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Evaluation of Critical Period of Crop Weed Competition for Enhanced Weed Management and Yield of Summer Pearl Millet

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The field experiment was conducted at Instructional farm of Department of Agronomy, Navsari Agriculture University, Navsari during summer season of 2021 to 2023 to study critical crop-weed competition in summer pearl millet. There were 10 treatments comprising of initial weed free

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periods of 10, 20, 30 and 40 days after sowing (DAS) and weedy 10, 20, 30 and 40 DAS along with weedy till harvest (un-weeded check) and weed free till harvest (weed free check), were replicated thrice in the randomized block design. Results revealed that maintaining a weed-free condition from 20 to 40 DAS significantly increased the yield of pearl millet, whereas the lower yield was recorded when weeds were allowed to grow during this period. The maximum competition between crop and weed was between 20 to 40 DAS, which can be considered as critical period of crop-weed competition. To avoid the yield loss, integrated weed management can effectively overcome the problems of weed shift and development of resistance in weeds and reduce the weed seed bank and manage the weeds below the economic threshold level to avoid any economic loss in summer pearl millet.

Keywords: Critical period; crop-weed competition; pearl millet; weed management.

1. INTRODUCTION

"Pearl millet (*Pennisetum glaucum* L.) is one of the important cereal crops globally after rice, wheat and maize. It is a unique crop among the major cereals and the staple food and fodder crop of the world's poor and most food insecure populations in the arid and semi-arid tropics. In India, the area and production of pearl millet during 2022-23 was 70.08 lac hectares and 95.31 lac tonne, respectively with productivity of 1360 kg/ha. In Gujarat, it is cultivated over an area of 2.03 lac hectares with a production and productivity of 3.63 lac tonnes and 1787 kg/ha, respectively" [1].

"Weed reduce crop yields by influencing crop growth and development throughout the growing season and by directly competing with the crop for limiting precious resources, like light, water or nutrients. A number of the factors that influence magnitude of crop yield losses from weed interference include the timing of weed emergence relative to the crop, weed density, pattern of weed growth and development. Weed management is one among the foremost critical factors influencing crop yield. By providing a window of weed-free growth early within the season, the size advantage that crop seedlings have over weeds can be utilized to reduce the intensity of direct competition for resources at the stages of crop development when yield is being determined. Weeds are identified as a significance drawback since they create biotic stress in realizing the genetic yield potential of this valuable crop. The amount of yield loss due to weed interference depends on the crop, weeds and growing conditions are quite different. Heavy infestation of weeds throughout the entire growing period may cause an entire loss of crop.

The losses from weed infestation in pearl millets include, direct yield loss from lower crop quality, indirect yield loss from reduced crop quality, higher cost of harvesting, cultivation, and agronomic activities and weeds' capacity to shelter insect pests and disease pathogens" Mishra et al., [2]. "Due to pearl millet's incredibly slow development in the early stages, weed competition was most noticeable during this period of the crop's growth. Therefore, it is more crucial to control weeds in pearl millet during the crop's early growth stage. They emerge and compete with the crop for nutrients, moisture, light, and space, which can reduce yield by as 35%" Nibhoria et al., [3]. The critical period of crop-weed competition is an important factor to consider while developing an integrated weed management system and alternative weed management strategies. In order to maximize the output of pearl millet, it is crucial to manage the weeds using a variety of techniques during the crop weed competition phase. Therefore, the present investigation was under taken to seek out losses in seed yield of summer pearl millet with the presence of weeds, to identify critical stage of weed crop competition in summer pearl millet and most effective stage (crop period) for weed control practice to be adopted in summer pearl millet by the farmers to reduce the yield losses and enhance the economic returns.

