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RESEARCH PAPER

Influence of zinc and iron bio-fortification on growth and yield of annual cereal fodder crops

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Abstract: A field study was conducted during *kharif* 2019 at Indian Grassland and Fodder Research Institute, Southern Regional Research Station, Dharwad, Karnataka, under rainfed conditions in red loamy soil in split plot design with three replications. Three annual cereal fodder crops (Fodder maize, sorghum and bajra) were in main plot and ten bio-fortification treatments in sub plots. Fodder maize (African tall) recorded significantly higher green fodder yield (42.4 t ha^{-1}) followed by fodder sorghum var. SSV 74 (39.4 t ha^{-1}). Fodder bajra (BAIF) recorded lower green fodder yield (35.6 t ha^{-1}). Among bio-fortification treatments all the three crops responded to application of their respective RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS. This treatment combination recorded significantly higher green fodder yield (43.7 t ha^{-1}), number of leaves per plant (14.2), leaf area (576.2 cm $plant^{-1}$), fresh biomass (196.8 g $plant^{-1}$) and total dry matter production (79.2 g $plant^{-1}$) and resulted in higher net returns. Application of RDF alone without zinc and iron recorded lower growth, yield and economics. Fodder maize with application of RDF (100:60:40 N:P_2O_5: K_2O kg ha^{-1}) + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS recorded significantly higher green fodder yield (47.4 t ha^{-1}) and also resulted in higher gross returns (₹ 1, 18,611 ha^{-1}), net returns (₹ 68,597 ha^{-1}) and B:C ratio (2.37) with good nutritional quality as compared to other treatment combinations. Fodder bajra with application of RDF (80:40:40 N:P_2O_5: K_2O kg ha^{-1}) alone recorded lower yield and economics.

Keywords: Bio-fortification, Fodder, Maize, Zinc

Introduction

Animal husbandry is an important sub-enterprise of agriculture in India. It is considered as backbone of agriculture as it provides essential dietary requirements like milk and meat. Livestock resource of India contributes 4.11 per cent of GDP and 25.6 per cent of total agriculture GDP (Dash, 2017).Economy and socio-economic growth of the country also depends on the livestock sector. Supply of regular and adequate amount of fodder to animals is essential to meet the food requirements of livestock industry in the country throughout the year on which success of the livestock industry depends. According to 20^{th} Livestock Census country's total livestock population is 536.76 million but, cropped area under fodder crops is limited to less than 4.5 per cent of the country's total cropped area. The present fodder resources in the country are inadequate and it can meet only 45 to 50 per cent of the requirement. To meet the needs of livestock population there is a need to increase the production of fodder and productivity of fodder crops.

Amongst the various annual cereal fodder crops maize (*Zea mays* L.), sorghum (*Sorgum bicolor* L.) and pearl millet (*Pennisetum glaucum)* are commonly grown in *kharif s*eason. Maize has an edge over other cultivated fodder crops due to its high production potential, wider adaptability, quick growing nature, succulency, palatability and excellent fodder quality. Fodder sorghum and bajra are also most important fodder crops of India. They are highly nutritious, palatable and can be fed as green, dry or as conserved fodder in the form of silage or hay. There are various constraints for low production and productivity of fodder crops. Most important constraint for low productivity of fodder crop is poor nutrient management. In nutrient management, micronutrients play an important role along with major nutrients in crop growth and productivity. Micronutrients are essential elements required in low concentrations and un less their supply is increased during crop growth, their deficiency may emerge and limit crop productivity.

Among the micronutrients the deficiency of zinc and iron are very common and have become bottlenecks in realizing higher productivity of fodder crops. Among the many nutrient management practices agronomic bio-fortification is one among them. Bio-fortification aims to increase nutrient levels in crops during plant growth rather than through manual means during processing of the crops. Agronomic bio-fortification of Zn and Fe can be done through seed treatment, soil application and foliar application. Combined soil and foliar application of Zn and Fe fertilizers under field condition is most effective and very practical way to maximize yield. Therefore, studies are undertaken with objective to increase growth, yield and economics of fodder crops through agronomic fortification of annual cereal fodder crops by enhancing the zinc and iron content.

Material and methods

The field experiment was conducted during *kharif* season of 2019-20 on red loamy soil at Indian Grassland and Fodder Research Institute, Southern Regional Research Station, Dharwad, Karnataka, which is located at 15º 26' latitude of North, 75º 07' longitude of East with an altitude of 678 m above mean sea level falling under Northern Transition Zone (Zone-8) of Karnataka.

