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Weed management in turmeric

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ABSTRACT

Pre-emergence metribuzin 0.7 kg/ha, pendimethalin 1.0 kg/ha and atrazine 0.75 kg/ha each followed by i) hand weeding (HW) (45 and 75 DAP, days after planting), ii) fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha (45 DAP) and iii) mulch + HW (75 DAP); pre-emergence oxyflourfen 0.3 kg/ha and oxadiargyl 0.25 kg/ha and post-emergence glyphosate 1.23 and 1.85 kg/ha (25 DAP) each followed by HW (45 and 75 DAP); HW (25, 45 and 75 DAP) and untreated control were evaluated at Palampur during 2014, 2015 and 2016 to develop an effective weed management strategy in turmeric for mid hill conditions of Himachal Pradesh. Treatments constituting fenoxaprop + metsulfuron-methyl were phyto-toxic resulting in poor turmeric crop canopy formation thereby more growth of *Ageratum* sp. and lower plant height, plant stand, daughter corms/mother corm, rhizome yield and economics. Other weed control treatments were effective in controlling *Echinochloa colona* and other grassy weeds. With every g/m^2 increase in weed dry weight, the fresh turmeric rhizome yield was reduced by 64.2 kg/ha. Pre-emergence atrazine/ metribuzin/pendimethalin *fb* mulch *fb* hand weeding had effectively controlled weeds and increased the fresh rhizome yield by 54.1 to 54.9%, cured rhizome yield by 57.6 to 59.4% and net return by 66.4 to 68.3% being comparable to hand weeding thrice. However, hand weeding thrice was the costliest treatment. Atrazine/metribuzin/pendimethalin *fb* mulch *fb* hand weeding had lower weed persistence index and weed index and higher weed management index, agronomic management index, integrated weed management index and overall impact index than other treatments. Residues of metribuzin, atrazine, pendimethalin, oxyfluorfen and metsulfuron –-methyl in soil and rhizomes of turmeric were found below detectable level. Based on overall impact index metribuzin *fb* mulch *fb* hand weeding, atrazine *fb* mulch *fb* hand weeding and pendimethalin *fb* mulch *fb* hand weeding in that order are recommended as an alternative to hand weeding thrice in turmeric.

Key words: Impact, Herbicides, Loss, Turmeric, Weed management, Yield

India is the largest turmeric producer, consumer and exporter. Turmeric is the most important spice crop of low and mid hill areas of Himachal Pradesh. It is finding an important place as an alternative to maize particularly in wild boars, stray animals and porcupines infested areas. It is a long duration slow growing crop. Turmeric takes a long time to emerge and develop a canopy structure sufficient to compete with weeds. Thus it is invaded by a variety of summer and winter annuals as well as perennial weeds. Weeds compete with crop for nutrients, moisture and space and cause 35-80% (Krishnamurthy and Ayyaswamy 2000, Kaur *et al.* 2008) or even higher (Tadesee Eshetu *et al.* 2015) yield reduction. Non availability of labour hinders the timely removal of weeds. Use of straw and tree leaves as mulch in turmeric is another approach adopted by farmers that conserve soil moisture and moderates soil temperature for the benefit of crop (Mahey *et al.* 1986, Kaur *et al.* 2008, Manhas *et al.* 2011), besides controlling weeds (Hossain 2005). Pre-emergence application of pendimethalin (Kumar and Reddy 2000, Channappagoudar *et al.* 2013), atrazine (Singh and Mahey 1992), metribuzin (Gill *et al.* 2000), oxyflourfen or oxadiargyl save the crop from severe weed competition at an early stage. However, sole dependence on any single method may not provide an effective weed management in a long duration crop like turmeric. Integration of herbicides and mulches (Dillon and Bhullar 2014; Kaur *et al.* 2008) or herbicides and hand weeding/hoeing (Kaur *et al.* 2008, Singh *et al.* 2002) or application of pre- and post-herbicides sequentially (Barla *et al.* 2015) have been adjudged as the best practices for managing weeds in turmeric. Keeping these points in view, a study was initiated to develop an effective weed management strategy in turmeric for the mid-hill conditions of Himachal Pradesh.

