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Effect of Zinc Fertilizer Rates on Growth and Panicle Yield of Grain Sorghum Cultivars

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ZINC is the most important micronutrient that limits crop production. Sorghum is highly susceptible to zinc deficiency. A green-house experiment was carried out at North-West University Research Farm to assess the effect of zinc fertilizer rates on the performance of different grain sorghum cultivars. The experiment was set as a 4 x 3 factorial fitted in a randomized complete block design. The treatment factors comprised three zinc rates (0, 5.6 and 10.6kg Zn/ha) and four grain sorghum cultivars (Avenger, Enforcer, NS5511 and PAN 8816). The measured parameters were plant height, number of leaves, chlorophyll content index, stem dry matter, leaf area, total dry matter, and panicle mass. The sorghum fertilized with 5.6kg Zn kg/ha had the highest chlorophyll content (69.90) at 77 days after planting. The highest chlorophyll content (70.90) was recorded with the Enforcer cultivar. The longest flowering days (83.93 days) was recorded with the application of 10.6 Zn kg/ha. The application of 10.6 Zn kg/ha produced the highest total dry weight of 370.20g and 93.00g, respectively. The PAN 8816 had the highest panicle mass (105.80g). The relationship between zinc rates, total dry matter, and panicle mass was positive and significant (R^2 = 1). Therefore, the application of 5.6 Zn kg/ha enhanced the growth of grain sorghum and 10.6 kg Zn/ha improved dry matter accumulation and panicle production. The Enforcer outperformed other cultivars for growth purposes, and PAN 8816 performed the best for panicle production.

Keywords: Grain sorghum, Panicle mass, Plant height, Total dry matter accumulation, Zinc deficiency.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] has long been recognized as one of the most important food crops grown in semi-arid locations with limited rainfall and soil conditions (Desta et al., 2022). Sorghum is the most important subsistence food crop in South Africa and the most vital crop for profitable food and beverage companies (Taylor, 2003; National Agricultural Marketing Council [NAMC], 2007). In terms of total production, sorghum grain is the fifth most important basic cereal after wheat, rice, maize, and barley (Heuze et al., 2015; Desta et al., 2022).

Sorghum is one of the world's most critical carbohydrate-rich grain crops, with the grain utilized for food, beverages and biofuels, and the stubble used as animal feed, fuel materials and barn construction in some regions (Werle et al., 2016; Hossain et al., 2022). More than 90% of sorghum grain seeds are used for food, with sorghum being the staple food in some parts of Africa and Asia; however, in the United States, sorghum is widely used for ethanol production, being the second most used grain for ethanol production and for animal feed (Mickelbart et al., 2015; Hossain et al., 2022). It is also regarded as a primary source of energy, protein, vitamins, and minerals for millions of people in semi-

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arid environments (Jacob et al., 2013; Nimir et al., 2021). Tag El-Din (2021) demonstrated that sorghum produces far more fodder than maize. Palé et al. (2009) and Desta et al. (2022) observed that grain sorghum is typically grown in difficult areas with high temperatures, insufficient rainfall, unstable soils with poor nutrient levels, and a limited growing season range.

It has been reported that above 50% of field crops are zinc deficiency. However, zinc deficiency varies from one field crop to another (Alloway, 2008; Montalvo et al., 2016). Researchers revealed that above 30% of the agricultural soil in the world is prone to zinc deficiency (Alloway, 2008; Xue et al., 2021). Tag El-Din (2021) showed that zinc deficiency is very common in many soil types, particularly in tropical regions with highly weathered soils. Zinc deficiency impairs plants' physiological functions, leading to a severe reduction in growth. Also, it leads to compromising productivity and low-quality agricultural products (Sadeghzadeh, 2013; Tag El-Din, 2021). Many studies showed that sorghum is highly susceptible to zinc deficiency which affects its growth and development by affecting the auxin production and rate of photosynthesis (Alloway, 2008; Ahmad et al., 2018). In the parts of world with low zinc concentration in the soil, fertilizing with this micronutrient is an important agricultural practice to ensure maximum yields of sorghum crops.

