



RESEARCH ARTICLE

Weed phyto-sociology, economic profitability and herbicidal residues as influenced by weed management and intercultural operations in turmeric (*Curcuma longa* L.)

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Abstract

Turmeric is a long-duration and widespread crop, so the presence of weeds in crops that appear late often creates an ideal environment for their growth. Therefore, to develop effective weed management, herbicide residue and harvest management in turmeric, a field experiment was conducted with twelve weed management practices, viz. metribuzin followed by (*fb*) hand weeding (HW) at 45 and 75 days after planting (DAP), metribuzin *fb* rice straw mulch *fb* HW at 75 DAP, pendimethalin *fb* two HW at 45 and 75 DAP, pendimethalin *fb* rice straw mulch *fb* HW at 75 DAP, atrazine *fb* two HW at 45 and 75 DAP, atrazine *fb* rice straw mulch *fb* HW at 75 days, oxyfluorfen *fb* two HW at 45 and 75 DAP, glyphosate *fb* two HW at 45 and 75 days, glyphosate *fb* two HW at 45 and 75 DAP, HW thrice at 25, 45 and 75 DAP, organic weed control (rice mulch) and un-weeded check was conducted at Typic Hapludalfs soil conditions of North Western Himalayas. *Alternanthera philoxeroides* comprised over 67 % of the total weed flora, followed by *Ageratum conyzoides* (16 %). Pre-emergence atrazine *fb* mulch *fb* HW resulted in increased mean fresh rhizome yield, gross returns and benefit cost ratio (BCR). The rise in yield due to harvesting during the second cropping cycle ranged from 59-221 %, gross returns from 63-230 %, net returns from 139-1300 % and BCR from 216-1874 %. After two years, the cultivation cost dropped by 23-29 %. However, herbicide residue estimation demonstrates that turmeric rhizomes and soil contain below detectable quantities of metribuzin, atrazine, pendimethalin, oxyfluorfen and metsulfuron-methyl, which do not hinder the quality of soil and produce. Using integrated weed management strategies, such as pendimethalin *fb* straw mulch *fb* HW, resulted in the most significant percent increase in net returns due to harvesting after two years and lower herbicidal residues compared to other weed management treatments.

Keywords: economics budgeting; herbicides residue; important value index; integrated weed management; straw mulch; weeds phyto-sociology

Introduction

Curcuma longa L. is the native of Southeast Asia and is the largest produce (78 %), consumer and exporter (60 %) in India (1-3). Because of its deep yellow-orange colour, it is frequently called "Indian saffron" (4). In the northwestern (NW) Indian Himalayas, particularly in Himachal Pradesh, turmeric is a significant spice crop that has a long duration and is mainly grown biennially (5). This crop favours diversification, which protects the soil during the rainy season and is otherwise much vulnerable to soil and nutrient losses (6, 7). Turmeric crop may be critically infested with weeds during early growing periods (5). Due to the complexity of the canopy structure, it takes time for the crop to emerge and compete with weeds (3); as a result, it is infested with both annual and perennial weeds. Turmeric competes for growth factors with weeds and weeds cause 35-80 % of the damage or even higher yield reduction and

increasing production costs (8-11). Manual methods are essential for timely weed management; lacking labour during critical crop stages hampers timely weeding operations (5). Using mulch in turmeric, soil moisture is conserved and temperature is moderated (9, 12, 13), besides controlling weeds over a longer duration (5, 14).

Additionally, mulching enhances infiltration by restoring soil moisture, lessening evaporation, changing the physical environment and preventing soil erosion (15). However, mulch's impact also varies significantly in terms of the materials utilized and how differently they affect the production of hydrothermal regimes in soil and plant material. Although in pre-emergence applications, pendimethalin (16-19), oxyfluorfen, or oxadiargyl protect the crop from severe weed competition at an early stage. Nevertheless, relying solely on a single method may not be effective in weed management

in a long-term crop such as turmeric. Weed management in turmeric can be achieved by integrating herbicides and mulches (9, 20), hand weeding and hoeing (9, 21) or by applying pre- and post-herbicides sequentially (11). However, continuous use of herbicides poses concerns for human health, poses hazards to soil microorganisms and contaminates air and surface water (22).

Turmeric is a long duration crop and pre-emergence herbicides alone are not enough to control weeds during the critical crop-weed competition (CRWC) period (23), therefore, integration of post-emergence herbicides with inter-cultural operations and straw mulch are the key factors to controlling weeds during the CRWC period (24). Turmeric planted in April or later emerges quicker and is unaffected by weeds that emerge in the winter and spring seasons (14). It takes 7-10 months after planting for a crop to be ready for harvest. Usually, harvesting extends from January to February. Generally, varieties mature in 8-9 months for early varieties, 7-9 months for medium varieties and in > 9 months for late varieties (25). Harvest time greatly impacted the fresh and dried rhizome yields (26, 27). A plant species must be harvested at the right time to increase yield, quality and economic profitability (28, 29). Turmeric is typically harvested after two growing seasons, rather than after one season. However, there is limited literature available on harvest management effects i.e. harvest of the crop after two years of planting rather than in the next year on weed phyto-sociology, productivity, profitability and herbicide residues in turmeric under rain-fed Typic Hapludalfs soil conditions (silty clay loam, moist and well drained) of the Northwestern Himalayas. In this study, we further hypothesize that combined chemical and inter-cultural operations, integrated weed management treatments, positively influence phyto-sociology and reduce weed competition, enhancing economic profitability and minimizing herbicidal residue levels in the soil and plant tissues. Considering these points, this investigation was conducted to study the effect of different herbicides with and without rice straw mulch and inter-cultural operations and harvest management on rhizome yield, economics, herbicide residues on soil and fresh rhizomes in the turmeric crop.

Materials and methods

Experimental site

Palampur (32°6' N latitude, 76°3' E longitude and 1290 m above sea level) was the site of an experiment during 2017-2018 and 2018-19. Summers are mild and winters are cool in this sub-temperate region having silty-clay loam soil in texture, acidic in reaction (pH 5.08), high in organic carbon (11.0 g/kg) and phosphorus (25.8 kg/ha) and medium in available N (323.0 kg/ha) and K (276.4 kg/ha). Rainfall in the region averages 2809 mm per year, with most (73 %) falling during the monsoon season (May-September). Winter rains are received from December to March. The monsoon season usually receives longer mean sunshine hours than winter (Fig. 1). The average maximum temperature of the region was 30.1 °C during May. In contrast, the minimum temperature was 4.5 °C during January month of the year.

Experiment description

A randomized block design experiment with three replications was conducted to assess the effects of integrated weed management treatments on weeds, productivity and residue estimates in the turmeric field. The soil was adequately moistened before planting so that a tractor with a disc plough and harrow could prepare the seed bed effectively. The clumps of soil were broken up and planks were used to level the field, making it easier to prepare for planting. The field layout was completed with the assistance of workers using manual labour. The 'Palampur Pitamber' variety was planted in rows 45 cm apart with a seed rate of 20 q/ha with hand ploughing after putting rhizomes in the soil and covering it properly. All the sowing methods were followed according to recommendations, except for weed management during April. During the off-season, glyphosate spraying and general cleaning of the fields were employed for weed control. Herbicides and inter-culture operations were conducted following the treatment plan. The treatment description has been given in Table 1. During 2018, last year's experiment continued after estimating the yield.