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MATERIALS AND METHODS

The field experiment was conducted for three consecutive years of 2014, 2015 and 2016 at the Research Farm of Department of Agronomy, Forages and Grassland Management in randomized block design to evolve herbicide based integrated weed management schedule in turmeric. The experimental soil was silty clay loam in texture, acidic in reaction, medium in available nitrogen, phosphorus and high in available potassium. The treatments consisted of pre-emergence application of metribuzin 0.7 kg/ha *fb* (followed by) hand weeding at 45 and 75 DAP; pre-emergence metribuzin 0.7 kg/ha *fb* fenoxaprop 67 g/ ha + metsulfuron-methyl 4 g/ha at45 DAP; pre-emergence metribuzin 0.7 kg/ha *fb* straw mulch 5 t/ ha (5-10 DAP) *fb* hand weeding at 75 DAP; pre-emergence pendimethalin 1.0 kg/ha *fb* hand weeding at45 and 75 DAP; pre-emergence pendimethalin 1.0 kg/ha *fb* fenoxaprop 67g/ha + metsulfuron-methyl 4 g/ha at 45 DAP; pre-emergence pendimethalin 0.7 kg/ ha *fb* straw mulch 5 t/ha at 5-10 DAP *fb* hand weeding at75 DAP, pre-emergence atrazine 0.75 kg/ ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ ha at 45 DAP, pre-emergence atrazine 0.75 kg/ha *fb* straw mulch 5 t/ha at 5-10 DAP *fb* hand weeding at 75 DAP; pre-emergence oxyflourfen 0.30 g/ha *fb* hand weeding at 45 and 75 DAP, pre-emergence oxadiargyl *fb* hand weeding at 45 and 75 DAP; glyphosate 1230 g/ha *fb* hand weeding at 45 and 75 DAP; glyphosate 1845 g/ha *fb* hand weeding at 45 and 75 DAP, hand weeding at 25, 45 and 75 DAP and weedy check (**Table 1**). Turmeric variety '*Palampur Pitamber*' was planted on July 1, 2014, May 15, 2015 and May 31, 2016 with recommended package of practices except treatments. The crop was harvested on 15 January 2015, 25 December 2015 and 19 December 2016. Herbicides were applied with knapsack power sprayer using 600 L water per hectare. Data on density and dry weight of weeds were recorded one month after the treatments imposed.

The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) for the randomized block design to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability level. Standard error of mean was calculated in each case. When the 'F' value from analysis of variance tables was found significant, the least significant difference was computed to test the significance of the difference between the two treatments. The data on weed count and dry weight were subjected to square root transformation ($\sqrt{x+0.5}$). The economic threshold (=economic injury level), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, was calculated after Rana and Kumar (2014) as below:

Economic threshold = Gain threshold/Regression coefficient

Where, gain threshold = Cost of weed control (Hc+Ac)/Price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/ biomass (x), Y = a + bx.

The different impact indices were worked out after Rana and Kumar (2014) as follow:

$$WPI = \frac{Weed\ weight\ in\ treated\ plot}{Weed\ weight\ in\ control\ plot}\ x\ \frac{Weed\ count\ in\ control\ plot}{Weed\ count\ in\ treated\ plot}$$

Weed management index (WMI)

$$WMI = \frac{Percent\ yield\ over\ control}{Percent\ control\ of\ the\ pest}$$

Agronomic management index (AMI)

$$AMI = \frac{Percent\ yield\ over\ control - Percent\ control\ of\ the\ pest}{Percent\ control\ of\ the\ pest\ (weed)}$$

Integrated Management index (IWMI)

$$IWMI = \frac{WMI + AMI}{2}$$

Efficiency index (EI)

$$EI = \frac{\frac{Yield\ of\ treatment - Yield\ of\ control}{Yield\ of\ control}\ x\ 100}{\frac{Weed\ weight\ in\ treatment}{Weed\ weight\ in\ control}\ x\ 100}$$

Additionally 'overall impact index' based on weed control efficiency, yield and economic parameters was determined, by calculating firstly the 'comparable unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean value of treatments for that parameter as given below:

$$U_{ij} = \frac{V_{ij}}{AM_j}$$

Where U_{ij} is the unit value for i^{th} treatment corresponding to j^{th} parameter, V_{ij} is the actual measured value for i^{th} treatment and j_{th} parameter and AM_j is the arithmetic mean value for j^{th} parameter.

Secondly, the overall impact index was calculated as an average of unit values (U_{ij}) of all the parameters under consideration:

$$OI_i = \frac{1}{N}\sum_{i=1}^{N} U_{ij}$$

where OI_i is the overall impact index for i^{th} treatment and N is the number of parameters considered in deriving the index.