Nevertheless, the small amounts required for this crop make even field spraying a challenging toil (Tag El-Din, 2021). However, Tag El-Din (2021) found that with increasing amounts of zinc fertilizer, the effect of zinc fertilizer decreased. The micronutrient zinc is an important agricultural strategy to ensure optimal production of sorghum crops in areas with low zinc concentrations in the soil. Different cultivars of the same crop respond to zinc fertilizer differently, and applying the zinc fertilizer to the soil is an effective strategy to increase crop yield (Alloway, 2008). Globally, zinc is the most important micronutrient limiting plant production, along with macronutrient such as nitrogen phosphorus, potassium and sulphur (Tag El-Din, 2021). Therefore, there is need to find the importance of zinc as a micronutrient for improving grain sorghum productivity and to highpoint its potential as a tool to alleviate zinc deficiency in grain sorghum production. However, the researcher observed little information on the influence of different zinc fertilizer rates on the performance of grain sorghum cultivars. It is hypothesized that the zinc fertilizer rates will significantly influence the performance of grain sorghum cultivars. Hence, the objective of this study was to investigate the response of grain sorghum cultivars to different zinc fertilizer rates.

Materials and methods

Description of the study area

The experiment was conducted at the North-West University Research Farm (Molelwane farm) in the green-house with geographical coordinates 25°48'04.3"S 25°38'20.8"E (Fig. 1). The area belongs to arid climate regions with a mean maximum temperature of 37°C, while the mean minimum temperature ranges from 7°C to 11^{o}C. The site area received a mean annual rainfall of 571mm during summer. Soil samples were collected from 0-15 cm depth from North-West University Campus and analyzed for physical and chemical properties. The soil was sandy clay loam with a pH of 6.79, total nitrogen of 0.38%, available phosphorus of 2mg/kg, potassium of 270mg/kg and zinc of 57. 2mg/kg. The soil is classified as Chromic Luvisol according to FAO/UNESCO, 1970.

Fig. 1. Green-house structure

Experimental design

The experiment was set as a 4 x 3 factorial fitted in a randomized complete block design with four replications. The study comprised twelve treatments with 48 experimental pots in total.

The first treatment factor was four sorghum grain cultivars (Avenger, Enforcer, NS5511 and PAN 8816), while the second treatment factor consisted of three zinc sulphate ($ZnSO_4$) fertilizer rates of 0, 5.6 and 10.6kg Zn/ha. Each experimental pot was filled with 14kg of soil, and four seeds were planted per pot. Each pot was fertilized with urea and phosphorus fertilized based on recommended rate (120kg N/ha and 60kg P/ha). Each pot was irrigated with 3 litres of water weekly based on field capacity, as described by Kebede et al. (2014) and Adebayo & Sebetha (2022). The fertilizers were applied after planting according to the soil analysis results. The zinc sulphate fertilizer application rates were 0kgZn/ha, 5.6kgZn/ha, 10.6kgZn/ha and rates per pot are 0g/pot, 0.112g/pot and 0.212g/pot. The urea and single super phosphate fertilizers were applied at 120kg/ha (1.59g/pot) and 60kgP/ha (1.96g/pot).

Data Collection

The growth parameters were collected at 49, 63 and 77 days after sowing. The growth parameters collected were plant height measured with the aid of a measuring tape and the number of leaves by physical counting. The chlorophyll content was measured with the aid of the Leaf porometer model SC-1 Decagon device, and stem diameter was measured with a vernier caliper and leaf area as described by Chinnamuthu et al. (1989). The shoot dry weight, root dry weight and panicle mass were measured with the aid of a measuring scale.

The collected was subjected to GenStat for analysis of variance (ANOVA). Means were separated at 5% significance using the LSD method.

Result

Effect of zinc fertilizer rates on plant height and Number of Leaves

The result showed that zinc fertilizer rates had no significant effect (P≥ 0.05) on the plant height and number of leaves of sorghum during 49, 63 and 77 DAS (Table 1). The sorghum supplied with 0 Zn kg /ha produced the tallest plant height of 86.0 and 108. 7 and 113. 60 cm at 49, 63 and 77 WAS, respectively. Cultivar had a significant effect (P<0.05) on sorghum plant height during 49, 63 and 77 DAP. At 49, 63 and 77 DAS, sorghum cultivars Avenger, Enforcer and NS5511 had significant and tallest plant heights of 89.7, 93.5 and 125.90cm than cultivar PAN 8816 (Table 1). The unfertilized sorghum produced the highest number of leaves (8.62, 10 and 10.44) at 4 63 and 77 DAS. The interaction between the zinc fertilizer rates and cultivar was significant.

