PLANT SCIENCE TODAY
Vol 13(sp1): 1-13
https://doi.org/10.14719/pst.11997

eISSN 2348-1900

RESEARCH ARTICLE

Effects of nutrient sources and weed management on yield and weed suppression in finger millet (*Eleusine coracana* L.)

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Received: 26 September 2025; Accepted: 12 January 2026; Available online: Version 1.0: 13 February 2026

Cite this article: Shraddha MK, Lalita R, Navnit K, Biswajit P, Sumit S, Ajeet K, Jystnarani P, Rajan K, Mukesh K, Suruchi K. Effects of nutrient sources and weed management on yield and weed suppression in finger millet (*Eleusine coracana* L.). Plant Science Today. 2026; 13(sp1): 1-13. https://doi.org/10.14719/pst.11997

Abstract

Finger millet (*Eleusine coracana* L.) is a climate-resilient and nutritious crop; however, imbalanced nutrient application and inadequate weed management can limit productivity. A field experiment conducted at Pusa Farm, Dr. Rajendra Prasad Central Agricultural University , Samastipur, Bihar, during kharif 2024. The experiment conducted in a split plot design with two nutrient sources (N_1: 100 % Recommended dose of nitrogen (RDN) via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via farmyard manure (FYM)) as main plot factor and four weed management practices (W_1: Butachlor at 1.0 kg ha^{-1} (Pre-emergence (PE)) followed by 2,4-D at 0.5 kg ha^{-1} (Post-emergence (PoE)); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free as sub-plot factor. Results showed that 100 % RDN increased plant height (101.79 cm), dry matter accumulation (897.8 g m^{-2}) and no. of tillers (5.18 plant^{-1}). Weed-free plots exhibited more tillers (5.76 plant^{-1}) and accumulation (827.1 g m^{-2}). The weed-free plots suppress weed by 75.4 %. In weed-free plots, nitrogen, phosphate and potassium consumption rose 19.4, 16.8 and 18.7 %, respectively. Application of oxyfluorfen (0.1 kg ha^{-1}) fb 2,4-D (0.5 kg ha^{-1}) resulted in highest net returns Rs. 88881 ha^{-1} with benefit-to-cost ratio (2.61). This 1 season study supports long-term experimentation, but it shows that 75 % RDN along with 25 % FYM and oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE) can boost finger millet productivity and profitability.

Keywords: climate-resilient and nutritious crop; finger millet; imbalanced nutrient application; inadequate weed management; productivity and profitability

Introduction

Finger millet (*Eleusine coracana* L.) is a key crop in India and highly valued for its drought resistance. It is grown extensively in rainfed and dryland areas (1), especially red soil. Finger millet, grown on 1.19 million hectares in India, produces 1.98 million tons of grain annually, averaging 1.64 tons per hectare. From 2015–2016 to 2019-20, finger millet output and area decreased in Bihar. In 2015-16, the crop yielded 9.90 thousand tonnes on 6.90 thousand hectares, with the highest yield of 1.43 t ha^{-1}. From 2019–2020, the area declined to 2.76 thousand hectares, resulting in a production drop to 2.19 thousand tonnes and a productivity of 7.96 t ha^{-1}. The 2022–2023 finger millet season saw an increase in area to 4.21 thousand hectares, yielding 4.18 tonnes and a productivity of 9.94 t ha^{-1} (2). Finger millet grains possess up to 61 % digestible ingredients, making them a suitable meal. Finger millet productivity is hindered by weeds, diseases and insect pests. Weeds can reduce yields by 20–40 % without proper management, competing for water, light, nutrients and space. Severe infestations can result in losses surpassing 80 %. Weeds cause yield losses of 25–26 % in kharif crops and 18–25 % in rabi crops, resulting in an annual agricultural production loss of around Rs 92202 crore in India (3). Rising labor and fertilizer costs have made herbicide use a more cost-effective weed management option for grains and millets. While herbicides are efficient, can lead to environmental issues such as soil and water contamination. Low-dose herbicides, effective at low doses per hectare, have been developed to overcome this issue. Weeds grow quickly and compete with crops for nutrients and moisture, frequently outperforming them. Implementing pre-sowing and early post-emergence (PoE) weed management measures is essential. Using chemical fertilizers alone can harm crop output and soil health. Achieving high productivity in finger millet requires effective nutrition management. Using inorganic sources like farmyard manure (FYM) and chemical fertilizers (NPK) together can improve yield and soil health. Farmyard manure boosts soil texture, microbial activity and water-holding capacity, making it essential for drought-tolerant crops like finger millet. In contrast, NPK fertilizers give quick nutrients for strong vegetative growth, panicle initiation and grain filling. Integrating organic and inorganic nitrogen sources promotes sustainability by minimizing chemical fertilizer use, lowering crop expenses and promoting environmental sustainability. Research shows that combining FYM with chemical fertilizers considerably boosts finger millet productivity (4). Herbicides with single-action mechanisms struggle to manage different weed species in millet fields. These measures not only reduce nitrogen losses from weeds but also improve crop nutrient uptake. Managing weeds effectively can reduce production costs and boost farmer profitability, especially in labor-intensive and costly locations. To address herbicide resistance, weed flora changes and chemical residue deposition previous researchers suggest using herbicides with diverse formulations, which have shown potential in managing weeds (5). Research in this area is sparse. Addressing knowledge gaps is crucial for increasing crop productivity and promoting sustainable agriculture. Growing finger millet in integrated systems leads to greater root development, tillering and grain filling. Additionally, these approaches reduce synthetic inputs, lower production costs and enhance environmental resilience. Because the study was conducted to evaluate the effects of different nutrient sources and weed management practices on the growth, yield, weed suppression and economics of finger millet cultivation.

Materials and Methods

Site of experiment

A study was conducted at Pusa Farm, Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur), Bihar, as depicted in Fig. 1. in 2024 during the kharif season. Pusa is situated at 25°59'N and 85°40'E, 52.9 m above sea level on the western bank of the Burhi Gandak River, this area is classified as subtropical. The field has deep, well-drained soil and level topography.

Experimental soil

Five random locations were chosen from the experimental site to collect composite soil samples from a depth of 0–15 cm before the experiment. Samples were collected by making a "V"-shaped incision in the ground with a shovel. The soil samples were dried, pulverized and sieved through a 20 mm mesh size in the lab. Standard methods were used to examine soil properties. The study utilized Entisol soil, a type of calcareous sandy loam typical of the alkaline Pusa region. Soil samples undergo physical and chemical analysis to assess properties using standard methods listed in Table 1 (6–11).

Weather during experimentation

The experimental farm in Samastipur district, Northern Bihar, has a subtropical-humid climate. The Agro-meteorology unit at Dr. Rajendra Prasad Central Agricultural University, Pusa, provided meteorological data for the crop growth season in this study (Fig. 2)

Treatment details

The experiment was conducted in split plot design (SPD) having two main plot factor (N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM) and 5 sub-plot factor (W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free) which replicated thrice (Fig. 1).

Cultural practices

The experiment was conducted in a fertile, uniform field. The land was then plowed twice with a soil turning plow. A flawless tilth was achieved by leveling the ground. Primary nutrients (N, K, P) were applied via urea, MOP, DAP and compost (FYM) at transplanting time as per the treatments. Rest amount applied in 2 splits at 15 DAP and 45 DAP . Finger millet was irrigated shortly after germination and during important growth phases. Data collected from net plot area by excluding border rows. The harvested samples were dried, hand-threshed, cleaned and weighed separately. Treatment-specific grain and straw yields were computed in kg ha^{-1}. Biometric observations were obtained for crop growth, yield and yield attributes over several periods.

Plant height (cm)

Five plants from each plot were randomly selected to measure heights. The crop height was measured in centimeters on a one-meter scale and other parameters also taken.

Leaf area index (LAI)

A leaf area meter was used to measure the leaf area of 5 destructively sampled plants at harvest time. Formula was then used to determine the LAI (12).

$$LAI = \frac{\text{Leaf area}}{\text{Ground area}}$$

Dry matter accumulation (g m^{-2})

A total of 5 plants were selected at random. The samples were cleaned, sun-dried, and then oven-dried at 70 ± 5 °C until a constant weight was obtained, after which the dry weight was recorded.

Number of tillers plant^{-1}

Tillers were recorded by taking five randomly chosen plants from each plot. The mean tillers of the plants were computed.

