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Influence of biochar and farmyard manure (FYM) amendments on translocation of nutrients in maize (*Zea mays* L.)

Sharanabasava[1*], Veeresh H[2], Prakash H Kuchanur[3], Sharan Bhoopal Reddy[4], M Y Ajayakumar[5], S N Bhat[6]
[1] Soil Science, College of Agriculture, Raichur, UAS, Karnataka, India
[2] Professor & Head (Soil Science), College of Agriculture, Raichur, UAS, Karnataka, India
[3] Professor & Head (Genetics and Plant Breeding), College of Agriculture, Bheemarayanagudi, UAS, Karnataka, India
[4] Assistant Professor (Soil Science), College of Agriculture, Bheemarayanagudi, UAS, Karnataka, India
[5] Professor & Head (Agronomy), College of Agriculture, Raichur, UAS, Karnataka, India
[6] Professor (Soil Science), College of Agriculture, Raichur, UAS, Karnataka, India
Corresponding Author: Sharanabasava
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Abstract
Field experiments were conducted during *kharif* 2024 and 2025 at College of Agriculture, Bheemarayanagudi (UAS, Raichur) to assess the effect of biochar and FYM on the root and shoot bioconcentration factors (BCFr, BCFs) and translocation factor (TF) of nutrients in maize (*Zea mays* L.). The experiment was laid out in a randomized complete block design with eleven treatments and three replications. The results revealed that the absolute control (T_{11}) recorded the highest BCFs and TF for N, P, K and micronutrients, while T_4 (RDF + FYM @ 5.0 t ha^{-1} + biochar @ 5.0 t ha^{-1}) recorded comparatively lower values for most of the parameters. As BCF is the ratio of plant to soil nutrient concentration, the high values in T_{11} reflects depletion of soil-available nutrients and thus low plant nutrition. On the other hand, the lower values under T_4 indicate that biochar and FYM retained nutrients in the soil and released them gradually in line with the crop demand. Further, BCF and TF should therefore be interpreted together with absolute nutrient uptake and soil fertility status. The experimental data also revealed biochar as the most effective amendment when it is applied in combination with FYM and inorganic fertilizers.

Keywords: Biochar, FYM, bioconcentration factor, translocation factor, maize

Introduction

Maize (*Zea mays* L. (2n=20)) is an annual C4 plant that belongs to Kingdom Plantae, Phylum Spermatophyte, Class Monocotyledonae, Order Cyperales and Family Poaceae. Maize is an important crop for billions of people as food, feed and industrial raw material. Globally, maize is known as "Queen of cereals" because it has the highest genetic yield potential among the cereals. In India maize occupies an area of 128.35 lakh hectares with a production of 461.49 lakh tonnes and productivity of 3595 kg ha^{-1} (Anon., 2025). Maize is now grown in about 170 countries around the world and it is cultivated throughout the year. USA, China, Brazil and Argentina are among the predominant maize growing countries. It is cultivated in more than 8.23 million ha mainly during the *Kharif* and *Rabi* season and Karnataka, Andhra Pradesh, Uttar Pradesh and Bihar account for 80 per cent of the total area in India. In Karnataka, maize is predominantly grown in Haveri followed by Davanagere and Belgaum districts. About 90.30 per cent of the area was covered under the *Kharif* season alone. In Karnataka maize occupies an area of 19.02 lakh hectare with a production of 63.51 lakh tonnes and average productivity of 3339 kg ha^{-1} (Anon., 2025).

As far as maize crop is concerned, it is an exhaustive and vigorously growing cereal crop and its yields are highly responsive to soil nutrient availability, making it an ideal test crop for assessing the effectiveness of various soil fertility treatments and amendments.

Biochar is a fine-grained, carbon-rich solid produced by the slow pyrolysis of biomass under oxygen-limited conditions. Its high content of recalcitrant aromatic carbon allows long-term carbon sequestration in soil (Glaser *et al*., 2002) [4]. In recent years it has emerged as a soil amendment that also contains mineral nutrient elements and shows promise for improving soil quality and crop productivity. It has been reported to improve soil fertility and increase crop yield with minimal risk to the soil and water environment.