Soil and turmeric rhizome samples were collected at harvest to determine the residue of the applied herbicides. The residues of metribuzin, pendimethalin, atrazine and oxyflourfen were quantified on GC equipped with electron capture detector. Metsulfuron-methyl was analyzed using Shimadzu HPLC.

RESULTS AND DISCUSSION

Effect on weeds

The major weeds of the experimental field were *Echinochloa colona, Digitaria sanguinalis, Panicum dichotomiflorum, Commelina benghalensis, Cyperus iria, Ageratum* sp. *(A. conyzoides, A. houstonianum*) *Polygonum* sp.*, Physalis minima, Bidens pilosa* and *Aeschynomene indica*. Weed control treatments brought about significant variation in the count of *Echinochloa colona* (**Table 1**). All the weed control treatments except atrazine 750 g/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha and metribuzin *fb* hoeing significantly reduced the population of *Echinochloa colona* and other grassy weeds over weedy check. Metribuzin *fb* straw mulch *fb* hoeing, pendimethalin *fb* hoeing, pendimethalin *fb* fenoxaprop + metsulfuron-methyl, pendimethalin *fb* straw mulch *fb* hoeing and atrazine *fb* straw mulch *fb* hoeing were as good as weed free in reducing the population of *E. colona* and other grassy weeds.

Weed control treatments could significantly affect the count of *Ageratum* sp. during 2015 and 2016. Metribuzin 700 g/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha, pendimethalin *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha and atrazine *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha had completely eliminated *Ageratum* up to 60 DAP. Lateron *Ageratum* appeared in large number. Thus in most of the treatments, its count were either equal or higher than weedy check. In the weedy check, count of *Ageratum* was maximum at 60 DAS and decreased thereafter probably owing to intra- or inter-specific competition. The trend in the count of other weeds was similar as *Ageratum* sp. However,

Table 1. Effect of weed control treatments on count (no/m^2) of weeds

Treatment	Dose (kg/ha, t/ha)	Time (DAP)	*Echinochloa* sp.		Other grassy weeds		*Ageratum*		Other broad-leaf weeds	
			2015	2016	2015	2016	2015	2016	2015	2016
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	4.57 (14.0)	1.6 (2.0)	2.62 (5.9)	2.3 (5.3)	4.2 (15.4)	3.5 (13.0)	2.28 (4.3)	0.7 (0.0)
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	3.50 (11.2)	2.6 (6.7)	3.76 (13.2)	4.5 (20.7)	1.0 (0.0)	18.7 (350.0)	2.21 (3.9)	0.7 (0.0)
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	1.51 (1.3)	1.2 (1.0)	1.0 (0.0)	3.9 (15.0)	1.7 (1.9)	1.2 (1.0)	1.87 (2.5)	0.7 (0.0)
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	1.48 (1.2)	1.3 (1.3)	1.0 (0.0)	2.4 (5.3)	3.6 (12.0)	4.9 (24.0)	4.31 (17.6)	2.3 (8.7)
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	2.21 (3.9)	1.9 (3.3)	1.0 (0.0)	5.2 (26.7)	1.0 (0.0)	19.5 (380.0)	2.28 (4.2)	2.6 (9.7)
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	1.41 (1.0)	1.1 (0.7)	1.0 (0.0)	4.6 (21.0)	4.23 (16.9)	1.3 (1.7)	2.93 (7.6)	1.9 (4.0)
Atrazine *fb* two HW	750	0-2, 45, 75	4.18 (16.5)	1.3 (1.7)	4.33 (17.8)	2.9 (8.0)	1.0 (0.0)	4.8 (23.3)	2.62 (5.9)	1.4 (2.0)
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	4.08 (15.7)	1.2 (1.3)	3.86 (13.9)	5.6 (31.7)	1.51 (1.3)	18.0 (325.0)	2.21 (3.9)	1.4 (1.7)
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	2.73 (6.5)	1.7 (2.7)	3.24 (9.5)	3.8 (16.7)	3.86 (13.9)	2.6 (8.3)	2.42 (4.9)	1.0 (0.7)
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	2.30 (4.3)	2.1 (4.0)	2.5 (5.7)	3.7 (14.7)	3.30 (9.6)	5.4 (28.3)	3.25 (10.6)	3.0 (11.3)
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	1.37 (2.9)	2.5 (7.0)	2.38 (4.7)	3.6 (14.3)	3.0 (8.0)	4.6 (21.7)	3.40 (9.5)	2.3 (6.3)
Glyphosate *fb 2* HW	1230	25, 45, 75	1.26 (0.6)	1.0 (0.7)	1.48 (1.2)	3.6 (15.7)	1.9 (2.6)	7.6 (68.3)	1.51 (1.3)	1.2 (1.3)
Glyphosate *fb 2* HW)	1845	25, 45, 75	1.22 (0.5)	1.2 (1.3)	1.41 (1.0)	1.7 (3.0)	1.73 (2.0)	4.3 (21.3)	1.41 (1.0)	1.9 (3.3)
Hand weeding threee	Thrice	25, 45, 75	1.26 (0.6)	0.9 (0.3)	1.73 (2.0)	1.7 (3.0)	2.52 (3.1)	4.2 (23.3)	1.73 (2.0)	0.9 (0.3)
Weedy check			5.41 (28.3)	3.6 (12.7)	5.68 (31.3)	10.2 (103.3)	4.92 (23.5)	1.7 (3.0)	4.41 (18.5)	1.8 (3.0)
LSD (p=0.05)			1.59	1.0	0.39	1.6	0.37	2.8	0.11	NS

