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Weed management in turmeric (*Curcuma longa*) through integrated approaches

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ABSTRACT

A field study was conducted at Ludhiana during 2006-07 and 2007-08 and at Nawanshah during 2007-08 to find out effective and economical approaches for weed management in turmeric (*Curcuma longa L.*). Pre-emergence pendimethalin 1.0 kg, metribuzin 0.70 kg and atrazine 0.75 kg/ha, each integrated with one hoeing at 60 days, paddy straw mulch 6 t and 9 t/ha; paddy straw mulch 6 t (recommended), 9 t/ha alone and 6 t/ha + two hoeing at 60 and 90 days; three hoeing at 30, 60 and 90 days and unweeded control were evaluated. Losses in rhizome yield due to weeds vary from 63.9 to 76.5%. Straw mulch 9 t/ha significantly reduced weed dry matter and recorded 29.2% higher rhizome yield than 6 t/ha. Averaged over two locations, pendimethalin + straw mulch 9 t/ha revealed the highest weed control efficiency (84.2%), fresh rhizome yield (29.6 t/ha), herbicide efficiency index (11.2), net returns (103 ◊ 10^3 Rs/ha) and benefit : cost ratio (2.30) and was at par with metribuzin and atrazine, both integrated with straw mulch 9 t/ha. The fresh rhizome yield with straw mulch 9 t/ha + herbicide combination was 48.2, 14.9, 15.3 and 225.5% higher than straw mulch 6 t, 9 t/ha alone, 6 t/ha + herbicide and unweeded control, respectively. Different weed control measures led to 104.8ñ289.1, 72.7ñ220.4 and 90.5ñ278.1% increase in N, P and K uptake by crop, respectively, over unweeded control. Uncontrolled weeds removed 60.6, 59.9 and 73.6% of total nutrients utilized by both crop and weeds. Integrated use of paddy straw mulch 9 t/ha with either of pendimethalin 1.0 kg, metribuzin 0.70 kg and atrazine 0.75 kg/ha was adjudged very effective for weed control and attaining the highest productivity and profitability in turmeric.

Key words: Herbicide, Integrated, Straw Mulch, Turmeric, Weeds

Turmeric (*Curcuma longa* L.) is a major spice crop, occupying 6% of the total area under spices and condiments in India. Its cultivation provides avenues for crop diversification, value addition and revenue generation. It is grown for its rhizomes, which are mainly used as a spice for flavouring and for coloring many food-stuffs. Curcumin (an essential oil) and oleoresin are also extracted from turmeric. Though India leads in production of turmeric with 75% of global production, its average productivity is quite low, mainly due to the competition offered by weeds which reduce yield by 30-75% (Krishnamurthy and Ayyaswamy, 2000). Slow initial growth and its poor canopy development provides an ideal environment for weeds to grow and compete with the crop. Farmers have to go for sequential weeding, which adds to the cost of weed management. Non-availability of labour hinders the timely removal of weeds. Straw mulch is another approach adopted by the farmers that conserves soil moisture and modifies soil temperature for benefit of crop, besides controlling weeds (Mahey *et al.,* 1986). Mulching suppresses weed growth and improves crop yield (Hossain, 2005). Pre-emergence herbicides viz. pendimethalin (Anil-Kumar and Reddy, 2000), atrazine (Singh and Mahey, 1992) and metribuzin (Gill *et al.,* 2000) help save the crop from severe weed competition at an early age. However, sole dependence on any single method may not provide a long-lasting and effective weed management in a long-duration crop like turmeric. Hossian *et al.* (2008) revelaed that for higher yield of turmeric the weeds need to be removed during 70 to 160 days after planting, indicating that it needs a longer period free from weeds than other crops. This necessitates developing effective and economically better integrated weed-control practices for realizing high productivity of turmeric. Keeping these points in view, the present study was planned.