2. MATERIALS AND METHODS

An experiment was conducted at Instructional farm of Department of Agronomy, Navsari Agriculture University, Navsari, in summer season of 2021 to 2023. The experimental farm is situated at 25^0 57′ 07.05" N latitude and 72^0 54′ 16.50" E longitudes, at an elevation of 38 m above mean sea level (MSL). The soil of the experimental field was clayey. There were 10 treatments comprising of initial weed free periods of 10, 20, 30 and 40 days after sowing (DAS) and weedy 10, 20, 30 and 40 DAS along with weedy till harvest (un-weeded check) and weed free till harvest (weed free check). To work out the weed count per unit area, a quadrant of size 0.5 x 0.5 m (count/0.25 m^2) was thrown randomly at one place in every plot and weeds were uprooted for population count at 10, 20, 30 and 40 DAS and at harvest and converted biomass g/1.0 m^2 and weed count as no/1.0 m^2 area. In weedy. check treatment, weeds were allowed to grow throughout crop growth period. The uprooted weeds were sun dried completely till reached to constant weight and eventually the dry weight was recorded for each treatment. The treatments laid out in Randomized Block Design (RBD) with three replications.

The pearl millet variety GHB 558 was sown with seed rate of 4.5 kg/ha in rows 45 cm apart. This variety is highly responsive to nitrogen fertilization, resistance to downy mildew, shoot fly and shoot borer tolerant as well as high yielding dual purpose variety. In general, the competitive potential of a crop usually depends upon its ability to access and utilize resources like light, moisture, nutrients, and space. Selecting a competitive cultivar is one way to potentially suppress the weed growth and seed production without the risk of sacrificing crop yield. The crop was fertilized with 120 kg N and 60 kg P_2O_5 in the form of urea and DAP, respectively. Half of the N and full dose of P were applied at the time of sowing, while the remaining N was applied at 20 DAS. In irrigated crop, irrigation given at sowing, 20-25 days after sowing, ear head emergence / flowering and grain filling stages. Complete weed removal was practiced through hand weeding in weed-free plots right from the germination. However, later weeds were hand pulled as and when emerged. In all other weed free treatments, viz. weed free up to 10, 20, 30, 40 DAS and up to harvest, the weeds were completely removed from the plot up to the respective days and after that the weeds were allowed to grow freely. In other treatments having certain weedy periods viz. weedy up to 10, 20, 30 ,40 DAS and up to harvest, the weeds were allowed to grow up to the respective days, thereafter, complete weed removal was practiced. Seed yield of each treatment was recorded and worked out as per cent of weed-free check.

2.1 Weed Control Efficiency

The weed control efficiency was computed at different stages as well as at maturity using following formula suggested by Kondap and Upadhaya [4].

$$WCE\ \% = \frac{DWC - DWT}{DWC} X\ 100$$

Where, WCE= Weed control efficiency (%); DWC= Dry weight of weeds in control plots (weedy check); DWT= Dry weight of weeds in treated plot.

2.2 Weed Index (%)

Weed index (WI) or weed competition index is defined as the reduction in yield due to presence of weeds in comparison to weed free plots. Weed index was worked out on the basis of formula suggested by Gill and Kumar [5].

$$WI\ \% = \frac{X - Y}{X} X\ 100$$

Where, X = Yield from weed free plot; Y = Yield from treated plot for which WI was worked out.

All the data obtained with reference to the weed count, weed biomass, crop growth and yield parameters were analyzed separately for each attribute according to the analysis of variance technique of Panse and Sukhatme [6]. The critical differences were calculated to assess the significant differences between treatment means. The weed count and weed biomass data were transformed by $\sqrt{X}$ + 0.5 for calculation of critical difference for significance.

3. RESULTS AND DISCUSSION

3.1 Weed Flora

“The total number of weed species present in the experimental field was twenty under thirteen families and three categories – five monocot weeds, thirteen dicot weeds and one sedge. The species under monocot weeds category were: *Dinebra retroflexa, Echinochloa crusgalli* L. Beauv, *Sorghum halepense* L. Pers.*, Digitaria sanguinalis* (L.) Scop and *Bracharia* spp., dicot weeds were *Trianthema portulacastrum* L., *Portulaca oleraceae* L., *Euphorbia hirta* L., *Amaranthus viridis* L., *Convolvulus arvensis* L., *Physalis minima* L., *Eclipta alba* Hassak., *Phyllanthus niruri* L., *Alternanthera sessilis* L., *Digera arvensis Forsk, Tridex procumbens* and *Vernonia cinerea* and those under sedge was *Cyperus rotundus* L. Species-wise data of weed composition revealed that *Dinebra retroflexa* among the monocot weeds and *Amaranthus viridis* L. among the dicot weeds were the most dominant at 40 DAS which comprised of about

70% of the total weed population.Prolific growth and wide distribution of *Amaranthus* are favoured by their germination potential and high seed production of species may excessively enrich the soil seedbank, which ensures their regeneration despite biotic and abiotic constraints and contributes to further infestations over time and locations" Korres et al., [7].

