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Integrated Weed Management in Finger Millet (*Eleusine coracana* L.)

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Abstract

A field experiment was conducted entitled 'Integrated weed management in finger millet (*Eleusine coracana* L.)' to standardize different practices for managing weeds in finger millet and to assess the economics during the rabi season (2022) at the Instructional Farm II, Karuvacheri, College of Agriculture, Padannakkad, Kerala. Field experiment was laid out in Randomized Block Design with ten treatments and three replications. Different treatments have imparted significant impact for different weed control parameters *viz*., weed density, weed dry weight and Weed Control Efficiency (WCE). Pre-emergent herbicide application delayed the emergence of weeds during the initial period of crop growth and further weed emergence could be managed by the application of post emergent herbicide and mulching respectively. Even though chemical weed management delivered better results for various parameters, Integrated Weed Management (IWM) was equally effective in managing diverse life cycles and survival strategies of weeds. Hence, pre-emergent application of bensulfuron methyl + pretilachlor followed by mulching was selected as the effective IWM tool for finger millet as sole dependence on herbicides would lead to excess use, resistance development, etc. Hand weeding at 20 and 40 DAS was also proved to be an effective weed management strategy in finger millet but due to high labour cost and their unavailability at crucial time cannot be recommended as an economically feasible method.

Keywords : Finger millet, Integrated weed management, Herbicide application, Mulching

India is the largest producer of millets (Anonymous, 2020) and the year 2023 was declared as the international year of millets with major focus on enhancing the production and productivity of millets (GoI, 2022). Out of the total major millets produced, finger millet or ragi (*Eleusine coracana* L.) accounts for about 85 per cent of the production in India (Sakamma *et al*., 2018) with a current production of 19.6 lakh tonnes (Anonymous, 2022).

Millets are becoming more popular especially among the urban and semi urban population of Kerala owing to its health benefits in alleviating nutrient imbalance and anemia. According to Gupta *et al*. (2017) finger millet is referred as a nutri-cereal or a nutraceutical crop and is viewed as a potential global answer to malnutrition. Finger millet has high content of calcium (344 mg/100g), dietary fibre (15-20%) and phenolic compounds (Gull *et al*., 2014). About 213 hectares of area are used to cultivate finger millet in Kerala which is mostly confined to the districts of Idukki and Palakkad (Anonymous, 2022). Weed infestation is a major challenge in finger millet cultivation which affected the economic yield of the crop and no specific weed management practice has been recommended for finger millet in the Package of practices recommendations-crops of (Anonymous, 2016). Hence, this study was undertaken to standardize the weed management practices in finger millet.

MATERIAL AND METHODS

During the *rabi* season in 2022, a field experiment using a Randomized Block Design with 10 treatments and three replications was carried out at the Instructional Farm II, Karuvacheri, College of Agriculture, Padannakkad (12° 14’45" North latitude and 75° 8’6" East longitude) at an altitude of 9 m above mean sea level (MSL). The variety of finger millet was KMR 301 and was sown in a spacing of 25 cm x 30 cm and the method of sowing was line sowing. The red sandy loam soil in the experimental plot had a pH of 5.83, EC value of 0.15 dSm^{-1}, low available nitrogen content (237.8 kg ha^{-1}), high available P content (50.2 kg ha^{-1}) and a medium K level (250.0 kg ha^{-1}). The crops did not show any toxicity symptom due to the usage of herbicides. The treatments being T_1 - pre emergence application of bensulfuron methyl + pretilachlor @ 660 g ha^{-1} (PE), T_2 - T_1 + Hand weeding (HW) at 20-25 DAS, T_3 - T_1 + mulching, T_4 - T_1 + post emergence application of bispyribac sodium @ 25 g ha^{-1} (POE) at 20 DAS, T_5 - POEM at 20 DAS + HW (40 DAS), T_6 - mulching + POEM (20 DAS), T_7 - mulching + HW (25 DAS), T_8 - HW (20 and 40 DAS), T_9 - mulching alone, T_{10} - weedy check/control.

Mulching with green leaves (any available green leaves in the surrounding) was done @ 7 t ha^{-1} (5 DAS). Nutrient management was done as per the package of practices recommendations (Anonymous, 2016).