The experiment was laid out in split plot design with three replications. The experiment consists of three annual cereal fodder crops in main plot *viz.*, Fodder maize, sorghum and bajra. Each crop consist of 10 treatments *viz.*, T_1- RDF alone; T_2- RDF + 10 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS; T_3- RDF + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS; T_4- RDF + 10 kg $ZnSO_4$ + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS;T_5- RDF + 15 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS; T_6- RDF + 15 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS; T_7- RDF + 15 kg $ZnSO_4$ +15 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ +1% $FeSO_4$ as foliar spray at 45 DAS; T_8- RDF + 20 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS; T_9- RDF + 20 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS; T_{10}- RDF + 20 kg $ZnSO_4$+20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ +1% $FeSO_4$ as foliar spray at 45 DAS. Here the main objective of the study was, to get the higher yield with higher quality and economics by optimizing the micronutrient dosage for enrichment. However, aim of comparing three different fodder crops was to know the suitable fodder crop for Northern Transition Zone of Karnataka (Zone 8).

Recommended dose of fertilizer of each crop was applied with 50 per cent of nitrogen and 100 per cent of phosphorus and potassium in the form of urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively as basal application. Along with recommended dose of fertilizer zinc and iron were applied to soil as per the treatment in the form of $ZnSO_4$ and $FeSO_4$ respectively. Remaining 50 per cent of nitrogen was top dressed and foliar application of one per cent zinc and iron also followed as per the treatment specification at 45 DAS. Fodder maize (African tall), fodder sorghum (SSV 74) and fodder bajra (BAIF Bajra) were sown in the lines at 45 cm spacing and covered by soil.

Growth and yield observations at harvest *viz.,* plant height, number of leaves, leaf area, fresh biomass production, dry matter production, green fodder yield and dry fodder yield were recorded as per the standard procedures. The data collected from the experiment during crop growth period were subjected to statistical analysis as described by Gomez and Gomez (1984). Besides, the mean values of main plot, sub plot and interactions were separately subjected to Duncan Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degrees of freedom.

Results and discussion

Performance of different annual cereal fodder crops

Green fodder is an economic source of nutrients for the dairy animals and it is highly digestible and palatable. The

Table 1. Growth parameters of annual cereal fodder crops as influenced by zinc and iron bio-fortification

Treatments	Plant height (cm)				Number of leaves				Leaf area (cm^2 plant^{-1})			
	Maize	Sorghum	Bajra	Mean	Maize	Sorghum	Bajra	Mean	Maize	Sorghum	Bajra	Mean
T_1	253.7^{ij}	260.6^{f-j}	254.0^{ij}	256.1^{e}	14.6^{a-c}	12.1^{f-h}	10.2^{j}	12.3^{c}	675.5^{d}	582.0^{g}	281.0^{i}	512.8^{e}
T_2	263.2^{d-j}	278.2^{a-e}	255.9^{h-j}	265.8^{cd}	15.0^{ab}	13.3^{d-f}	10.8^{ij}	13.0^{b}	710.1^{c}	579.0^{g}	285.0^{hi}	524.7^{de}
T_3	262.0^{e-j}	274.5^{a-g}	272.1^{b-h}	269.5^{bc}	15.3^{ab}	12.8^{ef}	10.9^{h-j}	13.0^{b}	719.0^{c}	610.3^{e-g}	300.3^{hi}	543.2^{cd}
T_4	262.1^{e-j}	274.8^{a-g}	264.7^{c-j}	267.2^{cd}	14.7^{a-c}	12.9^{ef}	10.5^{ij}	12.7^{bc}	719.6^{c}	624.4^{ef}	302.9^{hi}	549.0^{bc}
T_5	259.7^{g-j}	266.2^{b-j}	268.7^{b-i}	264.8^{cd}	14.5^{a-c}	12.9^{ef}	10.9^{h-j}	12.8^{bc}	731.2^{bc}	601.3^{fg}	301.0^{hi}	544.5^{bc}
T_6	263.5^{d-j}	261.5^{f-j}	250.9^{j}	258.6^{de}	14.3^{b-d}	11.4^{h-j}	11.2^{h-j}	12.4^{c}	730.1^{bc}	603.8^{fg}	303.0^{hi}	545.7^{bc}
T_7	276.8^{a-f}	281.8^{ab}	268.9^{b-i}	275.8^{ab}	15.1^{ab}	14.9^{ab}	11.3^{h-j}	13.8^{a}	755.9^{ab}	630.0^{ef}	308.3^{hi}	564.7^{ab}
T_8	272.0^{b-h}	279.5^{a-d}	263.3^{d-j}	271.6^{bc}	13.5^{c-e}	12.7^{e-g}	11.1^{h-j}	12.4^{bc}	728.5^{bc}	612.0^{e-g}	302.8^{hi}	547.8^{bc}
T_9	275.6^{a-g}	268.4^{b-i}	257.8^{h-j}	267.3^{cd}	15.6^{a}	15.1^{ab}	10.7^{ij}	13.8^{a}	720.1^{c}	621.2^{ef}	306.0^{hi}	549.1^{bc}
T_{10}	280.7^{a-c}	289.5^{a}	276.3^{a-f}	282.2^{a}	15.8^{a}	15.2^{ab}	11.6^{g-i}	14.2^{a}	768.8^{a}	641.0^{e}	319.0^{h}	576.2^{a}
Mean	266.9^{ab}	273.5^{a}	263.3^{b}		14.8^{a}	13.3^{a}	11.1^{b}		725.9^{a}	610.5^{b}	300.9^{c}	
		S.Em.±			S.Em.±				S.Em.±			
Main plot (A)		2.38			0.46				5.14			
Sub plot (B)		2.75			0.22				6.54			
A×B		4.77			0.38				11.34			