The biochar is currently evaluated on two main aspects. The first is its capacity to improve the physical, chemical and biological properties of soil, namely reduced acidity, higher cation exchange capacity, better nutrient retention, and enhanced microbial activity and mycorrhizal association. These improvements can raise the productivity of agricultural systems and help to combat land degradation. The second is its role in carbon sequestration, since its carbon occurs in stable forms that persist in soil for long periods (Gaskin *et al*., 2010) [3].

Farmyard manure (FYM), in contrast, is a conventional organic fertilizer prepared from the decomposed mixture of cattle dung, urine, straw and other farm residues. It supplies essential nutrients, including nitrogen, phosphorus and potassium, and improves soil structure, water retention and microbial activity. FYM thus enhances soil fertility and crop yield, recycles farm waste and reduces dependence on chemical fertilizers, thereby lowering their environmental impact. Its regular application helps to maintain soil health and supports long-term agricultural productivity and sustainability.

Keeping in view the importance of biochar, FYM and integrated nutrient management, the present study was

undertaken to compare different levels of synthetic fertilizer applied with biochar and FYM and to assess their effect on the root and shoot bioconcentration factors (BCFr, BCFs) and translocation factor (TF) of nutrients in maize (*Zea mays* L.), in order to understand nutrient accumulation in plant tissues relative to soil nutrient status and the root to shoot movement of nutrients under different organic and inorganic nutrient combinations.

Materials and Methods

Field experiments were carried out during *kharif* (2024 & 2025) season at Agricultural Experimental Block, College of Agriculture, Bheemarayanagudi, University of Agricultural Sciences, Raichur to study the effect of biochar and FYM on the root and shoot bioconcentration factors (BCFr, BCFs) and translocation factor (TF) of nutrients in maize (*Zea mays* L.). Eleven treatments and three replications were used in the experiment's randomized complete block design (RCBD). The treatments comprised of T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control. Calculated quantity of biochar and FYM are incorporated into the respective treatment plots 30 days before the sowing of *Kharif* maize. The experimental field is located in North Eastern Dry Zone (Zone-2) of Karnataka at 16.731 North latitude of 76.793 East longitude with 412 meters above mean sea level. The bioconcentration factor (BCF) of nutrients accumulation in plant roots and shoots relative to rhizosphere soil, crucial in environmental studies to understand potential bioconcentration of nutrients.

Root bioconcentration factor (BCF) = Croot / Csoil
Shoot bioconcentration factor (BCF) = Cshoot/ Csoil

The translocation factor is a crucial parameter in plant physiology that measures the movement of nutrients within a plant. It was estimated by dividing the BCF of the shoot by the BCF of the root (Bose and Bhattacharya, 2008) [2].

Translocation factor = BCFshoot / BCFroot

Results and Discussion

Effect of different treatments on bioconcentration factors (BCF) and translocation factors (TF) for NPK in *kharif* maize

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for nitrogen in maize during *kharif* 2024 and 2025 are presented in Table 1.

Table 1: Effect of different treatments on BCFr, BCFs and TF for nitrogen in maize during *Kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	16.72	20.13	18.42	43.04	56.45	49.75	2.57	2.80	2.69
T_2	22.19	17.35	19.77	35.63	30.35	32.99	1.61	1.75	1.68
T_3	22.14	17.31	19.72	36.00	30.16	33.08	1.63	1.74	1.68
T_4	23.24	18.17	20.71	35.82	30.51	33.16	1.54	1.68	1.61
T_5	21.53	16.84	19.19	35.05	29.83	32.44	1.63	1.77	1.70
T_6	20.84	16.29	18.57	35.07	29.93	32.50	1.68	1.84	1.76
T_7	17.97	14.05	16.01	35.18	29.97	32.57	1.96	2.13	2.05
T_8	20.05	15.68	17.87	35.22	30.00	32.61	1.76	1.91	1.83
T_9	15.68	12.26	13.97	36.58	31.15	33.87	2.33	2.54	2.44
T_{10}	16.79	13.13	14.96	35.84	30.53	33.19	2.13	2.32	2.23
T_{11}	18.40	27.41	22.91	52.56	83.83	68.20	2.86	3.06	2.96
S. Em. ±	0.30	0.27	0.29	0.55	0.64	0.60	0.03	0.03	0.03
C.D. at 5 %	0.89	0.79	0.84	1.63	1.88	1.76	0.08	0.09	0.09

