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Assessment of nutrient depletion by weeds under biofortification and weed management practices in finger millet (*Eleusine coracana* L.)

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Abstract
A field experiment was conducted at Udaipur, Rajasthan during the *kharif* seasons of 2023 and 2024 to evaluate the effect of zinc and iron biofortification in combination with different weed management practices on weed dynamics and nutrient depletion. The experiment was laid out in a split-plot design with three replications. Four biofortification treatments were assigned to main plots: B_0: Recommended Dose of Fertilizer (RDF) control, B_1: RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application, B_2: RDF + 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ as foliar application, and B_3: RDF + soil application of 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ combined with 0.5% $ZnSO_4$ and $FeSO_4$ foliar spray. Five weed management practices were allotted to subplots, W_0: weedy check, W_1: hand weeding twice at 20 and 40 DAS, W_2: atrazine 500 g ha^{-1} as pre-emergence, W_3: metsulfuron methyl + chlorimuron ethyl 4 g ha^{-1} as post-emergence, and W_4: bispyribac-sodium 25 g ha^{-1} as post-emergence. The results revealed that combined soil and foliar application of Zn and Fe (B_3) significantly reduced weed density and biomass and minimized nutrient depletion compared to the control. Among weed management treatments, the weedy check recorded the highest nutrient depletion, whereas hand weeding twice (W_1) proved superior to all herbicidal treatments in reducing weed infestation and conserving nutrients. The study highlights the synergistic role of micronutrient biofortification and effective weed management in improving nutrient use efficiency and weed suppression under field conditions.

Keywords: Nutrient, depletion, biofortification, weeds

Introduction
Finger millet (*Eleusine coracana* L.) is an important nutri-cereal crop widely cultivated in semi-arid and rainfed regions of India due to its high nutritional value, climate resilience and low input requirement. It is a rich source of calcium, dietary fiber, iron and essential amino acids, making it a key crop for nutritional security and sustainable agriculture. However, productivity of finger millet remains low in many regions primarily due to poor soil fertility, micronutrient deficiencies and severe weed infestation during the initial stages of crop growth. Micronutrient particularly deficiencies of zinc (Zn) and iron (Fe), is a major public health concern in many developing countries, including India. Cereals and millets constitute the staple diet of a large proportion of the population; however, these crops are often inherently low in essential micronutrients due to soil nutrient depletion and imbalanced fertilizer use. Agronomic biofortification through soil and foliar application of zinc and iron has emerged as a sustainable approach to enhance crop productivity, nutritional quality and nutrient use efficiency while maintaining soil health. Weed infestation is another critical constraint affecting crop growth attributes and yield, especially during the early growth stages. Weeds compete aggressively with crops for nutrients, moisture, light and space, resulting in substantial yield losses and increased nutrient depletion from the soil. Inefficient weed control not only reduces crop productivity but also lowers the effectiveness of applied fertilizers and micronutrients. Therefore, integration of effective weed management strategies with nutrient management practices is essential for

achieving higher crop productivity and resource-use efficiency. Chemical weed control has gained popularity due to labour scarcity and rising wages; however, indiscriminate herbicide use may lead to herbicide resistance, environmental concerns and shifts in weed flora. Mechanical methods such as hand weeding remain effective but are labor-intensive and costly. Hence, evaluating different weed management options, including pre- and post-emergence herbicides along with manual practices, is necessary to identify economically viable and environmentally sustainable weed control strategies (Kumawat *et al.*, 2024) [6].

Recent studies indicate that balanced micronutrient nutrition can influence crop competitiveness against weeds by improving early crop vigor, canopy development and nutrient uptake efficiency. Combined application of Zn and Fe through soil and foliar methods ensures better availability and translocation of nutrients throughout the crop growth period. However, limited information is available on the interactive effects of Zn and Fe biofortification and weed management practices on weed density, biomass and nutrient depletion under semi-arid conditions of Rajasthan.