RESULTS AND DISCUSSION

I. Growth Parameters

Plant Height (cm)

The different weed control strategies at 50 and 75 DAS had significant effects on plant height and the data is given in Table 1. Taller plants at 50 DAS were recorded by sequential application of bensulfuron methyl + pretilachlor @ 660 g ha^{-1} and bispyribac sodium @ 25 g ha^{-1} (T_4) which was comparable to the integrated application of bensulfuron methyl + pretilachlor @ 660 g ha^{-1} as pre-emergence along with hand weeding at 20 DAS (T_2), T_6, T_3, T_8, T_7 and T_1. Among the different weed management practices, combined application of bensulfuron methyl + pretilachlor @ 660 g ha^{-1} followed by bispyribac sodium @ 25 g ha^{-1} and the treatment where hand weeding was done at 20 and 40 DAS recorded taller plants than all other treatments at 75 DAS.

TABLE 1

Effect of different weed control treatments on plant height (cm) in finger millet

Treatments	Plant height (cm)		
	25 DAS	50 DAS	75 DAS
T_1	33.99	58.76 ^{abcd}	63.05 ^{abcd}
T_2	31.93	61.98 ^{a}	63.98 ^{ab}
T_3	33.16	61.76 ^{ab}	64.70 ^{ab}
T_4	34.75	62.00 ^{a}	67.58 ^{a}
T_5	32.51	58.70 ^{bcd}	62.51 ^{bcd}
T_6	31.36	61.80 ^{ab}	63.60 ^{abc}
T_7	31.53	60.50 ^{abc}	65.41 ^{ab}
T_8	27.66	61.10 ^{ab}	67.00 ^{ab}
T_9	32.62	57.81 ^{cd}	59.14 ^{cd}
T_{10}	31.85	55.57 ^{d}	58.83 ^{d}
SEm (±)	1.61	1.10	1.56
C.D (0.05)	NS	3.27	4.66

Reduced weed growth in the initial stages resulted in better utilization of light, nutrients and increased photosynthetic efficiency leading to taller plants (Bhargavi *et al.,* 2016). The application of pre-emergence herbicide followed by post emergence herbicide produced taller plants at various stages of development reducing the competitiveness of weed flora along with enhanced cell division in crops due to the efficient utilization of resources (Kumar *et al.*, 2022). Hussain *et al.* (2022) opined that when the soil surface is covered with mulch the developing weeds were shaded and they were unable to get appropriate or favourable environment to compete with the target crop. This physical suppression of weed development occurred as a result of mulch material which decreased the soil temperature, increased soil moisture and enhanced nutrient availability upon decaying.

Leaf Area Index

At 25 DAS the highest leaf area index was recorded by pre-emergence application of bensulfuron methyl + pretilachlor along with mulching which showed comparable result with that of application of pre-emergence herbicide bensulfuron methyl + pretilachlor @ 660 g ha^{-1} followed by post-emergence application of bispyribac sodium @ 25 g ha^{-1} and also mulching along with hand weeding (at 25 DAS). The highest value of Leaf Area Index (LAI) at 50 DAS was recorded by PE + POE application and was comparable to treatment where hand weeding was done twice at 20 and 40 DAS followed by PEM + Mulching. At 75 DAS (Table 2), the highest value for LAI was recorded by the sequential application of pre and post emergence herbicide (T_4). At the initial stages, emergence of weeds was controlled by pre-emergence herbicide and mulching where mulching could effectively control the weeds at initial stages which helps in the increase of crop canopy. Later, due to the shading effect of crops the weeds were unable to compete and ultimately resulted in the decreased weed population (Gupta *et al.*, 2022). The beneficial effects of growth characteristics and extended periods of weed free conditions brought about by improved management practices which provided enough space for foliar enlargement which led to increased LAI (Ashrafi *et al.,* 2020 and Prithvi *et al*., 2015).