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation of nitrogen in maize. During *kharif* 2024, as far as root is concerned, the higher BCFr was recorded in T_4 and the lower was in T_9. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_5. As far as translocation of nitrogen is concerned, the higher TF was in T_{11} and the lower was in T_4.

During *kharif* 2025, as far as root is concerned, the higher BCFr was recorded in T_{11} and the lower was in T_9. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_5. As far as translocation of nitrogen is concerned, the higher TF was in T_{11} and the lower was in T_4.

In the case of pooled data, the higher BCFr was observed in T_{11} (22.91), while the lower was in T_9 (13.97). The higher BCFs was observed in T_{11} (68.20) and the lower was in T_5 (32.44). As far as nitrogen translocation is concerned, the higher TF was in T_{11} (2.96) while the lower was in T_4 (1.61).

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for phosphorus in maize during *kharif* 2024 and 2025 are presented in Table 2.

Table 2: Effect of different treatments on BCFr, BCFs and TF for phosphorus in maize during *kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	65.13	98.68	81.91	106.38	163.47	134.92	1.63	1.66	1.64
T_2	64.82	45.88	55.35	62.88	45.14	54.01	0.97	0.98	0.98
T_3	62.07	43.82	52.94	60.99	42.95	51.97	0.98	0.98	0.98
T_4	63.00	44.43	53.72	58.66	41.96	50.31	0.93	0.94	0.94
T_5	65.83	46.27	56.05	64.59	46.04	55.31	0.98	1.00	0.99
T_6	64.67	44.39	54.53	65.98	45.92	55.95	1.02	1.03	1.03
T_7	56.73	38.66	47.70	67.10	46.38	56.74	1.18	1.20	1.19
T_8	63.21	43.20	53.20	67.07	46.50	56.78	1.06	1.08	1.07
T_9	48.85	32.91	40.88	67.05	45.80	56.42	1.37	1.39	1.38
T_{10}	52.63	35.50	44.06	66.36	45.40	55.88	1.26	1.28	1.27
T_{11}	68.11	229.84	148.97	117.54	373.01	245.27	1.73	1.62	1.67
S. Em. ±	0.93	1.48	1.20	1.12	2.39	1.76	0.02	0.02	0.02
C.D. at 5 %	2.73	4.37	3.55	3.31	7.06	5.19	0.05	0.05	0.05

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation for phosphorus in maize. During *kharif* 2024, as far as root is concerned, the higher BCFr was recorded in T_{11} and the lower was in T_9. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_4. As far as translocation of phosphorus is concerned, the higher TF was in T_{11} and the lower was in T_4.

During *kharif* 2025, as for as root is concerned, the higher BCFr was recorded in T_{11} and the lower was in T_9. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_4. As far as translocation of phosphorus is concerned, the higher TF was in T_{11} and the lower was in T_4.

In the case of pooled data, the higher BCFr was observed in T_{11} (148.97), while the lower was in T_9 (40.88). The higher BCFs was observed in T_{11} (245.27) and the lower was in T_4 (50.31). As far as phosphorus translocation is concerned, the higher TF was in T_{11} (1.67) while the lower was in T_4 (0.94).

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for potassium in maize during *kharif* 2024 and 2025 are presented in Table 3.