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MATERIALS AND METHODS

A field study was conducted at research farm of Punjab Agricultural University at Ludhiana (30° 56 'N latitude and 75° 52 'E longitude) during 2006-07 and 2007-08, and at Nawanshah (31° 07 'N latitude and 76° 08 'E longitude) during 2007-08. The soil at Ludhiana was loamy sand with pH 8.0, electrical conductivity, (EC) 0.20 dS/m organic C 0.29%, and available P 21.2 kg, available K 235 kg/ha, whereas the corresponding figures for Nawanshahr were sandy loam, 7.8, 0.1 dS/m, 0.57%, 15.5 kg and 346.5 kg/ha. There were 14 weed-control treatments, viz. pre-emergence pendimethalin 1.0 kg, metribuzin 0.70 kg and atrazine 0.75 kg/ha, each integrated with one hoeing at 60 days after planting, paddy-straw mulch 6 t and 9 t/ha; paddy-straw mulch 6 t (recommended) 9 t/ha alone and 6 t/ha + two hoeing at 60 and 90 days; three hoeings at 30, 60 and 90 days and unweeded control. A randomized block design was followed in four replications. Well-rotten farmyard manure (FYM) @ 30.0 t/ha on fresh-weight basis was thoroughly mixed into the soil two weeks before planting during 2006 and @ 20.0 t/ha during 2007 at Ludhiana; whereas at Nawanshahr FYM was not added in the field. The crop was planted on flat beds at 30 x 20 cm spacing on 5 May 2006 and 15 May 2007 at Ludhiana and on 20 May 2007 at Nawanshahr. The field was irrigated immediately after planting. All the herbicides were sprayed on the third day of planting at proper soil-moisture conditions and the paddy-straw mulch was spread, as per treatment, immediately after application of herbicides. The crop was harvested on 10 January 2007 and 2 January 2008 at Ludhiana and 16 January 2008 at Nawanshahr.

Data on weed population and dry-matter accumulation were recorded at 60 and 120 days at Ludhiana and were subjected to $\sqrt{x+1}$ transformation, whereas only visual observations on the effect of weed-control treatments on different weed species were recorded at Nawanshahr. Data on rhizome emergence were recorded at 30 and 50 days and were subjected to arc-sign transformation before analysis. The crop-leaf area index was recorded at 120 days, and the rhizome number and weight per plant along with fresh-rhizome yield were noted at the time of harvest. Nitrogen, phosphorus and potassium contents of weeds, rhizomes and above-ground parts of crop plants were estimated by standard laboratory procedures during 2006-07 at Ludhiana only; and nutrient depletion by weeds was estimated at 120 days whereas crop uptake at the time of crop harvest. The prevailing market prices of inputs and outputs were taken into account for economic analysis of different weed-control treatments. Main inputs for calculating the cost of cultivation included the cost of seed (Rs 15,000/ha), human labour (Rs 6,815/ha), fertilizers and manures (Rs 4,593/ha), one hoeing (Rs 1,880/ha), paddy-straw mulch (Rs 250/t), pendimethalin (Rs 1,502/kg), metribuzin (Rs 2,910/kg), atrazine (Rs 803/kg), tractor hours (Rs 2,000/ha), and harvesting and cleaning (Rs 9,400/ha), marketing and transport (Rs 110/t). The market price of fresh rhizomes was Rs. 5,000/t.