*RDF- Fodder maize – 100:60:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder sorghum – 80:40:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder bajra – 80:40:40 N:P_2O_5: K_2O kg ha^{-1}

RDF- Recommended dose of fertilizer DAS- Days after sowing

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Main plot (Fodder crops):	Sub plot (Zn and Fe levels)
M- Maize (var. African tall)	T_1 -* RDF
S- Sorghum (var. SSV 74)	T_2 - RDF + 10 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
B- Bajra (var. BAIF Bajra)	T_3 - RDF + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
	T_4 -RDF + 10 kg $ZnSO_4$ + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ +1% $FeSO_4$ as foliar spray at 45 DAS
	T_5 -RDF + 15 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
	T_6 -RDF + 15 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
	T_7 - RDF + 15 kg $ZnSO_4$ +15 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS
	T_8 - RDF + 20 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
	T_9 - RDF + 20 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
	T_{10} - RDF + 20 kg $ZnSO_4$+20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS

Table 2. Fresh biomass and dry matter production of annual cereal fodder crops as influenced by zinc and iron bio-fortification

Treatments	Fresh biomass production (g plant^{-1})				Dry matter production (g plant^{-1})			
	Maize	Sorghum	Bajra	Mean	Maize	Sorghum	Bajra	Mean
T_1	168.5^{j-l}	159.0^{l-n}	145.0^{o}	157.5^{f}	83.2^{e}	67.3^{i}	61.1^{j}	70.6^{f}
T_2	172.1^{i-k}	163.5^{k-m}	147.0^{o}	160.8^{ef}	83.3^{e}	69.1^{hi}	61.6^{j}	71.3^{f}
T_3	174.5^{h-k}	159.8^{l-n}	154.0^{m-o}	162.8^{ef}	88.7^{d}	69.8^{hi}	62.1^{j}	73.5^{e}
T_4	196.5^{b-d}	173.3^{h-k}	166.0^{kl}	178.6^{c}	92.6^{c}	69.0^{hi}	62.0^{j}	74.5^{e}
T_5	183.5^{f-i}	181.5^{f-i}	149.0^{no}	171.3^{d}	95.8^{b}	69.6^{hi}	63.0^{j}	76.2^{d}
T_6	184.0^{e-h}	166.5^{kl}	147.5^{o}	166.0^{de}	95.1^{b}	71.4^{gh}	62.4^{j}	76.3^{cd}
T_7	211.5^{a}	186.0^{d-g}	173.0^{h-k}	190.2^{b}	98.9^{a}	73.0^{fg}	62.4^{j}	78.1^{ab}
T_8	199.5^{bc}	190.5^{c-f}	172.5^{h-k}	187.5^{b}	98.7^{a}	71.4^{gh}	63.0^{j}	77.7^{bc}
T_9	203.5^{ab}	194.8^{b-e}	169.0^{j-l}	189.1^{b}	99.3^{a}	72.4^{fg}	62.6^{j}	78.1^{ab}
T_{10}	213.5^{a}	198.0b^{c}	179.0^{g-j}	196.8^{a}	99.7^{a}	74.3^{f}	63.8^{j}	79.2^{a}
Mean	190.7^{a}	177.3^{b}	160.2^{c}		93.5^{a}	70.7^{b}	62.4^{c}	
		S.Em.±			S.Em.±			
Main plot (A)		0.78			0.77			
Sub plot (B)		2.05			0.49			
A×B		3.55			0.84			

*RDF- Fodder maize - 100:60:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder sorghum -80:40:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder bajra - 80:40:40 N:P_2O_5: K_2O kg ha^{-1}

RDF- Recommended dose of fertilizer DAS- Days after sowing

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Main plot (Fodder crops):
M- Maize (var. African tall)
S- Sorghum (var. SSV 74)
B- Bajra (var. BAIF Bajra)