3.2 Effect on Weeds

"Table 1 shows that the weed count and dry matter accumulation decrease with the rise in weed free period from 10 to 40 DAS. With the advancement of crop growth stages after sowing there was considerable decrease in the weed population. At harvest the weed population reached a maximum of 198/m^2 in weedy conditions (W_{10}) from 56.74/m^2 at 10 DAS. Weed free condition up to 40 DAS resulted in a significant reduction in weed population and weed dry matter accumulation compare to weedy condition throughout growth period. The maximum total weed dry biomass (2660 kg/ha) at harvest was recorded in weedy upto harvest treatment (W_{10}), whereas it was lowest in weedy up to 10 DAS (W_6, 105 kg/ha), this might be due to the grater biomass accumulation in the weed at harvest when the weed free period extended beyond 20 DAS, strong crop canopy cover suppressed new flushes of weed which emerged at subsequent crop stages thus the crop smothered the late emerging weed which resulted in significantly lower in weed population and dry matter accumulation under the weed free treatments. Ten days after sowing, weed count were in the range of 51.49 – 56.74 /m^2 with the dry biomass of 118 – 129 kg/ha, whereas at harvest the number of weeds increase to 198/m^2 in weedy throughout growth period with the weed dry biomass 2660 kg/ha. The findings are in conformity with those reported" by Kiroriwal et al., [8] and Patel [9].

3.3 Growth Parameters

"Acute weed infestation in the plot maintained weedy up to maturity, adversely affected the plant height of pearl millet (Table 2). Keeping the crop free from weeds up to harvest or weedy up to 20 DAS and there after weed removal gave better plant height. At harvest, treatment W_5 (weed free up to harvest) shows highest plant height (169.19 cm) which was at par with W_6 treatment. Whereas, treatment W_{10} (Weedy up to harvest) recorded significantly lower plant height at harvest (148.29 cm). The higher values of plant height of this treatment might be due to better control of weeds throughout the crop growth period which likely resulted in better moisture and nutrient availability for the crop, creating more favourable growth conditions, consequently crop attained more growth having smothering effect on weed.The reason for this could be that there was minimal weed competition during the critical crop weed competition period (20 DAS to 40 DAS) due to the low density and dry weight of weeds. This enhanced the pearl millet crop growth attributes due to better utilization of resources through effective control of weeds. In comparison to the unweeded control, the pearl millet growth metrics were significantly enhanced by this weed management treatment because they preserved growth inputs such as light, space, moisture and nutrients, thereby improving the edaphic and nutritional environment in the root zone. These results are in accordance with the findings ofThese findings are in close conformity with those reported" by Yadav et al., [10], Samota et al., [11] and Chinayo et al., [12].

