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Effect of Zinc and Iron with Organic Sources on Growth, Yield, Quality and Economics of Pearl millet [Pennisetum glaucum (L) R. Br.]

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Research Article

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Posted Date: October 22nd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11452950/v1

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Additional Declarations: No competing interests reported.

Effect of Zinc and Iron with Organic Sources on Growth, Yield, Quality and Economics of Pearl millet [*Pennisetum glaucum* (L) R. Br.]

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Abstract

A field experiment was conducted during *kharif* season of 2024 at Agronomy Farm, College of Agriculture, Fatehpur-Shekhawati, Sikar, Rajasthan, India to study the effect of zinc and iron with organics on growth, yield, quality and economics of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. The soils of experimental plot was sandy to loam in texture, low in organic carbon (0.14%), available N (90.68 kg ha^{-1}), medium available P (8.60 kg ha^{-1}) and available K (125.24 kg ha^{-1}). The treatment consisted of 0.5% foliar spray of FeSO4 and ZnSO4 at 30 and 45 days after sowing with soil application of $FeSO_4$ and $ZnSO_4$ @ 15 kg ha^{-1} and 25 kg ha^{-1} respectively. Recommended dose of fertilizers *i.e.* N:P_2O_5:K_2O:40:20:00 kg ha^{-1} was applied through urea, DAP (as per package of practices of the crop). The experiment was laid out in randomized block

design with three replications and eleven treatments. The result showed that growth parameters *viz*., plant height (197.14 cm), dry matter accumulation (78.47 g plant^{-1}), and yield attributes *viz*., number of effective tillers plant^{-1} (4.0), length of ear head (29 cm), ear head diameter (3.28 cm), test weight (11.16 g), grain yield (2449.66 kg ha^{-1}) and stover yield (5691.88 kg ha^{-1}) were recorded maximum in treatment T_8 (75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS). Quality parameters higher chlorophyll content (52.53 SPAD value) recorded under the application of 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS (T_7) while, T_8 was found statistically at par with T_7 . However, the economic analysis revealed that treatment T_8 resulted in the highest net returns (₹65,973.20 ha^{-1}) and the maximum benefit-cost (B:C) ratio of 3.22**,** making it the most economically viable among all other treatments.

Article Highlights

- Application of 75% RDF + 25% nitrogen through vermicompost along with 0.5% foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS improved pearl millet growth and yield.
- Treatment T_8 recorded the maximum grain yield (2449.66 kg ha^{-1}) and stover yield (5691.88 kg ha^{-1}).
- Treatment T_8 achieved the highest net returns (₹65,973.20 ha^{-1}) and benefit–cost ratio (3.22), indicating superior economic profitability.

Keywords: Pearl millet, zinc, iron, vermicompost, foliar spray, grain yield, nutrient management, benefit–cost ratio.

1. Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a warm season, drought tolerant, coarse grain cereal crop. In arid and semi-arid regions of Asia and Africa. It is extensively grown on 30 million hectares and makes up nearly half of the world's millet production [1]. Commonly it is used for food, feed and forages purpose [2]. Pearl millet is a short day C_3 plant adapted to hot climate. It has better physiological traits than other cereals including resistance to drought law soil fertility and high salinity [3]. It is a *Kharif* season crop with 2n=14 chromosome number in gramineae/poaceae family and *Pennisetum genus*. Africa is the main centre of origin. It is suitable for gluten allergic people because it is gluten free and sustains its alkaline qualities after cooking. About 5% fat, 67% carbohydrates, 12.4% moisture, 11.6% protein, 2.7% mineral matters and 360 calories/100g are reported in pearl millet grain [4]. Pearl millet covers an area of 6.70 million ha with production of 9.46 million tonnes and productivity 1436 kg ha^{-1} in India [5]. Pearl millet grown in 4.54 million ha with 5.89 million tonnes production in Barmer (0.98 million ha), Jodhpur

(0.43 million ha), Jaipur (0.30 million ha), Nagaur (0.29 million ha), Alwar (0.28 million ha), Jalore, Churu, Sikar, Jhunjhunu and Bikaner etc districts of Rajasthan [6]. The intake of micronutrients in daily diet is less than 50% of recommended dietary allowances (RDA) in about 70% of Indian population, which indicates the severity of micronutrients deficiencies in India [7]. Humans include bullous pustular dermatitis, alopecia, diarrhea, emotional disorders, weight loss, intercurrent infections due to cell-mediated immune dysfunctions, hypogonadism in males, neurosensory disorders and problems with healing of ulcers due to deficiency of zinc. Severe deficiency of zinc, if untreated, may become harmful [8]. Following the green revolution in developing nations such as India, agricultural products with lower micronutrient contents unable to meet human nutrition requirements for zinc [9].