During both years, knapsack power sprayers applied herbicides using 600 L of water per hectare. At planting, the crop was treated with 30 kg N, 30 kg P₂O₅ and 60 kg K₂O with urea, SSP and MOP, respectively. After spraying herbicides on the second day, rice straw was used as mulch. During the second year, the crop was harvested in January 2019. On maturity,

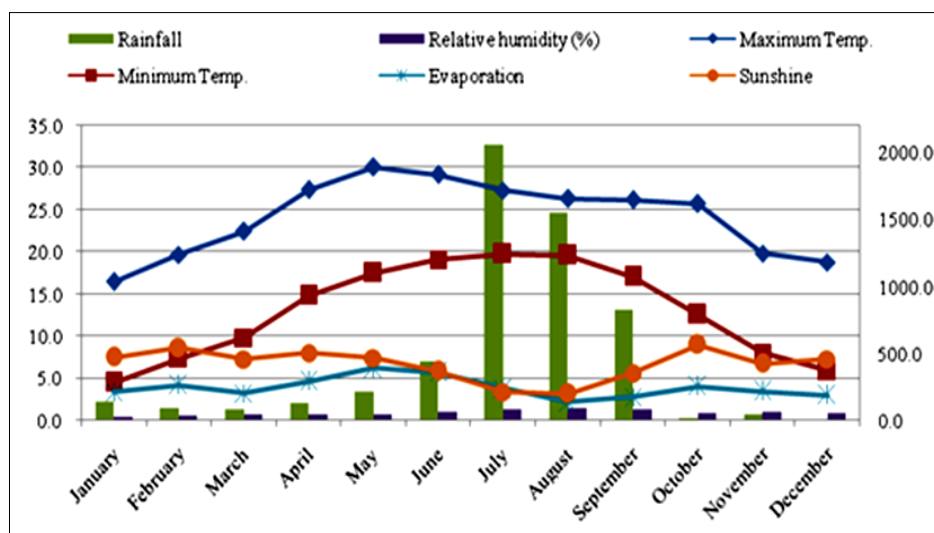


Fig. 1. Mean weather conditions of the experimental site.

Table 1. Treatment details and description

Treatment	First year	Second year	TOA herbicide (DAS)	TOA of straw application (DAS)	TOA of hand weeding (DAS)
T ₁	Metribuzin 0.7 kg/ha <i>fb</i> 2 HW	Metribuzin 0.7 kg/ha <i>fb</i> 2HW	2	-	45, 75
T ₂	Metribuzin 0.7 kg/ha <i>fb</i> straw mulch 10 t/ha <i>fb</i> 1HW	Metribuzin 0.7 kg/ha <i>fb</i> straw mulch 10 t/ha <i>fb</i> 1HW	2	2-5	75
T ₃	Pendimethalin 1.0 kg/ha <i>fb</i> 2 HW	Pendimethalin 1.0 kg/ha <i>fb</i> 2 HW	2	-	45, 75
T ₄	Pendimethalin 1.0 kg/ha <i>fb</i> straw mulch 10 t/ha <i>fb</i> 1 HW	Pendimethalin 1.0 kg/ha <i>fb</i> straw mulch 10 t/ha <i>fb</i> 1 HW	2	2-5	75
T ₅	Atrazine 0.75 kg/ha <i>fb</i> 2 HW	Atrazine 0.75 kg/ha <i>fb</i> 2HW	2	-	45, 75
T ₆	Atrazine 0.75 kg/ha <i>fb</i> straw mulch 10 t/ha <i>fb</i> 1 HW	Atrazine 0.75 kg/ha <i>fb</i> straw mulch 10 t/ha <i>fb</i> 1 HW	2	2-5	75
T ₇	Oxyfluorfen 0.30 kg/ha <i>fb</i> 2 HW	Pendimethalin 0.5 + atrazine 0.375 kg/ha <i>fb</i> 2HW	2	-	45, 75
T ₈	Glyphosate 5.0 mL/l <i>fb</i> 2 HW	Imazethapyr 75 g/ha <i>fb</i> 2HW	25	-	45, 75
T ₉	Glyphosate 7.5 mL/l <i>fb</i> 2 HW	Imazethapyr 100 g/ha <i>fb</i> 2HW	25	-	45, 75
T ₁₀	Hand weeding thrice	Hand weeding thrice	-	-	25, 45, 75
T ₁₁	Organic weed management (Mulch + HW)	Organic weed management (Mulch + HW)	-	2-5	25
T ₁₂	Un-weeded check	Un-weeded check	-	-	-

fb : followed by; **HW** : hand weeding, **TOA** : Time of application; **DAS** : Days after sowing

leaves turned yellow or dry and the crop from the net plots was harvested and dried. The rhizomes were gently pushed out of the soil without being cut or damaged. The harvested rhizomes were cleaned and fresh weight was taken to calculate the production per plot.

Data collection and phyto-sociology of weeds

In the first year, we recorded data on weeds' density and dry matter accumulation during November (180 DAP). Agro-ecosystem phyto-sociological surveys attempt to understand weed populations relationships to different crops and cropping systems to determine whether weeds and crops coexist. Therefore, these are useful in determining the most critical species during different crop growth seasons. Density (D), frequency (F) and abundance (A) were calculated as per the Eqn. 1-3. Relative density (RD), relative frequency (RF) and relative abundance were calculated according to equations reported in previous studies (30), Eqn. 4-6. The importance value index (IVI) is an appropriate measure for assessing the importance of species in vegetation since it considers several properties (31). IVI is calculated by combining the relative density, relative frequency and the relative abundance of one species in each plant density (32).