Herbicide, kg/ha; Mulch, t/ha; Figures in parentheses are the means of original values; Data transformed to square root transformation ($\sqrt{x+1}$); DAP - Days after planting treatment differences were not significant during 2016. This indicated contiguous or sporadic distribution of the weeds rather than uniform. Moreover, under Palampur conditions *Ageratum* usually appears by end of July or August in the available vacant space created after weeding or herbicidal control of other weeds. The lasting control of *Ageratum* is seldom achieved with pre-emergence herbicidal treatment only, so post emergence directed application is recommended.

Significantly highest total weed count (**Table 2**) was recorded under weedy check during 2014 and 2015. However, due to phytotoxicity of fenoxaprop + metsulffuron-methyl and subsequent higher emergence of *Ageratum*, total weed count under metribuzin/pendimethalin/atrazine *fb* fenoxaprop + metsulfuron treated plots was tremendously higher than other treatments as well as untreated check. However, other treatments resulted in significantly lower weed count than weedy check. Almost similar trend was observed with respect to dry weight of weeds where significantly minimum dry weight of weeds was recorded in metribuzin 700 g/ha *fb* hoeing remaining at par with pendimethalin 1000 g/ha *fb* hoeing and weed free treatment. Similar trend was observed with respect to weed control efficiency. The superior control of weeds due to integration of herbicides and mulches (Dillon and Bhullar 2014, Kaur *et al.* 2008) or herbicides and hand weeding/ hoeing (Kaur *et al*. 2008, Singh *et al*. 2002) or application of pre and post herbicides sequentially (Barla *et al.* 2015) in turmeric has been documented.

Effect on crop

There was significant variation in plant population due to treatments at harvest (**Table 3**). Due to phytotoxicity, pendimethalin/atrazine/ metribuzin *fb* fenoxaprop + metsulfuron-methyl resulted in significantly lower plant stand over the other treatments at harvest. The other treatments did not significantly differ from each other. Atrazine/ metribuzin/pendimethalin *fb* mulch *fb* hand weeding resulted in significantly higher daughter rhizomes over other treatments. Owing to phytotoxicity, metribuzin/pendimethalin/atrazine *fb* fenoxaprop + metsulfuron-methyl had significantly lower daughter rhizomes/mother rhizome over the other treatments. Oxyflourfen *fb* hand weeding also had lower rhizomes than hand weeding thrice or untreated

Table 2. Effect of treatments on total weeds count (no./m^2), total weed dry weight accumulation (g/m^2) and weed control efficiency