Agronomic bio-fortification depends mostly on the bio availability of micronutrients throughout the entire pathway from soil to plant, food and into the human body. Thus, agronomic bio-fortification is a great strategy to increase yields and enchance the nutritional quality by promoting zinc and iron quantity in diets. Pearl millet is good to diabetic patients because it has a low glycemic index which helps to digest slowly and release glucose at a slower rate than other foods [10]. The integrated use of micronutrients in combination with organic manures because of their high chelation and slow availability, which reduce micronutrient losses [11].

Zinc an important micronutrient that plays vital role in different enzymatic and physiological activities of the plant system. Zinc is an essential micro nutrient necessary for growth and development of the higher plants [12] and is involved in membrane integrity, enzyme activation and gene expression [13]. It is also valuable in the formation of chlorophyll and auxins. Zinc is the most common deficient micronutrient element in the soil around the world and about 50% soils of India are deficient in zinc [14].

Iron is a crucial plant nutrient for electron transport in photosynthesis. Iron fertilizers may overcome its deficiency and improve crop yields which will later increase crop productivity and income of the farmers [15]. It is necessary for several essential enzymes, including the cytochromes of the electron transport chain and is therefore needed for a variety of biological processes. Iron is compulsory for the upkeep of chloroplast structure and function in plants and is involved in the synthesis of chlorophyll [16]. Plant haemoglobin is identical to the human haemoglobin with Fe binding capacity and is most commonly found in nodulating legumes [17].

Organic matter plays a vital role in soil fertility maintenance. It is a key source of plant nutrients. In terms of intangible benefits vermicompost not only supplies essential elements to plant but also improves physiochemical and biological properties of soil replacement of nitrogen fertilizer in the

soil through application of vermicompost can caused reduction in the environmental pollution developed by washing nitrate from soil [18].

Farmyard manure adds humus and slowly-released nutrients to the soil, allowing nutrients and water to be retained more effectively. FYM improves the texture of sandy and light soils. It is commonly accepted that neither organic manure nor chemical fertilizers can attain yield sustainability under modern intensive farming [19]. Organic manures, like - FYM and vermicompost, not only improves soil health but also provide macro and micro nutrients [20]. Furthermore, the combined use of micronutrients and organics contributes to balanced nutrition, better root development, and improved grain quality in terms of iron and zinc concentration addressing both productivity and nutritional security [21].

2. Material and methods

2.1 Climate and weather

A field experiment was conducted at Research Farm, College of Agriculture, Fatehpur-Shekhawati, Sikar of Sri Karan Narendra Agriculture University, Jobner, Jaipur, Rajasthan, India during *kharif* season of 2024. Geographically, Fatehpur-Shekhawati, Sikar falls in semi-arid, sub-tropics and is situated at 27° 57′N latitude and 74°58′E longitude with an altitude of 324 meters above the mean sea level. This area falls in agro-climatic zone-IIa (Transitional Plains of Inland Drainage) of Rajasthan. Fatehpur-Shekhawati, Sikar has semi-arid climate characterized by hot and dry summer and severe cold during winter season. The mean maximum temperature is as high as 40 to 47 ^{0}C during summer and minimum temperature near – 5.2 to 0 ^{0}C accompanied by frost in peak winter months of December and January is common feature of the climate of this region (Agrometeological observatory, GKMS project, Agriculture Research Station, Fatehpur-Shekhawati, Sikar). The rainfall is unevenly distributed. The major part of the annual rainfall is received during monsoon season *i.e.,* last week of June to mid-September. Water is the most crucial and limited resource for this zone which is mainly available as ground water, of which major part is brackish. Dry spell occurs during crops season. The prevailing climatic conditions are very harsh, which limits the agricultural productivity of the zone. The mean weekly meteorological data during crop season from July to first week of October, 2024 pertaining to maximum and minimum temperature fluctuated between 30.3 and 40.3 °C and 16.5 and 28.4 °C during crop season respectively. The total rainfall was recorded to be 325.60 mm, the sunshine duration ranged from 0.7 to 9 hours while relative humidity maximum and minimum values varied between 80 and 94% and 41 and 85%. Twenty-four days were recorded as the maximum rainy days during crop season (*kharif*, 2024).

