

31 Major millets have larger seeds and are sown at a deeper depth than minor millets, pre-
32 emergence herbicides increase the efficiency of productivity and weed control in major
33 millets [7]. Very little research has been done on the topic of chemical weed control in foxtail
34 millet. Farmers are now more likely to use herbicides in minor millet fields to effectively
35 manage weeds because hand weeding has become more expensive in recent years. Hence,
36 the present study was undertaken to evaluate weed management strategies and the
37 differential effects of herbicides on weed dynamics and crop performance of foxtail millet
38 [*Setariaitalica* (L.) Beauv] grown under the irrigated conditions of Rayalaseema.

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40 **2. MATERIAL AND METHODS**

41 **2.1 Location of the experiment**

42 At the wetland farm of S.V. Agricultural College, Acharya N.G. Ranga Agricultural University,
43 Tirupati, Andhra Pradesh, India, a field experiment was carried out during the *kharif* 2020
44 rainy season. The texture of the soil was sandy clay loam, with a neutral reaction, low levels
45 of available nitrogen and organic carbon, and medium levels of available potassium and
46 phosphorus.

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48 **2.3 Experimental design**

49 Eleven treatments were included in the randomized block design trial, which was replicated
50 three times. On August 14, 2020, foxtail millet was sowed with a 30 x 10 cm spacing. Pre-
51 emergence application (PE) of 500, 500, and 15 g/ha of pretilachlor, isoproturon, and
52 pyrazosulfuron-ethyl, respectively, as well as twice-hand weeding and un-weeded check
53 were the weed management treatments (Table 1). Twenty days after sowing (DAS),
54 intercultivation or post-emergence application (PoE) of penoxsulam 20 g/ha was added to all
55 pre-emergence herbicides.

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57 **2.4 Procedure**

58 Herbicides for pre-emergence were treated at 1 DAS, whereas penoxsulam, an inter-
59 cultivation/post-emergence herbicide, was applied at 20 DAS. Applying all pre- and post-
60 emergence herbicides required the use of a knapsack sprayer with a 500 L/ha spray volume
61 and a flat fan nozzle. All of the plots received an equal dosage of 20 kg N and 20 kg P in the
62 form of urea and single super phosphate, respectively. The complete dose of phosphorous
63 was administered as basal at the time of sowing, and the nitrogen was treated in two splits:
64 half the dose was applied as basal and the other half as top dressing at 30 DAS. The
65 recommendations of the Acharya N.G. Ranga Agricultural University were followed in
66 adopting the remaining packages of practices. Using a 0.25 m² quadrat, category-specific
67 weed density and biomass were randomly recorded. November 5, 2020, was the harvest
68 date of the crop.

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70 **2.5 Statistical analysis**

71 To standardize the distribution of the weed density and biomass data, a square root
72 ($\sqrt{X + 0.5}$) transformation was applied. Based on the methodology proposed by [6], the
73 efficiency of weed suppression was calculated. At harvest, every component of yield was
74 documented. The benefit-cost ratio was computed by dividing the cost of cultivation by the
75 gross returns. The statistical analysis of the weed and crop data was conducted using the
76 analysis of variance for randomized block design, as recommended by [13]. At harvest in
77 foxtail millet, the nitrogen uptake (kg ha⁻¹) by weeds and crop was determined using the
78 techniques recommended by [17] and [11], respectively. Following the normal protocol, data
79 on plant height, dry matter production, yield qualities, grain yield and straw yield were
80 recorded at harvest. The net returns were calculated by taking the gross returns for each
81 treatment and subtracting the cultivation cost. The benefit-cost ratio was computed by
82 dividing the cost of cultivation by the gross returns.