Sub plot (Zn and Fe levels)
T_1 -* RDF
T_2 - RDF + 10 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
T_3 - RDF + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
T_4 -RDF + 10 kg $ZnSO_4$ + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ +1% $FeSO_4$ as foliar spray at 45 DAS
T_5 -RDF + 15 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
T_6 -RDF + 15 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
T_7 - RDF + 15 kg $ZnSO_4$ +15 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS
T_8 - RDF + 20 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
T_9 - RDF + 20 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
T_{10} - RDF + 20 kg $ZnSO_4$+20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS

demand of growing livestock population is met by producing higher green fodder yield. The green fodder yield can be increased by selecting suitable crop and by improving performance of growth and yield parameters *viz.,* plant height, number of leaves, leaf area, fresh biomass production and dry matter production (Table 1 and 2). Among the three annual cereal fodder crops fodder sorghum recorded higher plant height (273.5 cm) and it was on par with fodder maize (266.9 cm). However, higher number of leaves was recorded in fodder maize (14.8) followed by fodder sorghum (13.3) and lower plant height (263.3 cm) and number of leaves (11.1) were observed in fodder bajra. It might be due to varietal character of the particular crop and influence of the climatic factors like temperature and rainfall. Along with higher number of leaves fodder maize recorded significantly higher leaf area (725.9 cm^2), fresh biomass production (190.7 g plant^{-1}) and dry matter production (93.5 g plant^{-1}) followed by fodder sorghum and fodder bajra recorded lower values. Significantly higher leaf area (725.9 cm^2) in maize might be due to broader leaves with more length and breadth and efficient photosynthetic system which enabled the plant to intercept higher amount of radiation energy as compared to sorghum and bajra which produced comparatively narrow leaves. Increase in plant height, number of leaves and leaf area leads to increase in photosynthetic capacity of the plant which in turn responsible for production of higher fresh biomass, dry matter and its distribution in various parts of plant. Therefore, fodder maize recorded higher fresh biomass and dry matter production. Similar results were recorded by Arabhanvi (2017) who reported higher fresh fodder in maize (biofortification of vermicompost at 10 kg of each $ZnSO_4$ and $FeSO_4$) compared to sorghum which was revealed by Anilkumar (2017) in similar climatic conditions of Northern Transition Zone of Karnataka with 124.0 mm rainfall in 9 rainy days.

The growth parameters have a direct relationship with green fodder yield through photosynthetic activity, fresh biomass production and dry matter accumulation. A strong linear and positive relation between growth parameters and yield was established. Therefore, fodder maize recorded significantly higher green fodder of 42.4 t ha^{-1} (Fig.1a) and dry fodder yield of 20.8 t ha^{-1} (Fig. 1b) compared to fodder sorghum and bajra (Table 3). The increase in green fodder yield was to the tune of 7.61 and 19.10 per cent in fodder maize over fodder sorghum and bajra, respectively. The significantly higher green fodder yield was mainly due to higher growth parameters, varietal character, favorable climatic condition and better production of photosynthates and accumulation of dry matter. Lower yield

Table 3. Green and dry fodder yield of annual cereal fodder crops as influenced by zinc and iron bio-fortification

Treatments	Green fodder yield (t ha^{-1})				Dry fodder yield (t ha^{-1})			
	Maize	Sorghum	Bajra	Mean	Maize	Sorghum	Bajra	Mean
T_1	37.4^{k-m}	35.3^{m-o}	32.3^{p}	35.0^{f}	18.5^{e}	15.0^{i}	13.6^{j}	15.7^{f}
T_2	38.2^{j-l}	36.3^{l-n}	32.6^{p}	35.7^{ef}	18.5^{e}	15.4^{hi}	13.7^{j}	15.9^{f}
T_3	38.8^{g-l}	35.5^{m-o}	34.2^{n-p}	36.2^{ef}	19.7^{d}	15.5^{hi}	13.8^{j}	16.3^{e}
T_4	43.7^{b-d}	38.5^{h-l}	36.9^{lm}	39.7^{c}	20.6^{c}	15.3^{hi}	13.8^{j}	16.6^{e}
T_5	40.8^{f-i}	40.3^{f-j}	33.1^{op}	38.1^{d}	21.3^{b}	15.5^{hi}	14.0^{j}	16.9^{d}
T_6	40.9^{e-h}	37.0^{lm}	32.8^{p}	36.9^{de}	21.1^{b}	15.9^{gh}	13.9^{j}	17.0^{cd}
T_7	47.0^{a}	41.3^{d-g}	38.4^{h-l}	42.3^{b}	22.1^{a}	16.2^{fg}	13.9^{j}	17.4^{ab}
T_8	44.3^{bc}	42.3^{c-f}	38.3^{i-l}	41.7^{b}	21.9^{a}	15.9^{gh}	14.0^{j}	17.3^{bc}
T_9	45.2^{ab}	43.3^{b-e}	37.6^{k-m}	42.0^{b}	22.0^{a}	16.1^{fg}	13.9^{j}	17.3^{bc}
T_{10}	47.4^{a}	44.0^{bc}	39.8^{f-k}	43.7^{a}	22.2^{a}	16.5^{f}	14.2^{j}	17.6^{a}
Mean	42.4^{a}	39.4^{b}	35.6^{c}		20.8^{a}	15.7^{b}	13.9^{c}	
		S.Em.±				S.Em.±		
Main plot (A)		0.17				0.17		
Sub plot (B)		0.46				0.11		
A×B		0.79				0.19		