2.2 Experimental Design and soil

The field experiment was carried out according to randomized complete block design (RCBD) with eleven treatments and three replication. Treatments combination comprised of T_1: Control, T_2:100% RDF (N:P_2O_5:K_2O:40:20:00 kg ha^{-1}),T_3: 100% RDF + soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1},T_4: 100% RDF + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS,T_5: 100% RDF + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS, T_6: 75% RDF + 25% nitrogen through vermicompost + soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}, T_7: 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS, T_8: 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS, T_9: 75% RDF + 25% nitrogen through FYM + soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}, T_{10}: 75% RDF + 25% nitrogen through FYM + foliar spray of $FeSO_4$ + $ZnSO_4$ @ 0.5% at 30 DAS, T_{11}: 75% RDF + 25% nitrogen through FYM + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS. The soil texture of the experimental field was a sandy to loam with a pH of 8.3 and a specific electrical conductivity of 0.31dS/m in an aqueous soil suspension of 1:2.5. At the beginning of the experiment, the soil contained 0.14% organic carbon, 90 kg ha^{-1} of available nitrogen, 8.6 kg ha^{-1} available P_2O_5 and 125.2 kg ha^{-1} available K_2O.

2.3. Intercultural Operation

The experimental plot was opened with the help of tractor operated power tiller and was exposed to the sunlight for a week, after which the land was harrowed, plowed and cross-plowed several times followed by leveling to obtain a good tilth. The sowing was done at a depth of 3–4 cm. Seed treatment was also done before sowing by using imidachlorpid 600 Fs @ 8.75 g/kg seed. The pearl millet variety HHB-299 was sown at a spacing of 45 cm x 15 cm with a seed rate of 4 kg ha^{-1}. The recommended dose of fertilizers *i.e.* N:P_2O_5:K_2O:40:20:00 kg per hectare was applied through urea, DAP (as per package of practices of the crop). The field observations were recorded during crop growing season. There was no disease infestation on the crop.

2.4. Measurement and Calculation

2.4.1 Growth parameters

Plant height of five randomly selected and marked plants from each plot was measured from base of the plants up to growing tip of leaves at 20, 40, 60 DAS and at harvest and the average was calculated. Plant samples for dry matter study were collected at 20, 40, 60 DAS and at harvest. At each sampling, three plants were uprooted at random in each treatment in the sampling row. These

samples were shade dried followed by oven dried at 65°C till a constant weight was recorded. Later dry matter production was computed on hectare basis and expressed in kg ha^{-1}.

2.4.2 Yield parameters

2.4.2.1 Ear head length (cm)

Panicle length calculated from the base to the tip of the main tiller of the plant at maturity. Five randomly selected and marked plants of each plot.

2.4.2.2 Ear head diameter

The panicle from the main tiller of five randomly selected plants was recorded in centimetres, excluding bristles was measured using ″vernier caliper.”

2.4.2.3 Number of effective tillers per plant at harvest

Effective tillers per plant of five randomly selected plants from each plot was recorded at maturity.

2.4.2.4 Test weight

The sample of 1000-grain was taken from each plot and their weight was recorded using an electronic balance.

2.4.2.5 Straw yield

After harvesting and nipping the straw from each plot was left to sundry individually for a week and the weight of the sun-dried straw was recorded and converted to hectares.

2.4.2.6 Grain yield

The ear heads of each plot were harvested separately and threshed. The seeds obtained was weighed in kilogram and recorded as grain yield in kg ha^{-1}.

2.4.2.7 Harvest index

The ratio of economic (grain yield) to biological yield has been calculated and expressed as a percentage (Donald and Hamblin 1976).

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

2.4.3 Quality Parameters

2.4.3.1 Chlorophyll content

The chlorophyll content of the plants was measured using a chlorophyll meter, expressed in SPAD units, 45 days after sowing. The chlorophyll intensity meter (SPAD-520, Minolta, Japan) is a lightweight, portable diagnostic instrument that allows for quick and non-destructive measurement of total chlorophyll concentration in leaves. The measurement procedure takes only a few seconds. Using the SPAD-520, the chlorophyll intensity of the upper second successive leaf of each tagged plant was recorded.

2.4.4 Economic analysis

Economic analysis was conducted to assess the net monetary benefits of different treatments. The gross monetary returns in rupees per hectare were calculated based on green biomass yield.

2.4.4.1 Net return (₹ ha^{-1})

Net returns were calculated by deducting the cost of cultivation from the gross returns.