Table 3: Effect of different treatments on BCFr, BCFs and TF for potassium in maize during *kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	9.44	17.49	13.46	67.22	120.16	93.69	7.12	6.87	7.00
T_2	15.66	16.18	15.92	66.27	66.04	66.15	4.23	4.08	4.16
T_3	15.74	16.31	16.02	67.44	66.30	66.87	4.28	4.07	4.18
T_4	16.57	17.19	16.88	67.29	67.35	67.32	4.06	3.92	3.99
T_5	15.33	15.77	15.55	65.57	65.09	65.33	4.28	4.13	4.20
T_6	14.93	15.29	15.11	66.42	65.62	66.02	4.45	4.29	4.37
T_7	12.30	12.56	12.43	63.43	62.49	62.96	5.16	4.98	5.07
T_8	13.96	14.29	14.13	64.59	63.81	64.20	4.63	4.46	4.55
T_9	10.12	10.40	10.26	60.54	60.07	60.30	5.98	5.77	5.88
T_{10}	11.18	11.48	11.33	61.48	60.91	61.20	5.50	5.31	5.40
T_{11}	9.12	13.39	11.26	68.65	88.78	78.71	7.52	6.63	7.08
S. Em. ±	0.21	0.23	0.22	0.96	1.15	1.05	0.08	0.07	0.07
C.D. at 5 %	0.62	0.68	0.65	2.83	3.38	3.10	0.22	0.21	0.22

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation for potassium in maize. During *kharif* 2024, as for as root is concerned, the higher BCFr was recorded in T_4 and the lower was in T_{11}. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_9. As far as translocation of potassium is concerned, the higher TF was in T_{11} and the lower was in T_4.

During *kharif* 2025, as for as root is concerned, the higher BCFr was recorded in T_1 and the lower was in T_9. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_9. As far as translocation of potassium is concerned, the higher TF was in T_{11} and the lower was in T_4.

In the case of pooled data, the higher BCFr was observed in T_4 (16.88), while the lower was in T_9 (10.26). The higher BCFs was observed in T_1 (93.69) and the lower was in T_9

(60.30). As far as potassium translocation is concerned, the higher TF was in T_{11} (7.08) while the lower was in T_4 (3.99).

The bioconcentration and translocation factors for N, P and K in maize during *kharif* 2024 and 2025 showed considerable variation among treatments. The absolute control (T_{11}) generally recorded higher BCFs and TF values for N, P and K, while T_4 (RDF + FYM @ 5.0 t ha^{-1} + biochar @ 5.0 t ha^{-1}) recorded comparatively lower values for most parameters. The higher BCF and TF under T_{11} may be attributed to the depletion of available nutrients from the soil in the absence of external nutrient addition. Since BCF is expressed as the ratio of nutrient concentration in plant tissue to that in soil, a lower residual soil nutrient concentration can result in a higher BCF even when the overall nutrient supply is limited. In contrast, T_4 received adequate N, P and K through RDF along with FYM and biochar which helped maintain a comparatively higher residual nutrient pool in the soil. Biochar and FYM may have enhanced nutrient retention and gradual nutrient release, thereby maintaining nutrients in the soil for uptake according to crop demand. Thus, the comparatively lower BCF and TF values under T_4 can be associated with better maintenance of the soil nutrient pool, whereas the higher values under T_{11} mainly indicate greater nutrient depletion from the soil. The FYM and biochar may have enhanced nutrient retention and gradual nutrient release, thereby maintaining nutrients in the soil for uptake according to crop demand (Kirkham, 2006; Liu *et al*., 2019) [6, 7]. Figure 1 illustrates that based on the pooled mean values of *kharif* 2024 and 2025, the overall translocation of major nutrients in maize followed the order K > N > P irrespective of the treatments.