*RDF- Fodder maize -100:60:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder sorghum - 80:40:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder bajra - 80:40:40 N:P_2O_5: K_2O kg ha^{-1}

RDF- Recommended dose of fertilizer DAS- Days after sowing

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Main plot (Fodder crops):	Sub plot (Zn and Fe levels)
M- Maize (var. African tall)	T_1 -*RDF
S- Sorghum (var. SSV 74)	T_2 - RDF + 10 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
B- Bajra (var. BAIF Bajra)	T_3 - RDF + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
	T_4 -RDF + 10 kg $ZnSO_4$ + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ +1% $FeSO_4$ as foliar spray at 45 DAS
	T_5 -RDF + 15 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
	T_6 -RDF + 15 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
	T_7 - RDF + 15 kg $ZnSO_4$ +15 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS
	T_8 - RDF + 20 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
	T_9 - RDF + 20 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
	T_{10} - RDF + 20 kg $ZnSO_4$+20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS

of fodder bajra might be due to unfavorable climatic condition of Dharwad as it needs warm and sunny weather and it cannot tolerate heavy rainfall. Further, higher dry fodder yield might be due to higher dry matter accumulation and higher green fodder yield. Therefore, from current study it is clear that climatic conditions prevailed during the crop period with 893.5 mm of rainfall distributed in 50 rainy days, mean monthly maximum temperature ranged from 26.4 to 31.5 ºC, the minimum temperature ranged from 20.2 to 21.5 ºC and the mean monthly relative humidity ranged from 76.0 to 87.6 per cent were more ideal for the fodder maize to express its maximum potential than fodder sorghum and bajra. Similarly, Nikhilkumar and Salakinkoppa (2018) recorded green fodder yield of 10.5 t ha^{-1} in maize. However, Anilkumar (2017) recorded 7.51 t ha^{-1} in sorghum which indicates maize is suitable fodder crop in *kharif* Northern Transition Zone of Karnataka compared to sorghum.

Effect of zinc and iron bio-fortification on growth and yield parameters

Proper selection of fodder crops alone is not sufficient to meet the increasing fodder requirement of livestock. There is a need to increase the yield of fodder crops per unit area and time. Growth and yield of fodder crops can be optimized through agronomic bio-fortification of zinc and iron. Bio-fortification of fodder crops with application of RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS increased the growth rate and recorded significantly higher plant height (282.2 cm), number of leaves (14.2), leaf area (576.2 cm^2), fresh biomass weight (196.8 g plant^{-1}) and dry matter production (79.2 g plant^{-1}). It was followed by application of RDF + 15 kg $ZnSO_4$+ 15 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS. Further, application of RDF alone without zinc and iron recorded lower growth rate as compared to other bio-fortification treatments.

Among growth parameters, higher plant height and number of leaves (Table 1) might be due to application of zinc and iron, as zinc and nitrogen has synergistic effect on growth and development of plants. Similar results were found by Begum *et al.* (2017). The increase in leaf area could be attributed to higher rate of cell division and cell enlargement there by significant increase in leaf expansion (length and breadth) and rapid growth due to application of zinc and iron along with RDF. Sulthana (2015) reported similar findings with application of zinc and iron. Higher fresh biomass production was due to contribution of zinc and iron in enhancing the plant height, leaf area and photosynthates accumulation, thereby improving the plant biomass and dry matter production (Table 2). Patel *et al.*

