmers to reduce the cost of crop production and improve crop yield to a great extent. It is not only safe to the environment, but also safe to the user.

Mechanical weed control is comparatively faster and less labour intensive than hand weeding (Chivinge, 1990). Use of selective herbicides together with mechanical methods of weed control was recommended by Rapparini (1994). Duraisamy and Tajuddin (1999) reported that mechanical weeding is preferred to chemical weeding because weedicide application is generally expensive, hazardous and selective, besides mechanical weeding keeps the soil surface in better aeration and facilitates in moisture conservation. Power weeder was found useful for weeding in between standing rows of cash crops like cotton, tapioca and grape. The weeder could cover an area of one ha day^{-1} in 8 hr. The cost of weeding by this machine comes to only one-third of the weeding cost by manual labourers (Tajuddin, 2006). Yadav and Pond (2007) reported that mechanical weed control not only uproot the weeds between the crop rows but also keep the soil surface loose, ensuring better soil aeration and water intake capacity. Weed morphology and stage of growth would influence the selection and efficacy of weeding implement.

Gore *et al*. (2010) reported that cycle hoe weeder produced significantly higher grain yield and found to be effective in controlling grass as well as broad leaved weeds at 30 (69 and 44 per cent) and 60 DAS (63 and 67 per cent) in soybean. Effective and economical weed management in rainfed pigeonpea was obtained either by pre-emergence application of pendimethalin at 0.75 kg ha^{-1} on 3 DAS followed by one weeding with oleo weeder on 45 DAS or pre-emergence application of pendimethalin at 0.75 kg ha^{-1} on 3 DAS followed by one weeding with wheel hoe weeder on 45 DAS (Gowsalya *et al.*, 2010).

Jakhar *et al*. (2012) pointed that two rotary weeding at 20 and 40 DAS reduced the growth of weeds resulted in higher weed control efficiency in soybean over all other weed control treatments.

Chemical Method

Inadequate weed management practice is one of the major causes for low yield of crops. The conventional method of weed control through hand weeding is costly and non-available at critical stages. Herbicidal weed management becomes competitive and a promising way to control weeds at least at first few weeks after sowing of the crop. Studies by Yaduraju *et al*. (2006) reported that in India, herbicides are being used in approximately 20 million hectares, which constitute about 10 per cent of the total cropped area.

Pre-emergence herbicides

Pre-emergence herbicide application can help to control the weeds in the early crop growth stage. Baker and Terry (1991) reported that pre-emergence herbicide use would be appropriate not only for minimizing weed competition, but also for reducing the work load during the peak labour demand period, avoiding at least one or two intercultivation during the first 3 to 4 weeks of crop growth and to control weeds effectively. Guggari *et al*. (1995) observed that 30 to 55 per cent of the weeds can be controlled by pre-emergence application of herbicides. Crop-weed competition is minimized by pre-emergence spray of herbicides resulting in higher crop yield (Berevadia *et al*., 1996).

Metribuzin

Higher weed control efficiency (93%) was recorded with pre-emergence application of metribuzin followed by methabenziozuron (91%) and lower in oxyfluorfen with the efficiency of 80 per cent in potato (Rao and Singh, 1988). Pre-emergence application of metribuzin at 0.75 kg ha^{-1} was found most effective closely followed by oxyfluorfen (0.3 kg ha^{-1}) against both broad leaved and grassy weeds. The higher weed control efficiency (88%) and benefit cost ratio were recorded in PE metribuzin treated plot in potato (Jaiswal and Grewal, 1991). According to Maliwal and Jain (1991), Singh (1992) and Suryanarayana Reddy (1993), pre-emergence application of metribuzin recorded the lower weed dry matter in potato.

Jaiswal (1994) noticed that, weed control efficiency of different herbicide treatments ranged from 40 to 91 per cent and highest WCE (91%) was recorded in pre-emergence application metribuzin in potato. Chirita (1995) reported that 87% weed control and 14% yield increase with metribuzin + dimethanamide compared to weedy check, whereas Guttieri and Eberlein (1997) reported that yield increased with application of rimsulfuron + metribuzin (sencor) in potato.