Treatment	Dose (g/ha; t/ha)	Time (DAP)	Total weed count (no./m2)				Total weed dry matter (g/m2)				WCE (%)			
			2014	2015	2016	Mean	2014	2015	2016	Mean	2014	2015	2016	Mean
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	6.86 45.7)	6.37 (39.6)	4.4 (20.3)	5.9 (35.2)	4.94 (23.5)	6.04 (35.6)	4.4 (19.0)	5.1 (26.0)	65.9	62.5	95.3	86.2
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	5.84 (33.20	5.41 (28.3)	19.4 (377.3)	10.2 (146.3)	1.70 (19.2)	4.92 (23.2)	17.6 (308.3)	9.0 (116.9)	72.1	75.6	23.2	38.0
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	2.86 (7.2)	2.58 (5.7)	4.2 (17.0)	3.1 (10.0)	2.30 (4.3)	2.66 (6.1)	3.9 (16.7)	3.0 (9.0)	93.7	93.5	95.9	95.2
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	6.33 39.1)	5.64 (30.8)	6.3 (39.3)	6.1 (36.4)	4.72 (21.3)	5.21 (26.2)	5.4 (29.0)	5.1 (25.5)	69.0	72.5	92.8	86.5
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	5.50 29.2)	5.05 (24.6)	20.5 (419.7)	10.3 (157.8)	4.27 17.2)	4.69 (21.0)	17.7 (314.3)	8.9 (117.5)	75.8	77.9	21.7	37.7
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	4.07 (15.6)	6.41 (40.1)	5.3 (27.3)	5.2 (27.7)	1.31 (7.3)	3.40 (10.6)	5.6 (33.3)	4.0 (17.1)	89.4	88.8	91.7	90.9
Atrazine *fb* two HW	750	0-2, 45, 75	6.64 (43.1)	6.30 (38.8)	5.9 (35.0)	6.3 (39.0)	5.22 (26.3)	5.58 (30.2)	4.3 (18.3)	5.0 (24.9)	61.6	68.3	95.4	86.8
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	6.28 (38.5)	5.98 (34.8)	19.0 (59.7)	10.4 (144.3)	4.76 (21.9)	5.10 25.1)	17.4 (301.7)	9.1 (116.2)	68.2	73.6	24.9	38.4
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	6.50 41.3)	5.98 (34.8)	5.1 (28.3)	5.9 (34.8)	4.58 20.0)	4.82 (22.2)	4.4 (20.0)	4.6 (20.7)	70.9	76.7	95.0	89.0
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	5.86 (33.4)	5.59 (30.2)	7.5 (58.3)	6.3 (40.6)	4.79 (22.0)	5.31 (27.1)	5.2 (26.7)	5.1 (25.3)	68.0	71.5	93.4	86.6
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	5.48 (29.1)	5.10 (25.6)	6.8 (49.3)	5.9 (34.7)	3.94 14.6)	4.50 (19.2)	5.6 (31.7)	4.7 (21.8)	78.8	79.8	92.1	88.4
Glyphosate *fb 2* HW	1230	25, 45, 75	3.22 (9.4)	2.58 (5.7)	8.5 (86.0)	5.0 (33.7)	4.02 (15.2)	4.25 (17.1)	5.4 (31.7)	4.6 (21.3)	77.9	82.0	92.1	88.7
Glyphosate *fb 2* HW)	1845	25, 45, 75	2.68 (6.2)	2.34 (4.5)	5.1 (29.0)	3.4 (13.2)	2.19 (3.8)	3.19 (9.2)	4.4 (20.0)	3.2 (11.0)	94.4	90.3	95.0	94.2
Hand weeding threee		25, 45, 75	2.50 (5.3)	2.94 (7.7)	4.8 (27.0)	3.5 (13.3)	2.0 (3.0)	1.97 (2.9)	4.1 (16.7)	2.6 (7.5)	95.6	96.7	95.9	96.0
Weedy check			8.08 (63.6)	10.12 (101.6)	11.1 (122.0)	9.7 (95.7)	8.36 (68.9)	9.81 (95.3)	20.1 (401.7)	12.7 (188.6)	0.0	0.0	0.0	0.0
LSD (p=0.05)			1.74	0.45	2.8	2.7	2.14	1.54	1.8	3.2	-	-		