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates studied}} \quad (\text{Eqn. 1})$$

$$\text{Frequency (\%)} = \frac{\text{Total number of quadrates in which the species occurred}}{\text{Total number of quadrates studied}} \quad (\text{Eqn. 2})$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates in which the species occurred}} \quad (\text{Eqn. 3})$$

$$\text{Relative density (RD)} = \frac{\text{Density of individual species in the community}}{\text{Total density of weeds in the community}} \times 100 \quad (\text{Eqn. 4})$$

$$\text{Relative frequency (RF)} = \frac{\text{Frequency of individual species in the community}}{\text{Total Frequency of weeds in the community}} \times 100 \quad (\text{Eqn. 5})$$

$$\text{Relative abundance (RA)} = \frac{\text{Abundance of individual species in the community}}{\text{Total abundance of weeds in the community}} \times 100 \quad (\text{Eqn. 6})$$

$$\text{Important value index (IVI)} = \text{RD} + \text{RF} = \text{RA}$$

Weed control efficiency

The effectiveness of weed control treatments was calculated using Eqn. 7, as reported in a previous study (3), considering weed dry weight.

$$\text{Weed control efficiency (WCE)} = \frac{\text{Weed dry weight in control} - \text{Weed dry weight in treated plot}}{\text{Weed dry weight in control plot}} \times 100 \quad (\text{Eqn. 7})$$

Economic analysis

A net plot was dug and the rhizomes were weighed. Produce was recorded in kilograms (kg) before being converted to tons per hectare (t/ha). An economic analysis was conducted using input and output prices. The cost of cultivation was calculated by adding up input costs (33). The following economic indices have been calculated based on following formulas, Eqn. 8-10:

$$\text{Gross return (GR)} = \text{Economic value of crop} \times \text{yield of the crop} \quad (\text{Eqn. 8})$$

$$\text{Net return (NR)} = \text{GR} - \text{Total cost of cultivation (CC)} \quad (\text{Eqn. 9})$$

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Net returns over weedy (INR/ha)}}{\text{Variable cost}} \quad (\text{Eqn. 10})$$

*INR = Indian Net Rupees

Herbicide residue determination

At harvest, soil samples were collected to determine the herbicide residues on the turmeric rhizome. Gas chromatography (GC) with an electron capture detector was used to quantify metribuzin, pendimethalin, atrazine and oxyfluorfen residues. Shimadzu analyzed metsulfuron-methyl using high-performance liquid chromatography (HPLC).

Data analysis

A quadrat of 0.5 × 0.5 m was placed in each plot at 2 places to calculate the weed count at a monthly interval and then the mean value was calculated as weed count as an individual plot which was further added to calculate the total weed density in a particular treatment. To test whether significant differences resulted from the randomized block design, the data was analyzed using analysis of variance (ANOVA) using WASP 2.0 software and conclusions were drawn on a 5 % probability level (34). Each case was subjected to a standard error of mean calculation. When the 'F' value from the analysis of variance tables was significant, a minimum significant difference was calculated for each treatment.

Results and Discussions

Weed flora: Phyto-sociology and population

The results of phyto-sociological studies indicate that weed populations vary within a crop and that these variations correlate with production practices. Diverse weed management

strategies can be derived from these phyto-sociological studies (35). An important value index (IVI) would be high for dominating weed species. In October 2017, *Echinochloa colona*, *Digitaria sanguinalis*, *Commelina benghalensis*, *Cyperus iria*, *Cynodon dactylon*, *Paspalum dilatatum*, *Alternanthera philoxeroides*, *Ageratum conyzoides*, *Pennisetum cladeustum*, *Setaria glauca*, *Bidens pilosa* and *Aeschynomene indica* were found growing in turmeric. *Alternanthera philoxeroides* invaded the field at the first time and was the most important weed having the highest density, abundance, frequency, important value index (IVI) and summed dominance ratio (SDR) (Table 2).

However, *Alternanthera philoxeroides* is a perennial weed propagates through stolons which once emerge takes the space of the other weeds (36). In soybean-corn intercropping system, *Alternanthera philoxeroides* showed highest relative dominance (37). However, higher frequency and important value index for *A. philoxeroides* was also reported in previous studies (38). Based on their remarkable morphological and phenotypic versatility of *Cynodon dactylon*, *Cyperus iria* and *Digitaria sanguinalis*, the preponderance of species validates an excessive value of relevance in the phyto-sociological environment (39). The lowest phyto-sociological attributes in the study were found for *Setaria glauca* followed by *Bidens pilosa*. Changes in the climate, the makeup of the soil and management issues may all impact IVI values (40).

Effect of treatments on weed population (No./m²)

Weed control measures considerably impacted the population of *Digitaria sanguinalis* and *Galinsoga parviflora* at 90 days after planting (DAP) (Table 3). The count of *Digitaria sanguinalis* was significantly reduced by all weed management measures over weedy check at 90 DAP in turmeric. Atrazine/oxyfluorfen fb HW twice and pendimethalin/atrazine fb straw mulch fb HW, however, were unable to significantly reduce the count of *Galinsoga parviflora* over a weedy check. Due to weed management measures at 120 DAP (September), the count of *Ageratum conyzoides* greatly fluctuated. Organic weed management treatment had a higher count of this weed over weedy check and the other treatments except pendimethalin/atrazine/glyphosate fb HW. This year, the invasion of *Alternanthera philoxeroides* was brand-new and quite

Table 2. Weeds phyto-sociological characteristics during October, 2017 (N=36)

Weed species	TOI	TNI	D	F	A	RD	RF	RA	IVI	SDR
<i>Echinochloa colona</i>	21	864	24.0	58.3	41.1	6.0	8.4	7.1	21.4	7.1
<i>Ageratum conyzoides</i>	19	656	18.2	52.8	34.5	4.5	7.6	5.9	18.0	6.0
<i>Commelina benghalensis</i>	20	688	19.1	55.6	34.4	4.8	8.0	5.9	18.6	6.2
<i>Digitaria sanguinalis</i>	31	1680	46.7	86.1	54.2	11.6	12.4	9.3	33.3	11.1
<i>Cyperus iria</i>	30	1792	49.8	83.3	59.7	12.4	12.0	10.3	34.6	11.5
<i>Cynodon dactylon</i>	30	2352	65.3	83.3	78.4	16.2	12.0	13.5	41.7	13.9
<i>Paspalum dilatatum</i>	15	416	11.6	41.7	27.7	2.9	6.0	4.8	13.6	4.5
<i>Alternanthera philoxeroides</i>	34	4576	127.1	94.4	134.6	31.6	13.5	23.2	68.3	22.8
<i>Pennisetum cladeustum</i>	16	416	11.6	44.4	26.0	2.9	6.4	4.5	13.7	4.6
<i>Setaria glauca</i>	8	256	7.1	22.2	32.0	1.8	3.2	5.5	10.5	3.5
<i>Bidens pilosa</i>	12	336	9.3	33.3	28.0	2.3	4.8	4.8	11.9	4.0
<i>Aeschynomene indica</i>	15	448	12.4	41.7	29.9	3.1	6.0	5.1	14.2	4.7

TOI : Total occurrence of individual; **TNI** : Total number of individual; **D** : density; **F**: Frequency; **A** : Abundance; **RD** : Relative density; **RF**: Relative frequency; **RA** : Relative abundance; **IVI** : Important value index; **SDR** : Summed dominance ratio

Table 3. Effect of weed management measures on the weed count (No. m⁻²) during 2017