Table 1. Soil physico-chemical properties of initial soil sample (0–15 cm)

Sl. No.	Particulars	Value	Methods used	References
1.	Sand (%)	51.3	International pipette method	(6)
2.	Silt (%)	37.2		
3.	Clay (%)	11.5		
4.	Textural class	Sandy loam		
5.	Bulk density (g cc^{-1})	1.43	Core sampler method	(7)
6.	pH	7.82	Glass electrode *p*H meter (Soil: Water,1:2.5)	(8)
7.	Electrical Conductivity (dSm^{-1})	0.29	Conductivity Bridge (Soil: Water,1:2.5)	(8)
8.	OC (%)	0.45	Walkley and Black	(9)
9.	Available N (kg ha^{-1})	194.6	Alkaline $KMnO_4$ method	(10)
10.	Available P (kg ha^{-1})	16.9	Olsen's method	(11)
11.	Available K (kg ha^{-1})	115.4	Flame photo metric method	(8)

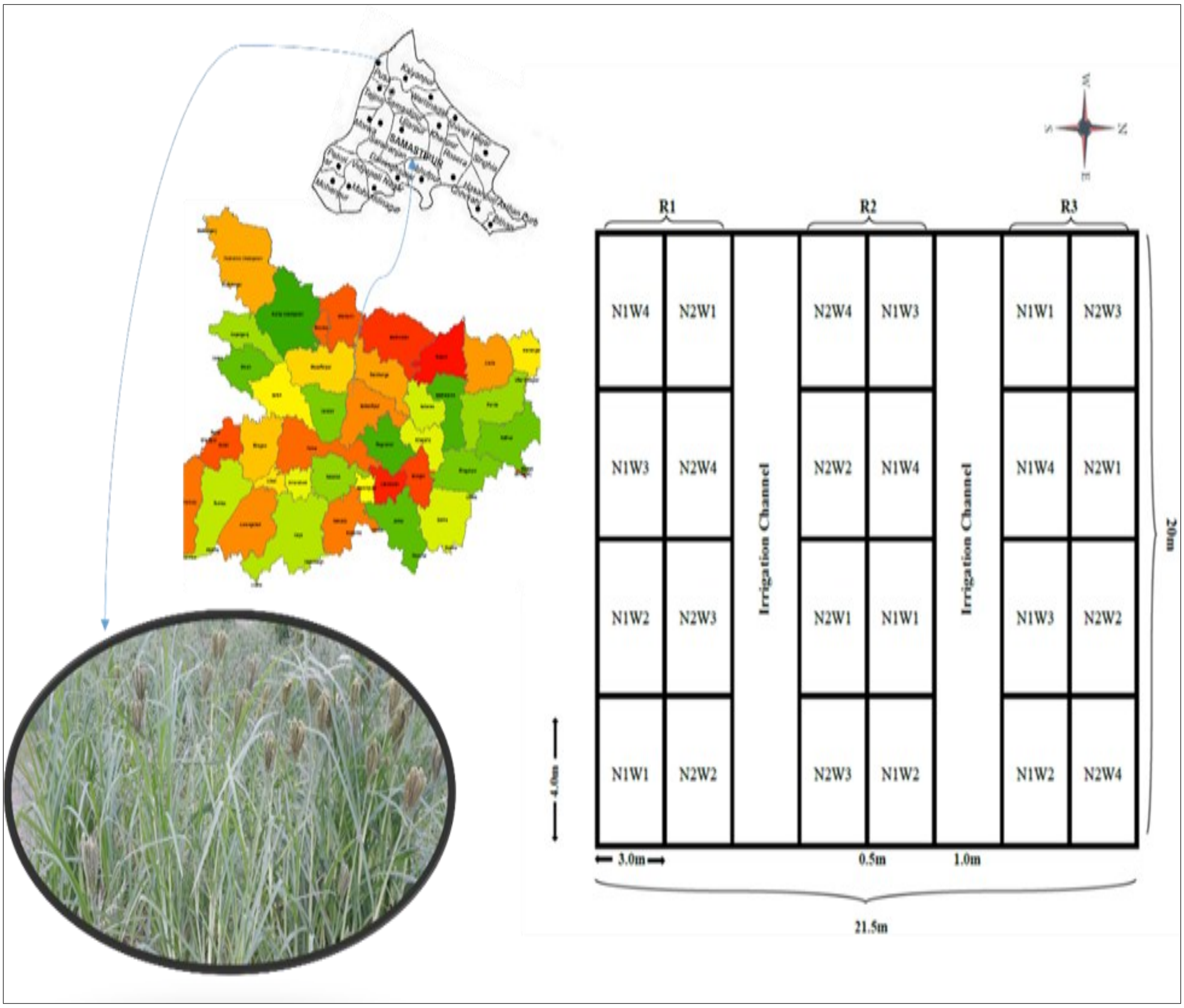

Fig. 1. Study location and layout of the experimental plots. N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application.

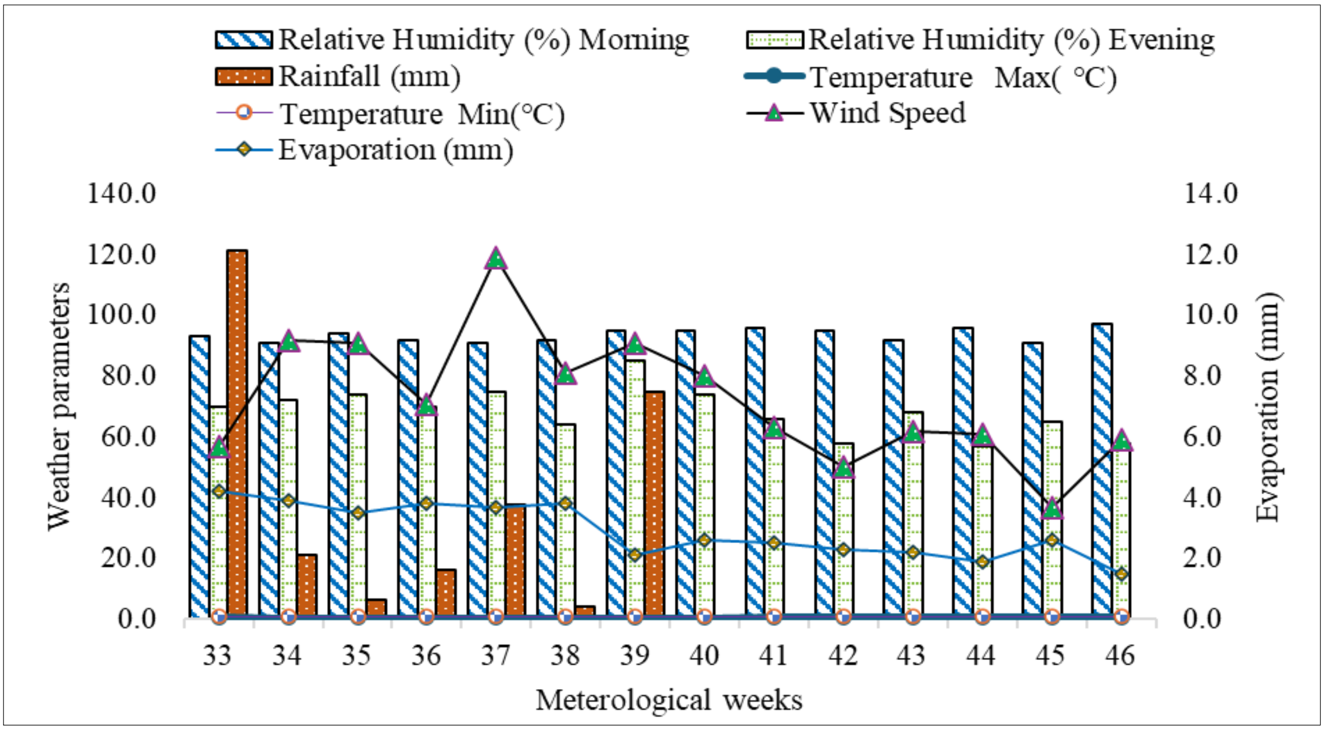

Fig. 2. Weather data of experimental field during kharif-2024.

Crop yield attributing character

Number of fingers plant^{-1}

The number of fingers on each 5 plants at random was counted and the average number of fingers of each plant was determined.

Length of finger (cm)

Finger length was measured from the base to the tip and the average length was presented in centimeters.

Finger weight plant^{-1}

Five randomly chosen plants had their total number of fingers harvested, dried and weighed individually. The average number of fingers was then calculated and expressed in grams' plant^{-1}.

Number of seeds finger^{-1}

After selecting five fingers at random, the quantity of grains that were found in each finger was counted and then averaged.

Test weight (g)

After threshing and cleaning the seeds were collected and dried in the sunlight. The 1000 seed-weight (test weight) was measured in gram.