Gill *et al.* (2000) observed that pre-emergence application of metribuzin 0.7 kg ha^{-1} recorded higher rhizome yield in turmeric. Vasuki (2005) reported that metribuzin at 1.0 kg ha^{-1} as pre emergence herbicide had lower weed density and higher weed control efficiency in sugarcane. Channappagoudar *et al.* (2007) reported that the tuber yield of potato was on par with pre emergence application of metribuzin 0.75 kg ha^{-1} and weed free check. Mishra and Singh (2009) revealed that pre - emergence application of metribuzin 0.5 kg ha^{-1} + one hand weeding at 30 DAS significantly reduced the population of all the weed species resulted in increased seed yield of soybean. Combined application of PE metribuzin at 1.5 kg ha^{-1} supplemented with post emergence application of 2, 4 D Na salt at 1.0 kg ha^{-1} was good for controlling all weeds in sugarcane (El-Shafai *et al.*, 2010). Studies by Tuti and Das (2011) revealed that application of metribuzin at 0.5 kg ha^{-1} effectively controlled weeds including *Cyperus rotundus* (L.) and increased weed control efficiency resulting in reduction of N, P and K uptake by weeds which in turn increased seed yield of soybean.

Pendimethalin

Shekhawat and Maliwal (199l) reported that pendimethalin @ 0.75 kg ha^{-1} as pre-emergence application resulted in greater reduction in dry weight of weeds and increase in tuber yield than fluchloralin (0.5 to 1.0 kg ha^{-1}) in potato.

Avilkumar and Reddy (2000) found that application of pendimethalin at 1.0 kg ha^{-1} resulted in significantly lower weed dry matter (127.8 g/m^2) as compared to atrazine at 1.0 kg ha^{-1}, fluchloralin @ 1.0 kg ha^{-1} and glyphosate at 0.5 kg $ha^{-1}$and rhizome yield and equivalent yield was significantly higher over unweeded control in maize + turmeric intercropping system. Ramachandra Prasad (2000) reported that pendimethalin and oxyfluorfen were most effective in lowering dry weight of grassy weeds as compared to alachlor and metalachlor in onion. Ajai *et al.* (2002) reported that pendimethalin 1.0 kg ha^{-1} + hand weeding (HW) at 80 DAP and oxyflurofen 0.4 kg ha^{-1} + HW at 80 DAP recorded 45 and 39 per cent more fresh rhizome yield, respectively than weedy plots in turmeric.

Yadav and Yadav (2003) reported that application of pendimethalin @ 1.0 kg ha^{-1} resulted in lower weed density (5 m^{-2}) and weed dry weight (19 g m^{-2}) with higher weed control efficiency (96.9%) and higher bulb yield (11 t ha^{-1}) in garlic. Babu (2008) reported that pre-emergence application of pendimethalin at 1.5 kg ha^{-1} recorded higher rhizome yield next to weed free in turmeric.

In onion, pendimethalin at 1.0 kg ha^{-1} + hand weeding and oxyfluorfen at 0.24 kg ha^{-1} recorded higher weed control efficiency of 80.6 and 73.4 per cent respectively (Patel *et al.*, 2011). Accoding to Channappagoudar *et al.* (2013), pre-emergence application of pendimethalin 1.0 kg ha^{-1} recorded the lowest weed dry matter followed by pendimethalin 1.5 kg ha^{-1}, while oxyfluorfen 0.30 kg ha^{-1} was least effective in turmeric.

Atrazine

Singh and Mahey (1991) studied the effect of different weed control treatments in turmeric. They found that application of atrazine resulted in marked reduction in dry matter accumulation of weeds after 30 days of sowing followed by metribuzin and straw mulching, The application of straw mulching recorded higher yield of fresh rhizomes (65 q ha^{-1}). Atrazine {2-chloro-4-(ethylamino)-6 isopropylamino-1, 3-5-triazine} is a widely used 5-triazine herbicide. It is used as pre-emergence herbicide in the control of broadleaf and grass weeds in a variety of commercial crops as well as roadside and fallow fields (Munier lamy *et al.*, 2002). Singh *et al.* (2003) pointed that atrazine at 0.50 kg ha^{-1} registered 79 per cent weed control efficiency followed by two hand weeding with 87 per cent WCE and one weeding followed by earthing up treatment with maximum (93%) WCE at 45 DAS indicating suppression of first flush of weeds successfully in maize.

