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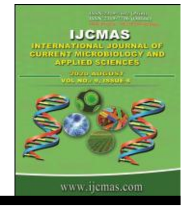

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Relative Adequacy of $ZNSO_4.7H_{2O}$ and ZN EDTA on the Photosynthetic Characters and Yield Attributes of Pearl Millet (*Pennisetum glaucum* L)

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A B S T R A C T

A field experiment was conducted in a randomized complete block design with three replications at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad during *kharif* 2017 to elucidate relative efficiency of $ZnSO_4.7H_2O$ and Zn EDTA on the photosynthetic character and yield attributes of pearl millet variety ICMV-221. Two sources of Zn i.e. $ZnSO_4.7H_2O$ and Zn EDTA were soil applied as basal dose @ 0 (control), 5, 10, 15 and 20 kg ha^{-1} before the sowing. Application of 20 kg ha^{-1} Zn EDTA showed earlier attainment of growth stages viz. flag leaf initiation, 50 % flowering and milky stage whereas physiological maturity was late. Leaf area, Chlorophyll content, SPAD value, leaf Zn content, photosynthetic characters, yield attributes viz. grain yield $plant^{-1}$, grain yield ha^{-1}, test weight, harvest index also reported being highest with 20 kg ha^{-1} Zn EDTA followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$, indicating the efficiency of Zn EDTA compared to $ZnSO_4.7H_2O$.

Introduction

Pearl millet (*Pennisetum glaucum* L.) the vital arid and semi-arid crop of India (Ramesh *et al.*, 2006) cultivated as both food and feed in over 8.3 m ha (Yadav *et al.*, 2011) and 27 m ha everywhere throughout the world. It is one of the major crops of China, India, South Eastern Asia, Sudan, Pakistan, Russia and Nigeria and comprises around 75 per cent of the total cereal production and represents an essential part of local diets (Lestienne *et al.*, 2005). In India major pearl millet growing states are Maharashtra, Gujarat and Rajasthan where pearl millet contributes for 20 to 63 per cent of the total cereal consumption (Rao *et al.*, 2006). On account of its resilience to difficult growing conditions, it tends to be grown in areas where other cereal crops, such as maize or wheat wouldn’t survive. The ongoing spurt in costs of wheat, rice and maize and growing demand for non-food uses (cattle and poultry feed, alcohol and starch industries) pearl millet become cheaper alternative sources (Reddy *et al.*, 2013). Further, the nutritional value of these crops offers much scope to the development of value enriched products in new health conscious consumer segments (Yadav *et al.*, 2011) as it contains more fibre and is good for diabetic and heart patients. However, Pearlmillet production is seriously hampered by some biotic and abiotic factors, thereby reducing its yield. Mineral nutrition is considered as the major limiting factor for productivity especially Zn, which is essential for the normal healthy growth and reproduction of the plant. The decline in the crop yield due to Zn deficiency comes from the reduction in a photosynthetic activity which causes reduced dry matter production. Zinc inadequacy induces overall inefficiency in net photosynthesis by 50 to 70% depending upon plant species and degree of insufficiency (Seethambaram and Das, 1985; Pandey and Sharma, 1989; Shrotri *et al.*, 1989; Hu and Sparks, 1991; Brown *et al.*, 1993). Zinc is a component of plant carbonic anhydrase (CA) enzyme which is directly involved in photosynthesis, encouraging the diffusion of CO2 through the liquid phase of the cell to the chloroplast (Tobin, 1970, Nelson *et al.*, 1969; Hatch and Slack, 1970). Zn deficiency also hampers stomatal conductance and transpiration rate. As Pearl millet is a C4 plant which requires high CA activity is highly affected by Zn deficiency. Zn deficiency in plant occurs due to low soil Zn accessibility, which is ascribed to Zn fixation by free CaCO3 in alkaline calcareous soil. So, there is a need to improve the soil Zn availability by application of Zn fertilizer to the soil. Keeping these views in mind a field experiment was conducted to see the relative efficiency of $ZnSO_4.7H_2O$ and Zn EDTA on the photosynthetic character and yield attributes of pearl millet.

Materials and Methods

A field experiment was conducted during *kharif* 2017 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad (latitude: 15^0 26’ N, longitude: 75^0 07’ E, altitude: 678 m). The objective was to unearth the effect of soil Zn fertilization on crop phenophases, leaf area, leaf zinc content, chlorophyll content, gas exchange character and yield attributes of pearl millet.