3.4 Yield Attributes and Yield

The weed competition adversely affected the yield attributing characters and seed yield of the pearl millet. Weed is an important factor lowering yield of pearl millet, which is responsible for reducing crop growth by two mechanisms. Primarily by competition for resources such as space, light, water, nutrients etc and by allellopathy, this involves releasing of toxin into the environment Bansal et al., [13]. Severe infestation of weed in the plots maintained weedy for initial 40 DAS and at harvest adversely affected the number of ear head per square meter compare to season long weed free condition (W_5) and weed free up to 40 DAS (W_4). Data presented in Table 2 showed lowest number of ear head/m^2 (59.03), grain yield/ear head (4.30 g), grain yield (2438 kg/ha) and straw yield (4278 kg/ha) in weedy throughout growth period (W_{10}). Maximum number of ear head/m^2, grain yield/ear head (g), grain yield (kg/ha) and straw yield (kg/ha) to the tune of 84.86, 4.97, 4162 and 7240 were recorded at weed free throughout growth period (W_5).The significantly higher grain yield (4162 kg/ha) and straw yield (7240 kg/ha) were obtained under treatment W_5 (weed free up to harvest) in pooled results and remained at par with treatments W_4, W_6 and W_7, however significantly lower grain yield (2438 kg/ha) and straw yield (4278 kg/ha) were recorded under treatment W_{10} (weedy up to harvest). Fig. 1 showed that keeping the crop weed free from 20 to 40 DAS increase the seed yield 3900 kg/ha to 4162 kg/ha as compared to the weedy throughout growth period, this shows that presence or absence of weed at any stage compete with the crop for nutrient, water and reduce the crop yield significantly. The unweeded control resulted in a noticeably lower production of grain and straw yield. By enhancing the source-sink connections, higher grain yield may most likely be the result of higher yield and yield attributes values observed under this treatment. These results are in conformity with the findings of Chaudhary et al., [14], Chinayo et al., [12], Kiroriwal et al., [8] and Munde et al., [15] The increase weed density and their biomass (Table 1) to such an extreme level under weedy check (W_{10}) might be attributed to uninterrupted growth of weed which ultimately suppressed the growth and yield attributing characters of pearl millet.

Table 1. Weed population and dry weight of weeds influenced by different treatments in summer pearl millet

Treatment	Weed population/m²					Dry weight (kg/ha)			
	10 DAS	20 DAS	30 DAS	40 DAS	At harvest	20 DAS	40 DAS	At harvest	Total
W_1: Weed free up to 10 DAS	0.71 (0.00)	5.41 (28.95)	8.02 (63.88)	9.03 (81.13)	10.62 (112.32)	7.43 (55)	18.16 (329)	25.54 (652)	34.31 (1177)
W_2: Weed free up to 20 DAS	0.71 (0.00)	0.71 (0.00)	6.42 (40.72)	7.32 (53.13)	9.42 (88.35)	0.71 (0.00)	12.77 (162)	20.88 (436)	26.13 (682)
W_3: Weed free up to 30 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	4.63 (20.94)	7.73 (59.30)	0.71 (0.00)	6.60 (43)	15.30 (234)	16.66 (277)
W_4: Weed free up to 40 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	5.94 (34.85)	0.71 (0.00)	0.71 (0.00)	10.80 (116)	10.80 (116)
W_5: Weed free up to harvest	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
W_6: Weedy up to 10 DAS	7.23 (51.76)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	10.28 (105)
W_7: Weedy up to 20 DAS	7.21 (51.49)	7.96 (62.91)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	10.89 (118)	0.71 (0.00)	0.71 (0.00)	16.30 (266)
W_8: Weedy up to 30 DAS	7.49 (55.56)	7.97 (63.01)	12.10 (145.95)	0.71 (0.00)	0.71 (0.00)	10.90 (118)	0.71 (0.00)	0.71 (0.00)	24.14 (582)
W_9: Weedy up to 40 DAS	7.51 (55.96)	8.23 (67.38)	12.30 (150.84)	12.96 (167.63)	0.71 (0.00)	11.26 (126)	29.30 (858)	0.71 (0.00)	38.32 (1468)
W_{10}:Weedy up to harvest	7.56 (56.74)	8.33 (68.94)	12.22 (148.95)	13.12 (171.58)	14.08 (198)	11.40 (129)	29.64 (878)	34.20 (1169)	51.58 (2660)
SE(d)	0.04	0.12	0.07	0.08	0.09	0.17	0.16	0.18	0.22
CD (P=0.05)	0.13	0.37	0.22	0.23	0.27	0.50	0.48	0.52	0.67
CV (%)	16.14	9.88	11.51	9.63	11.36	10.15	10.57	13.53	7.84

** = Actual value, ** = Transformed value ($\sqrt{X} + 0.5$)*

Table 2. Growth, yield attributes and yield as affected by different treatments in summer pearl millet