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora observed in the experimental field at Ludhiana included purple nutsedge (*Cyperus rotundus*), goose grass (*Acrachne racemosa*), large crabgrass (*Digitaria sanguinalis*), crow foot grass (*Eleusine aegyptiacum*), barnyard grass (*Echinochloa crusgalli*), love grass (*Eragrostis pilosa*), day flower (*Commelina benghalensis*), goose grass (*Eleusine indica*), garden spurge (*Euphorbia hirta*), sleeping plant (*Phyllanthus niruri*), horse purslane (*Trianthema portulacastrum*) and pig weed (*Amaranthus viridis*). At Ludhiana pendimethalin and metribuzin alone recorded effective control of *A. racemosa, E. crusgalli, E. aegyptiacum* and *D. sanguinalis* (Table 1). However, atrazine gave poor control of *D. sanguinalis* and was also ineffective against *A. racemosa*. *Cyperus rotundus* was not controlled by the herbicides and it grew profusely in the absence of other weeds. Application of paddy-straw mulch alone or along with herbicides reduced the population of *Cyperus rotundus* and other annuals compared with its non-application, and its higher rate was more effective. In the unweeded control, higher population of annual grasses did not allow *C. rotundus* to flourish and thus its population was lower than of all other weed-control treatments. The total weed population was the highest under unweeded control at 60 days but was on par with all the three herbicides used alone (Table 2). One hoeing resulted in emergence of more number of *C. rotundus* plants, which increased the total weed population compared with unweeded control when the data were recorded at 120 days. Visual observations at Nawanshahr revealed weed species similar to those recorded at Ludhiana except *P. niruri* and *T. portulacastrum,* which were not observed here. False amaranth (*Digera arvensis*), black nightshade (*Solanum nigrum*) and love grass (*Eragrostis tenella*) recorded only at Nawanshahr, which were effectively controlled by all the weed-control treatments. The effects of straw mulch and herbicides on different weed species at Nawanshahr were similar to that recorded at Ludhiana.

Pre-emergence application of all the three herbicides alone kept the weeds under check during the first 30 days (data not shown). However, poor and delayed sprouting favoured the weeds at later stages, which increased the dry matter of weeds. Straw mulch at both the rates was equally effective in reducing the dry-matter accumulation of weeds during the first 60 days; higher rate suppressed it for a longer period and proved superior at later stages of crop growth, though the differences were significant during 2006-07 only (Table 2). The-weed control efficiency with straw mulch at both the rates was similar at 60 days, but at 120 days it decreased sharply to 13.9% under 6 t and it was 51.6% under 9 t/ha. Early sprouting of rhizomes and higher emergence with straw mulch created favourable environment for the crop to grow and produce more leaf

Table 1. Effect of different weed-control treatments on population (no/m^2) of different weed species at Ludhiana (mean data of 2006-07 and 2007-08)

Treatment	*Cyperus rotundus*		*Echinochloa crus-galli*		*Eleusine aegyptiacum*		*Acrachne racemosa*		*Digitaria sanguinalis*	
	60 days	120 days	60 days	120 days	60 days	120 days	60 days	120 days	60 days	120 days
T_1- Pendimethalin 1.0* + hoeing at 60 days	6.64[a] (45.9)	8.86 (77.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.76 (2.1)	1.0 (0)	2.79 (6.8)	1.83 (3.7)
T_2- Pendimethalin 1.0 + straw mulch 6 t/ha	4.72 (22.2)	3.48 (11.1)	1.0 (0)	1.83 (3.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.83 (3.7)
T_3- Pendimethalin 1.0 + straw mulch 9 t/ha	5.06 (25.9)	2.57 (5.7)	*1.0 (0)*	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.82 (3.7)
T_4- Metribuzin 0.7 + hoeing at 60 days	4.72 (22.2)	4.37 (18.5)	2.15 (4.3)	1.83 (3.7)	2.57 (5.6)	1.0 (0)	2.02 (3.1)	1.0 (0)	2.59 (5.7)	2.59 (5.7)
T_5- Metribuzin 0.7 + straw mulch 6 t/ha	4.36 (18.4)	2.65 (7.4)	1.0 (0)	1.0 (0)	1.83 (3.7)	1.0 (0)	1.76 (2.1)	1.0 (0)	1.0 (0)	1.83 (3.7)
T_6- Metribuzin 0.7 + straw mulch 9 t/ha	4.70 (22.7)	2.59 (7.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.83 (3.7)
T_7- Atrazine 0.75 + hoeing at 60 days	4.72 (22.2)	2.65 (7.4)	2.03 (3.7)	1.0 (0)	1.83 (3.7)	1.0 (0)	5.6 (33.3)	1.0 (0)	3.51(11.5)	2.65 (7.4)
T_8- Atrazine 0.75 + straw mulch 6 t/ha	5.35 (29.5)	5.93 (34.8)	1.0 (0)	1.83 (3.7)	1.0 (0)	1.0 (0)	3.38 (10.4)	1.0 (0)	1.82 (3.7)	2.08 (4.0)
T_9- Atrazine 0.75 + straw mulch 9 t/ha	2.65 (7.4)	1.83 (3.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	2.19 (3.8)	1.0 (0)	1.0 (0)	1.82 (3.71)
T_{10}- Straw mulch 6 t/ha + hoeing at 60, 90 days	3.13 (9.1)	3.44 (11.1)	1.58 (1.5)	1.0 (0)	2.64 (6.0)	1.0 (0)	3.87 (14)	1.0 (0)	2.55 (5.5)	1.83 (3.7)
T_{11}- Straw mulch 6 t/ha	3.10 (11.1)	3.32 (10)	1.67 (1.8)	1.83 (3.7)	2.73 (8)	1.0 (0)	3.52 (11.4)	1.0 (0)	2.55 (5.5)	2.65 (7.4)
T_{12}- Straw mulch 9 t/ha	4.35 (18.3)	3.02 (8.1)	1.64 (1.6)	1.83 (3.7)	2.10 (3.4)	1.0 (0)	2.02 (3.1)	1.0 (0)	1.61 (1.6)	1.83 (3.7)
T_{13}- Hoeing at 30, 60, 90 days	4.32 (18.1)	6.36 (40.7)	1.0 (0)	1.83 (3.7)	3.46 (11)	1.0 (0)	1.0 (0)	1.0 (0)	3.93 (14.8)	1.0 (0)
T_{14}- Unweeded	1.83 (3.7)	1.0 (0)	1.82 (3.7)	1.0 (0)	4.49 (19.2)	4.4 (18.5)	3.56 (11.7)	1.0 (0)	3.48 (11.1)	2.65 (7.4)
SEm±	0.75	0.53	0.33	0.46	0.52	0.25	0.38	0	0.43	0.69
CD (P=0.05)	2.14	1.50	0.94	1.31	1.48	0.70	1.07	NS	1.24	NS