Kolage *et al*. (2004) reported that among the herbicides, pre-emergence spraying of atrazine at 1.0 kg ha^{-1} reduced the weed intensity substantially and recorded lower weed index and maximum weed control efficiency as compared to other herbicides used in maize. Rao *et al*. (2009) investigated that pre-emergence application of atrazine 1.5 kg ha^{-1} followed by hand weeding at 30 DAS recorded lower weed dry weight at 60 DAS and harvest in maize.

Oxyfluorfen

Singh (1988) reported that oxyfluorfen at 0.20 kg per ha as pre-emergence reduced the weed population by 85 per cent over weedy check and increase in herbicide dose caused burning effect on emerging sprouts in potato. Singh *et al*. (1990) concluded that per-emergence application of oxyfluorfen at 0.25 kg ha^{-1} gave maximum yield and higher weed control efficiency in onion. Singh *et al*. (1992) reported the maximum bulb yield and higher weed control efficiency with oxyfluorfen @ 0.25 kg ha^{-1} when applied 3 days before transplanting in onion. Porwal (1995) suggested that pre-emergence application of oxyflourfen (1.0 kg ha^{-1}), oxadiazon (1.0 kg ha^{-1}) and pendimethalin (1.25 kg ha^{-1}) supplemented with one hand weeding at 40 days after sowing showed 90 per cent weed control efficiency and reduced dry weed biomass to as low as 49.0-50.4 q ha^{-1} in garlic.

Yadav *et al*. (2000) reported that pre emergence application of oxyfluorfen at 0.15 kg ha^{-1} recorded higher net income over other treatments in soybean. Kolhe (2001) indicated that dry matter of weeds was significantly reduced due to application of pendimethalin, metalachlor, oxyfluorfen either alone or in combination with hand weeding at 35 DAP compared to weedy check in onion.

According to Ranpise and Patil (2001), pre-emergence application of oxyfluorfen at 0.40 kg ha^{-1} produced maximum yield (242 q ha^{-1}) followed by oxyfluorfen at 0.20 kg ha^{-1} (233 q ha^{-1}) as compared to all other treatments in onion. The lower yield was under control plot (50 q ha^{-1}) due to maximum weed intensity.

Pre-emergence application of oxyfluorfen at 0.125 kg ha^{-1} and pendimethalin at 0.5 kg ha^{-1} can be applied for better weed control and higher seedling production in onion as reported by (Sharma *et al*., 2009). Ratnam *et al*. (2012) recorded that pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} followed by post-emergence application of quizalofop ethyl @ 0.05 kg ha^{-1} followed by weeding at 60 and 90 DAP recorded higher fresh rhizome yield in turmeric. According to Sathya Priya *et al*. (2013), pre-emergence application of oxyfluorfen (23.5per cent EC) at 200 g ha^{-1} recorded lesser weed density and dry weight in onion.

Oxadiargyl

Mirza Hasanuzzaman *et al*. (2009) reported that pre-emergence application of oxadiargyl at 190 ml ha^{-1} + 1 hand weeding at 25 DAT recorded lesser weed density, dry weight and higher weed control efficiency and grain yield in rice. Pre-emergence application of oxadiargyl at 75 g ha^{-1} fb bispyribac-sodium 30 g ha^{-1} at 20 DAT was at par with HW twice at 20 and 40 DAT in achieving higher grain yield in transplanted rice (Deepthi Kiran and Subramanyam, 2010).

According to Naseeruddin *et al*. (2014), pre-emergence application of oxadiargyl 75 g ha^{-1} followed by post-emergence application of azimsulfuron 30 g ha^{-1} resulted in broad spectrum weed control coupled with the highest grain yield drum seeded rice (5.75 t ha^{-1}).

Post - Emergence Herbicides

Pre-emergence or pre plant incorporated herbicides have a narrow spectrum of weed control. Further if farmers skip the application of these herbicides due to one (or) the other reason, there is a need of alternative post-emergence herbicides for managing weeds. Post emergence herbicides have broad spectrum of activity.

Metsulfuron methyl

Karmakar *et al*. (1994) reported that toxic effects of this herbicide on dicots *viz*., *Digera arvensis*, *Euphorbia* *hirta*, *Cleome viscosa*, *Phyllanthus niruri* and monocots *viz*., *Cyperus rotundus* and *Cynodon dactylon*.