Material and methods: The experimental site was situated at the block E_1, Instructional Farm, Department of Agronomy, Rajasthan College of Agriculture, MPUAT, Udaipur (Rajasthan). The region falls under agro-climatic zone IVa (Sub-Humid Southern Plain and Aravalli Hills) of Rajasthan situated at longitude 73°42'E and latitude 24°35'N with an altitude of 582.17metre above the mean sea level.

The leaves of samples were collected weed from each plot and oven dried at 65 °C to a constant weight and samples were grind upto fine powder using 0.5 mm sieve in the laboratory and digested by keeping in hot plate using sulphuric acid and hydrogen peroxide for estimating nutrient content using standard methods of analysis. Nutrient Depletion by weeds the nutrient uptake of nitrogen, phosphorus, potassium depletion by weeds expressed in kg ha^{-1} was computed by using following formula:

$$\text{Nutrient depletion N, P \& K (kg ha}^{-1}) = \frac{\text{Concentration of nutrient (\%) x Dry matter of weeds (kg ha}^{-1})}{100}$$

Result and Discussion

Nutrient depletion by weeds at 30 DAS

Among the biofortification treatments, RDF control recorded the highest nutrient depletion during both years and in pooled mean. The pooled nutrient removal under this treatment was 7.18 kg ha^{-1} nitrogen, 1.42 kg ha^{-1} phosphorus and 7.42 kg ha^{-1} potassium, indicating greater nutrient loss due to unchecked weed growth. Application of zinc and iron through soil and foliar methods significantly reduced nutrient depletion by weeds. The lowest nutrient removal was observed under RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application + 0.5% $ZnSO_4$ and $FeSO_4$ as foliar application with pooled values of 5.35 kg ha^{-1} nitrogen, 1.08 kg ha^{-1} phosphorus and 5.54 kg ha^{-1} potassium. This treatment was statistically superior over the control and comparable with RDF + soil application of $ZnSO_4$ and $FeSO_4$ (Kumawat *et al.*, 2023) [7]. The reduction in nutrient depletion under biofortification treatments may be attributed to improved nutrient availability, enhanced crop growth and increased crop competitiveness against weeds, which resulted in lower weed biomass and nutrient uptake by weeds. Similar trends were observed for nitrogen, phosphorus and potassium during both years. The pooled data clearly showed a consistent decreasing trend in nutrient removal with the integration of soil and foliar biofortification compared to RDF alone. The differences among treatments were statistically significant as indicated (Table 1).

Weed management practices exerted a pronounced effect on nutrient depletion by weeds. The maximum nutrient removal was recorded in Weedy check during both the years and pooled mean, with values of 15.41 kg ha^{-1} nitrogen, 3.07 kg ha^{-1} phosphorus and 16.03 kg ha^{-1} potassium, indicating severe nutrient loss under uncontrolled weed infestation. In contrast, the minimum nutrient depletion was observed under hand weeding twice at 20 and 40 DAS with pooled values of 0.76 kg ha^{-1} nitrogen, 0.15 kg ha^{-1} phosphorus and 0.78 kg ha^{-1} potassium, which demonstrated the effectiveness of manual weed control in minimizing nutrient competition between crop and weeds. Among the herbicidal treatments, metsulfuron methyl + chlorimuron ethyl as PoE recorded lower nutrient depletion 4.39 kg ha^{-1} N, 0.89 kg ha^{-1} P and 4.50 kg ha^{-1} K compared to atrazine as PE and bispyribac-sodium as PoE. All weed control treatments significantly reduced nutrient removal when compared with weedy check. The substantial reduction in nutrient depletion under effective weed control practices might be due to suppression of weed density and biomass, leading to reduced uptake of nutrients by weeds and greater availability of nutrients to the crop. The statistical analysis confirmed that the observed differences were significant at 5% probability level Habib (2009), Mishra *et al.* (2015), Arabhnavi and Huluhalli (2017) and Durgude *et al.* (2019) [1, 2, 3, 8].