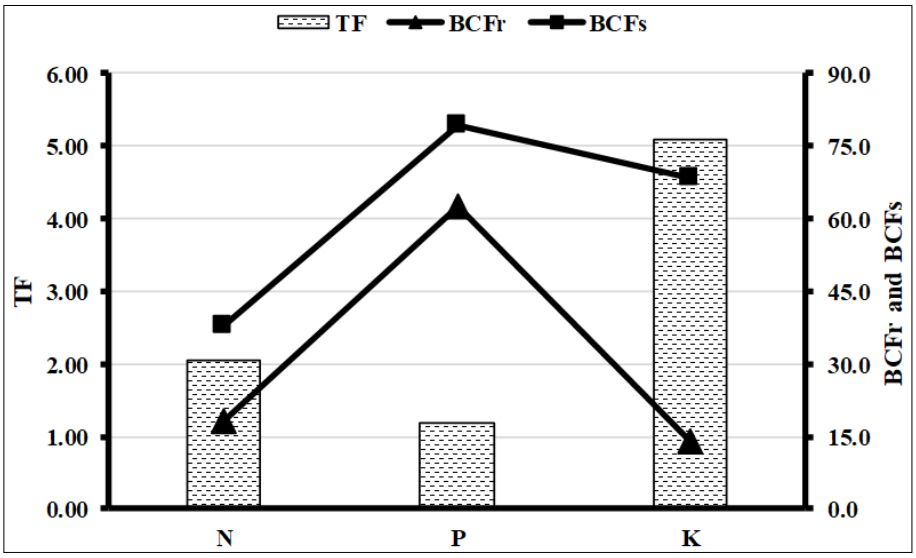


Fig 1: Effect of different treatments on bioconcentration factor (BCF) and Translocation factor (TF) for NPK in *kharif* maize (mean of pooled data of *kharif* 2024 and 2025)

Effect of different treatments on bioconcentration factors (BCF) and Translocation factors (TF) for micronutrients in *kharif* maize

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for Zn in maize during *kharif* 2024 and 2025 are presented in Table 4.

Table 4: Effect of different treatments on BCFr, BCFs and TF for Zn in maize during *Kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	1.67	2.34	2.01	81.96	114.98	98.47	49.06	49.06	49.06
T_2	1.65	2.00	1.83	82.31	100.25	91.28	50.01	50.01	50.01
T_3	1.67	2.01	1.84	83.05	99.97	91.51	49.83	49.83	49.83
T_4	1.63	1.97	1.80	83.07	100.66	91.87	51.12	51.12	51.12
T_5	1.71	2.09	1.90	82.90	101.54	92.22	48.58	48.58	48.58
T_6	1.74	2.12	1.93	83.50	101.31	92.40	47.87	47.87	47.87
T_7	1.72	2.10	1.91	82.89	101.49	92.19	48.31	48.31	48.31
T_8	1.67	2.10	1.89	80.74	101.40	91.07	48.24	48.24	48.24
T_9	1.57	1.91	1.74	81.24	98.90	90.07	51.75	51.75	51.75
T_{10}	1.59	1.96	1.78	81.66	100.65	91.16	51.33	51.33	51.33
T_{11}	1.93	2.75	2.34	145.38	229.89	187.63	75.14	83.59	79.37
S. Em. ±	0.02	0.03	0.03	1.29	1.76	1.52	0.75	0.77	0.76
C.D. at 5 %	0.07	0.09	0.08	3.81	5.18	4.50	2.23	2.28	2.25

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation of Zn in maize. During *kharif* 2024, as for as root is concerned, the higher BCFr was recorded in T_{11} and the lower was in T_9. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_9. As far as translocation of Zn is concerned, the higher TF was in T_{11} and the lower was in T_6.

During *kharif* 2025, a similar trend was observed, however the higher BCFr, BCFs and TF of maize values were comparatively higher than those observed in *kharif* 2024.

In the case of pooled data, the higher BCFr was observed in T_{11} (2.34), while the lower was in T_9 (1.74). The higher BCFs was observed in T_{11} (187.63) and the lower was in T_9 (90.07). As far as Zn translocation is concerned, the higher TF was in T_{11} (79.37) while the lower was in T_6 (47.87).

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for Mn in maize during *kharif* 2024 and 2025 are presented in Table 5.