Herbicide, kg/ha; Mulch, t/ha; Figures in parentheses are the means of original values; Data transformed to square root transformation ($\sqrt{x+1}$)

control. The rest of the treatments were comparable to hand weeding or weedy check in influencing daughter rhizomes/mother rhizome (**Table 3**). The weed control treatments brought about significant variation in the rhizome yield. All treatments were significantly superior to weedy check in influencing fresh rhizome yield. Metribuzin 700 g/ha *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha, pendimethalin *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha and atrazine *fb* fenoxaprop 67 g/ha + metsulfuron-methyl 4 g/ha were phytotoxic. The canopy formation could not take place and lately in these treatments *Ageratum* appeared prolifically. The yield was lower than other treatments probably owing to toxicity induced by the application of metsulfuron–methyl. This was in confirmation to earlier findings at this centre (Sachdeva *et al*. 2015). Barla *et al.* (2015) also reported toxicity of these treatments in turmeric at Birsa Agricultural University, Ranchi. Mulch proved to be the extremely important practice as the treatments constituting the straw mulch *viz*. pendimethalin/metribuzin/atrazine *fb* mulch *fb* hoeing resulted in significantly higher fresh rhizome yield over other treatments. Swain *et al.* (2007) also reported significantly higher fresh weight of rhizome per plant with application of paddy straw mulch as compared to no mulch. Weeds in unweeded check reduced the rhizome yield by 77.6% over the best treatment *i.e*. metribuzin/pendimethalin *fb* straw mulch *fb* hoeing. Metribuzin/pendimethalin/atrazine *fb* mulch *fb* hoeing increased fresh rhizome yield by three times over weed free. The corresponding cured rhizome yield under these treatments was also three times higher over weed free. The treatments metribuzin/pendimethalin *fb* hoeing was comparable to weed free in influencing the fresh and cured rhizome yield. The reduction in yield with increasing weed density has also been reported by Hossain *et al.* (2008).

Impact assessment

The economic threshold levels of weeds at the current prices of treatment and crop production on the basis of weed infestation in turmeric are given in **Table 4**. The economic threshold levels with the weed management practices studied varied between 4.8 to 11.2 g/m^2. It is clearly indicated that any increase in the cost of treatment would lead to higher value of economic threshold whereas an increase in price of crop produce would result in lowering the economic threshold. Hand weeding thrice had higher cost tending to increase the economic threshold more than the integrated weed management treatments. The linear relationship between weed dry weight (x) and fresh rhizome yield (Y) of turmeric is given here as under,

$$Y= 14132 – 64.2x \quad .... \quad (R^2= 0.602)$$

The equation explains that 60.2% variation in fresh rhizome yield due to weed dry weight could be explained by the regression equation. With every one gram per m^2 increase in weed weight, the fresh rhizome yield was expected to fall by 64.2 kg/ha.

Due to higher rhizome yield gross returns were highest following the application of atrazine *fb* mulch *fb* hand weeding. This was followed by metribuzin *fb*

Table 3. Effect of treatments on fresh and cured rhizome yield (t/ha)

Treatment	Dose (g/ha)	Time (DAT)	Daughter rhizome/ mother rhizome	Plant population (no./m^2)	Fresh rhizome yield (t/ha)				Cured rhizome yield (t/ha)			
			2016	2016	2014	2015	2016	Mean	2014	2015	2016	Mean
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	3.6	9.7	12.2	8.6	15.4	12.1	7.5	5.3	9.5	7.4
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	0.8	6.2	3.6	5.4	1.7	3.6	2.6	3.8	1.2	2.5
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	4.8	9.5	16.7	15.9	18.2	16.9	10.9	11.0	12.6	11.5
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	3.7	9.8	11.2	9.6	13.3	11.4	7.8	6.5	9.0	7.8
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	1.0	5.9	4.2	5.3	2.0	3.8	3.2	3.3	1.3	2.6
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	4.7	9.8	17.4	14.8	18.2	16.8	11.2	10.0	12.3	11.2
Atrazine *fb* two HW	750	0-2, 45, 75	3.9	10.1	11.2	5.0	17.0	11.1	8.1	3.2	10.9	7.4
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	1.1	6.0	3.5	4.6	1.6	3.2	2.1	2.6	0.9	1.9
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	5.4	9.4	16.5	11.2	22.2	16.6	12.1	8.5	14.4	11.7
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	2.7	9.5	11.5	10.9	10.9	11.1	8.9	8.4	7.3	8.2
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	3.7	9.5	14.3	11.7	15.4	13.8	9.8	8.9	10.1	9.6
Glyphosate *fb 2* HW	1230	25, 45, 75	3.3	9.6	11.4	8.5	12.5	10.8	5.9	4.5	6.6	5.7
Glyphosate *fb 2* HW)	1845	25, 45, 75	3.4	9.9	11.9	8.9	11.3	10.7	6.2	4.9	6.2	5.8
Hand weeding threee		25, 45, 75	3.8	9.9	13.7	13.4	15.8	14.3	11.1	11.0	9.8	10.6
Weedy check			3.7	9.5	7.9	2.9	12.1	7.6	4.9	1.8	7.5	4.7
LSD (p=0.05)			0.9	1.5	4.1	2.8	5.0	4.1	3.0	2.1	3.2	2.7