Crop yield studies

Grain yield (kg ha^{-1})

The grain yield was expressed in kilograms per hectare after accounting for the collected yield data from the net plot.

Straw yield (kg ha^{-1})

The straw that had been air-dried was removed after threshing of finger millet and measured in kilograms per hectare.

Harvest index (HI)

Economic yield divided by total biological yield was used to calculate the harvest index formula given by previous researchers (13).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

Observation of weeds

Species wise weed count

Weed density by species was randomly measured at two locations per plot in 0.25 m^{-2} on 30, 60 DAT and harvest. The average of two locations was calculated and represented as No. m^{-2} and these weeds were classified as grasses, sedges and broad-leaf weeds.

Dry weight of weed

Samples are taken for weed dry weight from a randomly chosen location within the gross plot area after sedge, grass and broad-leaved weeds have been separated. A hot air oven was used to dehydrate these samples until their dry weight was constant at 60 °C. The dry weight of weeds was measured separately for grasses, sedges and broad leaved weeds (BLW) as g m^{-2} at 30, 60 DAT and harvest.

Weed control efficiency (WCE)

It shows the efficiency of the herbicide or other methods to weed-control. When compared to a weedy check plot, it is the percentage decrease in weed dry matter caused by any weed management treatment. This index is used to compare various methods of weed control. Treatment is better if its WCE is higher and vice versa. The formula was used to calculate weed control efficiency (14).

$$WCE\ (\%) = \frac{WD_c - WD_t}{WD_c} \times 100$$

Where,

WCE = Weed control efficiency (%)

WD_{ut}= Weed dry matter in untreated plot

WD_t = Weed dry matter in treated plot

Weed index (WI)

It describes the decrease in yield of crops brought on by weeds when compared to a crop free of weeds. This is used to assess an herbicide's effectiveness. According to earlier reports, pesticide effectiveness increases with a lower weed index and vice versa (15).

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

Where,

WI = Weed Index (%)

X = Finger millet yield in weed free field

Y = Finger millet yield in herbicide applied field

Economics

The economic studies were carried out treatment wise by estimating the total cost involved in cultivation, gross returns as well as net profit in 1 hectare of land evaluated according to the market prices of various inputs and outputs during the analysis.

Total cost involved in cultivation (Rs ha^{-1})

It is the sum of the fixed and variable costs.

Gross return (Rs. ha^{-1})

A prevailing rate at the market was used to estimate the total income of the produce, i.e., grain + straw and thus gross returns were calculated in Rs .ha^{-1}.

Net return (Rs. ha^{-1})

Total cost involved in cultivation was subtracted from the gross return in case of calculating the net profit or return.

B: C ratio

The B:C ratio was computed using the given formula.

$$\text{Benefit : cost ratio} = \frac{\text{Net return (Rs ha}^{-1})}{\text{Cost of cultivation (Rs ha}^{-1})}$$

Data analysis using statistical methods

Transformation of data

Weed dry weight and weed count data differed greatly. The weed count and dry weight data were transformed using the square root formula $\sqrt{x + 0.5}$ in order to increase the accuracy of the analysis of variance.

Statistical analysis and interpretation of data

Data was analyzed following Gomez and Gomez (16). The statistical study has been performed using Fisher's approach of 'analysis of variance'. A 5 % threshold of significance was determined to be appropriate for the 'F' test. The table illustrates the least significant difference (LSD) values at the 5 % level of significance.

Results

Growth attributes

Results of the study revealed that plant height, dry matter accumulation at harvest and leaf area index at 90 days after transplanting did not significantly influence by the nutrient sources as depicted in Table 2. However, the tallest plant was observed in the N_1 treatment in which 100 % RDN was applied. While weed management practices significantly exert the effect on growth attributes. Plant height, dry matter accumulation and leaf area index increased by 18.7, 26.7 and 22.3 % in weed free plots over weedy check plots and it was significantly at par with W_1 and W_2. In our experiment, it was observed that no. of tillers plant^{-1} did not influence by the nutrient sources but significantly affected by weed management practices. It was found that maximum no. of tillers per plant were found in the hand weeded plots over the weedy check plots.

Yield attributes

Finger millet plants' reproductive characteristics, such as finger count, considerably affect crop productivity. Nutrient source treatments did not affect plant finger count. In field experiments, it was revealed that plots that received 100 % RDN from chemical fertilizer had the most fingers (18.28), slightly more than those that received 75 % through chemical fertilizers and 25 % from FYM (17.43) as revealed from Table 2. However, weed control considerably affected this metric. Weed-free (W_4) generated the most fingers per plant, 41.0 % more than the weeded plot and statistically equal to 2,4 D at 0.5 kg/ha (W_2) and oxyfluorfen at 0.1 kg/ha. Nutrient sources and weed control did not interact significantly.

In experimental study, it was found that the treatment receiving 100 % RDN by chemical fertilizer (N_1) had the longest finger length (7.19 cm) compared to 75 % nitrogen using the required amount of fertilizer and 25 % RDN using FYM, which measured 6.12 cm. The rapid availability of nutrients, especially nitrogen, under N_1 may have boosted spikelet growth and panicle elongation. Weed management practices significantly influenced finger length. The weedy check had the shortest fingers (6.08 cm), while the weed-free had the longest (7.37 cm).

Finger weight, which reflects both finger development and grain filling, is a crucial factor in finger millet yield. Our results showed that 100 % RDN by chemical fertilizer had a higher finger weight (9.55 g) than treatment 75 % nitrogen through chemical fertilizer combined with 25 % RDN by FYM (8.88 g) as depicted in Table 1. However, weed control greatly affected finger weight. The weed-free W4 treatment produced the highest finger weight (11.20 g), followed by oxyfluorfen at 0.1 kg per hectare and 2,4-D at 0.5 kg per hectare at 10.68 g. The weedy check (W_3) had the lightest finger weight, 6.07 g. Non-significant relationship between nutrient supply and weed management on finger weight.

Results of the study showed that 100 % RDN through chemical fertilizer produced 104.17 seeds finger-1, 4.1 % more than 75 % nitrogen with 25 % RDN through FYM. Difference was not statistically significant as indicated in Table 1. This yield metric was greatly affected by weed control. Compared to oxyfluorfen at 0.1 kg per hectare followed by PoE application of 2,4-D at 0.5 kg ha^{-1}, weed-free treatments had the most seeds per finger (115.67). The weedy check (W3) had the lowest seed count (79.50).

Test weight indicates finger millet grain density and maturity, a quality indicator. Table 2 revealed that nutrition source did not affect test weight. The test weight was higher in plots treated with 100 % nitrogen and the appropriate amount of chemical fertilizer (3.11 g) than 75 % RDN and 25 % through FYM (2.80 g). The maximum test weight was 3.29 in weed-free treatment, which was statistically equal to oxyfluorfen at 0.1 kg ha-1 (PE) followed by 2,4-D at 0.5 kg ha^{-1}. We found that weedy check treatments reduced test weight by 21.9 % over weedy free treatment.

No significant relationship between weed control and nutrient sources affected number of fingers per plant, finger length, finger weight and test weight.

Finger millet grain and straw yield

Results showed that in Fig. 3, there was no statistically significant difference in the grain, straw yield, or harvest index of finger millet depending on the nutritional sources. The plot that received 100 % recommended dose of nitrogen (RDN) by chemical fertilizer recorded a superior yield of 2.30 and 4.52 t ha^{-1} grain and straw yield as comparing the treatment with recommended dosage of chemical fertilizer provides 75 % nitrogen along with 25 % RDN through

Table 2. Finger millet growth and yield attributes as influenced by nutrient sources and weed management practices during kharif -2024

	Plant height (cm) at harvest	Dry matter accumulation (g m^{-2}) at harvest	Leaf area index at 90 DAT	No of tillers plant^{-1}	Number of fingers plant $^{-1}$	Finger length (cm)	Finger weight plant^{-1} (g)	Number of seeds finger^{-1}	Test Weight (g)
Nutrient sources (N)									
N_1	101.79	897.8	3.03	5.18	18.28	7.19	9.55	104.17	3.11
N_2	96.02	865.4	2.97	4.96	17.43	6.12	8.88	100.08	2.80
SEm (±)	1.76	9.4	0.08	0.12	0.47	0.17	0.26	2.59	0.07
LSD (*p*=0.05)	NS	NS	NS	NS	NS	1.04	NS	NS	NS
CV (%)	8.16	8.06	9.17	8.3	9.20	6.28	7.33	8.80	8.69
Weed management practices (W)									
W_1	96.57	773.1	3.07	5.00	17.58	6.45	8.93	102.00	2.87
W_2	103.58	802.9	3.13	5.26	19.35	6.72	10.68	111.33	3.10
W_3	89.38	652.7	2.60	4.25	14.31	6.08	6.07	79.50	2.57
W_4	106.08	827.1	3.18	5.76	20.18	7.37	11.20	115.67	3.29
SEm (±)	1.38	10.65	0.11	0.19	0.59	0.23	0.31	3.43	0.10
LSD (*p*=0.05)	4.27	30.4	0.35	0.58	1.81	0.72	0.97	10.58	0.31
CV (%)	8.43	8.05	9.27	9.1	8.1	7.21	7.43	8.23	8.21
N×W	ns	ns	ns	ns	ns	ns	ns	ns	ns

DAT: Days after transplanting; N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application PoE: Post-emergence application; LSD: Least significant difference; CV: Coefficient of variation; ns: non-significant.