Table 5: Effect of different treatments on BCFr, BCFs and TF for Mn in maize during *Kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	5.80	8.13	6.96	14.73	17.46	16.09	2.54	2.15	2.34
T_2	5.71	6.96	6.33	14.34	16.08	15.21	2.51	2.31	2.41
T_3	5.78	6.96	6.37	14.39	15.98	15.19	2.49	2.29	2.39
T_4	5.64	6.83	6.24	12.88	14.14	13.51	2.29	2.07	2.18
T_5	5.92	7.25	6.59	14.46	16.04	15.25	2.44	2.21	2.33
T_6	6.05	7.34	6.70	14.76	16.41	15.59	2.44	2.23	2.34
T_7	5.95	7.29	6.62	14.82	16.62	15.72	2.49	2.28	2.38
T_8	5.81	7.29	6.55	14.84	16.41	15.62	2.55	2.25	2.40
T_9	5.45	6.63	6.04	15.37	16.76	16.06	2.82	2.53	2.67
T_{10}	5.52	6.80	6.16	15.57	17.13	16.35	2.82	2.52	2.67
T_{11}	1.14	1.28	1.21	35.16	43.61	39.39	30.97	34.14	32.55
S. Em. ±	0.09	0.11	0.10	0.26	0.31	0.28	0.19	0.21	0.20
C.D. at 5 %	0.25	0.32	0.28	0.76	0.90	0.83	0.55	0.61	0.58

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation of Mn in maize. During *kharif* 2024, as far as root is concerned, the higher BCFr was recorded in T_6 and the lower was in T_{11}. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_4. As far as translocation of Mn is concerned, the higher TF was in T_{11} and the lower was in T_4.

During *kharif* 2025, as far as root is concerned, the higher BCFr was recorded in T_1 and the lower was in T_{11}. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_4.

As far as translocation of Mn is concerned, the higher TF was in T_{11} and the lower was in T_4.

In the case of pooled data, the higher BCFr was observed in T_1 (6.96), while the lower was in T_{11} (1.21). The higher BCFs was observed in T_{11} (39.39) and the lower was in T_4 (13.51). As far as Mn translocation is concerned, the higher TF was in T_{11} (32.55) while the lower was in T_4 (2.18).

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for Cu in maize during *kharif* 2024 and 2025 are presented in Table 6.

Table 6: Effect of different treatments on BCFr, BCFs and TF for Cu in maize during *Kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	6.09	7.69	6.89	16.74	21.14	18.94	2.75	2.75	2.75
T_2	5.34	6.22	5.78	14.96	17.44	16.20	2.80	2.80	2.80
T_3	4.72	5.42	5.07	13.18	15.14	14.16	2.79	2.79	2.79
T_4	4.54	5.16	4.85	12.99	14.79	13.89	2.86	2.86	2.86
T_5	5.38	6.27	5.82	14.63	17.07	15.85	2.72	2.72	2.72
T_6	5.60	6.55	6.08	15.02	17.57	16.30	2.68	2.68	2.68
T_7	5.39	6.40	5.89	14.58	17.32	15.95	2.71	2.71	2.71
T_8	5.49	6.48	5.98	14.84	17.50	16.17	2.70	2.70	2.70
T_9	6.19	7.48	6.83	17.95	21.68	19.81	2.90	2.90	2.90
T_{10}	5.89	7.12	6.51	16.95	20.47	18.71	2.88	2.88	2.88
T_{11}	5.44	8.22	6.83	22.91	38.49	30.70	4.21	4.68	4.45
S. Em. ±	0.08	0.10	0.09	0.23	0.31	0.27	0.04	0.04	0.04
C.D. at 5 %	0.24	0.29	0.26	0.69	0.90	0.79	0.12	0.13	0.13

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75

%) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation of Cu in maize. During *kharif* 2024, as far as root is concerned, the higher BCFr was recorded in T_9 and the lower was in T_4. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_4. As far as translocation of Cu is concerned, the higher TF was in T_{11} and the lower was in T_6.

During *kharif* 2025, as far as root is concerned, the higher BCFr was recorded in T_{11} and the lower was in T_4. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_4.

As far as translocation of Cu is concerned, the higher TF was in T_{11} and the lower was in T_6.

In the case of pooled data, the higher BCFr was observed in T_1 (6.89), while the lower was in T_4 (4.85). The higher BCFs was observed in T_{11} (30.70) and the lower was in T_4 (13.89). As far as Cu translocation is concerned, the higher TF was in T_{11} (4.45) while the lower was in T_6 (2.68).