Treatment	Plant height at harvest (cm)	Number of ear head per m^2	Grain yield/ ear head (g)	Grain yield (kg/ha)	Straw yield (kg/ha)
W_1: Weed free up to 10 DAS	150.30	67.15	4.50	2932	5090
W_2: Weed free up to 20 DAS	151.41	67.74	4.58	3103	5423
W_3: Weed free up to 30 DAS	155.37	73.58	4.66	3414	5960
W_4: Weed free up to 40 DAS	165.91	80.85	4.80	3952	6847
W_5: Weed free up to harvest	169.19	84.86	4.97	4162	7240
W_6: Weedy up to 10 DAS	167.55	81.71	4.85	4024	7022
W_7: Weedy up to 20 DAS	164.64	82.69	4.76	3900	6791
W_8: Weedy up to 30 DAS	153.13	69.37	4.61	3183	5569
W_9: Weedy up to 40 DAS	148.97	62.38	4.46	2717	4699
W_{10}: Weedy up to harvest	148.29	59.03	4.30	2438	4278
SE(d)	0.60	2.05	0.03	92.83	154.18
CD (P=0.05)	1.79	6.11	0.09	275.82	458.10
CV (%)	5.69	9.38	6.09	9.53	10.18

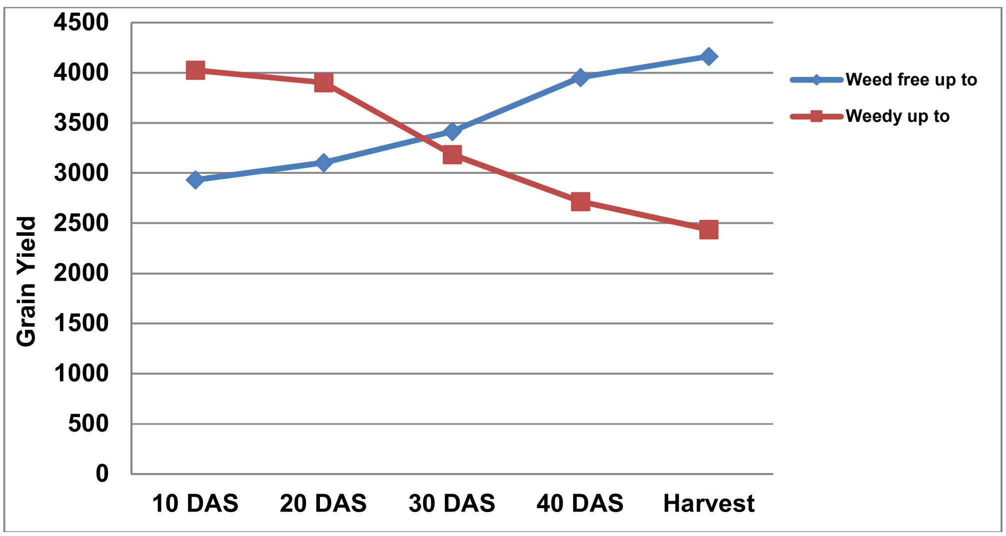

Fig. 1. Pearl millet as influenced by various critical period of crop-weed competition treatments

3.5 Weed Control Efficiency (WCE)

"Weed control efficiency is a measure of the efficiency of weed control methods in restricting the weed growth. The crop yield is directly proportional to weed control efficiency (WCE) and inversely related to weed index (WI). Table 3 shows that weed control efficiency decreased from 96.05 % at weedy conditions up to 10 DAS (W_6) to 90.03, 78.10, 44.79 to 0.0 at weedy conditions up to 20 (W_7), 30 (W_8), 40 DAS (W_9) and throughout growth period (W_{10}), respectively. Weed control efficiency improved gradually with the increasing weed free period from 10 DAS to 40 DAS. Weed control efficiency improved from 55.77 % with the treatment weed free up to 10 DAS (W_1) to 100% with the treatment weed free throughout growth period (W_5). Higher weed control efficiency (100%) was observed in treatment W_5 (weed free up to harvest), which was followed by in the trend of W_6> W_4> W_7>W_3 >W_8> W_2> W_1>W_9>W_{10}. Highest weed population and dry weight of weeds were recorded in weedy check compared to other treatments. The crop weed competition was markedly reduced by weed control treatments as is evident from the significant decrease in weed population, dry matter accumulation, and weed control efficiency. This was due to better control of weeds during crop growth period which lowered the total weed population and its dry weight. This is results are in accordance with" Patel [9] and Das et al., [16].