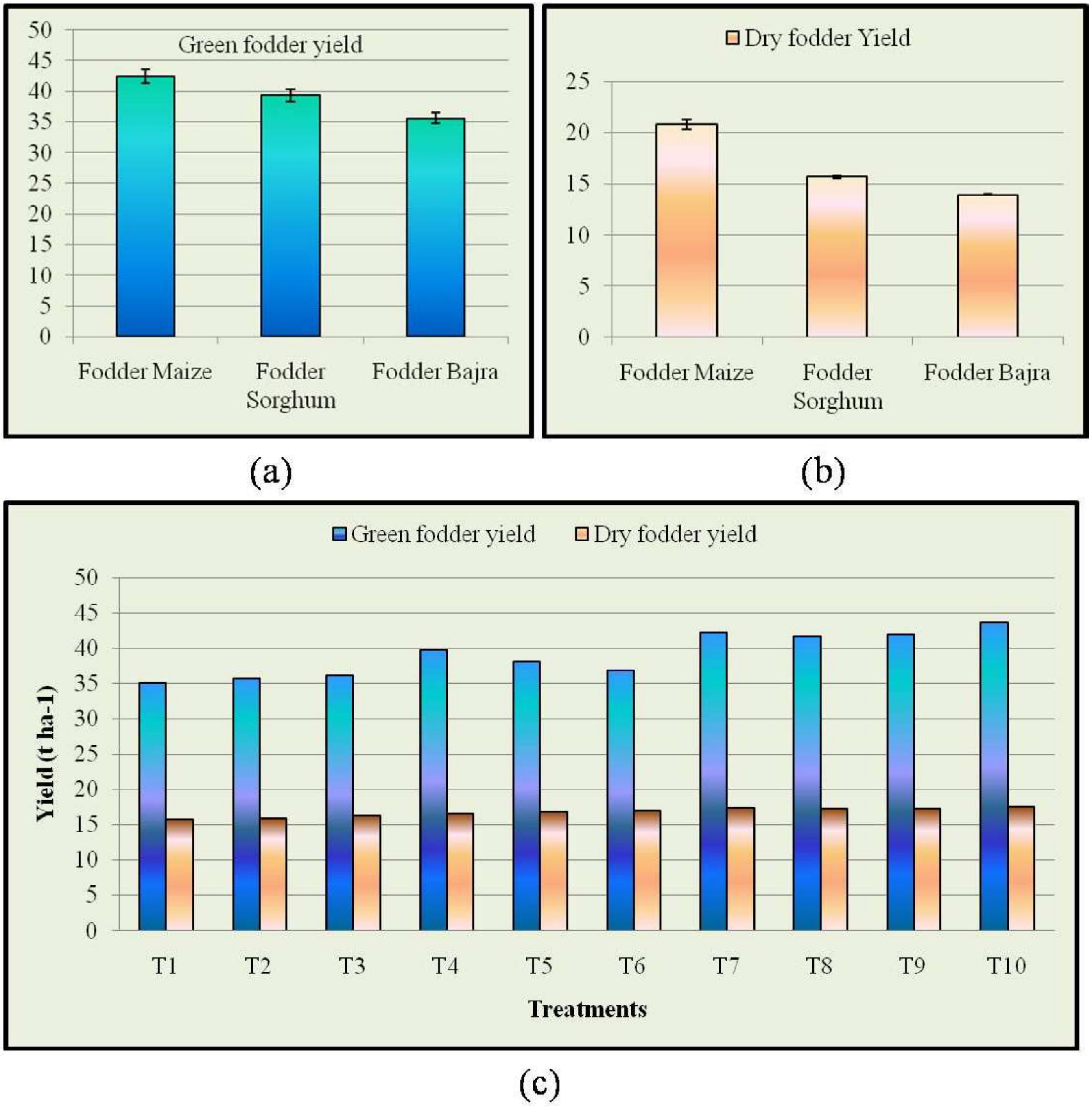

Fig. 1. (a) Green fodder yield (b) Dry fodder yield of annual cereal fodder crops (C) Influence of zinc and iron bio-fortification on green and dry fodder yield of fodder crops

(2007) also reported significant increase in dry matter yield of maize with soil application of zinc over its foliar application and no zinc application. The significant difference was noticed with respect to dry matter production and it's partitioning into different plant parts of crop growth due to nutrient management through bio-fortification. Zinc and iron act as catalysts in various growth processes and in hormone production as well as in protein synthesis, which have increased the dry matter accumulation.

Higher growth parameters recorded with application of RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS were led to production of significantly higher green and dry fodder yield (Table 3 and Fig. 1c). However, Increase in green fodder yield was to the extent of 24.86% over the application of RDF alone. Higher green fodder yield might be the reason for increase in dry fodder yield to the tune of 12.10% over RDF alone. The increase in green and fodder yield might be due to the role of zinc and iron in various growth processes like photosynthesis, nitrogen metabolism, protein synthesis and regulation of auxin concentration in the plants. Patel *et al.* (2007) reported increase in green fodder yield of maize by 24.45 per cent with zinc

Table 4. Economics of annual cereal fodder crops as influenced by zinc and iron bio-fortification

