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Effect of integrated weed management in turmeric (*Curcuma longa* L.) - A Review

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Abstract
Weed infestation is one of the limiting factors in successful crop production. Any plant competing with cultivated plants or that in some other way interfere with man's legitimate activities is considered to be a weed. Weeds are often referred to as unwanted, prolific, persistent, competitive and harmful to the environment. Weeds are a great menace and a reduction in crop yield has a direct correlation with weed competition. There are many methods of weed control like hand weeding, cultural method, chemical method and integrated weed management. Farmers usually perform hand weeding in turmeric crop but timely availability during critical stages of crop growth, the yield reduces drastically besides high labour wages reduces profit margin. Chemical method of weed control is not only cheaper but also feasible for timely application, however, it requires more care with reference to appropriate selection of herbicide, its dose and time of application. Efficacy of herbicides also depends on several factors like type of weed flora, soil type, organic matter content of the soil, weather condition etc. The information related to chemical method of weed control in turmeric is meager. Single method of weed control cannot control all the category of weeds in a particular situation. Hence combination of other weed control methods as well as combination of other herbicides with appropriate dose and time of application is required for maximum weed control efficiency. In this connection, the literature on various aspects related to the proposed study was collected and summarized in this chapter.

Keywords: Economics, Integrated Weed Management, Growth attributes, Phyto - toxicity, Turmeric, Weed density & Dry matter accumulation by weeds, Yield & yield attributes

Introduction

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 highly influenced by abiotic and biotic factors which affect their occurrence, abundance, range and distribution.

Bharty *et al.* (2017) [2] oserved taht *Ageratum conyzoides* (L.) (30.2%), *Celosia argentea* (L.) (4.81%), *Acalypha indica* (L.) (3.05%) among broad-leaved weeds; *Digitaria sanguinalis* (L.) (11.2%), *Panicum dichotomiflorum* (4.43%) among grassy and *Cyperus rotundus* (L.) (8.7%) among sedges were predominant in turmeric field. Among all the categories broad-leaved dominated (60.4%) followed by grassy (28%) and sedges (11.6%). Similar result was also reported by Bharty *et al.* (2016a) [10].

Barla *et al.* (2015) [7] reported that among grasses *Digitaria sanguinalis* (L.) (20 percent), *Cynodon dactylon* (10 percent), *Paspalum disticum* (5 percent), *Dactyloctenium aegyptium* (L.) (3.5 percent), *Eleusine indica* (2.5 percent) and *Echinochloa colona* (L.) (2 percent); among broad leaved weeds *Ageratum conyzoides* L. (25 percent), *Stellaria media* (L.) (3 percent), *Heliotropium esculentum* (2 percent), *Spilanthes acmella* (8 percent), *Ludwigia parviflora* (2 percent), *Commelina nudifolia* (2 percent) *and Tridex procumbens* (3 percent), *Celosia argentea* L. (2 percent) were major weed flora in experimental plot of turmeric. While among sedge weeds the *Cyperus rotundus* L. (7.5 percent) and *Kyllinga* spp. (2.5 percent) dominated.

Sathiyavani and Prabhakaran (2015,a) [51] reported that in the experimental fields of turmeric, *Digitaria* spp. *Cyperus rotundus* and *Eclipta prostrata* among grasses, sedge and broad leaved weeds were the predominant weeds.

Jadhav and Pawar (2014) [26] also observed that the dominant weed flora of turmeric experimental plot was *Acalapha indica, Euphorbia geniculata, Parthenium hysterophorus, Digeria arvensis* (among broad-leaved weeds), *Cynodon dactylon, Brachiria eraciformis* (among grassy weeds) and *Cyprus rotundus* (sedge).

According to Suresh *et al.* (2014) [59], *Echinochloa colona, Digitaria sanguinalis, Panicum dichotomiflorum, Commelina benghalensis, Cyperus iria, Ageratum conyzoides, Polygonum*

spp., *Physallis minima*, *Eragrotis* spp. and *Aeschynomene indica* were the predominant weeds in turmeric field of Himachal Pradesh.

However, according to Chinnusamy *et al*. (2012) [15] total of fourteen weed species belonging to 8 angiosperm families, were recorded in the fields of turmeric. *Sonchus aspera* (L.), *Chenopodium album* (L.), *Rumex dentatus* (L.), *Ageratum conyzoides* (L.), *Convolvulus arvensis* (L.), *Cynodon dactylon* (L.), *Oxalis corniculata* (L.), *Malva parviflora* (L.), *Malvastrum coromandelianum* (L.), *Trifolium resupinatum* (L.), *Euphorbia hirta* (L.) and *Phalaris minor*, were found to be the most prevalent weed species occurring in 90percent or more studied areas during one or the other growing season. Similar result was also observed by Tahira *et al*. (2010) [61] in Punjab.

Ratnam *et al*. (2012) [48] observed that grasses like *Echinochloa colona* (L.), *Dinebra retroflexa* (L.), *Cynodon dactylon* (L.) and *Panicum repens* (L.), sedge weeds like *Cyperus rotundus* (L.) and broad leaved weeds like *Phyllanthus niruri* (L.), *Celosia argentea* (L.), *Acalypha indica* (L.), *Eclipta alba* (L.) and *Commelina bengalensis* (L.) dominated in turmeric at Guntur, Andhra Pradesh.

Manhas *et al*. (2011) [34] observed that the dominant weeds in the experimental plot of turmeric were *Cyperus rotundus* (Motha), *Cynodon dactylon* (Khabbal), *Eleusine aegypticum* (Madhana) *and Euphorbia hirta* (Dodhak).