The computed values of root bioconcentration factor (BCFr), shoot bioconcentration factor (BCFs) and translocation factor (TF) for Fe in maize during *kharif* 2024 and 2025 are presented in Table 7.

Table 7: Effect of different treatments on BCFr, BCFs and TF for Fe in maize during *Kharif* 2024 and 2025

Treatments	BCFr			BCFs			TF		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
T_1	2.59	3.28	2.94	80.01	94.87	87.44	30.85	28.89	29.87
T_2	2.70	3.31	3.00	86.12	98.82	92.47	31.93	29.89	30.91
T_3	2.66	3.26	2.96	84.72	97.21	90.96	31.85	29.82	30.84
T_4	2.66	3.26	2.96	87.45	100.35	93.90	32.88	30.79	31.84
T_5	2.71	3.32	3.02	83.55	95.87	89.71	30.83	28.87	29.85
T_6	2.74	3.36	3.05	83.03	95.28	89.16	30.31	28.38	29.34
T_7	2.66	3.27	2.96	81.09	93.05	87.07	30.43	28.50	29.47
T_8	2.70	3.31	3.01	82.37	94.52	88.45	30.48	28.54	29.51
T_9	2.58	3.17	2.88	83.61	95.95	89.78	32.36	30.30	31.33
T_{10}	2.56	3.13	2.84	82.44	94.60	88.52	32.26	30.20	31.23
T_{11}	2.29	2.74	2.51	106.50	132.93	119.71	46.60	48.54	47.57
S. Em. ±	0.04	0.05	0.04	1.25	1.45	1.35	0.48	0.46	0.47
C.D. at 5 %	0.11	0.14	0.13	3.68	4.28	3.98	1.41	1.35	1.38

Note 1: BCFr: Root bioconcentration factor, BCFs: Shoot bioconcentration factor, TF: Traslocation factor

Note : T_1-RDF only (150:65:65 kg NPK ha^{-1}); T_2-RDF + FYM @ 10.0 t ha^{-1}; T_3-RDF + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_4-RDF + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_5-RDF + FYM @ 2.5 t ha^{-1} + Biochar @ 7.5 t ha^{-1}; T_6-RDF + Biochar @ 10.0 t ha^{-1}; T_7-RDF (75 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_8-RDF (75 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_9-RDF (50 %) + FYM @ 7.5 t ha^{-1} + Biochar @ 2.5 t ha^{-1}; T_{10}-RDF (50 %) + FYM @ 5.0 t ha^{-1} + Biochar @ 5.0 t ha^{-1}; T_{11}-Absolute control

In general, the application of different treatments influenced the bioconcentrations and translocation of Fe in maize. During *kharif* 2024, as far as root is concerned, the higher BCFr was recorded in T_6 and the lower was in T_{11}. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_1. As far as translocation of Fe is concerned, the higher TF was in T_{11} and the lower was in T_6.

During *kharif* 2025, as far as root is concerned, the higher BCFr was recorded in T_6 and the lower was in T_{11}. On the other hand, in the case of shoot, the higher BCFs value was in T_{11}, while the lower was in T_7. As far as translocation of Fe is concerned, the higher TF was in T_{11} and the lower was in T_6.

In the case of pooled data, the higher BCFr was observed in T_6 (3.05), while the lower was in T_{11} (2.51). The higher BCFs was observed in T_{11} (119.71) and the lower was in T_7 (87.07). As far as Fe translocation is concerned, the higher TF was in T_{11} (47.57) while the lower was in T_6 (29.34).

The Figure 2 illustrated the bioconcentration factors (BCFr and BCFs) and translocation factor (TF) of Zn, Mn, Cu and Fe in maize. The pooled mean values of *kharif* 2024 and 2025 showed a broadly consistent pattern across the four micronutrients. Among the micronutrients, the overall translocation from root to shoot followed the order Zn > Fe > Mn > Cu, irrespective of the treatments. The absolute control (T_{11}) generally recorded the higher BCFs and TF values for all the micronutrients, whereas BCFr showed greater variation among the treatments with the higher values recorded in T_{11} for Zn, T_1 for Mn, T_1 for Cu and T_6 for Fe. The comparatively lower values were generally observed under T_4 for BCFs of Mn and Cu and under T_6 and T_7 for TF.