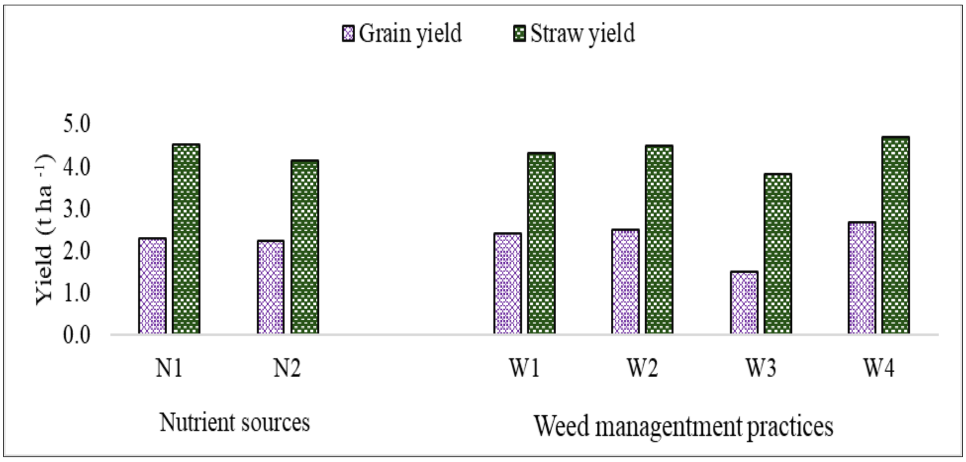

Fig. 3. Grain and straw yield as influenced by nutrient sources and weed management practices during Kharif -2024. N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application.

farmyard manure (FYM). The 75 % RDN through chemical fertilizer + 25 % RDN through FYM had a higher harvest index (34.68 %) than the 100 % RDN through chemical fertilizer treatment (33.42 %), although the differences were not statistically significant. Conversely, weed control techniques had a major impact on yield components. The highest grain production (2.66 t ha^{-1}), straw yield (4.70 t ha^{-1}) and harvest index (36.16 %) were obtained from weed-free treatment. The herbicidal treatments of 2,4-D at rate of 0.5 kg ha^{-1} and PE oxyfluorfen at rate of 0.1 kg ha^{-1} came right after this. Conversely, each parameter, the weedy check yielded the lowest results.

Interaction effect of grain yield

As shown in Fig. 4 significant interaction was observed for grain yield. The maximum grain yield (2.69 t ha^{-1}) was observed with 100 % RDN through chemical fertilizer × weed-free, followed closely by 75 % RDN by chemical fertilizer combined with 25 % RDN through FYM × weed-free treatment (2.62 t ha^{-1}). The lowest yield (1.47 t ha^{-1}) was observed under 75 % RDN through chemical fertilizer along with 25 % RDN through FYM × weedy check treatments. This suggests that although individual nutrient or weed treatments were important, their combination under optimal management especially with hand weeding produced the best grain yields.

Weed flora in the finger millet field

Among the grassy weeds commonly found are *Cynodon dactylon* (L.) Pers. (Bermudagrass), *Dactyloctenium aegyptium* (L.) Willd. (crowfoot grass), *Eleusine indica* (L.) Gaertn. (goosegrass) and *Echinochloa colona* (L.) Link (jungle rice). The broadleaf weeds include *Eclipta alba* (L.) Hassk. (false daisy), *Physalis minima* L. (wild gooseberry), *Corchorus trilocularis* L. (wild jute), *Phyllanthus niruri* L. (hazardana or stonebreaker) and the wild type of *Cucumis melo* L. (wild muskmelon). Sedges such as *Cyperus rotundus* L. (purple nutsedge) and *Cyperus esculentus* L. (yellow nutsedge) are also prevalent in the field.

Weed density

Weed density of grass

Results of the experiment revealed that plots receiving 100 % of the prescribed nitrogen dose from chemical fertilizer had lower grass weed density than those receiving 75 % RDN from chemical fertilizer and 25 % from farmyard manure (Table 3). The prescribed dosage of chemical fertilizer with 75 % nitrogen and 25 % RDN from farmyard manure increased grass weed density by 2.7, 3.7 and 7.6 % above 100 % RDN at 30, 60 DAT and harvest respectively. Weed-free plots had the lowest grass weed population at 30, 60 and harvest days after transplanting. Oxyfluorfen at 0.1 kg per ha as preemergence herbicide and 2,4-D at 0.5 kg per ha as PoE herbicide were more effective than butachlor at 1.0 kg per ha (PE) fb 2,4-D at 0.5 kg. Weedy check had the highest weed population (96.04, 133.94 and 147.4), demonstrating the importance of active weed removal. Nutrient-weed management interaction was non-significant at 30 and 60 DAT but significant at harvest.

Weed density of broad-leaved weeds (BLW)

Broad-leaved weeds weed density depends on weed control and nutrition levels. Table 3 shows that 100 % RDN by chemical fertilizer reduced BLW density by 6.6, 8.7 and 9.0 % at 30, 60 DAT and harvest, compared to 75 % and 25 % by FYM. At 30, 60 DAT and harvest, wide leaf weed density was 5.54, 9.87 and 14.41, respectively, after weed-free maintained 0.0. This treatment outperformed butachlor at 1.0 kg/ha (PE) and 2,4-D at 0.5 kg/ha (PoE), with 11.41, 23.41 and 30.14. Weedy check density was higher at each stage (55.52, 78.16, 93.87). The interaction between nitrogen supplies and weed management approaches was non-significant at 30 DAT and harvest but significant after 60 DAT as shown in Table 3.

Broad-leaved weeds interaction at 60 DAT

Results indicate a substantial interaction between weed management tactics (N × W) and nutrient sources on the measured parameter (Fig. 5a). The highest BLW (8.97) was achieved by the combination of N_2 (75 % RDN via chemical fertilizer + 25 % FYM) and W3, followed by N_1W_3 (8.76). In both W_1 and W_2, N_2 had higher BLW at 60 DAT (5.00 and 3.44, respectively) than N_1, suggesting that employing FYM instead of chemical fertilizers enhanced weed management techniques.

Weed density of sedges

Our research showed that the recommended dosage of chemical fertilizer provides 75 % nitrogen and 25 % RDN through FYM recorded the highest weed density of sedges (8.8, 12.19 and 15.5 weeds m^{-2} at 30, 60 DAT and harvest) compared to 100 % nitrogen (Table 3) and were not statistically significant. With no population of weeds at all phases, weed-free was the best strategy. Butachlor at 1.0 kg ha^{-1} and 2,4-D at 0.5 kg ha^{-1} performed worse than PE oxyfluorfen at 0.1 kg ha^{-1} and 2,4-D at 0.5 kg ha^{-1} Nutrient sources and weed control practices interacted significantly at 30 DAT but not at 60 DAT or harvest.