*Dose in kg/ha; [a] data subjected to $\sqrt{x+1}$ transformation, Figures in parentheses are original values

area, which helped the crop suppress the weeds over without mulch application. Integration of straw mulch 6 t/ha with herbicide reduced the dry matter of weeds significantly compared with the use of respective herbicide alone at early and of straw mulch 6 t/ha at later stage of crop. It indicated the synergistic effect of integrated approach for suppressing the weeds in a long-duration crop like turmeric. The increase in mulch rate from 6 to 9 t/ha, with the same herbicide reduced the dry-matter accumulation of weeds by 31.5 to 63.1%, showing the beneficial effect of using higher mulch rate even in the presence of a herbicide. Pendimethalin 1.0 kg/ha revealed the highest weed-control efficiency (84.2%) at 60 days, closely followed by atrazine 0.75 kg/ha (82.8%) and metribuzin 0.70 kg/ha (76.9%), all integrated with straw mulch 9 t/ha. These straw mulch and herbicide combinations maintained higher weed-control efficiency (67.0 to 77.4%) at 120 days also.

Effective control of weeds in turmeric has been reported with atrazine 0.62 kg/ha (Singh and Mahey, 1992), pendimethalin 1.0 kg (Anil Kumar and Reddy, 2000) and metribuzin 0.70 kg (Gill *et al.*, 2000). However, in our study the herbicides alone did not provide the desired long-term weed control because slow and delayed sprouting gave enough space for the weeds to multiply. Randhawa (1997) reported that wheat-straw mulch at 6 t/ha kept the weeds under check up to 120 days, but in our study it was up to 60 days only perhaps because paddy straw mulch decomposed faster than wheat-straw mulch, and hence its higher level of 9 t/ha proved better.

Nutrient depletion by weeds

Weeds in the unweeded control removed 103.5, 19.7 and 170.4 kg/ha N, P and K respectively (which were the highest), and 60.6, 59.9 and 73.6% total N, P and K removed by both crop and weeds (Table 2). The corresponding figures were only 4.9, 6.4 and 11.7% for metribuzin 0.70 kg/ha + straw mulch 9 t/ha. This indicates that where the removal of nutrients by weeds was more, the corresponding uptake by the crop was less and *vice versa*. The increase in straw-mulch level from 6 to 9 t/ha significantly reduced the nutrient depletion by weeds. As the differences in nutrient content in the weeds were non-significant among different weed-control treatments (data not presented), nutrient uptake by weeds followed a trend similar as that of dry matter of weeds.