Treatments	Gross returns (₹ ha^{-1})				Net returns (₹ ha^{-1})				B:C ratio			
	Maize	Sorghum	Bajra	Mean	Maize	Sorghum	Bajra	Mean	Maize	Sorghum	Bajra	Mean
T_1	93611^{j-l}	88333^{l-n}	80861^{o}	87602^{f}	46937^{j-m}	44606^{l-n}	39772^{mn}	43772^{f}	2.01^{kl}	2.02^{kl}	1.96^{l}	2.00^{d}
T_2	95556^{i-k}	90833^{k-m}	81528^{o}	89306^{ef}	48282^{h-l}	46506^{i-l}	40139^{mn}	44976^{ef}	2.02^{j-l}	2.05^{i-l}	1.97^{l}	2.01^{cd}
T_3	96944^{h-k}	88750^{l-n}	85556^{m-o}	90417^{ef}	49950^{g-k}	44703^{k-n}	44447^{k-n}	46367de	2.06^{h-l}	2.01^{j-l}	2.08^{g-k}	2.05^{c}
T_4	109167^{b-d}	96250^{h-k}	92222^{kl}	99213^{c}	61573^{cd}	51603^{f-j}	50513^{f-k}	54563^{c}	2.29^{a-e}	2.16^{e-i}	2.21^{c-g}	2.22^{b}
T_5	101944^{f-i}	100833^{f-i}	82778no	95185^{d}	52870^{f-i}	54706^{e-h}	41089^{mn}	49555^{d}	2.08^{g-k}	2.19^{d-i}	1.99^{kl}	2.08^{c}
T_6	102222^{e-h}	92500^{kl}	81944^{o}	92222de	53568^{e-h}	46793^{i-l}	40675^{k-n}	47012de	2.10^{f-j}	2.02^{j-l}	1.99^{kl}	2.04^{cd}
T_7	117500^{a}	103333^{d-g}	96111^{h-k}	105648^{b}	67946^{ab}	56726^{d-f}	52442^{f-i}	59038^{ab}	2.37^{a}	2.22^{b-g}	2.20^{c-h}	2.26^{ab}
T_8	110833^{bc}	105833^{c-f}	95833^{h-k}	104167^{b}	61459^{cd}	59406^{c-e}	52344^{f-i}	57737^{bc}	2.24^{a-f}	2.28^{a-e}	2.20^{c-h}	2.24^{b}
T_9	113056^{ab}	108197^{b-e}	93889^{j-l}	105047^{b}	64242^{a-c}	62330^{b-d}	50960^{f-k}	59177^{ab}	2.32^{a-d}	2.36^{ab}	2.19^{d-i}	2.29^{ab}
T_{10}	118611^{a}	110004^{bc}	99444^{g-j}	109353^{a}	68597^{a}	62937^{a-d}	55315^{e-g}	62283^{a}	2.37^{a}	2.34^{a-c}	2.25^{a-e}	2.32^{a}
Mean	105944^{a}	98487^{b}	89017^{c}		57542^{a}	53032^{b}	46770^{c}		2.19^{a}	2.16^{a}	2.10^{b}	
	S.Em.±				S.Em.±				S.Em.±			
Main plot (A)	431.42				431.42				0.01			
Sub plot (B)	1121.04				1121.04				0.02			
A×B	1941.69				1941.69				0.04			

*RDF - Fodder maize - 100:60:40 N:P_2O_5: K_2O kg ha^{-1}, Fodder sorghum - 80:40:40 N:P_2O_5: K_2O kg ha^{-1},
Fodder bajra - 80:40:40 N:P_2O_5: K_2O kg ha^{-1}

RDF- Recommended dose of fertilizer DAS- Days after sowing

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Main plot (Fodder crops):
M- Maize (var. African tall)
S - Sorghum (var. SSV 74)
B- Bajra (var. BAIF Bajra)

Sub plot (Zn and Fe levels)
T_1 -* RDF
T_2 - RDF + 10 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
T_3 - RDF + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
T_4 -RDF + 10 kg $ZnSO_4$ + 10 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ +1% $FeSO_4$ as foliar spray at 45 DAS
T_5 -RDF + 15 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
T_6 -RDF + 15 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
T_7 - RDF + 15 kg $ZnSO_4$ +15 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS
T_8 - RDF + 20 kg $ZnSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ foliar spray at 45 DAS
T_9 - RDF + 20 kg $FeSO_4$ ha^{-1} as basal + 1% $FeSO_4$ foliar spray at 45 DAS
T_{10} - RDF + 20 kg $ZnSO_4$+20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$ + 1% $FeSO_4$ as foliar spray at 45 DAS

application at 25 kg $ZnSO_4$ ha^{-1} over no zinc application. Further, lower green and dry fodder yield with application of RDF alone might be due to insufficient nutrient availability for growth and yield of the crop.