TABLE 1. Effect height and number of leaves of zinc fertilizer rates on plant

Treatment factors	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves	Plant height (cm)	Number of leaves
	49		63		77	
	Days after sowing					
Zn rates kg Zn/ha						
0	86.00a	8.63a	108.70a	10.00a	113.60a	10.44a
5.6	81.70a	8.61a	106.00a	9.75a	112.80a	10.25a
10.6	72.20a	7.38a	98.00a	9.12a	105.70a	9.25a
LSD (P≤0.05)	16.73	1.93	21.57	2.04	22.57	2.45
Cultivars						
Avenger	89.70a	8.58a	117.30a	10.17a	123.20a	11.83a
Enforcer	93.50a	9.92a	112.00a	10.75a	116.10a	10.00a
NS 5511	86.60a	8.67a	114.80a	10.92a	125.90a	10.92a
PAN 8816	50.30b	5.67b	72.80b	6.67b	77.50b	7.17b
LSD (P≤0.05)	19.31	2.224	24.9	2.35	26.00	2.15
Grand Mean	80.00	8.21	104.20	9.62	110.70	9.98
Zn x Cultivar	**	**	**	**	**	**

** Significant at (P≤0.01), * significant at (P≤0.05)

Influence of zinc fertilizer rates on chlorophyll content and leaf area

The chlorophyll content was not significantly (P≥ 0.05) affected by zinc fertilizer rates. The sorghum fertilized with 5.6kg Zn/ha had the highest chlorophyll content (58.00, 65.90 and 71.50 SPAD- units) at 49, 63 and 77 as Table 2. The sorghum cultivar avenger showed the highest and most significant chlorophyll content (63.20 and 81.70) at 49 and 77 WAS. However, at 63 DAS Enforcer sorghum cultivars had the highest chlorophyll content (70.90). The application of zinc fertilizer showed no significant effect on leaf area. The sorghum supplied with 0 kg Zn/ha rate had the highest leaf area (424 and 631cm^2) at 49 and 63 DAS. At 77 DAS, sorghum fertilized with 5.6kg Zn/ha produced the highest leaf area (605.00cm^2). The sorghum cultivars had a significant effect on leaf area. The Enforcer cultivar produced the highest leaf area (500.00cm^2) at 49 DAS. Nevertheless, the avenger cultivar showed the highest leaf area (696.00 and 716.00cm^2) at 69 and 77 DAS. The interaction of zinc fertilizer rates and sorghum cultivar significantly affected chlorophyll content and leaf area.

Response of stem diameter to different zinc fertilizer rates

The stem diameter was not significantly (P≥ 0.05) influenced by zinc fertilizer rates. The untreated sorghum showed the highest thickest diameter (18.29, 30 .60 and 33.30mm) at 43, 69 and 77 DAS. Sorghum cultivar had a significant effect on stem diameter. The enforcer cultivar had the thickest stem diameter (21.48, 33.30 and 37.00) at 49, 63 and 77 DAS. The interaction between zinc fertilizer rates and cultivar significantly affected the stem diameter (Table 3).

Effect of zinc fertilizer rates on flowering days

The flowering days was not significantly(P≥ 0.05) affected by different zinc fertilizer rates (Table 4). The application of 10.6kg Zn/ha had the longest flowering days of days compared to the other zinc fertilizer rates. The sorghum cultivars had a significant effect on flowering days. The Enforcer had the shortest flowering days (73.80 days) compared to other cultivars.

Influence of zinc fertilizer rates on dry matter accumulation and panicle mass

The dry matter accumulation and panicle mass were significantly (P≤ 0.05) affected by zinc fertilizer rates (Table 5). The sorghum treated with 10.6kg Zn/ha produced the highest dry shoot weight, root and total dry matter (185.30, 184.50 and 370.20g) compared to other zinc rates. Similarly, applying 10.6 kg Zn/ha recorded the highest panicle weight and the sorghum cultivar (NS 5511) produced the highest dry shoot weight, root and total dry weight (182.20, 184.10 and 366.00g) compared to other cultivars. The PAN 8816 had the highest panicle mass (105.80g) compared to the rest cultivars.