Treatment	<i>Digitaria</i> \$	<i>Gallinsoga</i> \$	<i>Ageratum</i> #	<i>Alternanthera</i> *	Total weed Count ¥	WCE (%)
Metribuzin <i>fb</i> 2 HW	7.7 ^a (58.7)	1.8 ^{ab} (5.3)	1.8 ^{ab} (5.3)	11.6 ^{bcd} (133.3)	17.1 ^{ab} (293.3)	36.8
Metribuzin <i>fb</i> straw mulch <i>fb</i> 1HW	7.2 ^a (53.3)	3.5 ^{ab} (16.0)	4.0 ^{ab} (21.3)	12.6 ^{cd} (160.0)	18.0 ^{abc} (325.3)	29.9
Pendimethalin <i>fb</i> 2 HW	7.7 ^a (58.7)	2.4 ^{ab} (10.7)	6.5 ^c (42.7)	12.2 ^{cd} (149.3)	16.5 ^{ab} (272.0)	41.4
Pendimethalin <i>fb</i> straw mulch <i>fb</i> 1 HW	8.8 ^a (80.0)	4.0 ^b (21.3)	2.8 ^{ab} (16.0)	12.0 ^{cd} (144.0)	19.5 ^{bc} (384.0)	17.2
Atrazine <i>fb</i> 2 HW	7.3 ^a (53.3)	5.2 ^c (26.7)	5.0 ^b (26.7)	9.8 ^{bc} (96.0)	18.0 ^{abc} (330.7)	28.7
Atrazine <i>fb</i> straw mulch <i>fb</i> 1 HW	7.7 ^a (58.7)	6.9 ^c (48.0)	0.7 ^a (0.0)	12.2 ^{cd} (149.3)	18.5 ^{abcd} (341.3)	26.4
Oxyfluorfen <i>fb</i> 2 HW	8.5 ^a (74.7)	4.0 ^b (21.3)	3.9 ^{ab} (21.3)	10.8 ^{bcd} (117.3)	16.3 ^a (266.7)	42.5
Glyphosate <i>fb</i> 2 HW	7.3 ^a (53.3)	2.4 ^{ab} (10.7)	2.4 ^{ab} (10.7)	11.1 ^{bcd} (122.7)	17.1 ^{ab} (293.3)	36.8
Glyphosate <i>fb</i> 2 HW	7.2 ^a (53.3)	0.7 ^a (0.0)	4.5 ^{ab} (26.7)	3.7 ^a (32.0)	18.6 ^{abcd} (346.7)	25.3
Hand weeding thrice	8.3 ^a (69.3)	0.7 ^a (0.0)	1.8 ^{ab} (5.3)	8.9 ^b (80.0)	16.2 ^a (266.7)	42.5
Organic weed management (Mulch + HW)	7.6 ^a (58.7)	1.8 ^{ab} (5.3)	8.0 ^c (64.0)	13.0 ^d (170.7)	20.7 ^{cd} (426.7)	8.0
Un-weeded check	11.8 ^b (144.0)	6.7 ^c (48.0)	3.5 ^{ab} (16.0)	13.1 ^d (170.7)	21.5 ^d (464.0)	0.0
SEm±	0.8	1.1	1.4	1.1	1.0	-
LSD (P<0.05)	3.0	3.0	4.0	3.0	3.0	-

Values given in parentheses are the means of original values; Data transformed to square root transformation ($\sqrt{x + 0.5}$); \$, 90 DAS (August); #, 120 DAS (September); *150 DAS (October); ¥, 180 DAS (November); **WCE**: weed control efficiency; **HW**: hand weeding; **fb**, followed by; **LSD**: Least significant difference; **SEm**: standard error of mean

problematic for turmeric. Only the glyphosate 7.5 mL/L *fb* HW twice significantly reduced the population of *Alternanthera philoxeroides*. Previous research concluded that post-herbicide application of glyphosate minimizes the viable stolon production of *Alternanthera philoxeroides* (41). Compared to organic weed management, all chemical treatments-including pendimethalin *fb* mulch *fb* HW and glyphosate 7.5 mL/L *fb* HW significantly lower the overall weed population. However, earlier studies indicated that overall weed population at 180 DAP was increased noticeably under different weed control techniques due to heavy monsoon rainfall accounting for 85 % of the total rainfall which promoted weed proliferation and reduced the efficacy of control measures through herbicide leaching, soil-herbicide binding and rainfall intensity and frequency (42, 43).

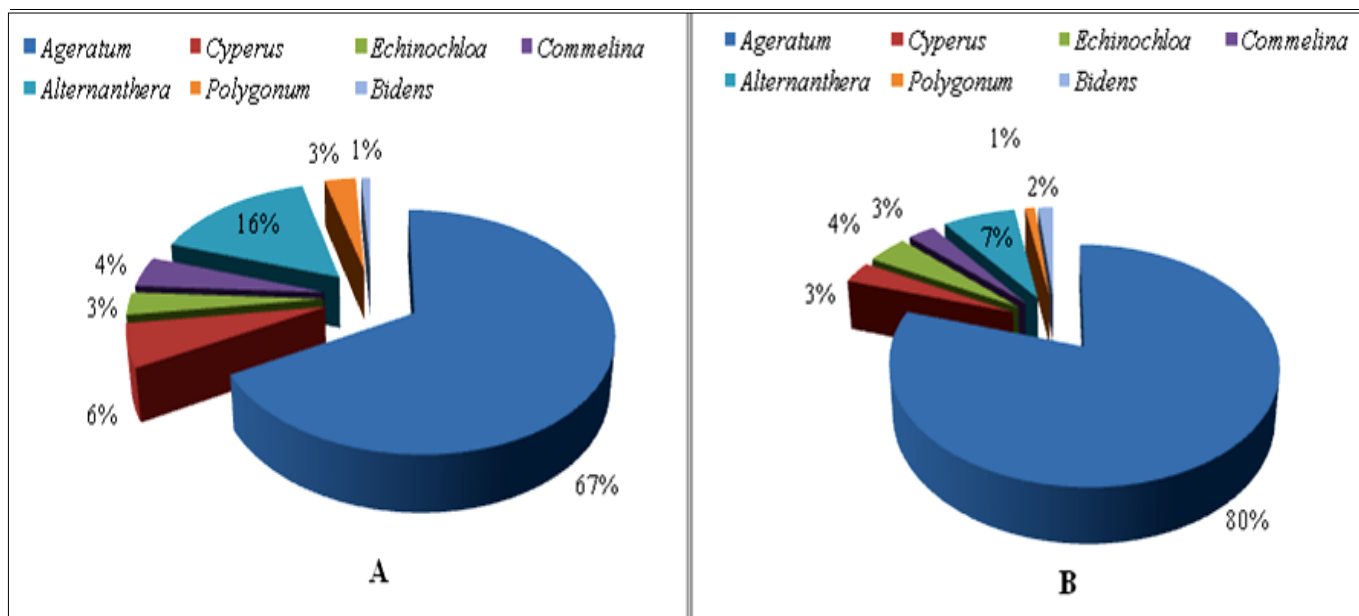
Additionally, the turmeric variety grew at a low height, leading to poor canopy formation and several weed flushes (3). But oxyfluorfen/pendimethalin *fb* HW twice had greater WCE than the other treatments. During 2018, the weed flora shifted to *Ageratum conyzoides* (67 %), *Cyperus iria* (5.8 %), *Echinochloa colona* (3.1 %), *Commelina benghalensis* (4.3 %), *Alternanthera philoxeroides* (15.8 %), *Polygonum alatum* (3.1 %) and *Bidens pilosa* (0.9 %) as is indicated in the overall scenario presented in Table 4 & Fig. 2 (A & B). During 2018, population of *Ageratum conyzoides*, *Echinochloa colona* and *Bidens pilosa* and total weeds under an undisturbed environmental scenario were higher as compared to the overall situation and vice-versa in the case of the rest of the weeds. It indicated that these weeds were more aggressive, but their population decreased when some control measures were adopted. The population of other weeds built up as they found space to grow after the population of the main weeds was reduced. *Ageratum conyzoides* and *Alternanthera philoxeroides* were recorded at all the stages of observation (July-November); *Cyperus iria* and *Commelina benghalensis* until September; and *Echinochloa colona* until August. *Commelina*

benghalensis and *Bidens pilosa* grew from August and September onwards, respectively. However, in December and January, none of the above species and new species were recorded and fields were clean except for the crop owing to the shedding and drying of vigorous turmeric growth, which served as a complete canopy cover.