Nutrient depletion by weeds at 60 DAS

Among the biofortification treatments, Control recorded the maximum nutrient depletion during both the years and in pooled mean. The pooled nutrient depletion under this treatment was 17.03 kg ha^{-1} nitrogen, 3.93 kg ha^{-1} phosphorus and 20.42 kg ha^{-1} potassium, indicating higher nutrient removal by weeds under untreated conditions. Application of zinc and iron significantly reduced nutrient depletion. The lowest nutrient depletion was observed under RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application + 0.5% $ZnSO_4$ & $FeSO_4$ as foliar application with pooled values of 12.77 kg ha^{-1} nitrogen, 2.97 kg ha^{-1} phosphorus and 15.55 kg ha^{-1} potassium. This treatment was statistically superior to all other biofortification treatments and showed a consistent reduction in nutrient depletion during both years (Pandey *et al.*, 2007) [9]. The treatment soil application of $ZnSO_4$ and $FeSO_4$ ranked next best with pooled values of 13.38 kg ha^{-1} nitrogen, 3.10 kg ha^{-1} phosphorus and 16.19 kg ha^{-1} potassium, followed by 0.5 per cent foliar application. The trend clearly indicated that combined soil and foliar application was more effective in minimizing nutrient loss compared to individual applications. The reduction in nutrient depletion under biofortification treatments may be attributed to improved nutrient availability to the crop, enhanced crop vigor and competitive ability against weeds, resulting in lower weed biomass and reduced nutrient uptake by weeds. The differences among treatments were statistically significant as evidenced by the C.D. ($P = 0.05$) values, Kumar *et al.*, (2013) and Pavithra *et al.* (2019) [5, 10]. Weed management practices exerted a marked influence on nutrient depletion. The maximum nutrient depletion was recorded under weedy check with pooled values of 28.34 kg ha^{-1} nitrogen, 6.57 kg ha^{-1} phosphorus and 34.00 kg ha^{-1} potassium, reflecting severe nutrient loss due to uncontrolled weed growth. The minimum nutrient depletion was observed under Hand weeding twice at 20 and 40 DAS with pooled values of only 2.96 kg ha⁻¹ nitrogen, 0.69 kg ha⁻¹ phosphorus and 3.59 kg ha⁻¹ potassium, indicating the effectiveness of manual weed control in minimizing nutrient removal by weeds. Among herbicidal treatments, metsulfuron methyl + chlorimuron ethyl as PoE recorded significantly lower nutrient depletion (10.14 kg ha⁻¹ N, 2.33 kg ha⁻¹ P and 12.34 kg ha⁻¹ K) compared to atrazine as PE and bispyribac-sodium as PoE. The treatment W4 ranked next, followed by atrazine Kaur *et al.*, (2010) [4] and Singh *et al.*, (2022) [11]. Overall, all weed control treatments significantly reduced nutrient depletion compared to the weedy check. The reduction in nutrient removal under effective weed management practices could be attributed to reduced weed density and biomass, leading to decreased nutrient uptake by weeds and greater nutrient availability to the crop. Statistical analysis confirmed that the observed differences were significant at the 5% probability level (Table 2).

Table 1: Effect of biofortification and weed management on weed nutrient depletion (kg ha^{-1}) at 30 DAS

Treatments	Nutrient depletion (kg ha^{-1})								
	Nitrogen			Phosphorus			Potassium		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Biofortification									
B_0: RDF (Control)	7.32	7.05	7.18	1.36	1.47	1.42	7.58	7.26	7.42
B_1: RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application	5.62	5.70	5.66	1.07	1.21	1.14	5.82	5.88	5.85
B_2: RDF + 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ as foliar application	6.43	6.54	6.49	1.22	1.38	1.30	6.66	6.75	6.70
B_3:RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application + 0.5% $ZnSO_4$ & $FeSO_4$ as foliar application	5.30	5.39	5.35	1.02	1.15	1.08	5.50	5.58	5.54
SEm±	0.12	0.16	0.07	0.02	0.02	0.01	0.09	0.09	0.05
C.D. (P= 0.05)	0.40	0.56	0.20	0.05	0.08	0.03	0.32	0.31	0.15
Weed Management									
W_0: Weedy check	15.18	15.65	15.41	2.86	3.28	3.07	15.84	16.21	16.03
W_1: Hand weeding twice at 20 and 40 DAS	0.73	0.79	0.76	0.14	0.17	0.15	0.74	0.82	0.78
W_2: Atrazine 500 g ha^{-1} as PE	4.99	4.64	4.81	0.95	0.98	0.96	5.13	4.76	4.94
W_3: Metsulfuron methyl + Chlorimuron ethyl 0.004 kg ha^{-1} as PoE	4.43	4.35	4.39	0.84	0.94	0.89	4.55	4.46	4.50
W_4: Bispyribac-sodium 25 g ha $^{-1}$ as PoE	5.52	5.42	5.47	1.05	1.15	1.10	5.68	5.58	5.63
SEm±	0.15	0.15	0.11	0.02	0.02	0.02	0.09	0.10	0.07
C.D. (P= 0.05)	0.42	0.43	0.30	0.07	0.06	0.05	0.25	0.29	0.19