Table 3. Weed density is influenced by nutrient sources and weed management practices during kharif -2024

Treatment details	Density of grass weeds (No. m^{-2})			Density of BLW (No. m^{-2})			Density of sedge weeds (No. m^{-2})		
	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest
Nutrient sources (N)									
N_1	4.47 (29.8)	5.39 (43.84)	5.82 (49.25)	3.44 (17.62)	4.31 (26.77)	4.88 (33.23)	2.75 (8.53)	3.06 (10.49)	3.53 (14.89)
N_2	4.59 (32.09)	5.59 (45.87)	6.26 (54.1)	3.73 (18.87)	4.7 (29.31)	5.27 (36.52)	2.88 (8.8)	3.33 (12.19)	3.68 (15.5)
SEm (±)	0.05	0.04	0.01	0.04	0.02	0.02	0.02	0.05	0.09
LSD (p=0.05)	0.32	0.23	0.04	0.26	0.14	0.12	NS	NS	NS
CV (%)	6.06	7.43	5.40	7.16	6.82	7.30	9.85	8.03	8.87
Weed management practices (W)									
W_1	4.35 (18.45)	5.31 (27.73)	6.17 (37.79)	3.45 (11.41)	4.89 (23.41)	5.53 (30.14)	3.1 (9.16)	3.55 (12.16)	3.92 (14.89)
W_2	3.07 (8.95)	4.25 (17.58)	4.55 (20.43)	2.44 (5.54)	3.21 (9.87)	3.86 (14.41)	3.18 (9.66)	3.39 (11.08)	3.75 (13.63)
W_3	9.82 (96.04)	11.59 (133.94)	12.16 (147.4)	7.48 (55.52)	8.87 (78.16)	9.71 (93.87)	3.97 (15.25)	4.65 (21.18)	5.65 (31.47)
W_4	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
SEm (±)	0.10	0.07	0.06	0.11	0.05	0.08	0.07	0.09	0.10
LSD (p=0.05)	0.31	0.21	0.18	0.35	0.15	0.26	0.21	0.27	0.30
CV (%)	6.40	6.05	5.43	7.80	9.70	8.01	8.88	9.78	8.59
N×W	ns	ns	ns	ns	0.22	ns	0.29	ns	ns

Data within parentheses are original values; Data analyzed using √x + 0.5 transformation; BLW: broad leaved weeds; DAT: Days after transplanting; N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; LSD: RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application; LSD: Least significant difference; CV: Coefficient of variation; ns: non-significant.

Interaction effect of sedges at 30 DAT

The interaction effect between nutrient sources and weed management practices (N × W) on sedge population revealed notable differences as shown in Fig. 5b. Combining N_2W_3 produced the highest sedge population (3.99), followed closely by N_1W_3(3.94). This suggests that weed management strategy W3 produced a relatively larger sedge population under both nutrient sources. Interestingly, when paired with W_4, the lowest sedge population (0.71) was consistently recorded under both N_1 and N_2, indicating that W_4 was the most effective strategy in reducing sedge infestation even when a different fertilizer source was used.

Dry weight

Dry weight of grasses

Findings of the experiments showed that the impact of nutrient sources on dry weight of grasses was statistically insignificant (Table 4). Application of treatment 75 % RDN through chemical fertilizer combined with 25 % RDN through farmyard manure had highest dry weight among nutrient sources. This was 3.0, 3.2 and 3.5 %, higher at 30, 60 DAT and harvest than the 100 % RDN through chemical fertilizer, respectively. Among weed control techniques, the weed-free treatment had the lowest dry weight of grasses across all growth stages. Oxyfluorfen (0.1 kg per ha) and 2,4-D (0.5 kg per ha) were next in line. Dry weight was significantly greater for butachlor a dose of 1.0 kg ha^{-1} and 2,4-D a dose of 0.5 kg ha^{-1} (4.61, 7.10 and 10.03 g m^{-2}). The weedy check plot had the highest grass dry weight at the 30, 60 DAT and harvest respectively (24.09, 33.55 and 37.05 g m^{2}).

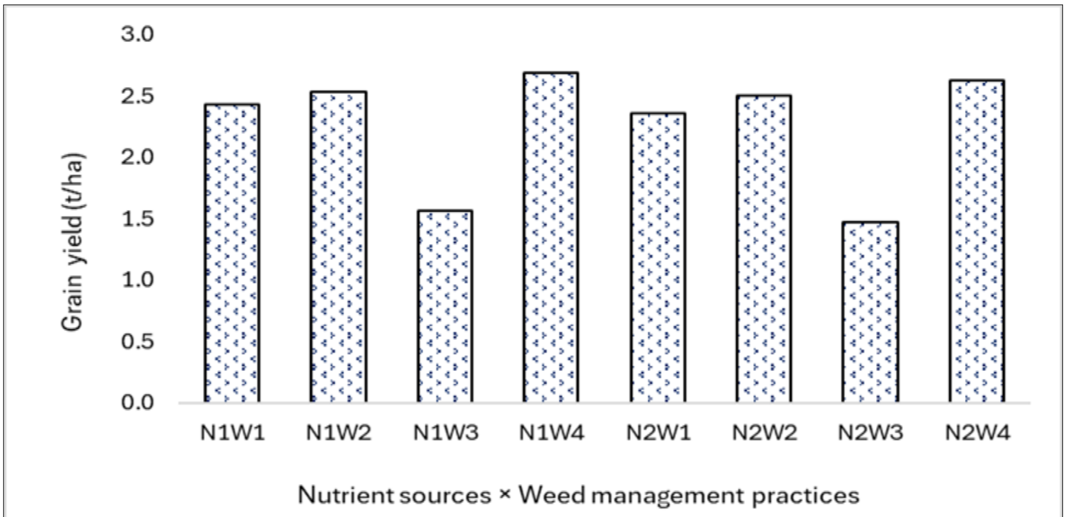

Fig. 4. Interaction effects between nutrient sources and weed management practices grain yield of finger millet during kharif -2024. N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application.

Table 4. Dry weight of weeds as influenced by nutrient sources and weed management practices during kharif -2024

Treatment details	Dry weight of grass weeds (g m^{-2})			Dry weight of BLW (g m^{-2})			Dry weight of sedge weeds (g m^{-2})		
	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest
Nutrient sources									
N_1	2.36 (7.4)	2.84 (11.08)	3.12 (12.88)	2.28 (6.94)	2.92 (11.2)	3.53 (15.83)	1.71 (2.84)	2.1 (4.54)	2.47 (6.54)
N_2	2.43 (8.08)	2.93 (11.48)	3.23 (13.6)	2.45 (7.57)	3.12 (12.18)	3.69 (16.66)	1.77 (2.93)	2.2 (4.96)	2.71 (7.96)
SEm (±)	0.06	0.02	0.03	0.02	0.02	0.01	0.03	0.01	0.02
LSD (p=0.05)	NS	NS	NS	0.11	0.10	0.11	NS	0.08	0.09
CV (%)	8.36	8.29	8.94	6.68	7.80	7.51	7.81	8.05	7.04
Weed management practices									
W_1	2.25 (4.61)	2.75 (7.1)	3.24 (10.03)	2.27 (4.68)	3.11 (9.19)	3.89 (14.69)	1.93 (3.28)	2.52 (5.89)	2.9 (7.95)
W_2	1.63 (2.24)	2.2 (4.39)	2.46 (5.61)	1.63 (2.27)	2.38 (5.21)	3.22 (9.91)	1.85 (2.94)	2.13 (4.03)	2.84 (7.61)
W_3	4.96 (24.09)	5.83 (33.55)	6.13 (37.05)	4.73 (21.87)	5.71 (32.07)	6.36 (39.94)	2.36 (5.11)	3.04 (8.77)	3.68 (13.06)
W_4	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
SEm (±)	0.09	0.08	0.08	0.11	0.06	0.06	0.09	0.06	0.06
LSD (p=0.05)	0.29	0.25	0.23	0.32	0.19	0.20	0.27	0.18	0.18
CV (%)	9.66	7.99	8.81	10.89	8.04	8.36	12.12	7.82	8.58
N×W	ns	ns	ns	ns	ns	ns	ns	ns	ns

Data within parentheses are original values; Data analyzed using $\sqrt{x}$ + 0.5 transformation; BLW: broad leaved weeds; DAT: Days after transplanting; N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; LSD: RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application; LSD: Least significant difference; CV: Coefficient of variation; ns: non-significant.