Table 5 summarises the overall impact of treatments on various weeds and the mean total weed population. *Ageratum conyzoides*, *Cyperus iria* counts and the overall weed count were significantly altered by weed control methods. *Ageratum conyzoides* population was considerably reduced by pendimethalin *fb* straw mulch *fb* HW while remaining statistically ($P < 0.05$) similar to metribuzin *fb* straw mulch *fb* HW, atrazine *fb* straw mulch *fb* HW and organic weed control treatment. However, compared to other integrated treatments, the count of *Cyperus iria* was statistically ($P < 0.05$) lower under atrazine *fb* straw mulch *fb* HW. Similarly, research reported about the lower population of *Cyperus* sp. under integrated weed management treatment with a combination of atrazine *fb* fenoxaprop +metsulfuron-methyl in turmeric crop (1). In treatments where mulch was used in conjunction with chemical weed control techniques and manual weeding, the population of these weeds was dramatically reduced. Similar results were also reported in previous studies (3, 44). However, weed control measures did not considerably impact *Echinochloa colona*, *Commelina benghalensis*, *Alternanthera philoxeroides*, *Polygonum alatum*, *Bidens pilosa* populations and other weeds. The total weed count did, however, significantly vary ($P < 0.05$) due to treatments. The overall weed count was significantly reduced when pendimethalin *fb* straw mulch *fb* HW was used and it remained comparable to atrazine *fb* straw mulch *fb* HW and organic weed control measures (mulch + HW). Although, compared to manual weeding three times, the application of integrated weed

Table 4. Weeds floristic composition in the experimental turmeric field during 2018

	Density (No./m ²)		Proportion	
	Overall	Undisturbed	Overall	Undisturbed
<i>Ageratum conyzoides</i>	238.2	412.7	67.0	79.9
<i>Cyperus iria</i>	20.6	16.0	5.8	3.1
<i>Echinochloa colona</i>	11.0	21.3	3.1	4.1
<i>Commelina benghalensis</i>	15.1	14.2	4.3	2.8
<i>Alternanthera philoxeroides</i>	56.0	38.7	15.8	7.5
<i>Polygonum alatum</i>	11.1	5.3	3.1	1.0
<i>Bidens pilosa</i>	3.3	8.0	0.9	1.5
	355.4	516.2	100.0	100.0

**Fig. 2.** Weeds floristic composition during 2018 (A: Overall situation; B: Undisturbed situation).**Table 5.** Effect of weed management measures on the mean weed count (No./m²) during 2018

	<i>Ageratum conyzoides</i>	<i>Cyperus iria</i>	<i>Echinochloa colona</i>	<i>Commelina benghalensis</i>	<i>Alternanthera philoxeroides</i>	<i>Polygonum alatum</i>	<i>Bidens Pilosa</i>	Total weed count	WCE (%)
Metribuzin fb 2 HW	21.1 ^e (444.0)	7.0 ^c (50.7)	2.8 (9.3)	4.2 (17.8)	5.7 (37.3)	2.9 (10.7)	0.7 (0.0)	23.8 ^f (569.8)	74.8
Metribuzin fb straw mulch fb 1 HW	8.8 ^{ab} (88.5)	3.2 ^{ab} (9.8)	2.1 (8.0)	5.7 (32.9)	9.3 (88.0)	2.9 (10.7)	1.4 (2.7)	15.4 ^{bc} (240.5)	79.2
Pendimethalin fb 2 HW	18.1 ^{cd} (329.3)	4.2 ^{abc} (21.3)	1.2 (1.3)	1.6 (2.7)	7.2 (65.8)	2.6 (8.0)	0.7 (0.0)	20.6 ^{def} (428.5)	52.5
Pendimethalin fb straw mulch fb 1 HW	6.2 ^a (41.1)	3.0 ^{ab} (8.9)	0.7 (0.0)	3.1 (12.4)	5.3 (34.7)	1.8 (5.3)	2.1 (8.0)	10.2 ^a (110.4)	54.2
Atrazine fb HW twice	15.2 ^{cd} (231.7)	3.2 ^{ab} (15.1)	3.6 (20.0)	2.9 (10.0)	7.3 (65.3)	5.4 (29.3)	1.4 (2.7)	19.3 ^{cdef} (374.1)	66.7
Atrazine fb straw mulch fb 1 HW	9.5 ^{ab} (91.3)	2.4 ^{ab} (7.1)	2.6 (8.0)	3.7 (15.1)	8.4 (72.0)	1.8 (5.3)	2.2 (5.3)	14.3 ^{ab} (204.2)	65.8
Pendimethalin + atrazine fb 2 HW	12.9 ^{bc} (198.7)	3.5 ^{ab} (14.2)	0.7 (0.0)	6.2 (45.3)	6.9 (54.7)	1.4 (2.7)	2.1 (8.0)	17.4 ^{bcd} (323.6)	52.5
Imazethapyr fb 2 HW	17.1 ^{cde} (304.7)	3.7 ^{ab} (13.3)	3.4 (16.0)	2.6 (6.2)	9.1 (92.0)	3.5 (16.0)	1.4 (2.7)	21.0 ^{def} (450.9)	61.7
Imazethapyr fb 2 HW	18.0 ^{cde} (323.8)	7.0 ^c (50.7)	4.7 (26.7)	2.8 (9.8)	4.7 (30.0)	4.6 (29.3)	1.4 (2.7)	21.7 ^{def} (472.9)	53.3
Hand weeding thrice	17.1 ^{cde} (298.0)	5.4 ^b (31.1)	4.1 (18.7)	2.6 (7.1)	2.1 (4.7)	0.7 (0.0)	0.7 (0.0)	18.8 ^{cdef} (359.6)	52.5
Organic weed management (Mulch + 1 HW)	8.8 ^{ab} (94.7)	2.2 ^a (8.9)	1.4 (2.7)	2.9 (8.0)	9.4 (88.7)	2.9 (10.7)	0.7 (0.0)	14.2 ^a (213.6)	55.0
Un-weeded check	19.9 ^{de} (412.7)	3.8 ^{ab} (16.0)	4.0 (21.3)	3.3 (14.2)	5.3 (38.7)	1.8 (5.3)	2.1 (8.0)	22.4 ^{ef} (516.2)	0.0
SEm±	1.8	1.0	1.2	1.0	1.6	1.1	0.8	1.5	-
LSD (P<0.05)	5.4	3.1	NS	NS	NS	NS	NS	4.5	-

Values given in parentheses are the means of original values; Data transformed to square root transformation ($\sqrt{x + 0.5}$); **WCE**, weed control efficiency; **HW**, hand weeding; **fb**, followed by; **LSD**: Least significant difference; **SEm**: standard error of mean

management treatments typically reduces the population of all weeds.