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84 **3. RESULTS AND DISCUSSION**

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86 **3.1 Dry weight and weed density**

87 Weed management significantly influenced rainfed foxtail millet. Hand weeding twice and
 88 pre-emergence pretilachlor at 500 g ha⁻¹ were most effective, except at 20 DAS. Hand
 89 weeding twice at 20 and 40 DAS might have controlled all the categories of weeds including
 90 perennial sedge *Cyperus rotundus* L. These results are in agreement with the findings of [2]
 91 with HW twice on 20 and 40 DAT in kodo millet. Pretilachlor 500 g ha⁻¹ followed by
 92 intercultivation (W₄), which was at par with PE pyrazosulfuron-ethyl 15 g ha⁻¹ fb intercultivation
 93 (W₆) and isoproturon 500 g ha⁻¹ fb intercultivation (W₅) in order of ascent, at all the stages of
 94 observation (Table 1). This might be due to broad spectrum weed control by the PE
 95 herbicides supplemented with intercultivation at 20 DAS. These results are in agreement
 96 with the findings of [14]. Isoproturon 500 g ha⁻¹ followed by penoxulam 20 g ha⁻¹ (W₈)
 97 showed the higher dry weight and density of total weeds due to its poor performance in
 98 controlling all the categories of weeds associated with foxtail millet. These outcomes agree
 99 with those of [7]. The highest dry weight and weed density were found in the unweeded
 100 check. The most effective method of controlling weeds was hand weeding twice at 20 and 40
 101 DAS (W₁₀). The only exception was pre-emergence application of pretilachlor at 500 g ha⁻¹
 102 with intercultivation at 20 DAS had a higher WCE than other pre-emergence herbicides.

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Table-1: Weed density m⁻², dry weight (g m⁻²) and weed control efficiency (%) as influenced by different weed management practices in foxtail millet

Treatments	Dose (g ha ⁻¹)	Time of application (DAS)	Weed density m ⁻²			Weed dry weight (g m ⁻²)			WCE (%)		
			20 DAS	60 DAS	At harvest	20 DAS	60 DAS	At harvest	20 DAS	60 DAS	At harvest
Pretilachlor	500	1	47.67 (6.67)	100.87 (10.06)	(131.67) 11.49	11.13 (3.32)	79.70 (9.12)	(94.37) 10.06	85.01	29.18	27.34
Isoproturon	500	1	63.53 (7.86)	102.17 (10.13)	(133.33) 11.57	24.25 (4.97)	81.27 (9.21)	(95.93) 10.14	67.35	27.78	26.13
Pyrazosulfuro n-ethyl	15	1	76.35 (8.92)	101.33 (10.09)	(132.50) 11.53	36.15 (6.05)	80.93 (9.19)	(95.60) 10.12	51.32	28.08	26.39
Pretilachlor fb IC	500	1+20	48.00 (6.75)	52.33 (7.27)	(69.33) 8.36	12.60 (3.57)	15.47 (3.99)	(32.07) 5.70	83.03	86.26	75.31
Isoproturon fb IC	500	1+20	63.67 (7.89)	55.00 (7.45)	(72.00) 8.51	24.61 (5.01)	19.10 (4.39)	(36.77) 6.07	61.47	83.03	71.69
Pyrazosulfuro n-ethyl fb IC	15	1+20	76.00 (8.86)	53.67 (7.36)	(70.00) 8.40	35.21 (5.95)	18.77 (4.32)	(35.73) 6.01	52.59	83.32	72.48
Pretilachlor fb penoxsulam	500 + 20	1+20	48.33 (6.87)	80.63 (9.01)	(104.33) 10.24	12.40 (3.54)	58.40 (6.60)	(68.40) 7.39	83.30	48.10	47.33
Isoproturon fb penoxsulam	500+ 20	1+20	63.50 (7.85)	124.17 (11.15)	(161.00) 12.70	25.21 (5.07)	100.77 (10.29)	(117.27) 11.56	66.05	10.46	9.70
Pyrazosulfuro n-ethyl fb penoxsulam	15+ 20	1+20	77.01 (8.89)	81.00 (9.03)	(106.50) 10.34	35.81 (6.01)	58.80 (6.67)	(69.60) 7.45	51.78	47.75	46.41
Hand weeding		20+40	136.67 (11.71)	18.33 (4.34)	(21.33) 4.67	72.13 (8.50)	2.90 (1.84)	(8.50) 2.98	-	97.42	93.45
Unweeded check			137.27 (11.74)	163.83 (12.82)	(192.33) 13.89	74.27 (8.64)	112.53 (11.58)	(129.87) 13.20	-	-	-
LSD (p=0.05)			0.88	0.92	1.06	0.57	0.73	0.84	0.80		