Net returns (₹ ha^{-1}) = Gross returns (₹ ha^{-1}) - Total cost of cultivation (₹ ha^{-1})

2.4.4.2 B: C ratio

B:C ratio calculates by following formula

$$\text{B: C ratio} = \frac{\text{Net returns } (₹\ ha^{-1})}{\text{Total cost of cultivation } (₹\ ha^{-1})}$$

2.5 Data Analysis

In order to draw reliable conclusions, the experimental data on soil and plant were statistically analyzed by using the method as described by Gomez and Gomez, (1984). The test of significance was carried out at 5% level of significance by referring to "F" table values. The data presented in the respective tables are the mean values of three replications at different crop growth stages.

3. Results and discussion

3.1 Growth attributes

Data pertaining to growth parameters were recorded and depicted in Fig. 1,2 and 3. The zinc and iron with organics significantly enhance plant height and dry matter accumulation of pearl millet as compared to control plot at different growth stages. The maximum plant height (47.9 cm) and dry matter accumulation (3.93 g $plant^{-1}$) at 20 DAS was recorded with the treatment T_3 which received 100% RDF + soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}. However, at 40 DAS significantly highest plant height (123.94 cm) and dry matter accumulation (19.51 g $plant^{-1}$) was observed with the treatment T_7. Further, on the later growth stages the significantly higher plant height and dry matter accumulation was observed with the treatment T_8 *i.e.* 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS *viz.*, 60 DAS (177.34 cm and 58.34 g $plant^{-1}$) and at harvest (197.14 cm and 78.47g $plant^{-1}$) which was statistically at par with T_5 and the minimum was recorded in control. The increased in the availability of iron to plant might have stimulated the metabolic and enzymatic activities thereby increasing the growth attributes of the crop [22]. The combination of organics, Zn and Fe with inorganic fertilizers might have released the sufficient amounts of nutrients by mineralization

which resulted in adequate amount of available nutrients and better environment for increased uptake of nutrients and consequently better crop growth [23]. The combined application of organics and foliar spray of micronutrients in alkaline soil condition is probably due to enhanced availability of major as well as micronutrients which enhanced more leaf area resulting in higher photosynthesis assimilates and thereby resulted in more dry matter accumulation [24-25].

3.2 Quality Parameters

With regard to quality parameters, the significantly higher chlorophyll content at 45 DAS (52.53), were recorded under treatment T_7 (75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS) superseded over rest of the treatments except T_8. Total chlorophyll content of pearl millet as influenced by the foliar application of iron and zinc [26]. Iron and zinc play critical role in metabolic process such as DNA synthesis, respiration, photosynthesis and iron also involve in synthesis of chlorophyll which is essential for maintenance of chloroplast structure and function [27-30].