Pragada *et al*. (2011) [44] reported that turmeric fields are severely infested with 118 weed species belonging to 99 genera and 36 families. Of these Asteraceae and Poaceae stood first and second with 20 and 19 species respectively followed by Amarantaceae (7); Euphorbiaceae and Rubiaceae with 6 species respectively; Convolvulaceae (5); Cyperaceae, Fabaceae and Malvaceae with 4 species each. *Parthenium hysterophorus* (3.71) was most abundant weed followed by *Elephantopus scaber* (3.17), *Merremia hederacea*, *Merremia tridentata* (3.00) and *Conyza* spp. (2.67) etc. *Parthenium hysterophorus* (3.03) followed by *Cyperus rotundus* (2.10) *Cynodon dactylon and Trianthema portulacastrum* (1.27) *Boerhavia diffusa* (1.07) etc., were found to be most densely populated weeds. *Cyperus rotundus* (96.67) *Parthenium hysterophorus* (81.67) *Boerhavia diffusa* (71.67) and *Cynodon dactylon and Trianthema portulacastrum* (68.33) etc. were high frequency species.

Kaur *et al*. (2008) [28] observed that predominant weed species like *Cyperus rotundus*, *Arachne racemosa*, *Digitaria sanguinalis*, *Dactyloctenium aegypticum*, *Echinochloa crusgalli*, *Eragrostis pilosa*, *Commelina benghalensis*, *Eleusine indica*, *Euphorbia hirta*, *Phyllanthus niruri*, *Trianthema portulacastrum* and *Amaranthus viridis* in turmeric field.

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) [35].

Avilkumar and Reddy (2000) [4] observed weed species like *Amaranthus viridis*, *Commelina benghalensis*, *Cyperus rotundus*, *Cynodon dactylon*, *Celosia argentea*, *Digitaria marginata*, *Digitaria muricata*, *Euphorbia hirta*, *Eleusine indica* and *Panicum repens* as the major weeds in turmeric and maize intercropping system.

Gill *et al*. (2000) [21] reported that the dominant weed flora in turmeric were *Digitaria* spp., *Cynodon dactylon*, *Cyperus rotundus*, *Eleusine indica*, *Dactyloctenium aegypticum*, *Euphorbia hirta*, *Commelina benghalensis* and *Eragrostis pilosa*.

Singh and Mahey (1991) [55] reported that infestation of weeds in turmeric were *Trianthema monogyna*, *Euphorbia hirta*, *Amaranthus viridis*, *Eleusina indica*, *Acrachene racemose*, *Cyperus rotundus* and *Digitaria sanguinalis*.

Critical period of crop - weed competition in turmeric crop

Critical period is the shortest time span in the ontogeny of crop growth when weeding results in highest economic returns. It is true to the some extent that it is neither economical nor feasible to maintain a completely weed free condition throughout the growth period of the crop. Therefore, it is must, to identify the stage of crop when the damage is maximum. Therefore, it is imperative that the critical period of crop-weed competition need to be determined so as to obtain the maximum benefits from effective and efficient weed management practices and 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 (Sathiyavani and Prabhakaran, 2015, b) [52].

The critical period of weed competition is an important consideration in the development of alternative weed management strategies (Swanton and Weise, 1991) [60]. 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) [23].

Njoku *et al*. (2012) [42] observed that yield was increasing as plots were kept weed free up to 12 weeks after planting (WAP) implying that turmeric should be weed free for the first 12 weeks to avoid drastic yield reduction. Under the weed intensity, weeding at 8week after planting (WAP) produced the highest yield of Turmeric rhizome. On the other hand, delayed weeding beyond the 8 weeks after planting (WAP) resulted in a noticeable yield depression in turmeric. This implied that the critical period of weed interference was between 8-12 weeks after planting (WAP).

Manhas *et al*. (2011) [34] stated that delayed emergence, slow initial growth, poor canopy development of turmeric provides ideal environment for weeds to grow and cover the ground quickly and compete with crop.

Hossain *et al*. (2007) [25] conducted a field experiment in Okinawa, Japan and he found that in the weedy control, the weed infestation was severe until 160 DAP. Thus, crop interference by the weed species was high, so it could be removed during 70 to 160 DAP for reduced labour requirements and to get higher yield of turmeric.

Thus, it can be inferred from above findings that in general the critical period for crop weed competition for resources in turmeric is about 60–70 DAP.

Losses in yield of turmeric crops due to weeds

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.

Turmeric is a long duration crop. Delayed emergence, slow initial growth of the crop and ample land space available due to wider spacing permit more sunlight to reach the soil resulting conducive environment for rapid weed growth and enormous damage to crop yield (Sathiyavani and Prabhakaran, 2015, a) [51].

Ratnam *et al*. (2012) [48] observed that uncontrolled weed

growth reduced turmeric rhizome yield by 80 percent.
Kaur *et al*. (2008) [28] reported that losses in turmeric rhizome yield due to weeds varied from 63.9 to 76.5 percent. Similar result was also obtained by Krishnamurthi and Ayyaswamy (2000) [32] that yield losses of turmeric due to weeds vary from 30 – 75 percent.
Hossain *et al*. (2007) [25] conducted a field experiment in Okinawa, Japan and he observed that only purple nut sedge (> 3,000 plants m^{-2}) did not significantly reduce turmeric yield, whereas the combined weed species reduced yield by greater than 40 percent.
It can be summarised from above facts that weeds cause drastic reduction in turmeric rhizome as well as similar crop yield to the extent of 70 to 80 percent in absence of effective weed control.

Effect of weed control methods on Weed Density and Dry matter accumulation by weeds

Manual weed control method

According to Anon[4] (2013) [3], at Pusa centre the lowest weed count and weed dry matter of turmeric were recorded under hand weeding at 25 and 45 DAS i.e., 4.2 no.m^{-2} and 10.23gm^{-2}.
Manhas *et al*. (2011) [34] reported that in turmeric crop the weed population and weed dry weight decreased with age of crop due to two hand weedings given at 70 and 100 days after planting (DAP).