Metsulfuron methyl at 3.5 to 4.5 g ha^{-1} gave good control of *Parthenium hysterophorus* which results in drying up of the weeds started from growing tips after a week of spray and dried completely within 20days (Mishra and Bhan, 1994). Studies conducted at Hisar revealed that metsulfuron at the rate of 2 to 8 g ha^{-1} provided 47 to 57 percent control of barnyard grass (Samar Singh *et al*., 1995). Accoding to Bodake *et al*. (2014), post-emergence application of metsulfuron- methyl at 0.004 kg ha^{-1} at 3WAS + 1 HW at 5WAS recorded higher green forage and dry matter yield in oat.

Fenoxaprop

Sarkar (2006) reported that post-emergence application of fenoxaprop-p-ethyl at 75 g ha^{-1} or quizalofop ethyl at 50 g ha^{-1} at 20 DAS effectively controlled the grassy weeds in Jute besides giving higher fibre yield. According to Walia *et al*. (2011), post emergence application of AEF 046360-8% + DIC 1468-14%-22% EC (fenoxaprop-P-ethyl+metribuzin) at 275 and 330 g ha^{-1} as well as Atlantis 3.6 WDG AT 14.4 g ha^{-1} increased wheat grain yield by 58.8, 64.2 and 67.3%, respectively as compared to unweeded (control) treatment.

In aerobic rice, post-emergence mixture of fenoxaprop + ethoxysulfuron at 30 DAS recorded higher grain yield in aerobic rice (Ramachandiran and Balasubramanian, 2012).

Post emergence combined application of fenoxaprop-p-ethyl at 60 g ha^{-1} + ethoxysulfuron 15 g ha^{-1} at 20 and 35 DAT and hand weeding twice recorded lesser weed density, dry weight and higher grain yield in system of rice intensification method of rice (Dewangan *et al*., 2014). According to Singh *et al*. (2014), lesser weed density and dry weight was recorded in fenoxaprop + ethoxysulfuron *fb* bispyribac at 60 + 15 and 25 g ha^{-1} in rice.

Glyphosate

Glyphosate at 2.00 kg ha^{-1} followed by hand weeding recorded lower weed density and dry weight in cotton (Nadanassababady and Kandasamy, 2002). Increased dosage and extended time of application are beneficial since glyphosate provides broad-spectrum control of many annual and perennial grasses, sedges, and broadleaf weeds in glyphosate- resistant cotton (Burke *et al*., 2005). Glyphosate mixed with *S*-metolachlor increased the control of late season annual grasses to 14-43 percentage points compared with the control by glyphosate alone in one North Carolina study in cotton (Clewis *et al*., 2006). According to Nithya Chinnusamy *et al*. (2013), post emergence spraying of potassium salt of glyphosate at 2700 g a.i.ha^{-1} twice on 25 and 65 DAS can be done for complete control of broad spectrum weeds with higher seed cotton yield in herbicide tolerant transgenic cotton during winter season.

Integrated Weed Management

There is no single method by which all the weeds can be controlled effectively. A judicious combination of chemicals and cultural cultivation practices for weed control reduces the expenditure as well as give benefit to the crop plants by providing proper aeration and conservation of moisture (Yadav *et al*., 2009). Integrated weed control is a weed density management system that uses all suitable techniques in a compatible manner to reduce weed density and maintain them at levels below those cause economic injury to crop cultivation.

Pre-emergence application of pendimethalin + straw mulch 9 t ha^{-1} recorded the higher weed control efficiency (84.2%), fresh rhizome yield (29.6 t ha^{-1}) and herbicide efficiency index (11.2) and was on par with metribuzin and atrazine both integrated with straw mulch 9 t ha^{-1} in turmeric (Kaur *et al*., 2008). According to Ratnam *et al*. (2012), pre-emergence application of oxyfluorfen 0.25 kg ha^{-1} followed by quizalofop ethyl 0.05 kg ha^{-1} at 30 DAS supplemented with hand weeding at 60 and 90 DAS recorded higher fresh rhizome yield in turmeric. Ashok Jadhav and Sanjay Pawar (2014) and Suresh Kumar *et al.* (2014) reported that pre-emergence application of metribuzin 0.7 ka ha^{-1} *fb* straw mulch 10 t ha^{-1} *fb* one HW recorded lower weed density and dry weight and higher WCE and rhizome yield in turmeric.