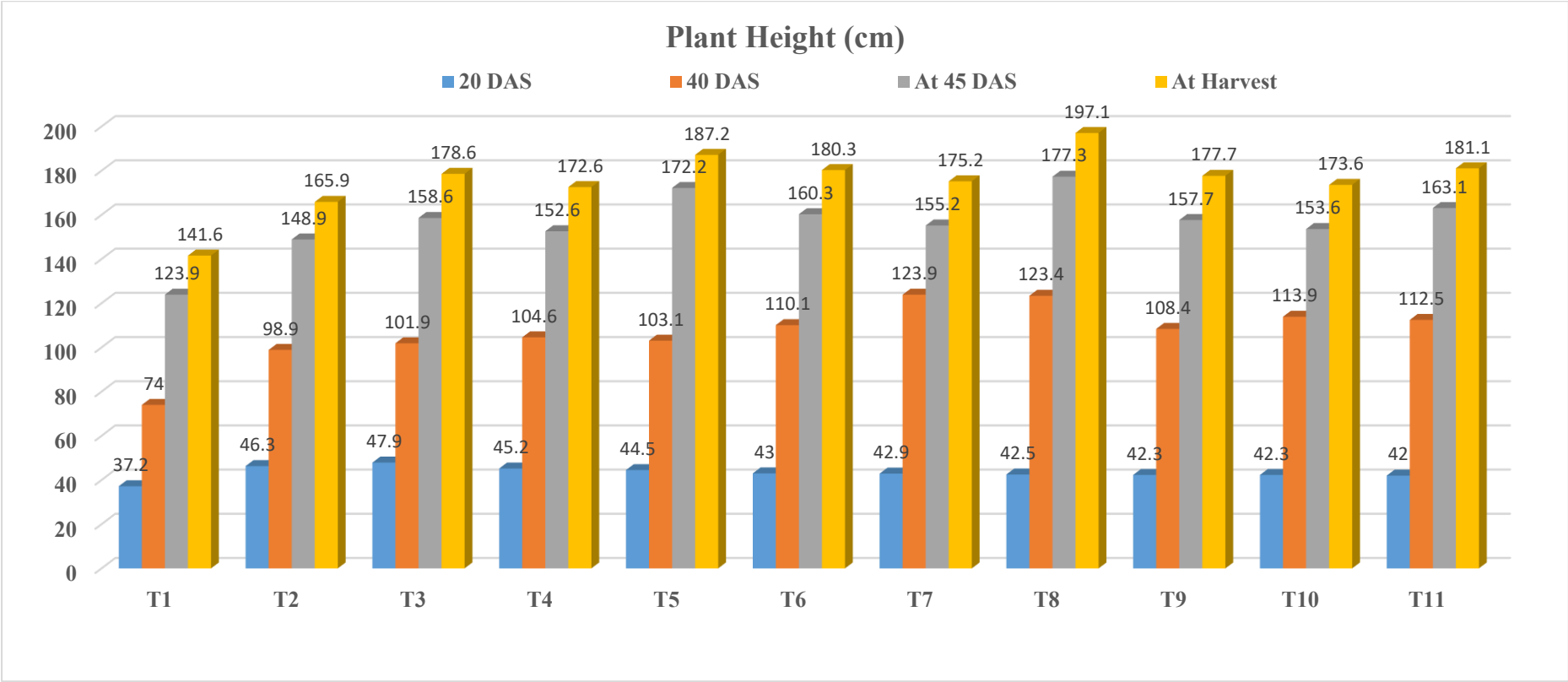

Fig.1 Effect of zinc and iron with organics on plant height (cm) at different growth stages of pearl millet