Effect on crop

The increase in the rate of straw mulch from 6 to 9 t/ha increased the fresh-rhizome yield by 29.2%, which was significantly higher at both the locations (Table 4). Integration of straw mulch 6 t/ha with herbicide or two hoeings gave rhizome yield on a par with that of straw mulch 9 t/ha, but these were significantly better than straw mulch 6 t/ha alone and combination of herbicide + hoeing. The increase in the rate of straw mulch from 6 to 9 t/ha in combination with pendimethalin 1.0 kg, metribuzin 0.70 kg and atrazine 0.75 kg/ha increased the rhizome yield by 14.3, 20.5 and 10.9% respectively, though the results were significant only for pendimethalin during 2007-08 at Ludhiana and for metribuzin during 2006-07 and 2007-08 at Ludhiana and Nawanshahr respectively. Averaged over two locations, the highest fresh-rhizome yield was recorded with pendimethalin 1.0 kg/ha (29.6 t/ha), followed

Table 2. Total population, dry matter accumulation and nutrient depletion by weeds under different weed control treatments at Ludhiana

Treatment	Total weeds (no/m^2)		Weed dry matter (g/m^2)				WCE (%)		Nutrient depletion at 120 days during during 2006-07 (kg/ha)		
	60 days	120 days	60 days		120 days		60 days	120 days			
			2006-07	2007-08	2006-07	2007-08			N	P	K
T_1	7.84[a] (60.4)	9.47 (88.7)	21.9 (479)	19.18 (367)	13.56 (185)	16.79 (281)	47.0	64.0	34.4	4.9	41.6
T_2	5.06 (24.6)	4.61 (20.2)	15.65 (246)	14.46 (208)	17.53 (308)	19.75 (389)	71.6	46.5	53.3	9.3	68.0
T_3	5.47 (28.9)	3.77 (13.2)	11.61 (137)	10.77 (115)	13.36 (180)	15.81 (249)	84.2	67.0	34.3	4.9	45.0
T_4	7.65 (57.4)	5.39 (28.1)	23.17 (537)	20.88 (435)	14.97 (226)	14.87 (220)	38.9	66.1	35.9	6.6	55.1
T_5	5.52 (29.5)	3.68 (12.5)	18.05 (326)	14.76 (217)	17.70 (313)	17.83 (318)	66.2	51.9	56.8	8.1	74.1
T_6	4.89 (22.9)	3.44 (10.8)	15.19 (237)	11.66 (135)	10.20 (106)	13.64 (185)	76.9	77.4	19.3	2.9	25.1
T_7	8.93 (78.7)	5.76 (32.2)	24.25 (589)	24.06 (578)	12.19 (148)	18.06 (325)	26.1	63.1	27.3	4.0	33.5
T_8	7.55 (55.9)	7.30 (52.2)	19.14 (366)	18.45 (340)	19.81 (394)	19.64 (386)	55.4	40.6	67.8	11.0	97.6
T_9	3.89 (14.1)	3.42 (10.7)	7.47 (71)	13.82 (190)	12.22 (153)	15.68 (245)	82.8	69.3	19.8	3.3	24.4
T_{10}	6.64 (43.0)	4.23 (16.9)	14.24 (265)	17.38 (301)	15.37 (309)	13.78 (189)	63.9	62.6	43.1	7.1	56.5
T_{11}	6.59 (42.4)	9.51 (89.3)	16.04 (268)	16.73 (279)	25.82 (667)	21.82 (475)	65.3	13.9	100.3	9.3	152.8
T_{12}	6.00 (35)	7.80 (59.9)	16.59 (276)	16.22 (262)	15.84 (324)	17.69 (312)	66.0	51.6	50.1	6.6	61.2
T_{13}	7.41 (53.9)	6.83 (45.7)	11.92 (141)	13.82 (190)	10.32 (106)	13.82 (190)	78.8	77.0	20.2	3.1	24.3
T_{14}	8.79 (76.2)	6.67 (43.4)	29.25 (860)	27.01 (728)	26.36 (699)	24.88 (618)			103.5	19.7	170.4
SEm±	0.45	0.65	1.57	1.49	2.20	1.91			0.9	1.4	12.3
CD (P=0.05)	1.29	1.85	4.47	4.25	6.27	5.43			2.6	4.0	34.9