Cultural weed control method (Mulching)

Weed control is one of the most important objectives of cultural operations. Following proper cultural operations is more than the half of 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 (Sathiyavani and Prabhakaran, 2015; b) [52].
Manhas *et al*. (2011) [34] studying on effect of quantum of straw mulch, found that in turmeric crop the weed population and dry weight with 9.38 t ha^{-1} straw mulch were significantly less as compared to 6.25 t ha^{-1} mulch, which in turn recorded significantly lesser weed population and dry weight than no mulch at 60 as well as 150 DAP. The beneficial effect of mulching in controlling weeds was due to delayed emergence of weeds and smothering effect on weed seedlings.
Kaur *et al*. (2008) [28] also compared the quantum of straw mulch and opined that straw mulch 9 t ha^{-1} significantly reduced weed dry matter and recorded 29.2 percent higher rhizome yield than 6 t ha^{-1}. Similarly, Hossain (2005) [24] was also viewed that mulching suppresses weed growth and improves the yield.
Nag *et al*. (2008) [39] suggested that mulch is a layer of material spread on top of the soil to conserve soil moisture, discourage the growth of weeds, help in preventing erosion and prevent large fluctuations in soil temperature. Mulch modifies the soil micro-climate around the growing plants.
According to Vanlalhluna and Sahoo (2008) [64], the crop yield from mulch application in turmeric and maize intercropping was low in the first year, which significantly increased after two years and the crop yield was higher under mulch treatments compared to without mulch.
Gill *et al*. (1999) [21] noticed that the application of straw mulch influence water evaporation, weed population and soil temperature and thereby the yield and cost of cultivation of turmeric.

Chemical weed control method

Under this section effect of various herbicides in controlling different species of weeds irrespective of crop have been documented.
Bharty *et al.* (2016a) [10] reported that among chemical weed control methods, application of glyphosate 1.85 l/ha at 25 DAP followed by two hand weeding at 45 and 75 DAP recorded significantly reduced total weed density at 30 DAP to the extent of 14.22 per cent compared to hand weeding at 25, 45 and 75 DAP while at 90 and 150 DAP metribuzin 0.7 kg/ha pre-emergence followed by fenoxaprop-p-ethyl 67g/ha + metsulfuron 4 g/ha at 45 DAP recorded 66.96 and 54.67 per cent reduced total weed density compared to hand weeding at 25, 45 and 75 DAP, respectively. Reduction in dry matter accumulation by total weeds also followed similar trend as that of weed density. Application of glyphosate 1.85 l/ha at 25 DAP followed by two hand weeding at 45 and 75 DAP recorded 2.67 % reduced total weed dry matter compared to hand weeding at 25, 45 and 75 DAP while at 90 and 150 DAP, metribuzin 0.7 kg/ha pre emergence followed by fenoxaprop-p-ethyl 67g/ha + metsulfuron 4 g/ha at 45 DAP recorded significantly reduced total weed dry matter to the tune of 44.24 and 52.27%, respectively compared to hand weeding at 25, 45 and 75 DAP. This report is also supported by Bharty *et al.* (2016b) [11] and Bharty *et al.* (2017) [2].
Barla *et al*. (2015) [7] obtained that application of metribuzin 0.7 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1} being similar to pendimethalin 1.0 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1}at 30 and 60 DAP.
Bera and Ghosh (2013) [8] observed that significantly decreased dry weights of weeds with imposition of weed control treatments over untreated control. At 10 days after application, atrazine @ 4 kg a.i. ha^{-1} recorded least weed biomass (12.25 g m^{-2}) which was statistically at par with atrazine @ 2 kg a.i. ha^{-1} (14.13 g m^{2}) and ametryn 80 percent WP @ 2.0 kg a.i. ha^{-1} (14.95 g m^{-2}). Twice hand weeding recorded least weed biomass which was statistically at par with application of atrazine 50 percent WP @ 1.0 kg a.i. ha^{-1}, atrazine 50 percent WP @ 2.0 kg a.i. ha^{-1}, atrazine 50 percent WP @ 4.0 kg a.i. ha^{-1} and ametryn 80 percent WP @ 2.0 kg a.i. ha^{-1} at 35 days after application. Whereas, at 60 days after application, atrazine 50 percent WP @ 4.0 kg a.i. ha^{-1} recorded least weed biomass (24.23 g m^{-2}) which showed statistical parity with all the treatments except atrazine 50 % WP @ 0.5kg a.i. ha^{-1} (34.87 g m^{-2}) and control (115.03 g m^{-2}).
Malik *et al*. (2013) [33] observed that metsulfuron 0.004 kg ha^{-1} was effective (88-90 percent) only against broad leaved weeds.
Sarkar and Majumdar (2013) [50] obtained that post-emergence application of fenoxaprop-p-ethyl controlled 61.2 percent of grasses in *Corchorus olitorius* L., as compared to un-weeded control. Similar results were obtained with fenoxaprop-p-ethyl (Sarkar, 2006; Ali *et al*., 2012) [49, 2].
Avilkumar and Reddy (2000) [4] reported that application of pendimethalin @ 1.0 kg ha^{-1} resulted significantly in lower weed dry matter as compared to atrazine @ 1.0 kg ha^{-1}, fluchloralin @ 1.0 kg ha^{-1} and glyphosate @ 0.5 kg ha^{-1} in maize + turmeric intercropping.
Singh and Mahey (1991) [55] studied the effect of different weed control treatments - pre-emergence - atrazine at 0.62 kg ha^{-1}, metribuzin at 0.80 kg ha^{-1}, pendimethalin at 0.75 kg ha^{-1}, oxadiazon at 0.75 kg ha^{-1}, piperophos at 0.50 kg ha^{-1}, diuron at 0.80 kg ha^{-1}, flurochloridone at 2.00 kg ha^{-1} and linuron at 1.00 kg ha^{-1}, pre-plant fluchloralin at 1.00 kg ha^{-1}, hand weeding twice 45 and 70 days after sowing and straw mulching at (6 t ha^{-1}) in turmeric. They found that all weed control treatments reduced weed populations compared

with the untreated control, but application of atrazine resulted in marked reduction in dry matter accumulation of weeds after 30 days of sowing followed by metribuzin and straw mulching, while, application of diuron recorded minimum dry matter of weeds after 60 days of sowing.