Total Plant Dry Matter Production (kg ha^{-1})

At 50 and 75 DAS, (Table 3) the highest value for dry matter production was recorded by bensulfuron methyl + pretilachlor @ 660 g ha^{-1} followed by the post-emergence application of bispyribac sodium @ 25 g ha^{-1} and was comparable with pre-emergence application of bensulfuron methyl + pretilachlor @ 660 g ha^{-1} along with mulching. At the harvesting stage highest dry matter production was recorded by bensulfuron methyl + pretilachlor @ 660 g ha^{-1} as pre-emergence followed by post-emergence application of bispyribac sodium @ 25 g ha^{-1} which was on par to T_3 where pre-emergence herbicide controlled the weeds and delayed the emergence and mulching helped in smothering weed population and hand weeding at 20 and 40 DAS (T_8). Hand weeding twice at 20 and 40 DAS emerged as an effective method for controlling weeds which led to increased

TABLE 2

Effect of different weed control treatments on leaf area index at 25, 50 and 75 DAS in finger millet

Treatments	Leaf area index		
	25 DAS	50 DAS	75 DAS
T_1	0.60 [bc]	1.06 [f]	2.75 [bcd]
T_2	0.61 [bc]	1.16 [e]	2.75 [bcd]
T_3	0.77 [a]	1.57 [bc]	3.06 [ab]
T_4	0.71 [ab]	1.67 [a]	3.18 [a]
T_5	0.58 [c]	1.49 [cd]	2.93 [bc]
T_6	0.60 [bc]	1.44 [d]	2.81 [cd]
T_7	0.69 [ab]	1.44 [d]	2.85 [cd]
T_8	0.63 [bc]	1.60 [ab]	3.03 [ab]
T_9	0.56 [cd]	1.02 [f]	2.64 [ef]
T_{10}	0.46 [d]	0.90 [g]	2.49 [f]
SEm (±)	0.03	0.03	0.05
C.D (0.05)	0.11	0.10	0.16

TABLE 3

Effect of different weed control treatments on total dry matter production (kg ha^{-1}) at 25, 50, 75 DAS and at harvest in finger millet

Treatments	Total dry matter production (kg ha^{-1})			
	25DAS	50 DAS	75 DAS	At Harvest
T_1	506.66	713.10 [fg]	2143.26 [cd]	3902.93 [cd]
T_2	517.86	786.80 [efg]	1913.30 [de]	3930.10 [cd]
T_3	566.40	1130.66 [ab]	2667.50 [ab]	4423.83 [a]
T_4	532.10	1191.00 [a]	3066.53 [a]	4561.32 [a]
T_5	529.00	1042.76 [bc]	2505.16 [bc]	4233.26 [b]
T_6	522.82	857.93 [de]	2157.17 [cd]	3995.93 [c]
T_7	543.66	973.30 [cd]	2288.31 [bcd]	4218.73 [b]
T_8	530.27	1100.20 [abc]	2613.43 [abc]	4420.00 [a]
T_9	534.33	838.10 [ef]	1889.08 [de]	3768.54 [d]
T_{10}	500.06	680.00 [g]	1617.10 [e]	3487.63 [e]
SEm (±)	0.13	44.81	161.13	58.94
CD (0.05)	NS	133.14	478.76	175.14

chlorophyll synthesis in crop, improved accumulation of photosynthates, better translocation, higher number of grains and panicles leading to a higher dry matter production and grain yield. However, challenges like labour shortage and rising labour wages and unavailability of labour at right time delays the weed control (Santigo-Arenas *et al*., 2022) and (Zhang, 2018).

II. Weed Parameters

Weed Density

Weed management practices had considerable impact on weed density at different growth stages (Table 4) wherein the lowest weed density at 15 DAS was observed in the plots where bensulfuron methyl + pretilachlor was applied as pre-emergence herbicide (at 3 DAS) along with mulching (T_3), recording a weed density of 12.00 m^{-2} which is followed by T_4, T_2 and T_1. The lowest weed density was significantly observed at 30 DAS where two hand weeding was proposed (20 and 40 DAS) resulting in a weed density of 14.00 m^2. This finding agrees with Ramadevi *et al.* (2021) wherein hand weeding significantly reduced the weed population. At 45 DAS, the lowest value for weed density was observed in plots where two hand weeding were done at 20 and 40 DAS (10.00 m^{-2}) and this was on par with that of T_5 (bispyribac sodium at 20 DAS + hand weeding at 40 DAS). Integrated management of weeds with herbicide application along with hand weeding at critical stages of crop growth could be an effective weed management strategy (Rao *et al.,* 2015). Among the different weed management practices, weed density was significantly reduced (60.33 m^{-2}) in the plots where application of pre-emergence herbicide bensulfuron methyl + pretilachlor was done along with post-emergence application of bispyribac sodium (T_4) at 60 DAS and this treatment was followed by T_3 and T_8 which were on par.