The overall weed population in this situation was substantially greater during second year of experimentation due to asymmetrical rainfall distribution at the Northwestern Himalayas. Alligator weed, also known as *Alternanthera philoxeroides*, was recently introduced to this area and poses a serious threat to the environment for farming, especially before the rainy season. However, considering its invasiveness, spreading strength, tolerance to environmental alteration and adaptive potential, *Alternanthera philoxeroides* has been described as one of the worst weeds in the world (45), as well as its adverse effects on the environment and the economy.

However, research noted that *Ageratum conyzoides* and *Echinochloa colona* were the two most significant weeds of the turmeric crop. Furthermore, *Ageratum conyzoides* typically emerges in late July or early August in open spaces left after other weeds have been cleared by weeding or herbicide treatment (46). Because it is difficult to control permanently with pre-emergence herbicides alone, a post-emergence directed application is recommended for effective management (32). However, research reported that hand weeding three times resulted in higher WCE. In turmeric, compared to different chemical treatments. Additionally, weed control can be significantly improved by using mulch in addition to herbicides or applying pre and post-emergence herbicides in succession in turmeric was reported (8, 14, 20, 21).

Effects of treatments on rhizome yield and economic profitability

In 2018, weed control treatments considerably increased fresh and cured rhizome yield compared to the weedy check (Table 6). A significant ($P < 0.05$) increased yield of fresh and cured rhizomes was obtained after the pre-emergence application of metribuzin *fb* straw mulch, *fb* HW. Fresh rhizomes yield in un-weeds reduced weeded check by 52.8 % compared to the best treatment, metribuzin *fb* straw mulch *fb* HW (Table 6). Similar fresh rhizome yield and cured rhizome yield (t/ha), higher than the weedy check treatment, were produced by hand weeding three times and organic weed management (mulch + HW). Mulch use boosted above-ground biomass in organic weed control, which increased rhizome output. Paddy straw mulch considerably

enhanced the fresh weight of rhizomes per plant (47). Although, turmeric yield and weed control rely on mulching materials (48), which have variable rates of soil moisture retention, resulting in increased shoot and root growth and crop biomass accumulation compared to treatment without mulch application (49, 50). However, compared to un-weeded check, the yield increased by around 50 % in treatment with a combination of manual weeding and mulching. Similarly, research indicates that un-unweeded check decreased the fresh rhizome production of the turmeric crop by 63-78 % (3, 8). In addition, integrating turmeric cultivation practices effectively suppresses weed growth and improves turmeric yields (8, 51-54).

The cost of cultivation under different weed management treatments varied from 110.8 (000' INR/ha) to 140.5 (000' INR/ha) (INR, Indian Net Rupees) for hand weeding three times. Weedy checks produced negative net returns since the cost was more significant than the gross yield. Maximum net returns and BCR (benefit in INR due to per INR invested in weed control) were accrued under metribuzin *fb* mulch *fb* HW and minimum under oxyfluorfen *fb* 2 HW. During the second year (2019), metribuzin *fb* straw mulch *fb* 1 HW resulted in a higher yield after one season (S1). In contrast, pendimethalin *fb* 2 HW had a higher rhizome yield when harvesting was done after two years and the mean of two seasons (Table 7). When the rhizomes were removed after the second year of crop rather than after every cropping season, the yield during the second year was much higher than during the previous year. It is undeniably true that the yield was noticeably higher when the crop was harvested following the second crop growth cycle than in the sum of the two annual harvests. Since organic weed control is just as successful as conventional herbicidal techniques and increases yields of fresh and cured rhizomes, mulching is crucial to turmeric cultivation. The results showed that weed management is necessary for both methods of treating turmeric, but hand weeding or incorporating metribuzin/atrazine with mulch worked better. The same is true for BCR and gross and net returns (Table 8 & 9). Atrazine *fb* straw mulch *fb* HW had a greater mean benefit cost ratio (BCR) (Table 9). Due to lower planting and harvesting costs, the average yearly cost of cultivation was lower after two seasons. The percentage increase in yield attributable to harvesting after two years ranges from 59-221 % under various treatments (Table 10); gross returns range from 63-231 %, net

Table 6. Effect of weed management measures on fresh, cured rhizome yield (t ha⁻¹) and economics (000' INR ha⁻¹) during 2018

Treatment	Fresh rhizome yield (t/ha)	Cured rhizome Yield (t/ha)	GR	CC	NR	BCR
Metribuzin <i>fb</i> 2HW	8.92 ^a	5.48 ^a	222.9 ^a	130.9	91.9 ^a	4.57
Metribuzin <i>fb</i> straw mulch <i>fb</i> 1HW	9.02 ^a	5.55 ^a	225.5 ^a	130.2	95.3 ^a	4.94
Pendimethalin <i>fb</i> 2 HW	7.55 ^{ab}	4.64 ^{ab}	188.7 ^{ab}	131.2	57.4 ^{ab}	2.82
Pendimethalin <i>fb</i> straw mulch <i>fb</i> 1 HW	7.18 ^{ab}	4.42 ^{ab}	179.5 ^{ab}	132.1	47.4 ^{ab}	2.22
Atrazine <i>fb</i> 2 HW	8.69 ^a	5.35 ^a	217.4 ^a	129.5	87.9 ^a	4.72
Atrazine <i>fb</i> straw mulch <i>fb</i> 1 HW	8.62 ^a	5.30 ^a	215.5 ^a	129.9	85.5 ^a	4.47
Oxyfluorfen <i>fb</i> 2 HW	6.29 ^{bc}	3.87 ^{bc}	157.2 ^{bc}	131.7	25.5 ^b	1.22
Glyphosate <i>fb</i> 2HW	7.96 ^a	4.90 ^{ab}	199.1 ^{ab}	129.1	70.0 ^{ab}	3.84
Glyphosate <i>fb</i> 2HW	7.54 ^{ab}	4.64 ^{ab}	188.4 ^{ab}	129.1	59.4 ^{ab}	3.26
Hand weeding thrice	7.78 ^{ab}	4.78 ^{ab}	194.4 ^{ab}	140.5	53.9 ^{ab}	1.81
Organic weed Management (Mulch + 1 HW)	7.78 ^{ab}	4.78 ^{ab}	194.4 ^{ab}	137.6	56.9 ^{ab}	2.13
Un-weeded check	4.26 ^c	2.62 ^c	106.5 ^c	110.8	-4.4 ^c	-
SEm±	0.70	0.43	17.5	-	17.5	-
LSD (p=0.05)	2.06	1.27	51.5	-	51.5	-
F value	0.57	0.41	2.27		1.77	
p value	0.78	0.86	0.34		0.41	

fb : followed by; **HW** : Hand weeding; **GR** : gross return (000' INR/ha); **CC** : Cost of cultivation (000' INR/ha); **NR** : net return (000' INR/ha); **BCR** : Benefit cost ratio; **INR** : Indian net rupees; **HW** : hand weeding; *fb*, followed by; **LSD** : Least significant difference; **SEm** : standard error of mean