TABLE 2. Influence of zinc fertilizer rates on chlorophyll content and leaf area

Treatment factors	Chlorophyll content	Leaf area (cm^2)	Chlorophyll content	Leaf area (cm^2)	Chlorophyll content	Leaf area (cm^2)
	49		63		77	
	Days after sowing					
Zn rates kg Zn/ha						
0	57.7a	424.00a	65.20a	631.00a	71.20a	596.00a
5.6	58.0a	390.00a	65.90a	602.00a	71.50a	605.00a
10.6	56.4a	361.00a	59.40a	550.00a	66.40a	565.00a
LSD (P≤0.05)	13.2	108.4	13.33	118.9	14.69	117.00
Cultivars						
Avenger	63.20a	427.00a	68.30a	696.00a	81.70a	716.00a
Enforcer	61.80a	500.00a	70.90a	635.00a	76.30a	596.00a
NS 5511	62.20a	426.00a	69.80a	684.00a	73.80a	641.00a
PAN 8816	42.20b	213.00a	45.00b	362.00b	47.00b	399.00b
LSD (P≤0.05)	15.24	125.5	15.39	137.3	16.97	135.10
Grand Mean	57.30	391.00	63.50	594.00	69.70	588.00
Zn x Cultivar	**	**	**	**	**	**

** Significant at (P≤0.01), * significant at (P≤0.05).

TABLE 3. Effect of zinc rates on stem diameter of different grain sorghum cultivars

Treatment factors	Stem diameter (mm)		
	49 DAS	**63 DAS**	**77 DAS**
Zn rates (kg Zn/ha)			
0	18.29a	30.60a	33.30a
5.6	17.17a	27.60a	33.10a
10.6	17.39a	28.00a	31.20a
LSD ($P \leq 0.05$)	4.60	6.46	6.06
Cultivars			
Avenger	19.67a	30.40a	36.20a
Enforcer	21.48a	33.30a	37.00a
NS 5511	19.27a	32.50a	36.70a
PAN 8816	10.26b	18.70b	20.10b
LSD($P \leq 0.05$)	4.596	7.45	6.99
Grand Mean	17.62	28.70	32.50
Zn x Cultivar	**	**	**

** Significant at ($P \leq 0.01$), * significant at ($P \leq 0.05$)

TABLE 4. Effect of zinc rates on the flowering day

Treatment Factors	Flowering Days
Zn rates (Zn kg/ha)	
0	78.23c
5.6	82.17b
10.6	83.93a
LSD ($P \leq 0.05$)	1.59
Cultivars	
Avenger	84.50a
Enforcer	73.80c
NS 5511	84.67a
PAN 8816	82.77b
LSD($P \leq 0.05$)	1.83
Grand Mean	81.44
Zn x Cultivar	**

** Significant at ($P \leq 0.01$), * significant at ($P \leq 0.05$)

TABLE 5. Influence of zinc rates on dry matter accumulation and panicle mass

Treatment factors	Dry shoot weight (g/pot)	Dry root weight (g/pot)	Total dry weight (g/pot)	Panicle mass (g/pot)
Zn rates				
0	154.50b	120.20b	275.00b	63.60b
1	149.30c	112.90b	262.50b	67.10b
2	185.30a	184.50a	370.20a	93.00a
LSD (P≤0.05)	19.09	14.63	38.19	11.48
Cultivars				
Avenger	142.70b	99.50c	242.60c	60.00b
Enforcer	157.90b	136.30b	294.70b	60.80b
NS 5511	182.20a	184.10a	366.00a	72.00b
PAN 8816	119.20c	136.90b	306.30b	105.80a
LSD(P≤0.05)	22.05	16.78	33.60	13.26
Grand Mean	163.00	139.20	302.50	74.60
Zn x Cultivar	**	**	**	**