Table 4

Effect of weed control treatments on weed density (no. m^{-2}) in finger millet

Treatments	Weed density (no. m^{-2})			
	15DAS	30 DAS	45 DAS	60 DAS
T_1	28.33 ^{c}	36.33 ^{c}	52.00 ^{e}	121.33 ^{b}
T_2	30.00 ^{c}	19.00 ^{g}	56.00 ^{d}	99.66 ^{de}
T_3	12.00 ^{d}	23.00 ^{e}	39.00 ^{g}	70.00 ^{g}
T_4	26.66 ^{c}	16.66 ^{gh}	27.00 ^{h}	60.33 ^{h}
T_5	98.00 ^{a}	27.00 ^{d}	12.33 ^{i}	88.66 ^{f}
T_6	29.00 ^{c}	19.33 ^{fg}	60.33 ^{c}	102.00 ^{d}
T_7	34.33 ^{b}	22.00 ^{ef}	46.66 ^{f}	97.00 ^{e}
T_8	100.00 ^{a}	14.00 ^{h}	10.00 ^{i}	68.00 ^{g}
T_9	30.66 ^{bc}	56.33 ^{b}	68.00 ^{b}	115.00 ^{c}
T_{10}	101.00 ^{a}	194.66 ^{a}	274.66 ^{a}	352.33 ^{a}
SEm (±)	1.42	0.97	1.21	1.56
CD (0.05)	4.22	2.90	3.60	4.63

*Original data subjected to square root transformation

Combined application of pre and post emergence herbicides has better result but when integrated with other management practices such as mulching and hand weeding has the potential to produce significant results. In the early stages of weed growth pre-emergence herbicide effectively controlled the weeds but its efficacy was limited in case of later emerged weeds. The application of post emergence herbicide bispyribac sodium enhanced the weed control by reducing the emergence of weeds at later stages and ensuring the precise time for application of post emergence herbicide was essential for reducing the crop yield loss *i.e.,* at critical period of crop weed competition which was 25 to 60 DAS according to Yatisha *et al*. (2020).

Weed Dry Weight (kg ha^{-1})

The lowest weed dry weight (Fig. 1) at 15 DAS was recorded by the integrated application of bensulfuron methyl and pretilachlor @ 660 g ha^{-1} at 3 DAS along with mulching and this result was comparable with treatment where PE + HW was carried out. At 30 DAS, two hand weeding at 20 and 40 DAS, recorded the lowest weed dry matter production and this could be attributed to the timely and effective control through hand weeding at critical stages (20 and 40 DAS) and comparable results were observed by T_4. At 45 DAS, lowest weed dry weight was recorded by two hand weeding at 20 and 40 DAS which was equivalent to T_5 where post-emergence application of bispyribac