Integrated weed control method

Barla *et al*. (2015) [7] stated that among chemical weed control methods application of metribuzin 0.7 kg ha^{-1} f.b. two hoeing being similar to metribuzin 0.7 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding and pendimethalin 1.0 kg ha^{-1} f.b. two hoeing at 30 DAP while at 60 DAP application of pendimethalin 1.0 kg ha^{-1} f.b. two hoeing recorded reduced density of grassy weeds compared to rest of the chemical methods of weed control. Application of atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding at 60 DAP recorded reduced broad leaved weed density at 30 and 60 DAP. Significantly reduced density of sedge weeds was observed by application of pendimethalin 1.0 kg ha^{-1} f.b. two hoeing which was similar to other chemical methods of weed control except metribuzin 0.7 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1}, pendimethalin 1.0 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1}, pendimethalin 1.0 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding and atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding. Among chemical methods of weed control application of pendimethalin 1.0 kg ha^{-1} f.b. two hoeing being similar to metribuzin 0.7 kg ha^{-1} f.b. two hoeing, pendimethalin 1.0 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1} at 30 DAP and also metribuzin 0.7 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding, pendimethalin 1.0 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding and atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding at 60 DAP recorded reduced weed dry matter compared to rest of the treatments as well as higher weed control efficiency (93.59 and 93.73 percent respectively).

Jadhav and Pawar (2014) [26] and Suresh *et al*. (2014) [59] reported that pre-emergence application of metribuzin 0.7 ka ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding recorded lower weed density and dry weight and higher weed control efficiency and rhizome yield in turmeric.

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) [69].

Kaur *et al*. (2008) [28] found that integrated use of paddy straw mulch at 9 t ha^{-1} with either pendimethalin at 1.0 kg ha^{-1}, metribuzin at 0.70 kg ha^{-1} and atrazine at 0.75 kg ha^{-1} was very effective for weed control and attaining the highest productivity and profitability in turmeric.

Gill *et al*. (2000) [21] observed that the herbicide treatments alone did not provide season-long weed control, but the integrated treatments achieved similar levels of control to the hand weeding plus hoeing treatment.

Weed control efficiency (W.C.E.)

Bharty *et al.* (2016b) [11] observed that application of glyphosate 1.85 l/ha at 25 DAP f.b. 2 hand weeding at 45 and 75 DAP record maximum weed control efficiency i.e., 71.1 % at 30 DAP while at 90 and 150 DAP metribuzin 0.7 kg/ha PE f.b. fenoxaprop-p-ethyl 67g/ha + metsulfuron 4 g/ha at 45 DAP recorded maximum weed control efficiency i.e., 83.4 and 76.4 % respectively.

Channappagoudar *et al*. (2013) [14] noticed that significantly higher weed control efficiency (percent) was noticed in weed free treatment because of the season long weed free conditions in that treatment and among the different herbicides alachlor at 1.0 and 1.5 kg a.i. ha^{-1}; butachlor at 1.0 and 1.5 kg a.i. ha^{-1}; pendimethalin at 1.0 and 1.5 kg a.i. ha^{-1}; pretilachlor at 1.0 and 1.5 kg a.i. ha^{-1}, oxyfluorfen at 0.2 and 0.3 kg a.i. ha^{-1}, application of pendimethalin 1.5 kg a.i. ha^{-1} has been found less phytotoxic and more efficient in controlling both monocot and dicot weeds with highest weed control efficiency (82 percent) in turmeric.

Ratnam *et al*. (2012) [48] found that pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} followed by post-emergence application of quizalofop ethyl @ 0.05 kg ha^{-1} and two hand weeding at 60 and 90 days after sowing (DAS) with highest weed control efficiency of 92 percent in turmeric.

Kaur *et al*. (2008) [28], when averaged over 2 locations - in Ludhiana and at Nawanshah (Punjab), they noticed that pendimethalin + straw mulch at 9 t ha^{-1} revealed the highest weed control efficiency (84.2 percent) and herbicide efficiency index (11.2) and was at par with metribuzin and atrazine, both integrated with straw mulch at 9 t ha^{-1} in turmeric crop.

Mannikeri (2006) [35] found that in turmeric crop among the different weed control treatments, hand weeding recorded significantly highest weed control efficiency (100 percent) and among the herbicides, application of pendimethalin showed the maximum weed control efficiency (76.24 percent).

Effect of specific herbicide on weed dynamics

Pre-emergence herbicides

Pre-emergence herbicide application can help to control the weeds in the early crop growth stage. Crop-weed competition is minimized by pre-emergence spray of herbicides resulting in higher crop yield (Berevadia *et al*., 1996) [9]. Guggari *et al*. (1995) [22] observed that 30 to 55 percent of the weeds can be controlled by pre-emergence application of herbicides. Baker and Terry (1991**)** [16] 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 inter cultivation during the first 3 to 4 weeks of crop growth and to control weeds effectively.

Metribuzin

Studies by Tuti and Das (2011) [62] 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.

Mishra and Singh (2009) [37] 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.

Vasuki (2005) [65] reported that metribuzin at 1.0 kg ha^{-1} as pre-emergence herbicide had lower weed density and higher weed control efficiency in sugarcane.

Gill *et al*. (2000) [21] observed that pre-emergence application of metribuzin 0.7 kg ha^{-1} recorded higher rhizome yield in turmeric.

Pendimethalin

Channappagoudar *et al*. (2013) [14] found that among various

herbicides, pendimethalin @ 1.0 kg a.i. ha^{-1} a recorded the lowest weed dry matter followed by pendimethalin @ 1.5 kg a.i. ha^{-1} at all the stages of crop growth, while oxyfluorfen @ 0.30 kg a.i. ha^{-1} was least effective in turmeric which is attributed to the differential efficacy of herbicides in suppressing the weed growth.

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 percent respectively (Patel *et al*., 2011) [43].

Babu (2008) [5] reported that pre-emergence application of pendimethalin at 1.5 kg ha^{-1} recorded higher rhizome yield next to weed free in turmeric.