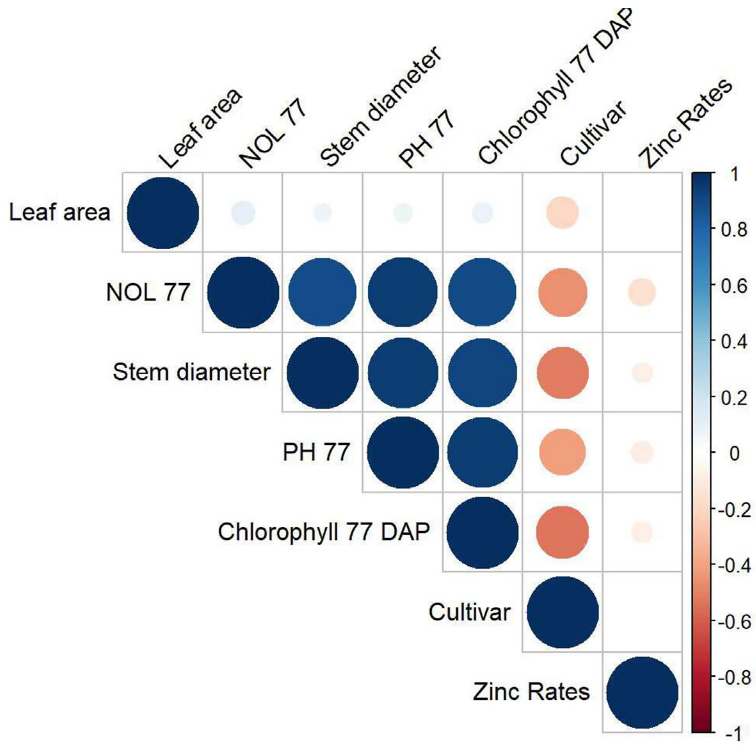
** Significant at (P≤0.01), * significant at (P≤0.05).

Pearson correlation, regression and principal component analysis

The Pearson correlation indicated a positive and significant relationship between growth parameters and grain sorghum cultivars. However, the zinc fertilizer rates had a negative and significant association with growth parameters and cultivars. The zinc fertilizer rates had positive and significant correlation with flowering dates of grain sorghum cultivars (R^2= 1), as indicated in Fig. 2. Figure 3 revealed that the different zinc fertilizer rates (10.6 Zn kg/ha) had a positive and significant association with the dry shoot weight of grain sorghum cultivars (R^2= 0.85). However, the zinc rates (5.6 and 10.6 Zn kg/ha) showed a positive and significant relationship with dry root weight (R^2= 0.64 and 0.85) compared to 10.6kg Zn kg/ha (Fig. 4). The relationship between zinc rates, total dry matter, and panicle mass was positive and significant (R^2= 1), as indicated in Figs. 5 and 6. The principal component (Dim 1; 63.28%) fixed many treatment factors equated to (Dim 2; 17.91).

Discussion

The zinc has been known as an essential trace element because zinc has metabolically important role in plant growth and development (Prajapati et al., 2023). The 5.6 Zn kg/ha towards 0 Zn kg/ha improved growth of grain sorghum cultivars. This indicated low rates of zinc fertilizer is required for optimum grain sorghum growth and development. This result agreed with reported of Ramazanalik et al. (2014) who indicated that plant required low concentration of zinc, as microelement, plays fundamental role in crop physiology however high concentration of this element as like as heavy metal elements provides reduction of growth and yield by making disorder in cell metabolism. Similarly, Sher et al. (2022) obtained tallest plant height (84.2cm) and spike length (10. 8cm) of wheat with the application of 0 Zn kg/ha. These results correlate with the findings from Hassan et al. (2005), who reported that there was a significant (P<0.05) decrease in sorghum plant height and biomass decrease in the soils with a high zinc rate. Bavec et al. (2007) observed that the variation of leaf area index is determined by fertilization, the genetic structure of the cultivar and the period of growth. In controlled environments, the influence of leaf length might have been a growth response to low light intensity, reducing the amount of plant nutrients for leaf breadth (Kim et al., 2010). According to Mirshekali et al. (2012), as the zinc rate increases in the soil, it decreases leaf area in some plant species, reducing the plant's photosynthetic activities.