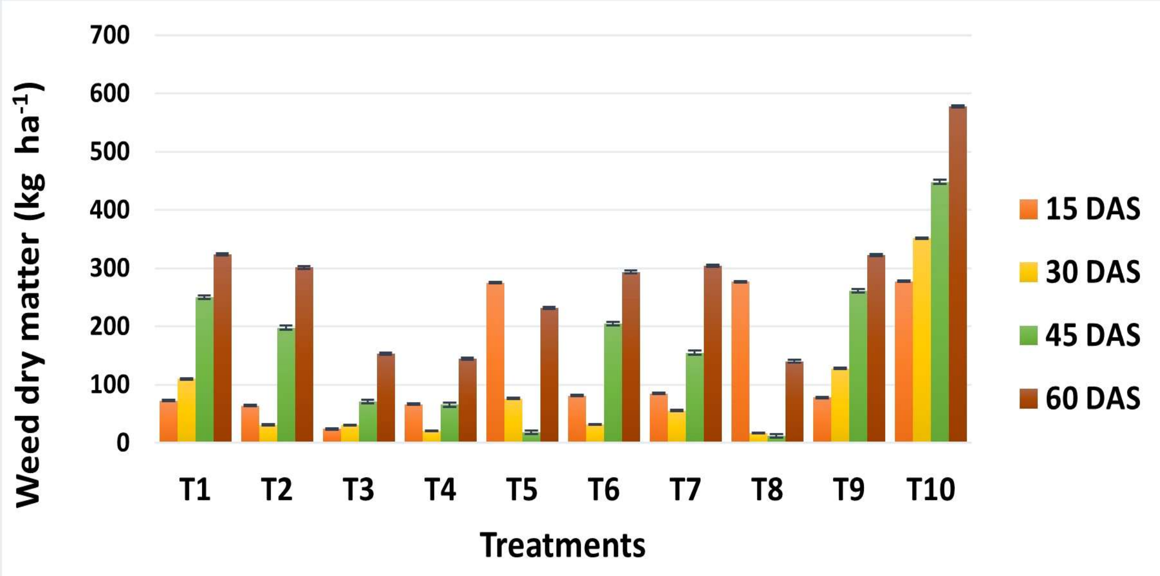

Fig. 1 : Effect of weed management practices on weed dry weight

sodium @ 25 g ha^{-1} was done followed by HW at 40 DAS. At 60 DAS, HW at 20 and 40 DAS reduced the weeds which potentially led to the effective removal of weeds.

Efficient weed management during the critical growth stage gives the crop an advantage over weeds in crop-weed competition and allows for greater resource utilization. Similar results using several weed control methods were noted by Prithvi *et al*. (2015). Shubhasree *et al*. (2023) highlighted that higher weed dry weight indicated severe weed competition and exploitation of nutrients and moisture by weeds which deprived the crop from the same. The application of pre and post emergence herbicide and integrating pre-emergence herbicide along with mulching could effectively suppress the weeds before they lead to high weed proliferation and hinder the crop growth (Kumar and Walia, 2003). However, higher finger millet yields and effective weed control were achieved through integrated weed management where IWM efficiently controls weeds, lowers the amount of nutrients absorbed by the weeds, making nutrients accessible to finger millet.

Weed Control Efficiency (%)

WCE at various growth stages revealed significant difference among the different treatments and is represented in Table 5 and Fig. 2.

At 15 DAS, the highest weed control efficiency was computed by T_3 with a WCE of 91.35 per cent. The application of pre-emergence works by inhibiting seed germination of weeds by disrupting protein synthesis and proteinase activity, which blocks the chained amino acids in weeds and ultimately inhibits their growth (Reddy *et al*., 2016). Significantly higher WCE at 30 DAS was computed by T_4 where sequential application of pre-emergence and post emergence herbicide were applied which effectively increased the weed control efficiency to 94.02 per cent. At 45 DAS, the treatment that computed significantly higher weed control efficiency (97.07%) was that of hand weeding twice at 20 and 40 DAS and was on par with T_5 computing a WCE of 95.98 per cent. At 60 DAS, the highest WCE (75.72%) was computed by two HW at 20 and 40 DAS with a comparable WCE (75.00%) as that of (T_4) sequential application of bensulfuron methyl and pretilachlor @ 660 g ha^{-1} and bispyribac sodium @ 25 g ha^{-1}. The significant increase in WCE of treatments may be due to improved weed control from the time of sowing until 60 DAS, which was the critical period for crop weed competition.