Yadav and Yadav (2003) [68] 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 (96.9percent) and higher bulb yield (11 t ha^{-1}) in garlic.

Ajai *et al*. (2002) [1] reported that pendimethalin 1.0 kg ha^{-1} + hand weeding at 80 DAP and oxyfluorfen 0.4 kg ha^{-1} + hand weeding at 80 DAP recorded 45 and 39 percent more fresh rhizome yield, respectively than weedy plots in turmeric.

Atrazine

Rao *et al*. (2009) [47] 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.

Kolage *et al*. (2004) [30] 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.

Singh *et al*. (2003) [57] pointed that atrazine at 0.50 kg ha^{-1} registered 79 percent weed control efficiency followed by two hand weeding with 87 percent weed control efficiency and one hand weeding followed by earthing up treatment with maximum (93 percent) weed control efficiency at 45 DAS indicating suppression of first flush of weeds successfully in maize.

Singh and Mahey (1991) [55] 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}).

Oxyfluorfen

According to Sathya *et al*. (2013) [53], pre-emergence application of oxyfluorfen (23.5 percent EC) at 200 g ha^{-1} recorded lesser weed density and dry weight in onion.

Ratnam *et al*. (2012) [48] recorded that the 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.

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) [54].

According to Ranpise and Patil (2001) [46], 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.

Kolhe (2001) [31] 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.

Oxadiargyl

According to Naseeruddin *et al*. (2014) [40], 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}).

Pre-emergence application of oxadiargyl at 75 g ha^{-1}f.b. bispyribac-sodium 30 g ha^{-1} at 20 days after transplanting was at par with hand weeding twice at 20 and 40 days after transplanting in achieving higher grain yield in transplanted rice (Deepthi and Subramanyam, 2010) [18].

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 (Sathiyavani and Prabhakaran, 2015 b) [52].

Metsulfuron

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 (Singh *et al*., 1995) [56].

Metsulfuron 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 20 days (Mishra and Bhan, 1994) [36].

Fenoxaprop-p-ethyl

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) [19].

According to Singh *et al*. (2014) [58], lesser weed density and dry weight was recorded in fenoxaprop-p-ethyl+ ethoxysulfuron f.b. bispyribac at 60 + 15 and 25 g ha^{-1} in rice.

In aerobic rice, post-emergence mixture of fenoxaprop-p-ethyl + ethoxysulfuron at 30 days after sowing recorded higher grain yield in aerobic rice (Ramachandiran and Balasubramanian, 2012) [45].

According to Walia *et al*. (2011) [67], post-emergence application of fenoxaprop-p-ethyl + metribuzin at 275 and 330 g ha^{-1}increased wheat grain yield by 58.8 percent, respectively as compared to un-weeded treatment.

Sarkar (2006) [49] 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.

Glyphosate

According to Chinnusamy *et al*. (2013) [16], post-emergence spraying of potassium salt of glyphosate at 2700 g a.i. ha^{-1} twice on 25 and 65 days after sowing can be done for complete control of broad spectrum weeds.

Glyphosate mixed with S-metolachlor increased the control of

late season annual grasses to 14-43 percentage points compared with the control by glyphosate (Clewis *et al*., 2006) [17].

Increased dosage and extended time of application are beneficial since glyphosate provides broad-spectrum control of many annual and perennial grasses, sedge and broad leaved weeds (Burke *et al*., 2005) [13].

Glyphosate at 2.00 kg ha^{-1} followed by hand weeding recorded lower weed density and dry weight (Nadanassababady and Kandasamy, 2002) [38].

Phyto-toxicity in turmeric plants

The length of time for which an herbicide remains active or persists in the soil is extremely important as it relates to the length of time that weed control can be expected. Residual toxicity is important, as it relates to phytotoxic effects that may prove injurious to succeeding crop, particularly in early stage.

Bharty *et al.* (2016a) [10] observed that plant injury of turmeric as a result of phyto-toxicity recorded at 60 DAP was maximum under integrated with metribuzin 0.7 kg/ha or pendimethalin 1.0 kg/ha or atrazine 0.75 kg/ha pre-emergence each followed by fenoxaprop-p-ethyl 67g/ha + metsulfuron 4 g/ha at 45 DAP i.e., 7.67, 8.00 and 8.33, respectively at a scale of 0-10 and among all the treatments, integration of metribuzin 0.7 kg/ha or pendimethalin 1.0 kg/ha or atrazine 0.75 kg ha pre- emergence each followed by straw mulch at 10 DAP followed by hand weeding at 75 DAP recorded reduced phyto-toxicity on turmeric plant. The phyto-toxic effect of herbicide on turmeric plants have also been reported by Bharty *et al.* (2017) [2] and Bharty *et al.* (2016b) [11].

Barla *et al*. (2015) [7] reported excessive phyto-toxicity of herbicides by metribuzin 0.7 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1}, pendimethalin 1.0 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1} and atrazine 0.75 kg ha^{-1} f.b. fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1} having 8 and minimum phyto-toxicity was by application of metribuzin 0.7 kg ha^{-1} f.b. two hoeing and application of metribuzin 0.7 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding and atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding having 2. It was clear that treatments containing fenoxaprop-p-ethyl and metsulfuron recorded maximum phyto-toxicity.

Sathiyavani and Prabhakaran (2015,b) [52] found slight to moderate phyto-toxicity symptoms in turmeric by application of glyphosate 1.03 and 1.54 kg ha^{-1} at the time of application of herbicides, however the crop recovered later.

Jadhav and Pawar (2014) [26], recorded no crop injury with the application of pre-emergence herbicide under study, however application of post-emergence herbicides fenoxaprop + metsulfuron 67 + 4 g ha^{-1} caused injury (50%) to turmeric.