Herbicide, kg/ha; Mulch, t/ha; Values given in parentheses are the means of original values

Table 4. Effect of treatments on economics and impact indices

Treatment	Dose (g/ha, t/ha)	Time (DAP)	GR	COC	NR	B:C	WI	WPI	WMI	AMI	IWMI	TEI	OIi	Gt	Et
Metribuzin *fb* two hand weeding	700	0-2, 45, 75	353083	98237	254847	2.59	3.1	0.38	1.82	0.45	1.14	4.13	1.04	311	7.1
Metribuzin *fb* fenoxaprop + metsulfuron	700, 67 + 4	0-2, 45	120333	93557	26777	0.29	87.8	0.41	1.41	0.29	0.85	-0.75	0.41	230	5.2
Metribuzin *fb* straw mulch *fb* HW	700, 5	0-2, 0-5, 75	546250	98587	447663	4.54	-28.6	0.46	2.55	0.61	1.58	29.89	1.55	317	7.2
Pendimethalin *fb* 2 HW	1000	0-2, 45, 75	368917	99062	269855	2.72	8.2	0.36	1.90	0.47	1.19	4.74	1.06	326	7.4
Pendimethalin *fb* fenoxaprop + metsulfuron	1000, 67 + 4	0-2, 45	123500	93182	30318	0.33	86.7	0.38	1.46	0.31	0.89	-0.72	0.43	223	5.1
Pendimethalin *fb* straw mulch *fb* HW	1000, 5	0-2, 0-5, 75	530417	100612	429805	4.27	-25.5	0.31	2.59	0.61	1.60	15.01	1.50	353	8.0
Atrazine *fb* two HW	750	0-2, 45, 75	351500	97877	253623	2.59	-11.2	0.32	1.80	0.44	1.12	4.26	1.01	305	6.9
Atrazine *fb* fenoxaprop + metsulfuron	750, 67 + 4	0-2, 45	88667	92397	-3730	-0.04	90.8	0.41	1.03	0.03	0.53	-0.98	0.34	210	4.8
Atrazine *fb* straw mulch *fb* HW	750, 5	0-2, 0-5, 75	554167	98627	455540	4.62	-46.9	0.30	2.77	0.64	1.70	13.33	1.50	318	7.2
Oxyfluorfen *fb 2* HW	300	0-2, 45, 75	389500	99912	289588	2.90	25.5	0.32	2.00	0.50	1.25	5.47	1.10	340	7.7
Oxadiargyl *fb 2* HW	250	0-2, 45, 75	456000	98300	357700	3.64	-3.1	0.32	2.29	0.56	1.43	8.89	1.29	312	7.1
Glyphosate *fb 2* HW	1230	25, 45, 75	269167	96908	172259	1.78	32.7	0.32	1.35	0.26	0.80	1.74	0.91	288	6.6
Glyphosate *fb 2* HW)	1845	25, 45, 75	273917	97694	176223	1.80	36.7	0.42	1.29	0.23	0.76	3.74	0.94	302	6.9
Hand weeding threee		25, 45, 75	505083	108737	396347	3.65	0.0	0.29	2.34	0.57	1.46	31.26	1.41	494	11.2
Weedy check			224833	80337	144497	1.80	23.5	1.00	-	-	-	0.00	0.51	311	-
LSD (p=0.05)			-	-	-	-	-	-	-	-	-	-	-	-	-

Herbicide, g/ha; Mulch, t/ha; GR- gross return (`/ha); COC- cost of cultivation (`/ha); NR- net return (`/ha); B:C- benefit cost ration; WI- weed index; WPI- Weed persistence index; WMI- Weed management index; AMI- Agronomic management index; IWMI- Integrated weed management index; TEI- Treatment/herbicide efficiency index; OIi- Overall impact index; Gt- Gain threshold; Et- Economic threshold.

mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding and hand weeding thrice. Net returns followed the trend almost similar to gross returns. However, net returns under metribuzin/ pendimethalin/atrazine *fb* fenoxaprop + metsulfuron-methyl were lower than the untreated check. B:C was highest under atrazine *fb* mulch *fb* hand weeding (4.62), followed by metribuzin *fb* mulch *fb* hand weeding (4.54), pendimethalin *fb* mulch *fb* hand weeding (4.27), hand weeding thrice (3.65) and oxadiargyl *fb* hand weeding ((3.64). Weed index, a measure of the efficiency of a particular treatment as percentage of yield potential under weed free (hand weeding thrice in the present investigation) was minimum under atrazine *fb* mulch *fb* hand weeding (-46.9), followed by metribuzin *fb* mulch *fb* hand weeding (-28.6), pendimethalin *fb* mulch *fb* hand weeding (-25.5), atrazine *fb* hand weeding (-11.2) and oxadiargyl *fb* hand weeding (-3.1). The rest of the treatments had plus value of weed index indicating that much percent loss in yield under them relative to the weed free. Due to phytotoxicity, atrazine/ metribuzin/pendimethalin *fb* fenoxaprop + metsulfuron-methyl, glyphosate *fb* hand weeding and oxyflourfen *fb* hand weeding had higher weed index than untreated check. Weed persistence index was lowest under hand weeding thrice followed by atrazine *fb* mulch *fb* hand weeding and pendimethalin *fb* mulch *fb* hand weeding. Weed management index, agronomic management index and integrated weed management index were highest under atrazine *fb* mulch *fb* hand weeding followed by metribuzin *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding and hand weeding thrice. Efficiency index indicating the weed killing potential of a herbicide/treatment and its phytotoxicity on the crop, was highest under hand weeding thrice followed by metribuzin *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding and atrazine *fb* mulch *fb* hand weeding.

Since the treatments were not consistent or differed in performance with respect to the parameters studied, an overall impact index (OI_i) considering efficiency of weed control, yield and economics was drawn to have a valid inference. The overall impact index was highest for metribuzin *fb* mulch *fb* hand weeding, followed by atrazine *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding, hand weeding thrice and oxadiargyl *fb* hand weeding. Oxyflourfen *fb* hand weeding, pendimethalin *fb* hand weeding, metribuzin *fb* hand weeding and atrazine *fb* hand weeding also had higher overall impact index than the threshold value of one. The other treatments had lower overall impact index than the threshold value.

Herbicide residues

Metribuzin, pendimethalin, atrazine, oxyflourfen and metsulfuron-methyl residues in soil and turmeric samples collected at harvest were found to be below detectable levels. The sensitivity of technique was 0.001 µg/ml for metribuzin and atrazine; 0.05 ng/ml for pendimethalin and 0.01 ng/ml for oxyflourfen. Recoveries of metribuzin residues from fortified soil (0.05, 0.10 and 1.0 µg/g) and turmeric (1.00 and 2.00 µg/g) ranged from 89.2 to 98.2% in soil and 80.6 to 83.8% in rhizome. The calibration curve of pendimethalin was linear over the concentration range upto 10 mg/ml. Recoveries of pendimethalin residues from fortified soil and turmeric rhizome ranged from 79.3 to 83.8% in soil and 79.1 to 88.2%, respectively, The calibration curve was linear over the concentration range of 1 mg/ml to 10 mg/ml of atrazine and that of oxyflurofen over the concentration range of 0.01 to 10 mg/ml. The recovery of oxyflurofen residues ranged from 78.9 to 89.0% in soil and 82.9 to 90.6% in turmeric. The calibration curve showed linearity over the concentration range from 0.01 to 2 µg/ml for metsulfuron-methyl. The per cent recoveries of metsulfuron-methyl were 86.0, 83.0 and 84.2 in soil and 80.6, 79.0 and 78.0 in turmeric rhizome, respectively. The durations of persistence of glyphosate under Indian conditions are less than one month; of metribizin, oxyflourfen and metsulfuron-methyl are 1-3 months; of pendimethalin 3-6 months and of atrazine are more than 6 months (Janaki *et al*. 2015). Thus it was obvious that the herbicides used in the present investigation were below detectable level in the soil and rhizomes of turmeric.

This study concluded that in order of preference metribuzin *fb* mulch *fb* hand weeding, followed by atrazine *fb* mulch *fb* hand weeding, pendimethalin *fb* mulch *fb* hand weeding, hand weeding thrice and oxadiargyl *fb* hand weeding can be recommended for effective weed management in turmeric under mid hill conditions of Himachal Pradesh.

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