The higher BCFs and TF values observed in T_{11} may be attributed to the lower availability of micronutrients in the soil under continuous nutrient removal without external nutrient addition, resulting in higher plant to soil concentration ratios. Thus, the higher BCF and TF values in the absolute control should not necessarily be interpreted as an indication of better micronutrient nutrition of the crop. In contrast, the comparatively lower BCF and TF values observed under biochar-FYM combinations, particularly T_4 and T_6, may reflect better maintenance and buffering of the soil micronutrient pool through organic amendments addition and gradual nutrient release (Halesh *et al*., 2023) [5].

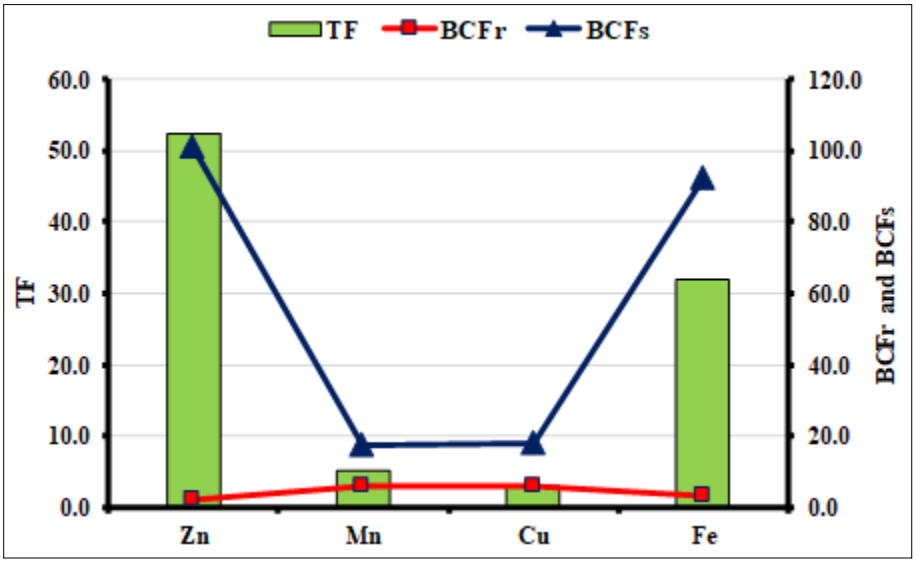


Fig 2: Effect of different treatments on bioconcentration factors (BCF) and Translocation factors (TF) for Micronutrients in *kharif* maize (mean of pooled data of *kharif* 2024 and 2025)

Conclusion

Overall, the absolute control (T11) recorded the highest shoot bioconcentration factor (BCFs) and translocation factor (TF) for N, P, K and micronutrients, while T4 (RDF + FYM @ 5.0 t ha^{-1} + biochar @ 5.0 t ha^{-1}) recorded comparatively lower values for most parameters. Because BCF is the ratio of plant to soil nutrient concentration, the high values in T11 reflect depletion of soil-available nutrients under continuous removal without external addition, not better plant nutrition. The lower BCF and TF under T4 indicate that biochar and FYM retained nutrients in the soil and released them gradually in line with crop demand, which maintained a larger, better-buffered soil nutrient pool. BCF and TF should therefore be read together with absolute nutrient uptake and soil fertility status, not on their own, as indicators of nutrient use. which indicates that biochar is most effective when combined with FYM and adequate inorganic fertilizer.

The absolute control (T11) recorded the highest BCFs and TFs for N, P, K and micronutrients, whereas T4 (RDF + FYM @ 5.0 t ha^{-1} + biochar @ 5.0 t ha^{-1}) exhibited comparatively lower values for most parameters. The elevated indices in T11 likely reflected soil nutrient depletion, while lower values under T4 indicated improved nutrient retention and gradual release. Thus, BCF and TF should be interpreted alongside nutrient uptake and soil fertility status to assess nutrient-use efficiency.

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