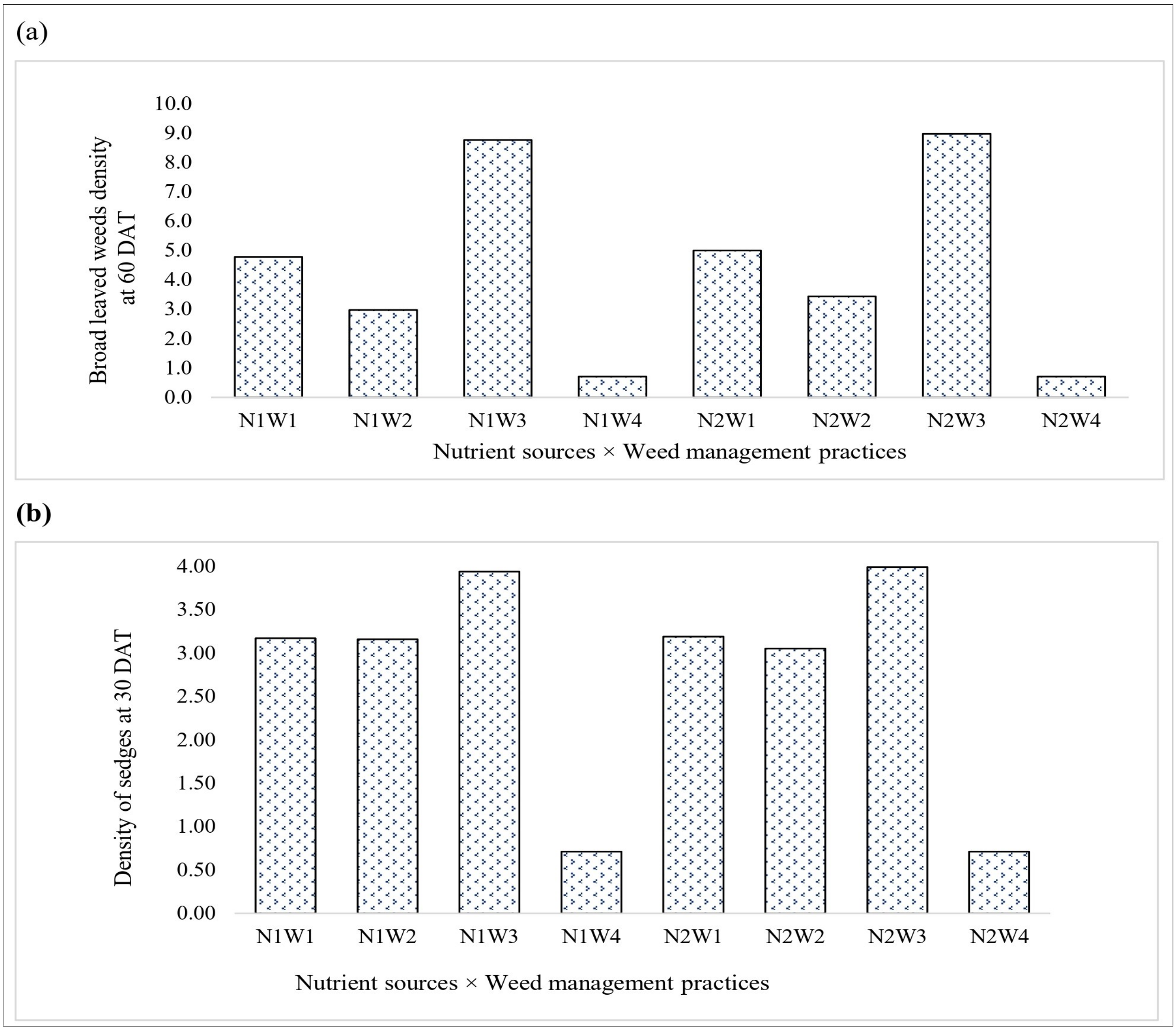

Fig. 5. Interaction effects between nutrient sources and weed management practices. a- Broad leave weeds density at 60 DAT; b- Density of sedges at 30 DAT during kharif -2024. N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application.

Interaction effects between nutrient sources and weed management practices were non-significant.

Dry weight of broad-leaved weeds (BLW)

Among nutrient sources, the treatment that received 25 % RDN through FYM and 75 % RDN through chemical fertilizer had the maximum dry weight of broad leaf weed, ranging 2.45, 3.12 and 3.69 g m^{-2} at 30, 60 days after transplanting and at harvest respectively as compared with the treatment that received 100 % RDN by chemical fertilizer, which resulted in somewhat lower dry weight at every stage as shown in Table 4. Weed-free resulted in the lowest dry weight of BLWs is 0.0 g m^{-2} at all stages. Oxyfluorfen at 0.1 kg per ha (PE) followed by 2,4 D at 0.5 kg per ha (PoE) was more effective (1.82, 3.33, 4.94 g m^{-2}) compared to treatment butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4 D at 0.5 kg ha^{-1} (PoE). The weedy check had the highest dry weight at all stages (23.11, 31.6, 35.91 g m^{-2}). At 30, 60 and harvest days following transplanting, there were no noticeable interactions between fertilizer sources and weed control techniques.

Dry weight of sedges

Our findings showed that 100 % RDN through chemical fertilizer recorded lower weed dry weight of sedges, ranging 1.71, 2.1 and 2.47 g m^{-2} at 30, 60 days after transplanting respectively, as compared to 75 % RDN through chemical fertilizer combined with 25 % RDN through farmyard manure (Table 4). However, weed-free treatment demonstrated 0.0 g m^{-2} dry weight throughout the stages. The dry weight of sedge was effectively reduced to 2.14, 3.06 and 4.49 g m^{-2} by the treatment oxyfluorfen at 0.1 kg per hectare followed by 2,4-D at 0.5 kg per ha at 30, 60 DAT and harvest, respectively. In comparison, butachlor at rate of 1.0 kg per hectare (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE) recorded slightly higher sedge dry weights. The weedy check had the highest dry weight of sedges (10.81, 13.5, 17.47 g m^{-2}). The effects of interactions between nutrient sources and weed control techniques were not significant at each stage.

Weed control efficiency (WCE)

In any kind of crop, there is a clear association between crop yield and WCE. While nutrient sources had no discernible impact, weed management interventions had a considerable impact on the effectiveness of weed control (Table 5). The hand-weeded treatment had the highest WCE (100 %) (Table 5) across all stages. Treatment PE oxyfluorfen, at a dose of 0.1 kg per hectare fb PoE 2,4-D at 0.5 kg per hectare, came next, with weed control efficiency of 67.74, 66.35 and 68.58 % at each stage. Lower efficiency was demonstrated by butachlor at 1.0 kg ha-1 (PE) fb 2,4-D at 0.5 kg ha^{-1} (PoE) and the weeded plot had 0 % WCE. At every stage, the interaction effects of weed control and nutrients were not significant (Table 5).

Weed index (WI)

Weed control techniques had a considerable impact on weed index, while nutrient sources had no significant effect. The weed-free plot, which is manual weeding (20 and 40 DAT) had the lowest WI is 0.0 %, suggesting no yield reduction followed by treatment oxyfluorfen at 0.1 kg per ha followed by 2,4-D at 0.5 kg per ha, which resulted in a yield drop of 5.28 %. (Table 5). The WI was higher at 9.72 % for butachlor at 1.0 kg per ha followed by 2,4-D at 0.5 kg per ha. The weedy check had the biggest yield loss because of weed infestation, with the highest WI (43.04 %) as indicated in (Table 5). The effects of interactions between nutrient sources and weed management practices were not significant.

Economics

The economic analysis revealed that nutrient sources had no significant effect on gross return, net return and B:C ratio. However, 100 % RDN through chemical fertilizer recorded higher gross return (Rs. 97225.24 ha^{-1}), net return (Rs. 55662.44 ha^{-1}) and B:C ratio (1.33) compared to 75 % RDN through chemical fertilizer + 25 % RDN through FYM, which had a lower B:C ratio (0.89). In contrast, weed management practices significantly influenced economic returns. The highest gross and net returns were observed in weed-free, while Oxyfluorfen at 0.1 kg ha^{-1} fb 2,4 D at 0.5 kg ha^{-1} recorded the highest B:C ratio (1.42), indicating better cost efficiency. The weedy check had the lowest return and B:C ratio (0.52), confirming the negative

Table 5. Weed indices and economics as influenced by nutrient sources and weed management practices during kharif -2024

Treatment details	Weed control efficiency (%)			Weed Index	Cost of Cultivation (Rs ha^{-1})	Gross Return (Rs. ha^{-1})	Net Return (Rs. ha^{-1})	B:C Ratio
	30 DAT	60 DAT	At harvest					
Nutrient sources								
N_1	65.58	63.85	60.79	14.29	41,592.80	97,255.24	55,662.44	1.33
N_2	65.31	62.25	59.29	14.73	49,103.25	92,753.65	43,650.40	0.89
SEm (±)	1.79	0.91	0.73	1.25	1881.45	6132.46	6216.78	0.03
LSD (*p*=0.05)	NS	NS	NS	NS	4449.63	NS	NS	NS
CV (%)	9.49	8.02	7.24	-	-	8.9	9.2	9.1
Weed management practices								
W_1	75.18	70.15	63.13	9.72	44,169.70	95,578.28	51,408.58	1.16
W_2	87.53	83.20	78.23	5.28	44,029.70	1,06,432.22	62,402.52	1.42
W_3	-	-	-	43.04	43,254.20	65,526.70	22,272.50	0.52
W_4	100	100	100	-	50,938.50	1,15,391.58	64,453.08	1.27
SEm (±)	1.64	1.14	0.86	2.87	1881.45	7343.79	7024.34	0.16
LSD (*p*=0.05)	5.05	3.50	2.64	8.85	4449.63	17368.07	16612.57	0.39
CV (%)	6.14	6.42	6.49	-	-	8.05	9.8	8.21
N×W	ns	ns	ns	ns	ns	ns	ns	ns

DAT: Days after transplanting; N_1: 100 % RDN via chemical fertilizer, N_2: 75 % RDN + 25 % RDN via FYM; W_1: Butachlor at 1.0 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1} (PoE); W_2: Oxyfluorfen at 0.1 kg ha^{-1} (PE) followed by 2,4-D at 0.5 kg ha^{-1}, W_3: Weedy check and W_4: Weed free; RDN: Recommended dose of nitrogen; FYM: Farmyard manure; PE: Pre-emergence application; PoE: Post-emergence application; LSD: Least significant difference; CV: Coefficient of variation; ns: non-significant.

impact of weeds. The interaction effect between nutrient source and weed management was non-significant (Table 5).