Herbicidal Effect on Soil Microflora

When herbicides are applied, most of the spray solution contacts the soil and may affect soil microorganisms that are important for sustainable agriculture, recycling of plant nutrients and maintenance of soil structure (Rosana *et al.,* 2007). Initial setback of microorganisms and regrowth thereafter with herbicide application was reported by Kumar *et al*. (1987). According to Subbaiah *et al*. (1994), herbicides like trifluralin, pendimethalin, fluchloralin and alachlor at higher concentrations drastically reduced the soil microbial population on 20 DAS as compared to lower concentrations and reached the original status on 40 days after the application of herbicides. Microbial populations equaled or exceeded with controls at 50 and 60 days of herbicide application. Voos and Groffman (1997) reported that a relationship exists between size of the soil microbial biomass and herbicide degradation capacity in an ecosystem. Ahmed and Vyas (1997) reported that pre-emergence application of oxyfluorfen at 0.25 kg ha^{-1} or 0.5 kg ha^{-1} did not affect fungal population with respect to control in medium black soil. In contrast to generalizations that glyphosate is tightly bound and inactivated in soil, numerous studies show that glyphosate is available to soil and rhizosphere microbial communities as a substrate for direct metabolism leading to increased microbial biomass and activity (Haney *et al.,* 2000). Post-emergence application of oxyfluorfen at 0.12 kg ha^{-1} in rice increased the number of phosphate solubilizing microorganisms in the rhizosphere soil (75.8 CFU X 10^{4} per gram of soil) with respect to control (61.2 CFU X 10^{4} per gram of soil) as observed by Das *et al.* (2003). Lupwayi *et al*. (2004) found that shifts in microbial community structure in response to herbicides even when microbial population was unaffected relative to the control. Singh and Singh (2009) recorded initial reduction in microbial counts due to inhibitory effect of pre-emergence application of oxyfluorfen and pendimethalin. At later stage of 20 and 40 days after spray, these herbicides in irrigated summer groundnut lost their potency, probably due to their degradation in soil. Nalini (2010) noted that pre-emergence application of pendimethalin (38.7% EC) at 4.0 kg ha^{-1} three DAS followed by HW and earthing up on 45 DAS exerted a significant detrimental effect on soil bacteria, fungi and actinomycetes and reduced the microbial count only up to 30 days after herbicide spray in cotton. Sathya Priya (2011) noticed that higher doses of oxyfluorfen and pendimethalin had initially reduced the soil microbial population and the population recovered within 30 days after herbicide spray. In wheat, Sharma *et al.* (2014) reported that post-emergence application of metsulfuron-mehyl 4 g ha^{-1} followed by one mechanical weeding at 50 DAS recorded lesser microbial population in soil.

Soil Weed Seed Bank

Weed seed bank refers to the weed seeds in the soil that is able to germinate under convenient conditions (Roberts, 1981). Monitoring the changes in weed seed bank for extended period enables us to have an insight into efficiency of the applied measures of weed control and to predict weed occurrence in the following period (Cavers, 1995; Buhler *et al*., 1997 and Ambrosio *et al*., 2004). Weed seed bank represents constant source of weeds, which enables their continuous occurrence in the field (Boutsalis and Powles, 1998). It is variable in space and time and largely depends on application of cultural practices, crop rotation (Vanasse and Leroux, 2000) and herbicide choice (Dorado *et al*., 1999; Ovaisi *et al*., 2006). Ramsdale *et al*. (2006) reported that under no-till and conventional system, soil seed banks consisted of about 87 per cent broadleaf and 13 per cent grasses species, whereas under the mulch-till system soil seed bank consisted of 68 per cent broadleaf and 32 per cent grasses species in spring wheat-soybean cropping systems.

Weed seed bank in the soil are exposed to various influences and changes and the result of its studies provide immediate, but not general insight into the situation in the field (Menalled, 2008). In a weed seed bank study, application of pre-emergence oxyfluorfen (23.5% EC) at 300 and 400 g ha^{-1} resulted in lesser density of grasses, broadleaved weeds and total weeds (Sathya Priya, 2011).

Herbicide Residue Analysis

Sulfonylurea herbicides show a wide range of persistence in both laboratory and field conditions, depending upon soil pH, temperature, and soil moisture. Several authors reported that persistence of sulfonylurea herbicides increased with increasing rate of application (Kotoula-Syka *et al*., 1993), increasing soil pH and decreasing organic matter content (Goetz *et al*., 1989; Castro *et al*., 2002 and Bedmar *et al*., 2006).