Table 7. Effect of weed control measures on turmeric fresh rhizome production (t ha⁻¹)

Treatment	Rhizome yield (t/ha)								
	2018	2019			2018+2019				
		S1	S2	Mean	S1	S2	Mean		
Metribuzin <i>fb</i> 2 HW	8.92 ^a	13.8 ^{ab}	36.2 ^{cd}	25.0 ^{bc}	22.7 ^a	36.2	29.5		
Metribuzin <i>fb</i> straw mulch <i>fb</i> 1 HW	9.02 ^a	14.0 ^a	42.8 ^{ab}	28.4 ^{ab}	23.0 ^a	42.8	32.9		
Pendimethalin <i>fb</i> 2 HW	7.55 ^{ab}	11.7 ^d	46.5 ^a	29.1 ^{ab}	19.2 ^c	46.5	32.9		
Pendimethalin <i>fb</i> straw mulch <i>fb</i> 1 HW	7.18 ^{ab}	11.1 ^{de}	45.7 ^{ab}	28.4 ^{ab}	18.3 ^c	45.7	32.0		
Atrazine <i>fb</i> 2 HW	8.69 ^a	13.5 ^{ac}	42.0 ^{ab}	27.7 ^{abc}	22.2 ^a	42.0	32.1		
Atrazine <i>fb</i> straw mulch <i>fb</i> 1 HW	8.62 ^a	13.4 ^a	46.1 ^{ab}	29.7 ^a	22.0 ^{ab}	46.1	34.0		
Oxyfluorfen <i>fb</i> 2 HW	6.29 ^{bc}	9.7 ^e	36.6 ^{cd}	23.2 ^c	16.0 ^d	36.6	26.3		
Glyphosate <i>fb</i> 2 HW	7.96 ^{ab}	12.3 ^{bcd}	37.0 ^{cd}	24.7 ^c	20.3 ^{bc}	37.0	28.7		
Glyphosate <i>fb</i> 2 HW	7.54 ^{ab}	11.7 ^d	41.2 ^{bc}	26.4 ^{abc}	19.2 ^c	41.2	30.2		
Hand Weeding thrice	7.78 ^{ab}	12.1 ^c	41.6 ^{ab}	26.8 ^{abc}	19.8 ^c	41.6	30.7		
Organic weed management (Mulch + 1 HW)	7.78 ^{ab}	12.1 ^c	43.6 ^{ab}	27.8 ^{ab}	19.8 ^c	43.6	31.7		
Weedy check	4.26 ^c	6.6 ^f	34.2 ^d	20.4 ^d	10.9 ^e	34.2	22.5		
Mean		11.8	41.1		19.5	41.1			
		T	S	T×S (1)	T×S (2)	T	S	T×S (1)	T×S (2)
SEm±	0.7	0.9	0.5	1.8	1.6	0.9	0.6	2.0	1.7
LSD(P<0.05)	2.1	2.6	1.5	5.2	4.5	2.7	1.7	NS	NS
F value	0.96		0.31	1.46	4.99		2.14	1.50	0.51
p value	0.61		0.92	0.47	0.17		0.36	0.46	0.81

S1: harvesting after one season; **S2:** harvesting after two years; **T7, T8 and T9** were replaced with atrazine + pendimethalin *fb* HW, imazethapyr 75 g/ha *fb* HW twice and imazethapyr 100 g/ha *fb* HW twice, respectively during the second year; **T,** treatment; **S,** season; **T×S (1),** interaction of treatments with first season; **T×S (2),** interaction of treatments with second season

Table 8. Turmeric mean cultivation costs and profits under various weed control measures

	CC (000 ³ INR/ha/annum)			GR (000 ³ INR/ha/annum)			
	S1	S2	Mean	S1	S2	Mean	
Metribuzin <i>fb</i> 2 HW	136	103	119	298 ^a	489	393	
Metribuzin <i>fb</i> straw mulch <i>fb</i> HW	135	102	119	301 ^a	578	440	
Pendimethalin <i>fb</i> 2 HW	136	103	120	252 ^{bc}	628	440	
Pendimethalin <i>fb</i> straw mulch <i>fb</i> 1 HW	137	104	121	240 ^c	617	428	
Atrazine <i>fb</i> 2 HW	135	101	118	291 ^a	567	429	
Atrazine <i>fb</i> straw mulch <i>fb</i> 1 HW	135	102	118	288 ^a	622	455	
Oxyfluorfen <i>fb</i> HW	137	103	120	210 ^d	494	352	
Glyphosate <i>fb</i> 2 HW	134	101	117	266 ^b	500	383	
Glyphosate <i>fb</i> 2 HW	134	101	117	252 ^{bc}	556	404	
Hand Weeding thrice	146	113	129	260 ^{bc}	561	411	
Organic weed management (Mulch + 1 HW)	143	110	126	260 ^{bc}	589	424	
Weedy check	115	82	99	142 ^e	461	302	
Mean	135	102		255	555		
				T	S	T×S (1)	T×S (2)
SEm±	-	-	-	13	8	27	23
LSD(P<0.05)	-	-	-	36	23	NS	NS
F value					0.32		
P value					0.91		

S1: harvesting after one season; **S2:** harvesting after two years; Mean, mean of season first and second; **GR,** Gross return; **INR,** Indian Net Rupees; **HW:** hand weeding; *fb*: followed by; **LSD:** Least significant difference; **SEm:** standard error of mean; **T:** treatment; **S:** season; **T×S (1),** interaction of treatments with first season; **T×S (2),** interaction of treatments with second season