NOL 77 = Number of leaves at 77 WAS, PH 77 = Plant height at 77 WAS

Fig. 2. Pearson correlation of zinc rates, cultivars and growth parameters

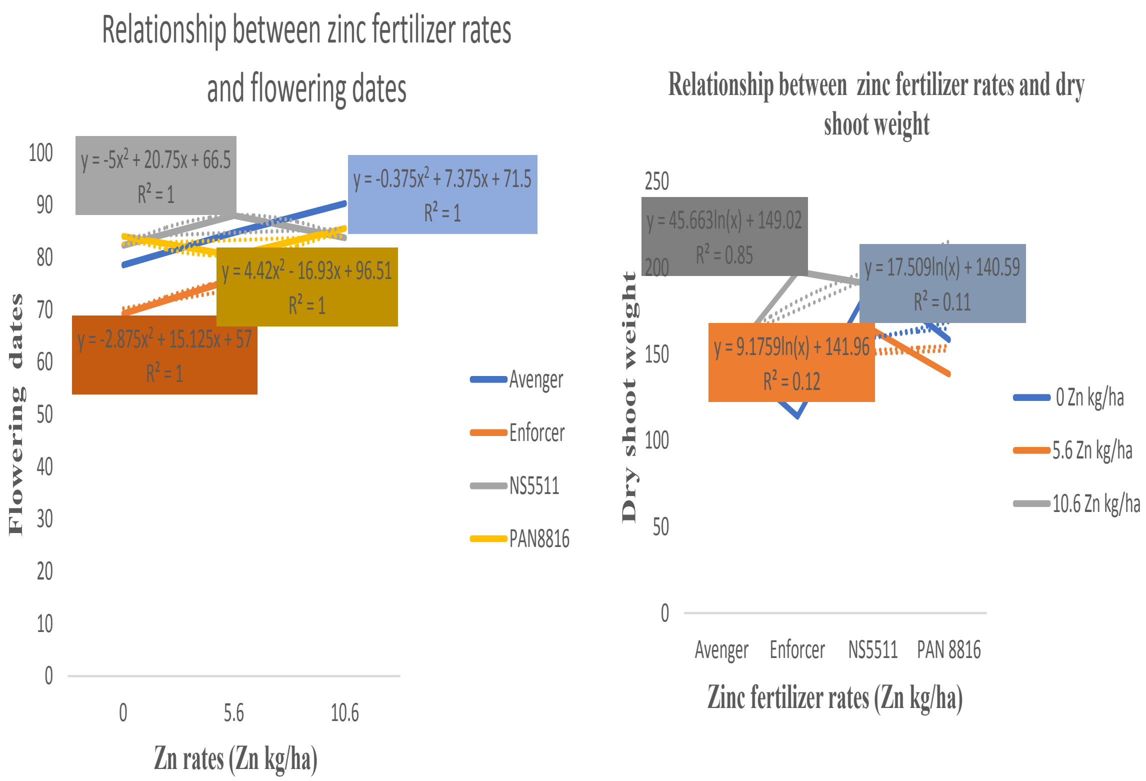


Fig. 3. Relationship between zinc rates, flowering date and dry shoot weight

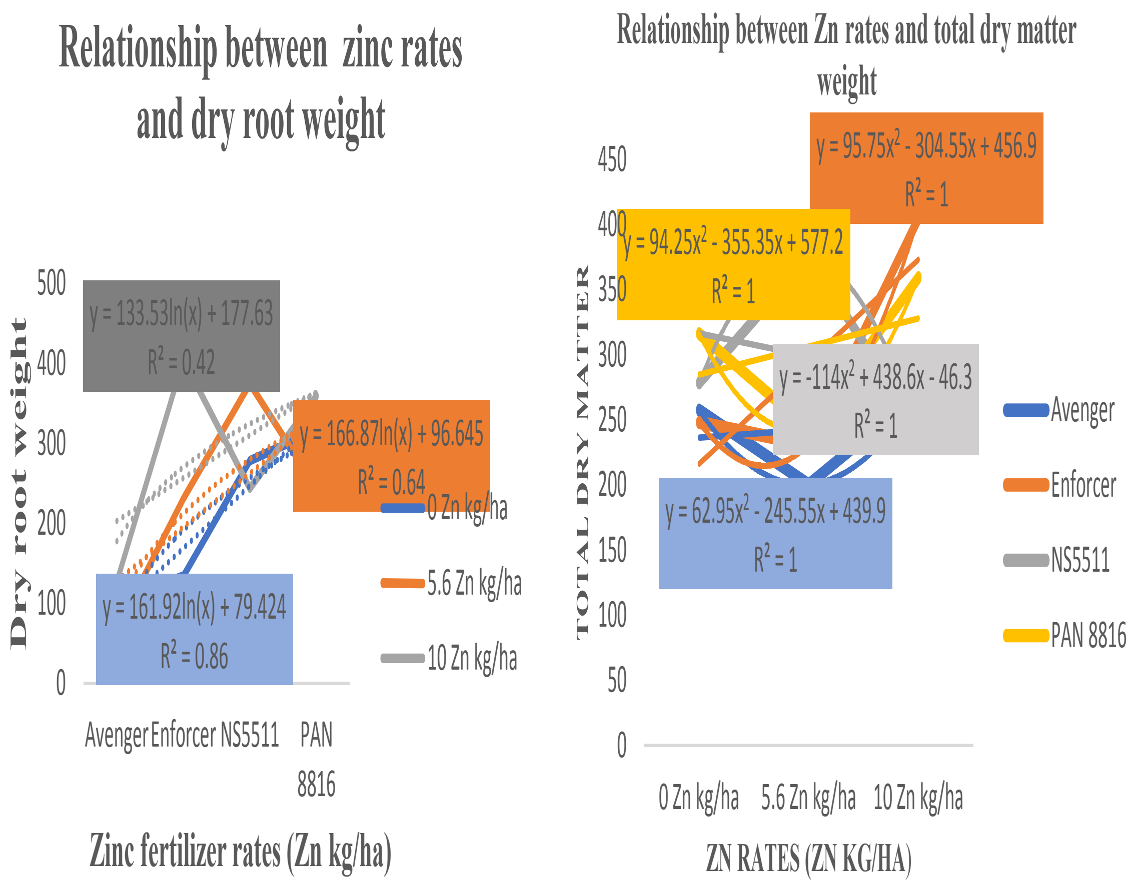


Fig. 4. Relationship between dry root weight and total dry matter weight

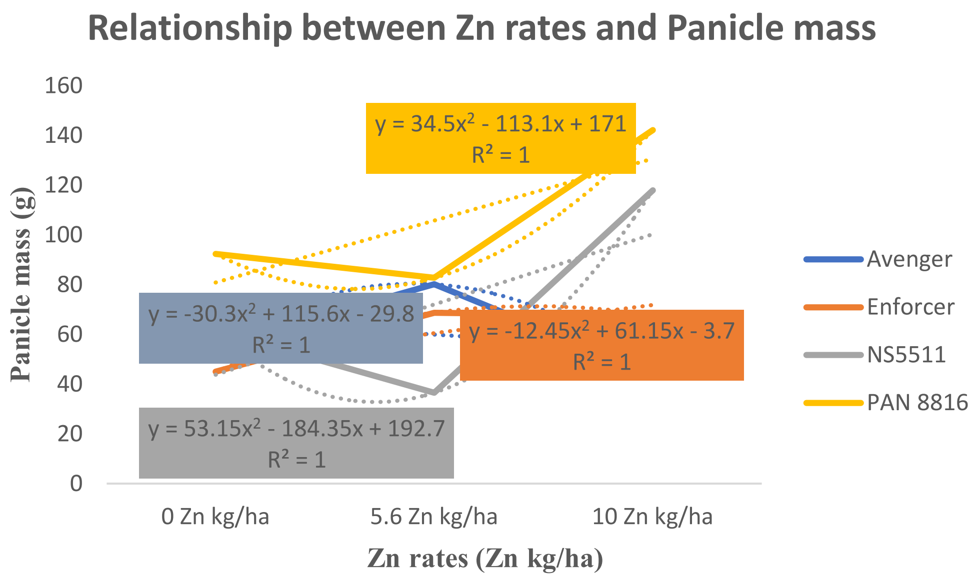


Fig. 5. Relationship between zinc fertilizer rates and panicle mass

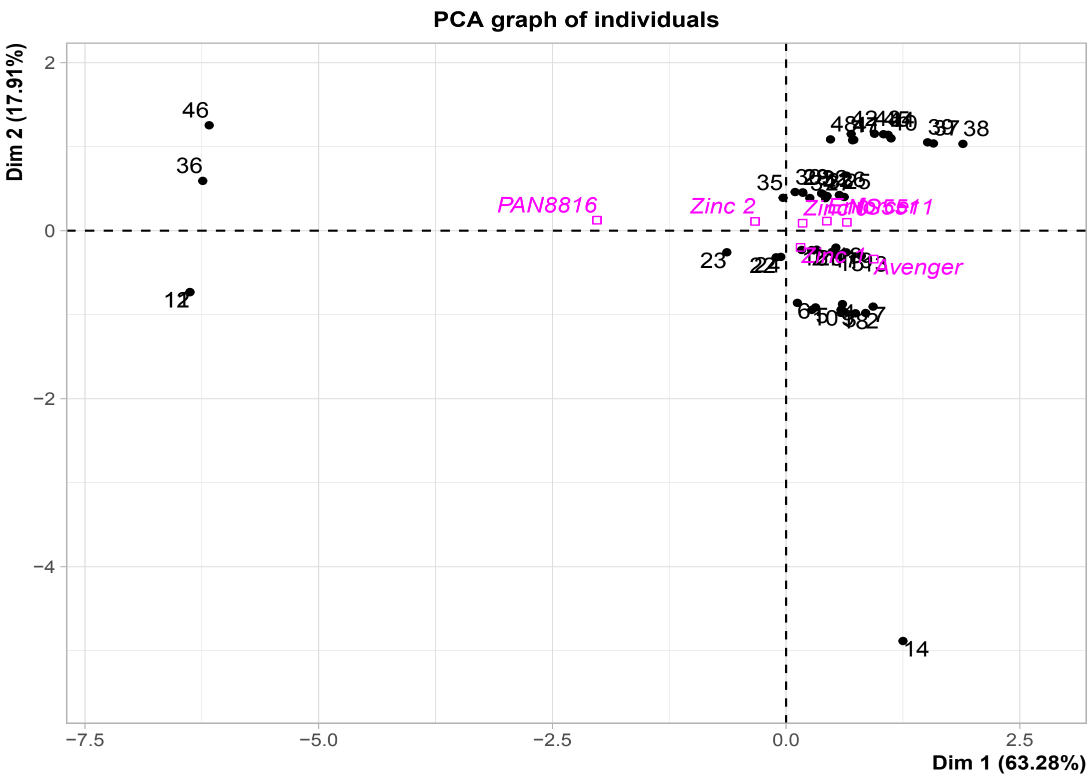


Fig. 6. Principal component analysis of zinc fertilizer rates and cultivars of grain sorghum

Zinc is the micronutrient that affected a wide variety of physiological processes (Prajapati et al., 2023). The application of 10.6 Zn kg/ha enhanced flowering days, dry matter accumulation and panicle mass. Sriniva & Jain (2023) reported that the application of zinc was significantly influence biomass accumulation in sorghum. Liu et al. (2020) indicated increasing zinc fertilized improve shoot biomass of maize. Liu et al. (2017) further revealed that adequate zinc supplied led to assimilation of the available supply nutrients. Yaser et al. (2016) reported