Table 2: Effect of biofortification and weed management on weed nutrient depletion (kg ha^{-1}) at 60 DAS

Treatments	Nutrient depletion (kg ha $^{-1}$)								
	Nitrogen			Phosphorus			Potassium		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Biofortification									
B_0: RDF (Control)	17.08	16.99	17.03	3.85	4.01	3.93	20.53	20.31	20.42
B_1: RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application	13.37	13.39	13.38	3.02	3.18	3.10	16.24	16.14	16.19
B_2: RDF + 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ as foliar application	15.52	15.39	15.45	3.49	3.64	3.57	18.76	18.46	18.61
B_3:RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application + 0.5% $ZnSO_4$ & $FeSO_4$ as foliar application	12.77	12.78	12.77	2.89	3.06	2.97	15.61	15.49	15.55
SEm±	0.22	0.28	0.13	0.08	0.07	0.04	0.32	0.35	0.17
C.D. (P= 0.05)	0.78	0.96	0.37	0.28	0.23	0.13	1.10	1.23	0.52
Weed Management									
W_0: Weedy check	28.06	28.62	28.34	6.35	6.80	6.57	33.84	34.17	34.00
W_1: Hand weeding twice at 20 and 40 DAS	2.96	2.95	2.96	0.68	0.71	0.69	3.61	3.57	3.59
W_2: Atrazine 500 g ha^{-1} as PE	19.39	18.94	19.17	4.34	4.51	4.42	23.30	22.68	22.99
W_3: Metsulfuron methyl + Chlorimuron ethyl 0.004 kg ha^{-1} as PoE	10.21	10.07	10.14	2.29	2.37	2.33	12.45	12.22	12.34
W 4: Bispyribac-sodium 25 g ha^{-1} as PoE	12.80	12.59	12.69	2.90	2.99	2.94	15.73	15.36	15.54
SEm±	0.16	0.19	0.13	0.07	0.05	0.04	0.20	0.26	0.16
C.D. (P= 0.05)	0.46	0.55	0.35	0.21	0.14	0.12	0.57	0.74	0.46

Conclusion

The combined application of zinc and iron through soil and foliar methods proved to be the most effective biofortification strategy in minimizing nutrient loss. Among biofortification treatments, RDF + 25 kg $ZnSO_4$ + 20 kg $FeSO_4$ as soil application + 0.5% $ZnSO_4$ & $FeSO_4$ as foliar application) recorded the lowest depletion of nitrogen, phosphorus and potassium, indicating better nutrient utilization by the crop and reduced nutrient uptake by weeds. This treatment consistently performed superior over RDF alone and individual soil or foliar applications. With respect to weed management practices, Hand weeding twice at 20 and 40 DAS resulted in minimum nutrient depletion, followed by metsulfuron methyl + chlorimuron ethyl as post-emergence**,** which proved to be the most effective herbicidal treatment. In contrast, the weedy check recorded maximum nutrient depletion, confirming the severe nutrient loss under uncontrolled weed infestation. Overall, the integration of combined soil and foliar biofortification along with effective weed management practices is recommended for minimizing nutrient depletion by weeds, improving nutrient use efficiency and enhancing sustainable productivity of finger millet under similar agro-climatic conditions.

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