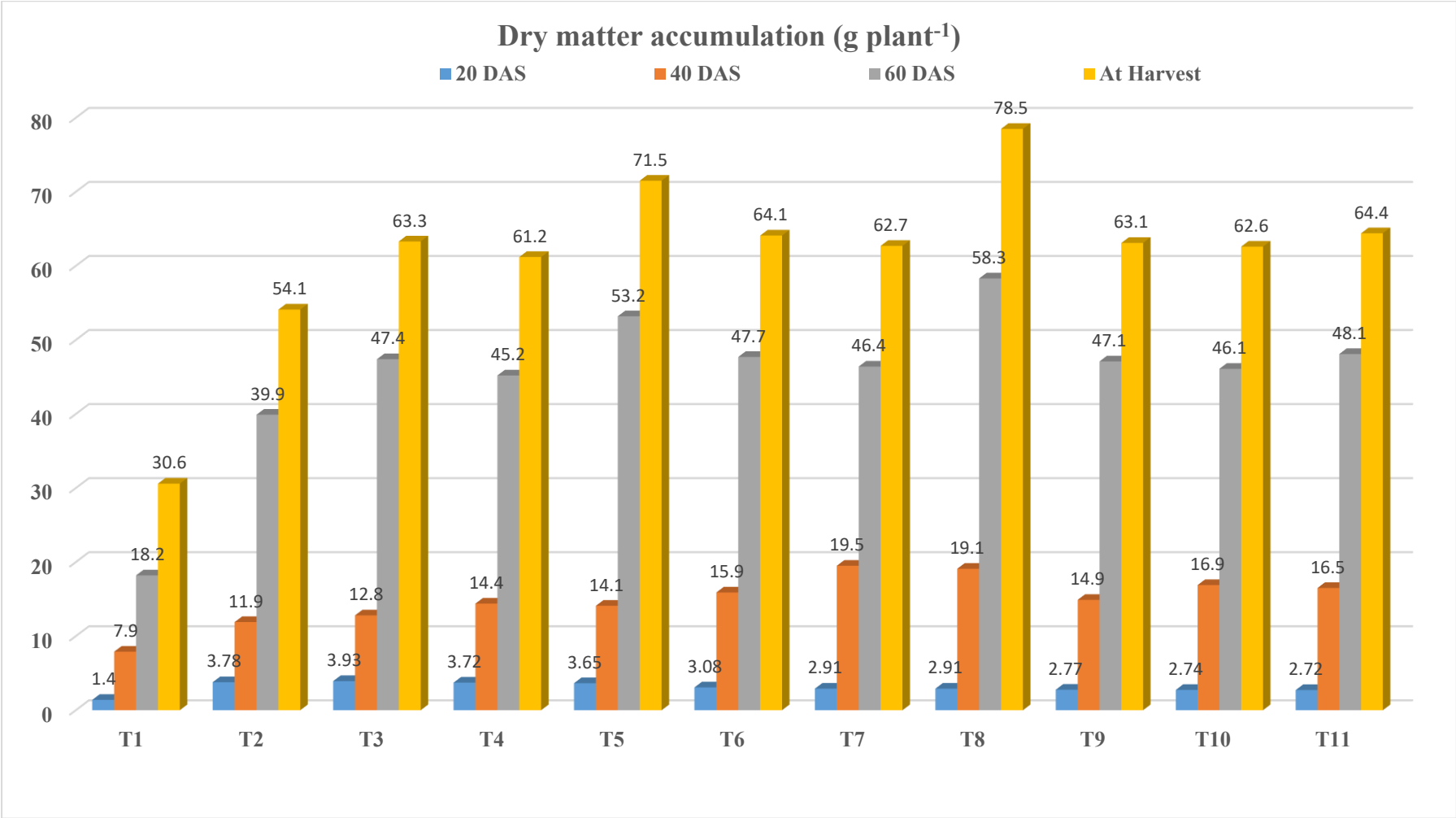

Fig.2 Effect of zinc and iron with organics on dry matter accumulation (g plant^{-1}) at different growth stages of pearl millet