[a]Data subjected to $\sqrt{x+1}$ transformation, Figures in parentheses are original values; WCE = Weed-control efficiency
Details of treatments are given in Table 1.

Table 3. Growth and yield attributes of turmeric under different weed control treatments

Treatment	Rhizome emergence at Ludhiana (%)		Leaf-area index at Ludhiana (120 days)		Rhizomes (no/plant)			Rhizome weight/ plant (g)		
	30 days	50 days			Ludhiana		Nawanshahr	Ludhiana		Nawanshahr
	2006-07		2006-07	2007-08	2006-07	2007-08	2007-08	2006-07	2007-08	2007-08
T_1	23.1[a] (16)	73.1(91)	2.67	1.75	21.0	10.7	5.67	296.0	161.4	171.3
T_2	76.9 (94)	85.0 (98)	5.86	2.48	23.2	13.5	6.67	376.2	225.4	216.7
T_3	71.7 (89)	89.9 (100)	5.93	2.90	25.9	15.4	7.67	431.0	233.4	225.3
T_4	22.8 (16)	70.3 (89)	2.11	1.51	19.5	11.9	5.33	299.7	180.0	160.7
T_5	74.5 (93)	87.4 (99)	5.29	2.85	22.7	13.7	7.67	321.0	220.0	248.7
T_6	74.4 (93)	81.7 (98)	6.34	3.01	27.8	16.2	7.33	420.5	234.0	260.7
T_7	20.2 (14)	74.9 (91)	2.20	1.06	19.2	11.1	6.00	266.2	160.0	160.0
T_8	74.4 (91)	83.5 (98)	3.87	2.45	24.2	16.1	6.77	354.7	258.6	218.7
T_9	76.6 (94)	84.2 (99)	5.00	2.50	25.1	14.0	8.30	417.0	228.6	247.3
T_{10}	72.7 (91)	85.9 (99)	4.38	2.72	21.9	15.4	7.70	392.5	222.6	231.3
T_{11}	70.0 (88)	86.4 (99)	3.02	2.25	21.8	14.1	7.00	297.0	200.0	233.3
T_{12}	80.1 (94)	88.1 (99)	4.55	2.67	23.9	16.1	7.30	397.2	258.6	248.0
T_{13}	15.7 (8)	74.0 (92)	2.43	2.05	19.5	11.8	7.00	287.5	204.6	192.0
T_{14}	14.9 (7)	57.7 (71)	1.37	1.01	17.0	10.7	4.77	221.2	161.4	136.7
SEm±	3.2	2.4	0.37	0.16	1.2	1.86	0.37	15.7	32.0	7.0
CD (P=0.05)	9.2	6.9	1.05	0.45	3.5	NS	1.07	44.7	NS	20.2

[a]Data subjected to arcsine transformation. Figures in parentheses are original values
Details of treatments are given in Table 1.

immediately by metribuzin 0.70 kg/ha (29.4 t/ha) and atrazine 0.75 kg/ha (27.9 t/ha), all integrated with straw mulch 9 t/ha. The straw mulch 9.0 t/ha + herbicide combination increased the rhizome yield by 48.2% compared with the recommended practice of straw mulch 6 t/ha alone while this increase was 15.3, 14.9 and 225.5% compared with that from straw mulch 6 t/ha + herbicide, straw mulch 9.0 t/ha alone and the unweeded control respectively. Pendimethalin 1.0 kg/ha + straw mulch 9.0 t/ha recorded the highest value of herbicide-efficiency index (11.2), which was very closely followed by metribuzin 0.70 kg/ha (11.0) and atrazine 0.75 kg/ha (10.4), both integrated with straw mulch 9.0 t/ha. These results justify the need for integrated use of herbicides and higher rate of straw mulch for achieving better weed control and higher crop productivity.