Upasani *et al*. (2013) [63] also observed that although application of pendimethalin @ 1.0 kg ha^{-1} as pre-emergence controlled weeds effectively but simultaneously also showed phyto-toxicity on turmeric plant resulting reduced turmeric yield. Pre-emergence application of metribuzin (0.7 kg ha^{-1}) or pendimethalin (1.0 kg ha^{-1}) or atrazine (0.75 kg ha^{-1}) followed by application of fenoxaprop-p-ethyl 67 g ha^{-1}+ metsulfuron 4 g ha^{-1} at 3-4 leaf stage of weeds recorded maximum phyto-toxicity of turmeric plant, resulting reduced turmeric yield.

Effect of weed control methods on growth of turmeric

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) [29].

Bharty *et al.* (2017) [2] found that among weed control methods, application of atrazine 0.75 kg/ha PE fb straw mulch at 10 DAP fb hand weeding at 75 DAP recorded maximum dry matter accumulation by turmeric leaves to the extent of 7.27, 42.2 and 80.5% higher at 30, 90 and 150 DAP respectively compared to hand weeding at 25, 45 and 75 DAP. Similarly, application of atrazine 0.75 kg/ha PE fb straw mulch at 10 DAP fb hand weeding at 75 DAP also recorded significantly higher stem dry matter accumulation which were 63.5 and 70.6 % higher compared to hand weeding at 25, 45 and 75 DAP, at 90 and 150 DAP respectively. Moreover, similar result was also observed in case of dry matter accumulation by rhizomes as atrazine 0.75 kg/ha PE fb straw mulch at 10 DAP fb hand weeding at 75 DAP recorded significantly higher dry matter accumulation by rhizomes to the tune of 180, 152 and 154% compared to hand weeding at 25, 45 and 75 DAP, at 90, 150 and 210 DAP respectively. Application of atrazine 0.75 kg/ha pre-emergence fb straw mulch at 10 DAP fb hand weeding at 75 DAP also recorded maximum total dry matter accumulation by plants which were 8.95, 136, 140 and 154% higher than hand weeding at 25, 45 and 75 DAP, at 30, 90, 150 and 210 DAP respectively.

Barla *et al*. (2015) [7] found that application of metribuzin 0.7 kg ha^{-1} f.b. two hoeing being similar to application of atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one handweeding and hand weeding at 25 and 45 DAP recorded m maximum leaf area index.

Sathiyavani and Prabhakaran (2015b) [52] observed that at 60 DAP of turmeric, pre-emergence application of metribuzin 0.7 kg ha^{-1} + hand weeding on 45 and 75 DAP recorded significantly taller (44.7 cm) plants than other weed control treatments. Dry matter production was significantly influenced by different weed control treatments. There was a steady increase in dry matter production from 60 to 240 DAP. At 60 DAP, the dry matter production was lucidly higher (2,387 kg ha^{-1}) in pre-emergence application of metribuzin 0.7 kg ha^{-1} + hand weeding on 45 and 75 DAP. At 180 and 240 DAP, the same trend was observed. The dry matter production was drastically reduced in atrazine 0.75 kg ha^{-1} pre-emergence + fenoxaprop-p-ethyl 67 g ha^{-1} + metsulfuron 4 g ha^{-1}on 45 DAP, pendimethalin 1.0 kg ha^{-1} pre-emergence + fenoxaprop-p-ethyl 67 g ha^{-1}+ metsulfuron 4 g ha^{-1} on 45 DAP and metribuzin 0.7 kg ha^{-1} pre-emergence + fenoxaprop-p-ethyl 67 g ha^{-1}+ metsulfuron 4 g ha^{-1} on 45 DAP besides un-weeded check at 180 and 240 DAP. Pre-emergence application of metribuzin 0.7 kg ha^{-1} + hand weeding on 45 and 75 DAP resulted in conspicuously higher dry matter production at 180 and 240 DAP (9,561 and 11,518 kg ha^{-1}, respectively) and it was at par with pre-emergence pendimethalin 1.0 kg ha^{-1} + hand weeding on 45 and 75 DAP and hand weeding at 25, 45 and 75 DAP. More plant dry matter production with pre-emergence application of metribuzin 0.7 kg ha^{-1} + hand weeding on 45 and 75 DAP might be due to lesser weed competition, as weeds might have been killed from their germination phase and keeping weeds at lower density.

Channappagoudar *et al*. (2013) [14] observed that among various herbicides studied, pendimethalin resulted in higher total dry matter production of turmeric. Leaf area and leaf area index (LAI) increased from 60-120 days after planting and decreased from 180 days after planting to harvest. The

highest leaf area index was recorded in weed free check (1.24). Among the herbicides, the application of pendimethalin @ 1.5 and 1.0 kg a.i. ha^{-1} resulted in higher values for leaf area and leaf area index (LAI) at all the stages. However, application of oxyfluorfen @ 0.20 kg a.i. ha^{-1} resulted in lower values for leaf area index (0.75). The same trend was noticed at 120, 180 and 240 days after planting. At 60 days after planting, number of leaves were significantly higher in weed free check (9.23 $plant^{-1}$) followed by pendimethalin @ 1.5kg a.i. ha^{-1} (8.07 $plant^{-1}$), pendimethalin @ 1.0 kg a.i. ha^{-1} (8.05 $plant^{-1}$) and alachlor @ 1.0 kg a.i. ha^{-1} (7.60 $plant^{-1}$). The relative growth rate values during 60 to 120 days after planting indicated that, it was significantly higher in weed free check (0.036 g g^{-1} day^{-1}) followed by pendimethalin @ 1.5 kg a.i. $ha^{-1}$and pendimethalin @ 1.0 kg a.i. ha^{-1}. During 120-180 DAP the relative growth rate values were found to be significantly higher in weed free check (0.026 g g^{-1} day^{-1}), followed by pendimethalin @ 1.5 kg a.i. ha^{-1}, pendimethalin @ 1.0 kg a.i. ha^{-1} and alachlor @ 1.5 kg a.i. ha^{-1}, which were on par with each other. Similar trend was also observed at 180 to 240 days after planting and 240 days after planting to harvest.