Table 9. Turmeric mean net returns and BCR under various weed control measures

	Net return (000 ³ INR/ha)				BCR			
	S1	S2	Mean	S1	S2	Mean		
Metribuzin <i>fb</i> 2 HW	162 ^a	386	274	1.19 ^a	3.76 ^d	2.47 ^{bc}		
Metribuzin <i>fb</i> straw mulch <i>fb</i> 1 HW	166 ^a	476	321	1.23 ^a	4.67 ^{ab}	2.95 ^{ab}		
Pendimethalin 2 HW	116 ^c	525	320	0.85 ^{cd}	5.10 ^a	2.97 ^{ab}		
Pendimethalin <i>fb</i> straw mulch <i>fb</i> 1 HW	103 ^c	513	308	0.75 ^d	4.93 ^{ab}	2.84 ^{ab}		
Atrazine <i>fb</i> 2 HW	156 ^a	466	311	1.16 ^{ab}	4.60 ^{bc}	2.88 ^{ab}		
Atrazine <i>fb</i> straw mulch <i>fb</i> 1 HW	153 ^{ab}	521	337	1.13 ^a	5.12 ^a	3.13 ^a		
Oxyfluorfen <i>fb</i> 2 HW	73 ^d	391	232	0.53 ^e	3.78 ^d	2.16 ^c		
Glyphosate <i>fb</i> 2 HW	132 ^b	399	266	0.98 ^{bc}	3.96 ^c	2.47 ^{bc}		
Glyphosate <i>fb</i> 2 HW	118 ^c	455	286	0.88 ^{cd}	4.52 ^{ab}	2.70 ^{abc}		
Hand Weeding thrice	114 ^c	448	281	0.78 ^{cd}	3.98 ^c	2.38 ^{bc}		
Organic weed management (Mulch + 1 HW)	117 ^c	479	298	0.82 ^{cd}	4.37 ^{bcd}	2.60 ^{abc}		
Weedy check	27 ^e	379	203	0.24 ^f	4.64 ^{bc}	2.44 ^c		
Mean	120	453		0.88	4.45			
	T	S	T×S (1)	T×S (2)	T	S	T×S (1)	T×S (2)
SE(m±)	13	8	27	23	0.12	0.07	0.25	0.21
LSD(P<0.05)	36	23	NS	NS	0.35	0.21	0.71	0.61
F value		1.47				0.67	1.71	0.23
p value		0.91				0.73	0.42	0.95

S1: harvesting after one season; **S2:** harvesting after two years; Mean, mean of season first and second; **BCR:** Benefit cost ratio; **INR:** Indian net rupees; **HW:** hand weeding; *fb*: followed by; **LSD,** Least significant difference; **SEm:** standard error of mean; **T:** treatment; **S:** season; **T×S (1),** interaction of treatments with first season; **T×S (2),** interaction of treatments with second season

Table 10. Percent increase owing to harvesting after two years of growth over the harvesting after first years of growth

	Rhizome yield	GR	NR	BCR	CC
Metribuzin <i>fb</i> 2 HW	58.7	63.4	138.6 ^c	216	24.6
Metribuzin <i>fb</i> straw mulch <i>fb</i> 1 HW	86.5	92.1	186.5 ^b	281	24.8
Pendimethalin <i>fb</i> 2 HW	145.0	152.3	353.3 ^{ab}	501	24.5
Pendimethalin <i>fb</i> straw mulch <i>fb</i> 1 HW	175.3	183.6	399.7 ^a	561	24.4
Atrazine <i>fb</i> 2 HW	92.1	97.8	198.5 ^{bc}	297	24.9
Atrazine <i>fb</i> straw mulch <i>fb</i> 1 HW	113.2	119.5	240.3 ^{bc}	352	24.8
Oxyfluorfen <i>fb</i> 2 HW	130.3	137.2	434.4 ^a	607	24.5
Glyphosate <i>fb</i> 2 HW	84.2	89.7	202.6 ^{bc}	303	25.0
Glyphosate <i>fb</i> 2 HW	118.8	125.4	286.4 ^{abc}	415	25.0
Hand weeding thrice	117.1	123.6	294.0 ^{abc}	411	22.9
Organic weed management (Mulch + 1 HW)	126.2	133.0	310.0 ^{abc}	435	23.4
Weedy check	221.1	230.7	300.2 ^{abc}	1874	29.1
SE(m±)	33.6	34.7	138.6		
LSD(P<0.05)	NS	NS	186.5		
F value			0.42		
p value			0.86		

fb : followed by; **HW**: Hand weeding; **GR**: gross return (000' INR/ha); **CC**: Cost of cultivation (000' INR/ha); **NR**: net return (000' INR/ha); **BCR**: Benefit cost ratio; **INR**, Indian Net Rupees; **HW**: hand weeding; *fb* : followed by; **LSD**: Least significant difference; **SEm**, standard error of mean

returns from 139-1300 % and BCR from 216-1874 %. After two years, the comparable drop in cultivation costs was 23-29 %.

Herbicide residue estimation

Atrazine, oxyfluorfen, metribuzin, pendimethalin and metsulfuron-methyl residues in soil and samples of turmeric taken during harvest were discovered to be below detectable levels. The method's sensitivity was 0.001 g/mL for metribuzin and atrazine, 0.05 mg/mL for pendimethalin and 0.01 mg/mL for oxyfluorfen. Fortified soil (0.05, 0.10 and 1.0 g/g) and turmeric (1.0 and 2.00 g/g) yielded residues of metribuzin in a range of 89.2-98.2 %, whereas rhizomes yielded residues in the range of 80.6-83.8 %. Pendimethalin has a linear calibration curve up to 10 mg/mL. Pendimethalin residues were recovered from reinforced soil and turmeric rhizome in 79.3-83.8 % and 79.1-88.2 %, respectively. The calibration curves of atrazine and oxyfluorfen over the 1 mg/mL concentration ranges to 10 mg/mL and 0.01-10 mg/mL were linear, respectively. There was a 78.9-89.0 % recovery of oxyfluorfen residues in soil and 82.9-90.6 % recovery of residues in turmeric. Metsulfuron-methyl recovery percentages in soil were 86.0, 83.2 and 84.2; in turmeric rhizome, they were 80.6, 79 and 78 %. This indicates that the herbicides employed in this investigation were not detectable in the turmeric soil or rhizomes. Atrazine and pendimethalin are persistent for three to six months, while glyphosate is persistent for less than a month, oxyfluorfen is persistent for one to three months and metribuzin is persistent for more than six months (55). The persistence of atrazine and pendimethalin at below threshold levels was also reported in previous findings (3). However, previous research have indicated the toxicity of these herbicides on turmeric (11).

Conclusion

In conclusion, integration of pre-emergence atrazine *fb* straw mulch *fb* HW, pendimethalin *fb* mulch *fb* HW and metribuzin *fb* mulch *fb* HW is advised for the best weed control, productivity and profitability in the turmeric crop. Furthermore, the findings underscore the environmental safety of these practices, as pesticide residues were found to be below detection limits in both the soil and the turmeric rhizomes. The extended growing

season contributes to greater yields and enhanced economic returns, offering a promising solution for sustainable turmeric farming in the Northwestern Himalayas.

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Authors' contributions

SSR conceptualized the research design and supervised the field experiments. NS conceptualized the research design and supervised the field experiments. SK collected data, analyzed the data and contributed to writing the manuscript. AS¹ and AS² collected data, analyzed the data, contributed to writing the manuscript and revised and corrected the manuscript. PC revised and corrected the manuscript. AK revised and corrected the manuscript. MS revised and corrected the manuscript. All authors read and approved the final version of the manuscript [AS¹ - Ankit Saini and AS² - Singh].

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

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