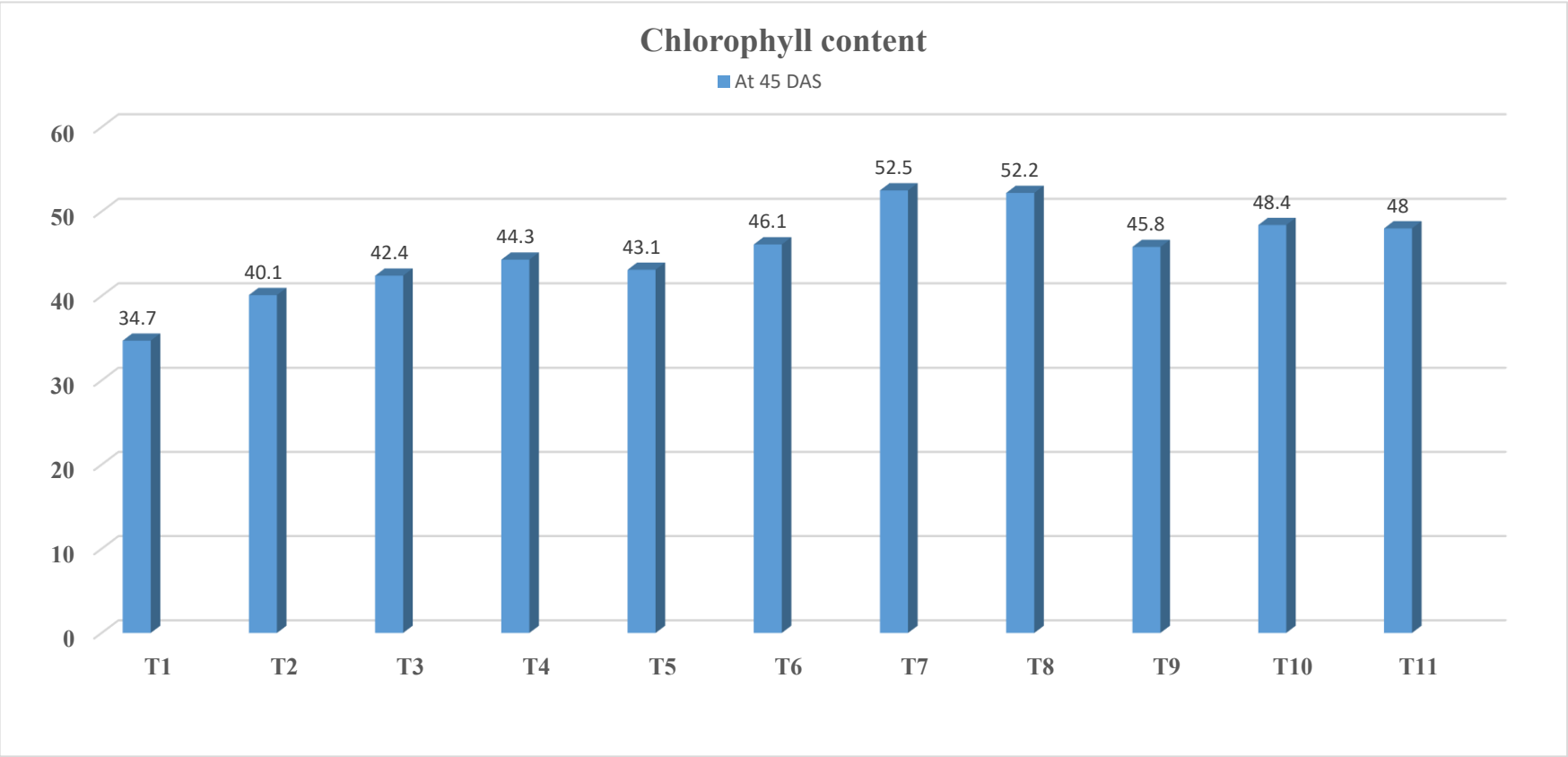

Fig.3 Effect of zinc and iron with organics on Chlorophyll content at different growth stages of pearl millet

3.3 Yield attributes and yield

Data related to yield attributes was recorded at harvest and presented in Table 1. The significantly highest ear head length (29.00 cm), ear head diameter (3.28 cm), number of effective tillers at harvest (4.00) and test weight (11.16 g) of pearl millet recorded with T_8 in which 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS was given and closely followed by plot T_5 in which 100% RDF + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS. The treatment T_8 was significantly higher over treatment rest of all treatments. Significantly maximum grain yield (2449.66 kg ha^{-1}) was recorded in T_8. Similarly maximum stover yield (5691.88 kg ha^{-1}) was recorded in T_8 also which was significantly superior over rest of the treatment. The harvest index of pearl millet it was observed that the harvest index of was not significantly influenced by treatments. This increase in yield might be due to effective utilization of applied nutrients. The positive and significant improvement increase in yield attributes due to foliar application of $FeSO_4$ and $ZnSO_4$ would have resulted in enhanced grain and stover yield. Zinc and iron plays a major role in biosynthesis of IAA and especially due to its role in initiation of primordial reproductive part and portioning of photosynthetic towards them which promotes the yield. Similar result was also observed by [31-32]. Increase in yield and yield attributes in pearl millet was also due to iron role in starch formation and protein synthesis as well as maintenance and synthesis of chlorophyll in plants. Similar findings were also reported by [33]. Increase in pearl millet straw yield with the use of vermicompost with foliar spray of zinc sulphate and iron sulphate. Similarly, many other researchers also claimed increased straw yield of pearl millet with the use of different organic materials alone and in combination with mineral fertilizer and foliar spray of micronutrients [34-37]. Vermicompost plays an important role in improving yield, it increases microbial activity and when applied, the soil will be enriched with a variety of nutrients that will be available for the indigenous micro flora. It also increases the availability of nitrogen and phosphorus and improve the microbial activity in the soil [38].

Table: 1 Effect of zinc and iron with organics on yield attributes, grain yield, straw yield and harvest index of pearl millet.

	Treatments	Ear head length (cm)	Ear head diameter (cm)	Effective tiller plant^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1	Control	20.0	2.01	1.97	8.50	1328	3348	28.4
T_2	100% RDF	22.3	2.40	2.57	9.16	1825	4323	29.7
T_3	100% RDF + Soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}	24.9	2.75	3.10	9.71	2066	4809	30.1
T_4	100% RDF + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS	24.2	2.67	2.97	9.40	1999	4742	29.7
T_5	100% RDF + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS	27.1	3.03	3.57	10.40	2272	5281	30.1
T_6	75% RDF + 25% nitrogen through vermicompost + Soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}	25.1	2.76	3.12	9.73	2084	4848	30.1
T_7	75% RDF + 25% nitrogen through vermicompost + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS	24.5	2.70	3.03	9.60	2021	4765	29.8
T_8	75% RDF + 25% nitrogen through vermicompost + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS	29.0	3.28	4.00	11.20	2449	5691	30.1
T_9	75% RDF + 25% nitrogen through FYM + Soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}	24.7	2.73	3.08	9.67	2053	4779	30.1
T_{10}	75% RDF + 25% nitrogen through FYM + Foliar spray of $FeSO_4$ + $ZnSO_4$ @ 0.5% at 30 DAS	24.4	2.69	3.00	9.57	2014	4758	29.8
T_{11}	75% RDF + 25% nitrogen through FYM + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS	25.1	2.79	3.12	9.82	2095	4871	30.1
	SEm±	**0.64**	**0.07**	**0.13**	**0.22**	**57.1**	**135.8**	**1.0**
	CD (P=0.05)	**1.88**	**0.21**	**0.37**	**0.65**	**168.5**	**400.7**	**NS**
	CV (%)	**4.49**	**4.64**	**7.25**	**4.00**	**5.0**	**5.0**	**5.8**

3.4 Economics

Highest gross return (₹95608.99 ha^{-1}), net return ((₹65937.2 ha^{-1}) and benefit-Cost ratio (3.22) were obtained with the application of 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS (T_8) and closely followed by application of 100% RDF + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS (T_5).