Njoku *et al*. (2012) [42] obtained that the plant height of ranged to as high as 70.6 cm and as small as 43.9 cm. The maximum height was obtained as weeding increased to 16 week after planting from 4, 8 or 12 weeks after planting, while further weeding decreased height implying that beyond this point weeding becomes uneconomical. Weeding in turmeric at 8 weeks after planting (i.e., up to 8 weeks after planting no weeding is applied) produced the maximum plant height. However, the longer weeding is delayed, the more the reduction in height was observed. This reduction in height as a result of weed will also be translated to reduction in yield, thereby confirming the report of Njoku *et al*. (2007) [41] who had reported that taller plants intercepts light more which helps in high yield.

Manhas *et al*. (2011) [34] found that in turmeric crop application of straw mulch @ 9.38 t ha^{-1} produced significantly taller plants and more tillers and leaves per plant than the application of mulch @ 6.25 t ha^{-1}, which in turn was significantly superior to no mulch. Similar results were reported by Junior *et al*. (2005) [27] and Verma and Surnaik (2006) [66].

According to Kaur *et al*. (2008) [28], un-weeded control recorded lesser leaf area index than all other herbicide treatments in turmeric.

Hossain *et al*. (2007) [25] conducted a field experiment in Okinawa, Japan and he observed that plant height and number of leaves and tillers per plant of turmeric increased rapidly from 70 to 160 days after planting. Season-long weed infestation significantly reduced shoot biomass and rhizome yield of turmeric.

Effect of weed control methods on yield attributes and yield of turmeric

Bharty *et al.* (2016a) [10] reported that application of atrazine 0.75 kg/ha pre emergence followed by straw mulch at 10 DAP followed by hand weeding at 75 DAP recorded 50.54 per cent higher fresh yield than hand weeding. However, the higher yield owing to treatments integrated with metribuzin 0.7 kg/ha or pendimethalin 1.0 kg/ha or atrazine 0.75 kg/ha PE each fb straw mulch at 10 DAP fb hand weeding at 75 DAP can be justified as combined effect of better weed control and reduced phyto-toxicity. These results were in agreement with results of Bharty *et al.* (2016a) [10] and Bharty *et al*. (2017) [2] who have also observed higher yield of turmeric under the treatments having straw mulch along with metribuzin or pendimethalin or atrazine each followed by hand weeding at 75 DAP.

Barla *et al*. (2015) [7] found that application of metribuzin 0.7 kg ha^{-1} f.b. by two hoeing recorded 30.98 percent and 57.42 percent higher yield than weed free and weedy check, respectively. However, it was similar to application of metribuzin 0.7 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding, pendimethalin1.0 kg ha^{-1} f.b. two hoeing, pendimethalin 1.0 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding and atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding. Higher turmeric yield were in tune with higher weed control efficiency caused by application of metribuzin or pendimethalin each integrated with hoeing or straw mulch.

Jadhav and Pawar (2014) [26] observed that metribuzin 0.7 kg ha^{-1} PE f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding recorded significantly highest fresh rhizome yield (12.16 t ha^{-1}) as compared to other treatments except the treatments included the straw mulch application and un-weeded check recorded the significantly lowest fresh rhizome yield (3.02 t ha^{-1}) with a yield loss of 80%.

Channappagoudar *et al*. (2013) [14] recorded that maximum turmeric yield was in weed free check (7.08 t ha^{-1}), among herbicides application of pendimethalin at 1.5 kg a.i. ha^{-1} pre-emergence resulted higher rhizome yield (6.03 t ha^{-1}) followed by pendimethalin at 1.0 kg a.i. ha^{-1} (5.74 t ha^{-1}).

Upasani *et al*. (2013) [63] found that application of metribuzin 0.7 kg ha^{-1} followed by two hoeing recorded significantly higher turmeric yield as 24.95 t ha^{-1} as compared to rest of the treatments.

Ratnam *et al*. (2012) [48] reported that pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} followed by post-emergence application of quizalofop ethyl @ 0.05 kg ha^{-1} and two hand weeding at 60 and 90 days after sowing (DAS) recorded the highest fresh rhizome yield (6.6 t ha^{-1}) which was on par with hand weeding at 30, 60 and 90 days after sowing (DAS), which recorded the highest fresh rhizome yield (8.5 t ha^{-1}) of turmeric crop.

Njoku *et al*. (2012) [42] observed increased yield of turmeric (9.90 t ha^{-1}) as the plots were left weed free up to 24 weeks after planting with slight depression at 16 weeks after planting (7.70 t ha^{-1}) and 20 weeks after planting (7.60 t ha^{-1}). However, the yield obtained at 24 weeks after planting (9.90 t ha^{-1}) was not significantly different from that of 12 weeks after planting (8.86 t ha^{-1}). This implies that turmeric should be kept weed free for the first 12 weeks after planting to avoid drastic reduction in yield. Under the weed infested regime, highest rhizome yield was obtained when weeding was delayed up to 8 weeks after planting (9.50 t ha^{-1}) after which there was general yield reduction with yield reduction ranging between 3 and 55 percent.

Manhas *et al*. (2011) [34] observed that the highest fresh rhizome yield of turmeric with 9.38 t ha^{-1} mulch (i.e. 25.3 t ha^{-1}), which was significantly higher than 6.25 t ha^{-1} (i.e. 20.0 t ha^{-1}), which in turn was superior to no mulch (i.e. 14.5 t ha^{-1}). Similarly, increase in the number and weight of rhizomes $plant^{-1}$ due to mulch has been reported by Junior *et al*. (2005) [27].

According to Kaur *et al*. (2008) [28], pendimethalin + straw mulch at 9 t ha^{-1} recorded highest turmeric fresh rhizome yield (29.6 t ha^{-1}) and was at par with application of metribuzin and atrazine, both integrated with straw mulch at 9 t ha^{-1}. The fresh rhizome yield with straw mulch at 9 t ha^{-1} + herbicide combination was 48.2, 14.9, 15.3 and 225.5percent higher

than straw mulch at 6 t, 9 t alone, 6 ha^{-1} + herbicide and unweeded control, respectively. Similarly, Nag *et al*. (2008) [39] also observed that yield of turmeric was substantially higher fetching higher economic returns to the growers.