Yield Parameters

The different yield attributing parameters like grain weight panicle^{-1}, grain yield hill^{-1} and length of panicle were significantly influenced by different treatments

TABLE 5

Effect of weed control treatments on weed control efficiency (%)

Treatment	Weed control efficiency (%)				Average WCE (%)
	15 DAS	30 DAS	45 DAS	60 DAS	
T_1	73.84 c	68.71 e	44.17 f	43.94 f	51.94 d
T_2	76.56 b	91.18 b	55.83 d	47.86 f	67.85 b
T_3	91.35 a	91.28 b	84.14 b	73.42 b	85.11 a
T_4	75.96 b	94.02 a	85.34 b	75.00 a	82.57 a
T_5	0.96 g	78.29 d	95.98 a	59.86 c	58.77 c
T_6	70.82 e	90.99 b	54.25 e	49.16 d	66.30 b
T_7	69.32 f	84.17 c	65.42 c	47.38 e	66.56 b
T_8	0.36 h	95.07 a	97.27 a	75.72 a	67.10 b
T_9	71.79 d	41.71 f	42.51 g	44.23 f	50.05 d
T_{10}	-	-	-	-	-
SEm (±)	0.011	0.003	0.032	0.033	1.83
CD (0.05)	0.035	0.009	0.097	0.099	5.45

*Original data subjected to square root transformation

and the highest value was recorded by T_4 and was comparable with T_3. The parameters like no. of panicles $hill^{-1}$ and test weight did not show any significant difference.

Effective weed management enhanced the accumulation of photosynthates and increased the translocation which in turn raised the number of grains and panicles, eventually increasing grain production (Zhou *et al*., 2023).

Grain Yield and Straw Yield (kg ha^{-1})

The highest grain (1332.52 kg ha^{-1}) and straw yield (1926.33 kg ha^{-1}) was recorded by (T_4) where bensulfuron methyl + pretilachlor @ 660 g ha^{-1} as pre-emergence and post-emergence application of bispyribac sodium @ 25 g ha^{-1} was done and the data is represented in Table 6. Pre-emergence herbicide application (bensulfuron methyl + pretilachlor) reduced the weed population at their initial stages by preventing weed seeds from germination and bispyribac sodium applied an early post-emergence herbicide limit the weed development at a later stage, leading to decreased weed competition and increased yield. Pre-emergence application along with mulching recorded higher grain (1314.80 kg ha^{-1}) and stover yield (1916.00 kg ha^{-1}). Higher yields were recorded for this variety under increased levels of nutrients in red sandy loam soils as reported by Aparna and Karthikeyan (2023).

The application of various weed control has significantly affected the productivity of grain and straw. The effectiveness of these measures may be

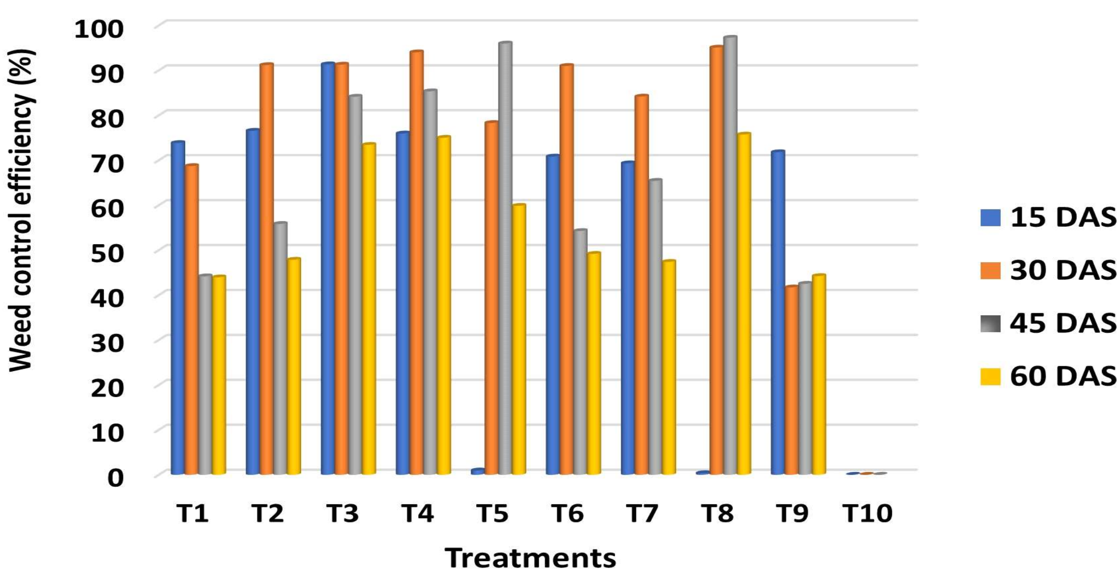

Fig. 2 : Effect of weed management practices on weed control efficiency

TABLE 6

Effect of different weed control treatments on grain and straw yield, kg ha $^{-1}$