Table 3. Economics of pearl millet as influenced by various critical period of crop-weed competition treatments

Treatment	Weed control efficiency (%)	Weed index (%)	Cost of cultivation (₹/ha)	Gross realization (₹/ha)	Net realization (₹/ha)	BCR
W_1:Weed free up to 10 DAS	55.77	29.55	29204	89184	59980	2.05
W_2:Weed free up to 20 DAS	74.35	25.46	31300	94591	63290	2.02
W_3:Weed free up to 30 DAS	89.58	17.99	33396	104031	70635	2.12
W_4:Weed free up to 40 DAS	95.64	5.06	35492	120121	84629	2.38
W_5:Weed free up to harvest	100.00	0.00	39684	126686	87002	2.19
W_6:Weedy up to 10 DAS	96.05	3.31	35492	122618	87126	2.45
W_7:Weedy up to 20 DAS	90.03	6.30	33396	118747	85351	2.56
W_8:Weedy up to 30 DAS	78.10	23.53	31300	97068	65768	2.10
W_9:Weedy up to 40 DAS	44.79	34.72	29204	82544	53339	1.83

3.6 Weed Index (%)

"Weed index is a measure of reduction in the pearl millet yield due to competition stress offered by weeds as against weed free treatment. The data pertaining to weed index as influenced by different treatments are presented in Table 3. The different treatments exerted their effect on weed index. Increase of weed free period from 10 DAS (W_1) to 40 DAS (W_4) decreased the weed index gradually from 29.55 % to 5.06 and reached to zero in weed free conditions throughout growth period (W_5). Among the weedy treatments, weed index increased from 3.31 % to 34.72 % and maximum weed index 41.43 % was recorded in the treatment weedy up to harvest (W_{10}). The higher weed biomass resulted more weed index and lower weed biomass reduced the weed index. This shows that reduction in the yield of pearl millet was associated with presence or absence of weeds at different growth stages (Table 1 and 2). These findings are in agreement with the results reported" by Singh et al., [17]. As a result of satisfactory control of weeds owing to reduction in the crop weed competition, which may be attributed to marked decrease in weed population, weed dry weight and there by better crop growth, increased number of ear head per square meter, grain and straw yield through better utilization of available resource like fertilizers, water, sunlight and space due to less competition of crop and weeds.

3.7 Economics and Critical Period for Weed-Crop Competition

The maximum gross returns (₹ 126686/ha) recorded by treatment W_5 where as maximum net returns (₹ 87126/ha) recorded by treatment W_6 and maximum B:C ratio (2.56) recorded by treatment W_7 (Table 3). Weed free period beyond 20 DAS produced higher yield and net returns with positive B:C ratio. Weedy period beyond 30 DAS produced significantly lower seed yield with significantly lower net returns and B:C ratio as compare with weed free period 40 DAS and above these result indicates that increase in pearl millet seed yield would be possible with increasing number of weed free days. Among the weedy treatments weedy up to 40 DAS results of significant reduction in seed yield of pearl millet along with lower net returns were obtained. Hence the present study suggested maintenance of weed free crop up to 40 DAS to achieve better yield as well as higher return. From the data in Table 3 it can be observed that reduction in seed yield of pearl millet was observed greater when weeding delayed from 20 to 40 DAS. These findings corroborate the reports of Deshveer and Deshveer [18], Patel [9] and Das et al., [16].

4. CONCLUSION

Pearl millet is susceptible to weed infestation during the early stages of growth, thus the crop needs to be kept weed-free, especially 20 to 40 DAS after sowing. Increased weed competition period increases the competitive ability of both crop and weed while decrease the physiological aspects of growth and development and finally yield attributes and yield of a pearl millet. Weed control at critical period of crop weed competition is economical and it reduces the cost of chemicals and time saving in pearl millet. Instead of relying on any single method of weed control, all the feasible methods are to be integrated, which will not only minimize the environmental impact of herbicide use but also sustainably boost profitability to the large pearl millet growers.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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