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Data given in parenthesis are original values. Original data subjected to square root transformation.
 WCE: weed control efficiency; IC: Intercultivation; fb: followed by

3.2 Crop growth parameters

3.2.1 Phytotoxicity and Plant population m⁻²

114 Isoproturon at 500 g ha⁻¹ (W₂, W₅, W₈) exhibited mild phytotoxicity, (Table 2)
 115 disappearing within 20 days. On average, it reduced initial and final plant population by
 116 18.55% and 20.50%. Pre-emergence pretilachlor at 500 g ha⁻¹ and pyrazosulfuron-ethyl at
 117 15 g ha⁻¹ showed no phytotoxicity. Post-emergence penoxulam at 20 g ha⁻¹ at 20 DAS
 118 resulted in severe crop injury and stunted growth exhibited phytotoxicity ratings of '1' and '5',
 119 respectively, on a 0-10 scale. Penoxulam inhibit the acetolactate synthase enzyme activity,
 120 a key enzyme responsible for biosynthesis of branched chain amino acids, which inturn
 121 making crop plants deficit in protein synthesis in meristematic tissues lead to discolouration
 122 of foliage and stunted growth. These outcomes agree with [15] findings with PE application of
 123 pretilachlor 0.75 kg ha⁻¹ *fb* PoE application of penoxulam 25 g ha⁻¹ at 20 DAS in aerobic
 124 rice.

125 **3.2.2 Plant height and LAI**

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 127 Pre-emergence of pretilachlor at 500 g ha⁻¹ with intercultivation (W₄) showed optimal growth
 128 parameters, akin to pre-emergence pyrazosulfuron-ethyl at 15 g ha⁻¹ with intercultivation
 129 (W₆) and isoproturon at 500 g ha⁻¹ with intercultivation (W₅). This might be due to effective
 130 control of all the categories of weeds because of pre-emergence herbicides supplemented
 131 with intercultivation. Pre-emergence application of pretilachlor and pyrazosulfuron inhibit the
 132 protein synthesis and ALS enzyme activity, respectively in target plants. Significantly high
 133 stature and LAI of crop plants might be due to absence of any phytotoxic effect of the above
 134 two herbicides on foxtail millet and maintained weed free environment during early stages of
 135 crop growth supplemented with intercultivation, which resulted in increased internodal length
 136 of the stem and thereby increased the plant height. These results are in conformity with
 137 findings [16] with PE application of bensulfuron methyl (0.6 % G) + pretilachlor (6.0 % G) 3
 138 kg ha⁻¹ (pre-mix) *fb* intercultivation at 45 DAS. Notably effective among pre-emergence
 139 herbicides, pretilachlor at 500 g ha⁻¹ performed comparably to pyrazosulfuron-ethyl (W₃).
 140 Hand weeding twice might have created favourable environment for enhancing internodal
 141 length which inturn increase plant height because of maintenance of weed free environment.
 142 The results are in conformity with the finding of [5] in drill sown finger millet. However,
 143 sequential isoproturon at 500 g ha⁻¹ followed by penoxulam at 20 g ha⁻¹ at 20 DAS (W₈)
 144 exhibited reduced growth and LAI due to penoxulam phytotoxicity, falling behind the
 145 unweeded check (W₁₁), which displayed significantly lower growth parameters than other
 146 weed management practices. Pre-emergence application of isoproturon 500 g ha⁻¹ applied
 147 plots (W₂, W₅, W₈) computed lesser LAI, which were significantly lesser than rest of the weed
 148 management practices in recording LAI due to stunted growth, reduced number and size of
 149 leaves because of its slight phytotoxicity at initial stages of crop growth. These results are in
 150 conformity with the finding of [3] with PoE application of isoproturon in wheat.