The higher yields during 2006-07 than 2007-08 might be attributed to heavy fertilization of the experimental field with FYM during the first year and planting of the crop in the field for the first time. In 2007-08 the turmeric was planted in the same field and with lower rate of FYM (due to its less availability) and the crop was also planted late, which decreased the rhizome yield. Lower yield levels at Nawanshahr may be because the crop was planted late and raised in the absence of FYM. This indicates that heavy FYM fertilization is essential for getting sustained productivity of turmeric. Similar observations on yield and yield attributes of turmeric, recorded at different locations, indicated that the results of weed-control approaches were applicable under both high and low productivity situations.

The greater weed pressure and delayed sprouting of rhizomes in the treatment receiving herbicide alone reduced the nutrient uptake by the crop, which resulted in poor development of crop canopy and leaf area, thereby decreasing the size and number of rhizomes per unit area (Table 3). Though one hoeing at 60 days after planting following herbicide application helped check the weeds, but the damage done earlier could not be compensated in terms of yield attributes. Early and greater sprouting of rhizomes in the mulched plots gave dominance to the crop over weeds, as a result the crop utilized higher amounts of nutrients from the soil and produced more leaf area and more as well as heavy rhizomes as compared with the non-mulch plots. Nwokocha *et al.* (2006) revealed that straw mulch contains higher percentage of organic matter and improves the soil structure when compared with non-mulch control, and the decomposition of the mulch materials provides soil-organic matter, which helps stabilize the soil aggregates, thus making the soil conducive for rhizome development. Integration of herbicide and straw mulch helped in long-term and better control of weeds over the use of herbicide or straw mulch alone. Hossian *et al.* (2008) indicated that for higher yields turmeric needs a longer period free from weeds than other crops. In the unweeded control plots, the weeds grew luxuriantly and competed with the crop, and thus decreased the yield of rhizome due to poor crop growth. The losses in fresh-rhizome yield in the unweeded control varied from 63.9 to

Table 4. Nutrient uptake by crop, fresh-rhizome yield and economics under different weed-control treatments

Treatment	Nutrient uptake during 2006-07 (kg/ha)						Rhizome yield (t/ha)			Cost of cultivation	Net returns	B : C ratio	Herbicide efficiency index at Ludhiana
	Rhizomes			Above-ground parts			Ludhiana		Nawan-shahr (2007-08)	(x 10^3 Rs/ha)	(x 10^3 Rs/ha)		
	N	P	K	N	P	K	2006-07	2007-08		(Mean of 2 locations)			
T_1	126.0	21.5	123.9	50.3	8.2	28.6	30.8	11.8	16.8	43.4	55.7	1.28	2.8
T_2	155.9	27.2	169.1	55.4	9.7	25.7	41.7	16.1	19.8	43.9	85.4	1.94	5.3
T_3	169.1	30.3	174.1	73.8	11.2	32.3	45.1	22.3	21.3	44.8	103.0	2.30	11.2
T_4	100.4	16.8	117.9	44.8	7.7	26.7	26.3	12.5	14.9	43.8	45.8	1.04	2.2
T_5	121.9	21.0	132.1	63.2	10.1	29.8	35.4	19.6	18.2	44.3	77.8	1.75	4.8
T_6	180.2	29.9	188.6	81.7	12.4	42.4	46.3	19.2	22.7	45.4	101.7	2.24	11.0
T_7	99.0	17.1	98.2	38.8	5.7	18.2	24.8	9.1	13.6	42.2	45.3	1.07	1.4
T_8	140.2	23.1	166.5	74.4	11.8	40.0	39.2	17.1	19.2	42.9	82.7	1.93	3.9
T_9	165.1	28.2	171.3	83.1	12.5	35.5	43.2	19.6	20.9	43.7	95.8	2.19	10.4
T_{10}	138.8	24.9	145.3	55.7	10.1	28.4	36.2	21.7	16.6	46.2	78.1	1.69	5.7
T_{11}	100.7	17.9	118.6	42.4	9.3	27.6	28.3	16.2	14.0	41.6	55.8	1.34	2.4
T_{12}	142.4	24.4	153.0	76.9	12.5	34.7	38.2	19.5	17.9	42.7	83.3	1.95	5.2
T_{13}	106.7	20.0	128.9	53.4	9.0	28.6	30.2	18.5	13.9	45.9	58.5	1.27	7.5
T_{14}	36.6	6.9	43.2	30.7	6.3	17.9	10.9	7.7	8.2	37.8	6.8	0.18	
SEm±	4.9	1.8	11.7	2.8	0.8	1.2	2.2	0.9	1.0				
CD (P=0.05)	14.2	5.2	33.4	8.1	2.4	3.5	6.2	2.6	3.0				