Discussion

Nutrients and weed management greatly affected plant height. Table 2 shows that 100 % RDN chemical fertilizer produced the tallest plants at every growth stage. The quick availability of mineral nitrogen supports cell elongation, internodal extension and active vegetative development. Previous researchers found comparable results in finger millet (17). Another study conducted at West Bengal also confirmed that balanced NPK treatment improves plant stature by increasing elongation and chlorophyll content (18). The weed-free treatment, which entailed hand weeding at 25 and 40 DAT, had the tallest plants. This shows that timely herbicide treatment mitigated weed interference and allowed vertical growth as well as hand weeding. Researchers observed in their study that weed-free and effective herbicide regimes increased finger millet and sorghum plant height (19). Chemical weed management promoted plant height expression by reducing early light and nutrient competition, as confirmed a previous report (20). Findings revealed that dry matter accumulation rose steadily from 30 DAT to harvest. Table 1 showed that chemical fertilizers provided 100 % RDN, had slightly higher DMA (141.5, 518.6 and 897.8 g m^{-2}) over 75 % of the recommended nitrogen and 25 % of the recommended nitrogen through FYM but the differences were not statistically significant. This might be due to the fact that integrated nutrient sources may not be fully reflected in short-term results. Solo chemical fertilization boosted finger millet growth and biomass due to rapid nutrient availability (21). The weedy check recorded the lowest dry matter accumulation (118.3, 475.3 and 652.7 g m^{-2}), while weed-free treatments had the highest dry matter accumulation (150, 535.8 and 827.1 g m^{-2}), followed by oxyfluorfen at 0.1 kg ha^{-1} and 2,4-D at 0.5 kg ha^{-1} may be ascribed to effective, comprehensive and prolonged weed management, leading to less crop–weed competition and enhanced resource use, hence boosting output (22).

The LAI monitors canopy and photosynthetic surface development. Leaf area index increased to 60 DAT, then reduced due to senescence, as indicated in Table 2. The treatment that got 100 % RDN through chemical fertilizer had higher LAI across growth stages than 75 % RDN and 25 % RDN through FYM due to the early availability of nutrients that enhance leaf expansion. In another previously conducted study found that higher nitrogen treatment increased rice's vegetative vigor and delayed leaf senescence (23). In a study, it was also observed that chemical fertilization had a greater early effect on wheat canopy (24). Finger millet has a higher LAI under 100 % RDF (25). The weed-free treatment had the highest LAI values throughout all stages and was statistically comparable to oxyfluorfen at 0.1 kg per hectare and fb 2,4-D at 0.5 kg per hectare, proving that chemical weed management reduces light and nutrient competition. Herbicide-treated finger millet plots had leaf area values comparable to manually weeded ones. Herbicides administered before and after emergence reduce weed influence and strengthen canopies (26).

Finger millet yield depends on tillering. In the current study, the number of tillers increased with plant age and was marginally higher under 100 % RDN through chemical fertilizer than under 75 % RDN through chemical fertilizer and 25 % RDN through FYM, although the differences were not always statistically significant. Chemical fertilization may have hastened axillary buds due to its rapid nutrition availability. Other researchers found that full-dose NPK promoted finger millet tiller development (27). The W4 treatment produced the most tillers and was statistically comparable to oxyfluorfen at 0.1 kg ha^{-1} (PE) fb 2,4-D at 0.5 kg ha^{-1} as PoE. This suggests chemical management can replace hand weeding (28).

Yield attributes

Yield attributes such as number of fingers per plant, finger length, finger weight, seeds per finger and test weight showed notable improvement under 100 % RDN through chemical fertilizer as indicated in Table 2. Throughout the reproductive stage, the constant supply of vital nutrients promoted the growth of spikes and seeds. Longer, heavier and more full fingers are probably the result of enhanced assimilating partitioning to reproductive organs caused by rapid food intake. Similar results showing that improved yield-contributing features were a result of nutrient sufficiency (29). Because there were less crop-weed rivalry and more resources available, the W_4 treatment which is Weed-free, performed the best across yield measures, statistically matching oxyfluorfen at rate of 0.1 kg ha^{-1} as PE followed by 2,4-D a dose of 0.5 kg ha^{-1} as PoE. Plots treated with herbicides and free of weeds greatly enhanced yield characteristics like seed filling and panicle weight compared to weedy settings (30). The W_4 treatment which is weed-free had the greatest grain and straw yields among the weed management treatments and they were statistically comparable to oxyfluorfen at rate of 0.1 kg ha^{-1}as PE followed by 2,4-D at rate of 0.5 kg ha^{-1} as PoE. This suggests that by successfully lowering weed competition, chemical weed control was just as capable of maintaining production potential. Similar findings were reported previously, who found that integrated weed control improved harvest efficiency and production performance (31). Additionally, significant interaction effects validated integrated crop management systems by confirming that the combination of weed reduction and nutrient adequacy produced the best yield outcomes.

Total and species-wise weed density (No. m^{-2})

Results of the study showed that weed density was greater under 75 % RDN via chemical fertilizer + 25 % RDN through FYM compared to 100 % RDN because of the delayed and constant nutrient release by FYM, Nutrient sources have no effect on weed density as shown in Table 3. Plants and weeds alike benefit from the nutrients' extended availability. Weeds benefit from FYM homogeneity because it increases the soil's nutrient availability. Weed density was significantly impacted by management techniques following 30, 60 and harvest days after transplanting, the weed-free plot exhibited the lowest weed population. In comparison to butachlor at 1.0 kg per ha (pre-emergence) followed by 2,4-D at 0.5 kg ha^{-1}, application of oxyfluorfen at 0.1 kg ha^{-1} as a pre-emergence (PE) herbicide and 2,4-D at 0.5 kg per ha as a PoE herbicide effectively reduced weeds. A total of 10.87, 13.13 and 14.31 no.m^{-2} of weeds were found in the weedy check (Table 3) which is consistent with experimental findings (32). These results are also in agreement with those of (33, 34) delayed and constant nutrient release by FYM leads to greater weed density under 75 % RDN via chemical fertilizer + 25 % RDN through FYM compared to 100 % RDN. Experimental study showed that weed density was significantly impacted by management techniques at 30, 60 and at harvest after transplanting, the weed-free plot exhibited the lowest weed population. In comparison to application of butachlor at1.0 kg per ha (PE) followed by 2,4-D at 0.5 kg per ha, oxyfluorfen at 0.1