Even at low rates, chlorimuron and metsulfuron herbicides can persist in the soil throughout more than one growing season and may injure rotational crops (Junnila *et al*., 1994 and Vicari *et al*., 1994). Pendimethalin at 1.0 and 1.5 kg ha^{-1} did not persist for more than 60 days in soybean soil (red sandy loam soil) as reported by Devi *et al*., 2000. Harvest-time residues of the herbicide decreased gradually over the years and at the end of five years less than 3 per cent of applied pendimethalin was recovered from soil as against 18 per cent in the first year (Kulshrestha *et al*., 2000). No leaching of pendimethalin was observed below 10 cm during 230 days of cotton growing condition (Tsiropoulos and Lolas, 2004). Metribuzin is considered to be of short to moderate persistence in soils, the half-lives measured have been specified at between 5 and 50 days (Perez *et al*., 2006). Pendimethalin at 1.0 kg ha^{-1} applied to different *rabi* crops persisted in soil upto 75 DAS and afterwards degraded completely leaving no toxic residue in post harvest soil (Arora and Tomar, 2008). Atrazine residue studies carried out in sorghum based cropping system showed at higher levels i.e. 0.5 and 1.0 kg ha^{-1}of atrazine application the residues (estimated with colorimeter) were 0.0725, 0.1150 and 0.625, 0.110 ppm respectively in grain and straw. The atrazine residue was not detectable in subsequent crop of finger millet in both grain and straw (Chinnusamy *et al*., 2008).

Straw samples contained 0.01 and 0.03 mg g^{-1} and in the soil 0.028 and 0.03 mg g^{-1} of oxyfluorfen residues were detected when applied at 240 and 500 g a.i. ha^{-1}, respectively. However in rice grains, 0.018 and 0.106 mg g^{-1} of oxyfluorfen residues were found in 240 and 500 g a.i. ha^{-1} treated plots (Shobha, 2009). Chenhui Shi *et al.* (2010) reported that in rice 0.001 mg kg^{-1} and 0.005 mg kg^{-1} of oxadiargyl residue was found in grain and soil, respectively. Residue of oxyfluorfen was not found in post-harvest soil and plant sample as reported by Jayakumar (2010) in tea and Sathya Priya (2011) in onion. According to Janaki (2014), the residue of metribuzin in soil was below the detection level in all the treatments irrespective of doses in post-harvest soil of sugarcane. Revathi (2014) reported that 0.0333 ppm of metsulfuron methyl residue found in post-harvest soil sample of rice.

Economics

According to Mannikeri (2006), the weed free control (hand weeding) resulted in maximum B:C ratio (2.74:1) followed by the application of pendimethalin (2.39:1) and clomazone (2.19:1) in turmeric.

Babu (2008) reported that among herbicide treatments, the application of pendimethalin at 1.5 kg ha^{-1} recorded the maximum B:C ratio (2.13) closely followed by pendimethalin at 1.0 kg ha^{-1} (2.10) in turmeric. In turmeric, pre-emergence application of pendimethalin + straw mulch 9 t ha^{-1} recorded higher net return (₹ 1,03,000) and B:C ratio (2.30) compared to all other treatments (Kaur *et al*., 2008).

Ratnam *et al*. (2012) reported that among the weed management treatments, the higher net return of ₹ 1,21,073 ha^{-1} and B:C ratio of 0.61 was recorded with pre-emergence application of oxyfluorfen 0.25 kg ha^{-1} followed by quizalofop ethyl 0.05 kg ha^{-1} at 30 DAS supplemented with hand weeding at 60 and 90 DAS in turmeric. According to Jadhav and Pawar (2014), pre-emergence application of metribuzin 0.70 kg ha^{-1} followed by straw mulch 10 t ha^{-1} followed by one hand weeding recorded higher net return (₹ 144630) and B:C ratio (1.47).

After scanning the literatures on different aspects of weed management in turmeric it is understood that the research information on number of pre-emergence herbicide formulation for efficient weed control in turmeric is scanty and very little work has been done. Hence, an attempt has been made to evaluate the integrated weed management with pre and post emergence herbicides in turmeric.

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