Details of treatments are given in Table 1.

76.5% whereas the highest yield gain (231.5%) was recorded with pendimethalin 1.0 kg/ha + straw mulch 9 t/ha. Gill *et al.* (2002) recorded the highest fresh-rhizome yield with metribuzin 0.70 kg/ha, whereas Mahey *et al.* (1986), Randhawa (1997) and Hossain (2005) reported beneficial effect of straw mulch on rhizomes yield compared with without mulch. But in our study the combination of herbicide and straw mulch proved statistically better than the use of either herbicide or straw mulch alone.

Nutrient uptake by crop

Integration of metribuzin 0.7 kg/ha + straw mulch 9 t/ha recorded the highest utilization of 180.2 kg N, 29.9 kg P and 188.6 kg K/ha by the rhizomes (Table 4). In the unweeded control plot the rhizomes utilized 14.2, 5.2 and 33.4 kg/ha N, P and K respectively, which were only 20.3, 23.1, 22.9% when compared with the application metribuzin 0.70 kg/ha + straw mulch 9 t/ha. Effective control of weeds over a longer period with herbicide and straw mulch combination helped the crop produce more dry matter and grab a major share of nutrients, leaving very less for the weeds. As the nutrient content did not vary among different weed-control treatments, the utilization of nutrients followed a trend similar to that of rhizome yield. The increase in straw mulch level from 6 to 9 t/ha significantly increased the nutrient utilization by rhizomes. Nutrient uptake by above-ground parts of the crop showed a trend similar to that recorded for rhizomes.

Economics

Pre-emergence pendimethalin 1.0 kg/ha recorded the highest net returns (103×10^3 Rs/ha) as well as benefit : cost ratio (2.30), closely followed by metribuzin 0.70 kg/ha and atrazine 0.75 kg/ha (96×10^3 Rs/ha; 2.19), all integrated with straw mulch 9 t/ha (Table 4). The corresponding figures were very lower for three hoeings and the lowest was under the unweeded control. The increase in the rate of straw mulch from 6 to 9 t/ha increased the net returns by 49.3% and benefit : cost ratio by 0.61 points. Averaged over herbicides, net returns with herbicide + straw mulch 9 t/ha combination were 79.5, 20.2, 22.2 and 71.2% higher than compared with straw mulch 6 t, 9 t, 6 t/ha + herbicide, and three hoeings, respectively. The cost of cultivation did not show much variation among different weed-control treatments except it was higher in treatments which involved two or three hoeing due to higher labour charges, and was comparatively lower in straw mulch-alone treatments owing to lower cost of straw mulch. Hence the net returns under different weed-control treatments showed a trend almost similar to that of rhizome yield.

It was concluded that paddy-straw mulch was essential for proper sprouting and establishment of turmeric rhizomes. Higher rate of paddy-straw mulch 9 t/ha was significantly better than recommended rate of 6 t/ha. The integrated use of paddy-straw mulch 9 t/ha with either of pendimethalin 1.0 kg, metribuzin 0.70 kg or atrazine 0.75 kg/ha was adjudged very effective for weed control and for attaining the highest productivity and profitability in turmeric.

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