Net return and benefit: cost ratio was observed under the 75% RDF + 25% nitrogen through vermicompost + foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS. The higher B:C ratio may be attributed due to higher grains yield in combination with lower fertilizer treatment cost. Greater B:C ratio due to foliar application of Fe and Zn indicated better response of pearl millet [39], that application of micronutrients gave the highest net monetary returns. These findings are also in line [40].

Table: 2 Effect of zinc and iron with organics on economics of Pearl millet.

	Treatments	Total cost (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net return (₹ ha^{-1})	Gross benefit: cost ratio
T_1	Control	25078.00	53292.53	28214.5	2.13
T_2	100% RDF	26927.81	71693.58	44765.8	2.66
T_3	100% RDF + Soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}	28755.81	80708.69	51952.9	2.81
T_4	100% RDF + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS	27407.61	78577.63	51170.0	2.87
T_5	100% RDF + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS	28146.41	88692.11	60545.7	3.15
T_6	75% RDF + 25% nitrogen through vermicompost + Soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}	27260.05	81379.75	54119.7	2.99
T_7	75% RDF + 25% nitrogen through vermicompost + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS	28932.96	79274.21	50341.3	2.74
T_8	75% RDF + 25% nitrogen through vermicompost + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS	29671.76	95608.99	65937.2	3.22
T_9	75% RDF + 25% nitrogen through FYM + Soil application of $FeSO_4$ @ 15 kg ha^{-1} and $ZnSO_4$ @ 25 kg ha^{-1}	31158.11	80203.93	49045.8	2.57
T_{10}	75% RDF + 25% nitrogen through FYM + Foliar spray of $FeSO_4$ + $ZnSO_4$ @ 0.5% at 30 DAS	29809.91	79061.40	49251.5	2.65
T_{11}	75% RDF + 25% nitrogen through FYM + Foliar spray of $FeSO_4$ and $ZnSO_4$ @ 0.5% at 30 DAS and 45 DAS	30548.71	81798.77	51250.1	2.68

5. Conclusion

On the basis of research result, substituting 25% of nitrogen with vermicompost, combined with 75% recommended dose of fertilizers (RDF) and foliar application of $FeSO_4$ and $ZnSO_4$ at 0.5% concentration at 30 and 45 days after sowing (DAS), significantly enhanced the growth, yield and quality of the pearl millet crop. Organically amended plots consistently showed improved performance across plant and soil parameters. Foliar application of $FeSO_4$ and $ZnSO_4$ (0.5% at 30 and 45 DAS) promoted better absorption of Zn and Fe by plants compared to their basal application, particularly under saline soil conditions. Judicious integration of organic amendments with chemical fertilizers is essential to halt soil degradation and ensure sustainable crop production. Based on the findings, the application of 25% nitrogen through vermicompost, 75% RDF and foliar sprays of $FeSO_4$ and $ZnSO_4$ at 0.5% concentration (at 30 and 45 DAS) is could be recommended for sustainable pearl millet cultivation. However, this study is from one year experiment and for better result and validation further study need to done.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable**.**

Consent for publish Not applicable

Data Availability Statement All relevant data supporting the findings of this study are included within the article. Additional data can be made available from the corresponding author upon reasonable request. No publicly available repository was used for this study.

Competing interests

The authors declare no conflicts of interest.

Funding The authors declare that no grants, funds, or other support were received during the preparation of this manuscript.

Author contributions

All authors contributed to the conception and design of the study. Experimental setup and field experimentation were carried out by Jyoti Chaudhary, Hanuman Singh Jatav. Data collection and laboratory analysis were performed by Jyoti Chaudhary, Lokesh Kumar Jat, Hanuman Singh Jatav. Statistical analysis and interpretation of the results were carried out by Mujahid Khan. The first draft of the manuscript was written by Jyoti Chaudhary, and the manuscript was reviewed and revised by Jyoti Chaudhary, Lokesh Kumar Jat, Kailash Chand Verma, Champa Lal Khatik, and Jitendra Yadav. All authors read and approved the final manuscript.

Acknowledgment

I express gratitude to my advisor Dr. Hanuman Singh Jatav and all the faculty members of Department of Soil Science for constant support and guidance to carry out the whole experimental research study.

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