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1	928.79 ^{e}	1505.94 ^{f}
T_2	1205.36 ^{c}	1624.03 ^{e}
T_3	1314.80 ^{a}	1916.00 ^{a}
T_4	1332.52 ^{a}	1926.33 ^{a}
T_5	1242.09 ^{bc}	1748.60 ^{d}
T_6	1211.80 ^{c}	1765.54 ^{c}
T_7	1199.41 ^{c}	1630.85 ^{e}
T_8	1300.56 ^{ab}	1864.58 ^{b}
T_9	1058.60 ^{d}	1496.23 ^{f}
T_{10}	620.86 ^{f}	1421.11 ^{g}
SEm (±)	22.11	3.35
CD (0.05)	65.69	9.97

attributed to the overall increase in production qualities, reduced competition from weeds, greater light penetration allowing photosynthesis, decreased nutrient depletion caused by weeds and higher nutrient absorption by the crop.

Economics

In finger millet cultivation, the economic assessment of different weed management strategies was worked out in Table 7.

Results showed that the cost of cultivation under the treatment where hand weeding is imposed (T_2, T_7, T_5 and T_8) were found to be highest as these treatments involves hand weeding at their critical stages of crop growth which is a labour intensive method for controlling weeds coupled with high wages were is a major issue in weed management, hence hand weeding may be used as part of integrated weed management (Rao, 2021). Significantly higher Gross return was recorded by T_4 where bensulfuron methyl + pretilachlor and bispyribac sodium was applied and T_3 where weeds were effectively controlled and led to high grain and straw yield and in T_8 where hand weeding was done twice with more

TABLE 7

Effect of weed control treatments on net returns and B:C ratio in finger millet

Treatments	Economics			
	Gross returns (Rs. ha^{-1})	Cost of cultivation (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	Benefit: Cost Ratio (BCR)
T_1	52337 ^{e}	37696	14641 ^{de}	1.39 ^{d}
T_2	65609 ^{bc}	54363	11246 ^{ef}	1.21 ^{fg}
T_3	72568 ^{a}	39096	33472 ^{a}	1.86 ^{a}
T_4	73448 ^{a}	39376	34072 ^{a}	1.87 ^{a}
T_5	68134 ^{b}	50797	11737 ^{cd}	1.34 ^{de}
T_6	66893 ^{bc}	38297	28596 ^{b}	1.74 ^{b}
T_7	65390 ^{c}	50617	14773 ^{de}	1.29 ^{ef}
T_8	71634 ^{a}	63117	8518 ^{f}	1.13 ^{g}
T_9	58110 ^{d}	37367	20744 ^{c}	1.55 ^{c}
T_{10}	36434 ^{f}	35117	1226 ^{g}	1.03 ^{h}
SEm (±)	1081	-	1577	0.04
CD (0.05)	2621	-	3826	0.09

labour cost. The net return was highest in T_4 where combination of pre and post emergence herbicide was applied and in T_3 plot where pre-emergence herbicide along with mulching was done. The application of bensulfuron methyl + pretilachlor and bispyribac sodium resulted in a higher B:C ratio of 1.87 for T_4, which was comparable to T_3 (1.86). This was due to control of weeds at appropriate time and by using correct strategy which increased grain and straw yield and decreased cultivation costs.

Data on the benefit-cost ratio (B:C) showed that treatments with a combination of pre and post-emergence herbicides had a higher B:C ratio but over reliance on herbicides causes herbicide resistance, weed population shifts, negative impact on biodiversity, health hazards, residue hazards etc. (Rao *et al.,* 2010). IWM is a systemic approach which is based on scientific principles which effectively manages weeds by minimizing risks to both environment and human and this provides farmers with diverse strategies to control weeds by reducing the chances of weed escape and development of weed resistance to any single weed management strategy (Patel, 2023).

The work suggests that integrated weed management by combining diverse weed management methods can be more cost effective and provide crops with a competative advantage and is comparable with chemical and physical methods of weed management.

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