Mannikeri (2006) [35] found that among different weed control treatments, weed free control recorded significantly highest fresh rhizome yield (26.27 t ha^{-1}), cured rhizome yield (5.59 t ha^{-1}). Among the herbicides, application of pendimethalin showed the significantly higher fresh rhizome yield (26.67 t ha^{-1}), cured rhizome yield (5.59 t ha^{-1}) followed by application of chlomazone (@ 1.0 kg a.i. ha^{-1}) in turmeric.

Avilkumar and Reddy (2000) [4] found that the turmeric rhizome yield and equivalent yield was comparable in all weed control treatments i.e., pendimethalin @ 1.0 kg ha^{-1}, atrazine @ 1.0 kg ha^{-1}, fluchloralin @ 1.0 kg ha^{-1} and glyphosate @ 0.5 kg ha^{-1} and was significantly superior over unweeded control in maize + turmeric intercropping system.

Gill *et al*. (2000) [21] reported that the highest percentage increase in yield of turmeric over the control was achieved by application of metribuzin 0.70 kg ha^{-1} pre-emergence, followed by diuron 1.0 kg ha^{-1} and the integrated control treatments of diuron, metribuzin and atrazine.

Singh and Mahey (1991) [55] found that straw mulch resulted maximum turmeric fresh rhizome yields (6.31 t ha^{-1}), a 214.5 percent increase over the unweeded control.

Effect of weed control methods on economics of turmeric production

Bharty *et al.* (2017) [2] found that maximum net return (Rs. 621216/ha) and B:C ratio (4.45) was under atrazine 0.75 kg/ha PE fb straw mulch at 10 DAP fb hand weeding at 75 DAP. The higher net return was a result of 41.4 % higher yield and 28.8% reduced cost of cultivation compared to mean yield and cost of cultivation recorded by rest of the chemical methods of weed control.

Barla *et al*. (2015) [7] reported that application of metribuzin 0.7 kg ha^{-1} f.b. two hoeing recorded higher gross return (6,16,519 ` $ha^{-1}$), net return (5,03,419 ` ha^{-1}) and benefit: cost ratio (4.45) and was similar to application of metribuzin 0.7 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding, pendimethalin 1.0 kg ha^{-1} f.b. two hoeing, pendimethalin 1.0 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding and atrazine 0.75 kg ha^{-1} f.b. straw mulch 10 t ha^{-1} f.b. one hand weeding. The higher net return was as a result of 48.21 percent higher yield and 2.62 percent reduced cost of cultivation compared to mean yield and cost of cultivation recorded by rest of the chemical methods of weed control in turmeric crop.

Jadhav and Pawar (2014) [26] have also reported that application of metribuzin 0.70 kg ha^{-1} pre-emergence followed by straw mulch 10 t ha^{-1} followed by one hand weeding recorded higher net return (1,44,630 ` ha^{-1}) and benefit: cost ratio (1.47) in turmeric crop.

Channappagoudar *et al*. (2013) [14] noticed highest benefit: cost ratio by application of pendimethalin at 1.5 kg a.i ha^{-1} compared to other herbicides in the trial as alachlor at 1.0 and 1.5 kg a.i. ha^{-1}; butachlor at 1.0 and 1.5 kg a.i. ha^{-1}; pendimethalin at 1.0 kg a.i. ha^{-1}; pretilachlor at 1.0 and 1.5 kg a.i. ha^{-1} and oxyfluorfen at 0.2 and 0.3 kg a.i. ha^{-1} in turmeric crop.

Upasani *et al*. (2013) [63] reported that application of metribuzin 0.7 kg ha^{-1} followed by two hoeing recorded significantly higher net return 5,10,563 ` ha^{-1} and benefit: cost ratio 4.51 of turmeric as compared to rest of the treatments.

Ratnam *et al*. (2012) [48] found that pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} followed by post-emergence application of quizalofop ethyl @ 0.05 kg ha^{-1} and two hand weeding at 60 and 90 days after sowing significantly recorded the highest fresh rhizome yield of turmeric with benefit: cost ratio of 0.61 and was on par with hand weeding at 30, 60 and 90 DAS.

Manhas *et al*. (2011) [34] stated that there was a significant increase in net return and B:C ratio with each increase in mulch level and maximum net return and benefit: cost ratio were obtained with 9.38 t ha^{-1} mulch (i.e. 155.6 x 10^3 ` $ha^{-1}$ and 4.36), significantly higher than mulch application at 6.25 t $ha^{-1}$ (net return - 111.4 x $10^3$ ` ha^{-1} and benefit: cost ratio- 3.21) and no mulch (net return- 67.3 x 10^3 ` ha^{-1} and benefit: cost ratio- 2.12) in turmeric.

Babu (2008) [5] reported that among herbicide treatments, the application of pendimethalin at 1.5 kg ha^{-1} recorded the maximum benefit: cost ratio (2.13) closely followed by pendimethalin at 1.0 kg ha^{-1} (2.10) in turmeric.

Kaur *et al*. (2008) [28], when averaged over 2 locations - in Ludhiana and at Nawanshah (Punjab), they noticed that in turmeric pendimethalin + straw mulch at 9 t ha^{-1} revealed the highest net returns (10^3 x 10^3 ` ha^{-1}) and benefit: cost ratio (2.30) and was at par with metribuzin and atrazine, both integrated with straw mulch at 9 t ha^{-1}.

Mannikeri (2006) [35] obtained that among different weed control treatments in turmeric, weed free control recorded significantly highest benefit: cost ratio (2.74) and among the herbicides, application of pendimethalin showed the significantly higher benefit: cost ratio (2.39) followed by application of chlomazone (@ 1.0 kg a.i. ha^{-1}).

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 meager 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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