that zinc application at rates of 7 and 10.50 had minimum numbers of days (157 days) to physiological maturity. Guo et al. (2016) reported that applying zinc sulphate between 5-10kg Zn/ha is suitable for correcting zinc in rice through a basal application.

The grain sorghum cultivar of Avenger and Enforcer cultivars were outperformed other cultivars in term of growth. This showed that growth and development of different cultivars depends upon the genetic make – up of cultivars. Khan et al. (2007) stated that the genetic makeup of the plants or the hormonal balance and cell division rate of the various cultivars may vary, which could also explain the variance in plant height. The Avenger and Enforcer cultivars had the highest number of leaves per plant, possibly due to their very good standability. Based on the cultivar, high chlorophyll content was observed from cultivar Avenger and Enforcer, which are early and medium maturing cultivars compared to PAN 8816. These results align with the findings of Ayub et al. (2010), where differences in stem diameter within the sorghum cultivars were reported. This indicated that Enforcer reaches maturity early, which is differentiated from the rest of the cultivars. This showed that the reproductive parameters of sorghum needed a higher quantity of zinc fertilizer than growth traits. This agreed with the findings of Manyathi (2014), who showed that PAN 8816 produced the highest fresh mass, dry weight and seed yield compared to other varieties.

This revealed that the growth of grain sorghum required 5.6 kg/ha of zinc fertilizer compared to the reproductive stage. This result is consistent with the observation of Tag El-Din (2021), who reported that as the zinc fertilizer rates increased, the effect of zinc fertilizer was reduced.

Conclusion

The result showed that grain sorghum cultivars required a low rate of zinc fertilizer (5.6 Zn kg/ha) close to 0 Zn kg/ha for growth. However, the cultivars needed a higher quantity of zinc fertilizer of 10.6 Zn kg/ha for grain purposes. The Avenger and Enforcer cultivars are best for growth purposes such as fodder. PAN 8816 is best for grain purposes. The study suggested that for the fodder purpose, grain sorghum should be grown with the application of 5.6 Zn kg/ha, and grain purpose can be fertilized with 10.6 Zn kg /ha.

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