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 152 **Table-2: Crop growth parameters as influenced by different weed management**
 153 **practices in foxtail millet**
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Treatments	Dose (g ha ⁻¹)	Time of application (DAS)	Phytotoxicity scoring		Plant population m ⁻²		Plant height (cm)	Leaf area index
			PE herbicides	PoE herbicides	Initial	Final		
Pretilachlor	500	1	0	-	30.67	30.00	105	1.76
Isoproturon	500	1	1	-	26.67	25.67	105	1.70
Pyrazosulfuron-ethyl	15	1	0	-	31.67	31.00	105	1.74
Pretilachlor <i>fb</i> IC	500	1+20	0	-	31.67	31.67	117	1.91
Isoproturon <i>fb</i> IC	500	1+20	1	-	26.67	25.33	116	1.88
Pyrazosulfuron-ethyl <i>fb</i>	15	1+20	0	-	31.67	31.00	116	1.90

IC								
Pretilachlor <i>fb</i> penoxsulam	500+ 20	1+20	0	5	31.67	30.00	77	1.36
Isoproturon <i>fb</i> penoxsulam	500+ 20	1+20	1	5	25.67	24.33	67	1.31
Pyrazosulfuron-ethyl <i>fb</i> penoxsulam	15+ 20	1+20	0	5	31.33	31.00	76	1.32
Hand weeding		20+40	-	-	31.33	31.00	128	2.16
Unweeded check			-	-	32.23	32.00	93	1.55
LSD (p=0.05)					3.17	3.01	10	0.047

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3.3 Yield and Yield components

The highest yield attributing characters, grain and straw yield was produced by hand weeding twice at 20 and 40 DAS (W_{10}). These results are in conformity with findings of [4] in finger millet, with two hand weedings as it control all categories of weeds followed by pre-emergence application of pretilachlor 500 g/ha with inter-cultivation at 20 DAS (Table 3) due to effective control of all categories of weeds by PE herbicides during early stages of crop growth and supplemented with intercultivation controlled established weeds, which in turn enhanced the availability of growth resources to crop leading to higher number of panicles m^{-2} and there was less competition for growth resources, which increased photosynthates translocation to developing grains. These outcomes concurred with the direct-seeded finger millet research conducted by [18]. The unweeded check (W_{11}) outperformed sequential pre-emergence herbicides with penoxulam at 20 g ha^{-1} (W_7 , W_9 , W_8) due to penoxulam phytotoxicity and poor weed control efficiency.

Table-3: Yield and Yield components as influenced by different weed management practices in foxtail millet

Treatments	Dose (g ha^{-1})	No. of panicles (m^{-2})	Dry matter production (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	HI (%)	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C
Pretilachlor	500	47.00	4617	1309	3008	30.37	40775	18815	1.86
Isoproturon	500	47.00	4604	1182	2962	28.02	36947	14900	1.68
Pyrazosulfuron-ethyl	15	47.00	4611	1284	2978	30.12	39996	18363	1.85
Pretilachlor <i>fb</i> IC at 20 DAS	500	62.67	5754	1961	3592	35.42	60637	35077	2.37
Isoproturon <i>fb</i> IC at 20 DAS	500	56.00	5298	1660	3348	33.55	51460	25813	2.11
Pyrazosulfuron-ethyl <i>fb</i> IC at 20 DAS	15	58.33	5380	1745	3435	33.75	54067	28834	2.14

Pretilachlor <i>fb</i> penoxsulam at 20 DAS	500+ 20	37.33	3297	779	2438	24.22	26999	2241	1.09
Isoproturon <i>fb</i> penoxsulam at 20 DAS	500+ 20	32.00	3220	690	2250	23.47	25317	472	1.02
Pyrazosulfuron-ethyl <i>fb</i> penoxsulam at 20 DAS	15+ 20	33.33	3256	724	2397	22.92	25914	1483	1.06
Hand weeding twice		70.00	6496	2353	3944	37.47	72547	34867	1.92
Unweeded check		2.292	3951	861	2881	22.92	27257	7077	1.35
LSD (p=0.05)		6.72	4617	315	419	4.11	3220	4634	0.17

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Hand weeding twice (W_{10}) resulted in the highest gross returns, harvest index (HI) this might be due to increased grain and straw yield as a result of weed free environment during entire crop growth period. These results are in conformity with findings of [4] in finger millet followed by pre-emergence pretilachlor at 500 g ha⁻¹ with intercultivation (W_4), showing comparable net returns. However, hand weeding twice had a lower benefit-cost ratio due to increased weeding costs. The lowest gross and net returns, along with a lower benefit-cost ratio, were observed with pre-emergence isoproturon at 500 g ha⁻¹ with penoxsulam at 20 g ha⁻¹ (W_8), significantly lower than the unweeded check (W_{11}) in terms of net returns and benefit-cost ratio but comparable in gross returns. Post-emergence application of penoxsulam showed severe phytotoxicity on crop and poor weed control efficiency of penoxsulam applied plots reduced the grain and straw yield of crop.