kg per ha as a PE herbicide and 2,4-D at 0.5 kg per ha as a PoE herbicide effectively reduced weeds. A total of 10.87, 13.13 and 14.31 no. m^{-2} of weeds were found in the weedy check. Timely pesticide spraying and hand weeding significantly reduced weeds, as demonstrated by these statistics. Consequently, there were more weeds, grasses, sedges and BLW in the weedy check. These factors have contributed to the weedy check's increased dry weight and weed density. These results are consistent with the findings of earlier studies (32). Dry weeds were more prevalent in a patch that received 75 % RDN from chemical fertilizer and 25 % from FYM compared to 100 % RDN. Farmyard manure promotes weed development all through the crop cycle due to its slow and constant nitrogen delivery. The competitiveness indicator known as weed dry weight was significantly impacted by weed treatment. Table 4 shows that W_2 had the second-highest harvest weed dry matter at 16.48 g m^{-2}, while the weed-free plot had the lowest at 0.00 g m^{-2}. Due to uncontrolled weed growth, the weedy check revealed a maximum dry weight of 39.58 g m^{-2}. Weed dry matter reduction under W_4 and W_2 indicates effective weed control. Because these plots did not undergo any weed control measures, the weed seed bank from previous seasons has grown and is unaffected by the transplantation process. Successful weed management during the crop growth period led to lower weed density and dry weight at harvest, which in turn reduced the population and dry weight of sedges, grasses and broad-leaved weeds. These results agree with those of previous studies (33, 34). Although the weed density was not significantly affected by the nutrients used, showed that a combination of 75 % RDN from chemical fertilizer and 25 % RDN from FYM resulted in higher weed density than 100 % RDN from chemical fertilizer, largely because of the gradual and constant release of nutrients from FYM and makes the soil more weed-friendly by improving its structure, water retention and microbial activity. Weeds also benefit from FYM's consistent application since it makes soil nutrients easily available. The data clearly demonstrate that the weed population was significantly reduced by timely application of herbicides and manual weeding. This is why there were more grasses, sedges, broad-leaved weeds and overall weed density as shown by the weedy check (Table 4) and these findings are in line with earlier field studies (32). The dry weight of weeds was found to be greater in a plot that got 75 % RDN through chemical fertilizer and 25 % RDN through FYM compared to 100 % RDN through chemical fertilizer. Nutrients from FYM are consistently and gradually released throughout the crop cycle, which helps weeds grow. So, the weed biomass increases under N_2, leading to a higher dry weight throughout the life cycle. Table 4 shows that at harvest, the weed-free plot had the lowest weed dry matter whereas W_2 had the second-lowest at 16.48 g m^{-2}. The weedy check showed the highest dry weight (39.58 g m^{-2}) because weed growth was uncontrolled. Reduced weed dry matter under W_4 and W_2 conditions is evidence of efficient weed control. Since no weed control methods were implemented in these plots, the initial deposition of weed seeds in the soil from prior seasons has led to an enlarged weed seed bank in the soil that remains undisturbed for any activity after transplantation. The primary reason for the decline in sedges, grasses, broad-leaved weeds and overall weed population and dry weight in these treatments was the reduced weed density and dry weight at harvest, which resulted from effective weed management at every stage of the crop growth period. These results agree with those reported earlier (34).

Weed control efficiency (WCE %)

Weed control efficiency measures how well a treatment inhibits weed growth in comparison to the untreated control. Weed control efficiency was slightly higher under N_1 (65.58, 63.85 and 60.79 % at 30, 60 DAT and harvest, respectively) compared to N_2. This may be due to the quick nutrient uptake in N_1 limiting weed growth, while the slow, continuous release of nutrients from FYM in N_2 supported prolonged weed emergence. The hand-weeded plot achieved 100 % WCE in each level of the weed management techniques, as shown in Table 5. Weed control efficiency values of 87.53, 83.20 and 78.23 % were demonstrated by the application of the herbicide oxyfluorfen at 0.1 kg per hectare prior to emergence and 2,4-D at 0.5 kg per hectare after emergence. Due to the efficient suppression of weeds by both hand weeding and herbicide combinations, it was found that greater weed control efficiency under these treatments at all crop growth stages was associated with significantly reduced total weed dry weight. Greater weed management efficacy with reduced weed competition supports these findings. In contrast, the weedy check treatment showed zero percent weed control effectiveness (35–37).

Weed index (WI %)

The weed index was slightly lower in N_1 (14.29 %) than N_2, indicating marginally less yield loss due to weed competition. Weed control measures have a considerable impact on the WI, which determines the yield loss caused by weeds as depicted in Table 5. The weed-free treatment (W_4) registered 0.0 % WI, followed by W_2 (5.28 %). The weedy check (W_3) had the highest WI (43.04 %), indicating a significant yield penalty due to heavy weed competition. This large difference underscores the economic importance of weed management. Similar conclusions were drawn previously, who reported yield losses exceeding 40 % in finger millet and maize in the absence of effective weed control (41).

Economics

Results of the study revealed that nutrient sources, 75 % RDN via chemical fertilizer and 25 % via FYM had the highest cost (Rs. 49103.25 ha^{-1}) due to labor and shipping, while 100 % RDN via chemical fertilizer had a lower cost (Rs. 41592.80 ha^{-1}) as depicted in Table 4. The W4 treatment (Weed-free) had the greatest cost (Rs. 50938.50 ha^{-1}) for weed management, requiring human weeding twice (25 and 40 DAT). The weedy check cost the least (Rs. 43254.20 per hectare) due to the lack of weed management techniques. These values reflect the real-world trade-off between effective management and input investment, as observed by previous studies, which reported higher costs for integrated and manual weed management systems (38, 39).

Influence of nutrient sources on gross return was not significant, N1 (Rs. 97255.24 ha^{-1}) yielded somewhat higher than N2 (Rs. 92753.65 ha^{-1}) and reported higher return (Table 5). Weed-free plots yielded the highest gross return (Rs.115391.58 ha^{-1}), followed by PE oxyfluorfen and 2,4-D (Rs.106432.22 ha^{-1}). The weedy check had the lowest gross return (Rs.65526.70 ha^{-1}), indicating significant yield losses due to competition. Weeds lowered finger millet yield and income (40, 41). After deducting cultivation costs from gross return, N1 yielded the best net return (Rs. 55662.44 ha^{-1}), while N2 yielded only Rs.43650.40 ha^{-1}. W4 (Weed-free) yielded the highest net return (Rs.64453.08 ha^{-1}), outperforming all other treatments statistically followed by W2 (Rs.62402.52 ha^{-1}), confirming the economic sustainability of herbicide-based weed management.

The weedy check (W_3) had the lowest net return (Rs.22272.50 ha^{-1}), indicating that there is economic loss from weed infestation. Previous researchers found similar results in coarse and small millets (42). Similar patterns were seen when net return was calculated by removing cultivation costs from gross return. N_1 yielded the largest net return (Rs.55662.44 ha^{-1}) statistically superior to other treatments (Table 5). While not much lower (Rs. 62402.52 ha^{-1}), W_2 showed the economic viability of herbicide-based weed management. Weed infestation caused a reduced net profit of Rs. 22272.50 ha^{-1}, as determined by the weedy check (W_3). N_1 yielded the largest net return (Rs. 55662.44 ha^{-1}), while N_2 yielded just Rs. 43650.40 ha^{-1} W_4 (weed-free) yielded the highest net profit (Rs. 64453.08 ha^{-1}) statistically outperforming all other treatments. W_2 followed closely (Rs. 62402.52 ha^{-1}), indicating economic viability of herbicide-based weed control. Weed infestation caused financial loss, with the weedy check (W_3) yielding the lowest net return (Rs. 22272.50 ha^{-1}). Similar effects with coarse cereals and micro millets reported previously (42, 43). The B:C ratio of N_1 was 1.33, whereas N_2 was 0.89, showing that partial substitution of inorganic fertilizers with FYM was less cost-effective in the short run. W_2 had the highest B:C ratio (1.42), suggesting chemical weed control was the most cost-effective. W_4 (Weed-free) had the highest absolute profit but a lower B:C ratio (1.27) due to higher manual labor expenditures. Weedy check (W_3) had the lowest B:C ratio (0.52), indicating economic loss from uncontrolled weeds. This research agrees with previous study (44, 45).

Conclusion

Based on the findings of the present one-season field investigation, can be concluded that nutrient sources and weed control techniques significantly influenced the growth and yield of finger millet. Grain and straw yields were highest under 100 % RDN × weed-free (N_1W_4), recording 2.69 t $ha^{-1}$of grain yield, which was 82.99 % higher than the lowest-yielding combination. However, most nutrient source effects were statistically non-significant except finger length. Weed management practices had a significant impact on weed dynamics. The weed-free condition recorded complete control and 100 % WCE, followed by PE oxyfluorfen at rate of 0.1 kg ha^{-1} fb PoE 2,4-D at rate of 0.5 kg per hectare which was statistically at par in terms of weed suppression. The weedy check plot resulted in the highest weed density (272.75 m^{-2}) and lowest crop performance, highlighting the importance of timely and effective weed management in minimizing crop-weed competition. The most economically viable treatment was 100 % RDN through chemical fertilizer × weed-free (N_1W_4), with the highest net return (Rs. 68071.32 ha^{-1}) and B:C ratio (1.68), followed closely by oxyfluorfen at 0.1 kg ha^{-1} fb 2,4-D at 0.5 kg ha^{-1}× 100 % RDN. The weedy check showed the lowest economic return.

Authors' contributions

SMK, LR, NK and MK conceived and wrote the article. LR, SMK, NK, AK, JP, BP, MK, SK and SS prepared and wrote the original draft. SMK, LR, SS, JP, BP, MK, SK, RK and AK reviewed and edited the manuscript. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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