Interaction effect of fodder crops and zinc and iron bio-fortification

Production of sufficient quantity of fodder to meet the increasing demand from the livestock industry was depends on selection of suitable crop and appropriate dose of nutrients. Along with that response of particular crop to applied dose of nutrients is also plays an important role in getting higher yield. Among the interactions, interaction of zinc and iron bio-fortification treatments at main plot level recorded significant differences in growth parameters and green fodder yield. Fodder maize, sorghum and bajra with application of RDF+ 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS recorded significantly higher plant height, number of leaves, leaf area, fresh biomass production and dry matter production (Table 1 and 2). Same treatment recorded significantly higher green fodder yield of 47.4, 44.0 and 39.8 t ha^{-1} in respective crops and MT_{10} was on par with interaction of maize with T_7 (47.0 t ha^{-1}). Lower green fodder yield was observed in maize (37.4 t ha^{-1}), sorghum (35.3 t ha^{-1}) and bajra (32.3 t ha^{-1}) with application of RDF. The increase in green fodder yield might be due to the role of zinc and iron in various growth processes like photosynthesis, nitrogen metabolism, protein synthesis and regulation of auxin concentration in the plants. Patel *et al.* (2007) reported increase in green fodder yield of maize by 24.45 per cent with zinc application at 25 kg $ZnSO_4$ ha^{-1} over no zinc application. These findings are in accordance with those obtained by Kaushik *et al.* (2010) in fodder sorghum with application of RDF + 15 kg $ZnSO_4$+ 0.2 per cent of $ZnSO_4$ foliar spray and Kumar *et al*. (2012) in fodder bajra with application of 20 kg $ZnSO_4$ ha^{-1} as basal.

Among overall interactions, fodder maize with application of RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS recorded significantly higher number of leaves (15.8), leaf area (768.8 cm^2), fresh biomass weight (213.5 g plant^{-1}) and dry matter production (99.7 g plant^{-1}). However, fodder sorghum with same treatment recoded higher plant height (289.5 cm) followed by fodder maize. Higher number of leaves and leaf area (Table 1) might be due to suitable climatic conditions and sufficient nutrient availability. Further, significantly higher fresh biomass weight might be due to role of zinc and iron in increased growth rate which led to accumulation of higher photosynthates and in turn increased the dry matter production (Table 2). Increase in fresh bio-masss and dry matter production might be the reason for getting the higher green and dry fodder yield (Table 3).

Higher green fodder yield (47.4 t ha^{-1}) was recorded in fodder maize with application of RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS and it was on par with the yield of MT_7 (47.0 t ha^{-1}). Lower yield of 32.3 t ha^{-1} was observed in fodder bajra with application of RDF alone without zinc and iron which was on par with BT_2 (32.6 t ha^{-1}). Increase in green fodder yield to the extent of 46.74 per cent over RDF. Therefore, favorable climatic condition and sufficient nutrient availability were responsible for getting higher green fodder yield. However, because of non ideal climatic condition and insufficient nutrient availability fodder bajra recorded lower plant height, number of leaves, leaf area, fresh biomass production and dry matter production with application of RDF alone which in turn responsible for the lower green fodder yield of the fodder bajra.

Effect of fodder crops and zinc and iron biofortification on economics

Among fodder maize, sorghum and bajra, higher cost of cultivation was recorded in fodder maize (₹ 48,402 ha^{-1}) due to higher fertilizer and seed requirement which in turn increased the cost compared to sorghum (₹ 45,455 ha^{-1}) and bajra (₹ 42,517 ha^{-1}). Significantly higher gross returns (₹ 1,05,944 ha^{-1}), net returns (₹ 57,542 ha^{-1}) and B:C (2.19) ratio were recorded in fodder maize followed by fodder sorghum. It might be due to higher green fodder yield of fodder maize as compared to fodder sorghum. Further, due to lower green fodder yield, fodder bajra recorded lower gross returns, net returns and B: C ratio (Table 4).

Application of RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$as foliar spray at 45 DAS was recorded higher gross returns, net returns and B: C ratio (Table 4) to the extent of 24.83, 42.29 and 16 per cent, respectively compared to application of RDF alone which might be due to higher green fodder yield. However, lower gross returns, net returns and B:C ratio were recorded with application of RDF due to lower monetary returns because of lower yield. These results are in agreement with the findings of Mohan and Singh (2014).

Significantly higher green fodder yield of fodder maize with application of RDF + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS resulted in realizing higher economics *viz.,* gross returns (₹ 1,18,611 ha^{-1}), net returns (₹ 68,597 ha^{-1}) and B:C ratio (2.37) might be due to higher monetary returns. However, due to lower green fodder yield of bajra with application of RDF without zinc and iron recorded lower gross returns, net returns and B:C ratio of ₹ 80,861, ₹ 39,772 ha^{-1} and 1.96, respectively.

Conclusion

From the study it was inferred that among the three annual cereal fodder crops, fodder maize was found to be an ideal crop for getting higher green and dry fodder yield (42.4 and 20.8 t ha^{-1}) followed by fodder sorghum. Bajra is a low fodder yielder under climatic condition of Northern Transition Zone of Karnataka. Hence, it was concluded that application of RDF (100:60:40 N:P_2O_5: K_2O kg ha^{-1}) + 20 kg $ZnSO_4$+ 20 kg $FeSO_4$ ha^{-1} as basal + 1% $ZnSO_4$+1% $FeSO_4$ as foliar spray at 45 DAS, found optimum for obtaining higher maize green and dry fodder yield and higher monetary returns.

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