3.4 Nutrient uptake by weed and crop

Outperforming other treatments, hand weeding twice (W_{10}) reduced weeds' intake of nutrients (Table 4) and increased the crop uptake of nutrients. This might be due to effective control of all the categories of weeds and cumulative effect of increased biomass production and higher nitrogen content accumulated in the crop. Sufficient levels of nitrogen is known to improve the root cation exchange capacity, which might had enhanced absorption of the other nutrients. These results are in conformity with findings of [1] with HW twice at 20 and 40 DAT in kodo millet. Intercultivation after pre-emergence pretilachlor at 500 g ha⁻¹ (W_4) successfully decreased weeds' nutrient outflow and increased the crop uptake of nutrients. This could be because these weed management techniques eliminated all weeds, which decreased the dry weight of all weeds and hence reduced nutrient intake. These outcomes agree with those of [12]. Nutrient absorption by weeds was enhanced by isoproturon at 500 g ha⁻¹ and penoxsulam at 20 g ha⁻¹ (W_8) but uptake by crop was lower as compared to other treatments. This might be due to reduced dry matter production as a result of severe phytotoxicity of penoxsulam on foxtail millet and thereby reduced the dry matter production of crop in these weed management practices and finally decreased the nutrient uptake. Heavy weed infestation in unweeded check drained nutrient uptake by 45.67, 18.03 and 35 kg ha⁻¹ of nitrogen, phosphorous and potassium, respectively. These results are in conformity with findings of [12] in direct sown finger millet.

Table-4: Nutrient uptake (kg ha⁻¹) by weeds and crop as influenced by different weed management practices in foxtail millet

Treatments	Dose (g ha ⁻¹)	Nutrient uptake by weeds (kg ha ⁻¹)			Nutrient uptake by crop (kg ha ⁻¹)		
		N	P	K	N	P	K
Pretilachlor	500	30.00	13.33	22.67	41.33	11.17	48.33

Isoproturon	500	32.33	14.00	24.17	36.67	10.33	46.00
Pyrazosulfuron-ethyl	15	30.50	13.00	23.67	40.00	11.00	45.67
Pretilachlor fb IC at 20 DAS	500	11.67	6.00	12.00	63.33	16.93	57.00
Isoproturon fb IC at 20 DAS	500	14.20	6.67	14.17	59.67	15.83	55.00
Pyrazosulfuron-ethyl fb IC at 20 DAS	15	13.33	7.00	13.33	62.00	16.33	55.00
Pretilachlor fb penoxsulam at 20 DAS	500 + 20	24.67	10.33	19.00	25.67	6.00	29.33
Isoproturon fb penoxsulam at 20 DAS	500+ 20	36.33	16.23	30.67	21.00	5.33	26.67
Pyrazosulfuron-ethyl fb penoxsulam at 20 DAS	15+ 20	26.33	10.63	19.33	23.00	5.00	28.33
Hand weeding twice		5.00	2.00	5.67	73.00	19.67	64.67
Unweeded check		45.67	18.03	35.00	25.33	6.17	31.00
LSD (p=0.05)		2.53	1.07	2.37	4.51	1.27	4.60

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4. CONCLUSION

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In order to effectively manage weeds in foxtail millet, the field experiment showed that pre-emergence pretilachlor at 500 g ha followed by intercultivation at 20 DAS produced higher grain production and benefit-cost ratio. The grain yield was higher when hand weeding twice, but the benefit-to-cost ratio was not as high as it would have been with the ideal pre-emergence pretilachlor technique. In areas with abundant and economical labour for hand weeding, it remains a viable option. Notably, pre-emergence isoproturon at 500 g ha⁻¹ and post-emergence penoxsulam at 20 g ha⁻¹ at 20 DAS exhibited phytotoxicity ratings of '1' and '5', respectively, on a 0-10 scale thereby reduced the growth and yield of crop.

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