Soil properties and treatment details

The site of the experimental site was a deep black clay soil with 0.53 mg kg^{-1} available soil Zn content. The variety of ICMV-221 was used as the test crop. Two sources of Zn i.e. $ZnSO_4.7H_2O$ and Zn EDTA were used as basal dose @ 0 (control), 5, 10, 15 and 20 kg ha^{-1} were soil applied as basal dose @ 0 (control), 5, 10, 15 and 20 kg ha^{-1} before the sowing. At the time of sowing it was fertilized with 50:25:0 kg ha^{-1} N: P_2O_5: K_2O.

Crop phenophases

Crop phenophases *viz*. days to flag leaf initiation, 50 % flowering, milky stage and physiological maturity of five randomly tagged plants from each plot were recorded from the days of sowing.

Leaf area

Leaf area per plant was calculated at 30 DAS, 60 DAS and at harvest by length and breadth method. The sum of all the leaves per plant was expressed in decimeter square (dm^2).

Leaf Zn content

For estimation of leaf Zn content, leaf samples were collected at 50 % and harvesting stage. Samples were washed properly with distilled water, dried under shade and then in a hot air oven at 65^0C till a constant weight was obtained and samples were powdered. The diacid (HNO_3: $HClO_4$) digested samples were used for Zn estimation with atomic absorption spectrophotometer (GBS Avanta Ver. 2.02 Model, Germany) (Tandon, 1998).

SPAD value and chlorophyll content

Relative chlorophyll content (SPAD value) was measured using SPAD chlorophyll meter at 30 and 60 DAS. Chlorophyll content (mg g^{-1} fresh weight) was also measured on a fully expanded third leaf from the top by DMSO (Dimethyl sulfoxide) method at 30 and 60 DAS (Shoaf and Lium, 1976).

Photosynthetic parameters

The net photosynthetic rate (µ mol CO_2 m^{-2} s^{-1}), stomatal conductance (µ mol m^{-2} s^{-1}) and transpiration rate (µ mol H_2O m^{-2} s^{-1}) were measured by using portable IRGA (Lichor 6400-*XT)* system at 30 and 60 DAS.

Yield attributes

Grain yield $plant^{-1}$ (g), grain yield ha^{-1} (kg ha^{-1}), test weight (g) and harvest index were noted after harvesting of the crop to verify the effect of Zn application on the yield attributes.

Statistical analysis

Statistical analysis and the data interpretation was as per the Gomez and Gomez (1984) and the treatment means were computed by applying Duncan's Multiple Range Test (DMRT). The mean values of treatments subjected to DMRT using the corresponding error mean sum of squares and degrees of freedom values at five per cent probability under MSTATC programme. Correlation studies were made between leaf Zn content at 50% flowering and SPAD value and the photosynthetic rate at 60 DAS at five per cent probability level was according to Panse and Sukhatme (1967).

Results and Discussion

Effect of Zn application on phenophases of bajra

The performance of a crop depends largely on its phenophases in terms of yield. In the present investigation, it has been observed that days to flag leaf initiation, 50 per cent flowering and milky stage were comparatively earlier in the treatments receiving 20 kg ha^{-1} Zn EDTA (36.67, 49 and 55.33 days respectively) and 20 kg ha^{-1} $ZnSO_4.7H_2O$ (37, 49 and 56.67 days respectively) than that of control (39, 51.33 and 61.67 days respectively) (Table 1).

A higher dose of Zn, an activator of growth hormone indole acetic acid (IAA) may be attributed to the sound crop growth rate. Whereas, the physiological maturity was late in 20 kg ha^{-1} Zn EDTA (84.33 days) and 20 kg ha^{-1} $ZnSO_4.7H_2O$ (83.33 days) application compared to control (79 days). This might be ascribed to the larger accumulation of photosynthates in grain which persisted for a longer period in Zn treated plots (Ullah *et al.,* (2002) and Kumar and Bohra (2014).

Leaf area to soil Zn application

Leaf area $plant^{-1}$ recorded maximum when treated with 20 kg ha^{-1} Zn EDTA (7.13, 28.70 and 19.87 dm^2 respectively) followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$ treatment (6.67, 28.68 and 19.66 dm^2 respectively) and minimum leaf area $plant^{-1}$ was observed in the control plot (4.82,22.78 and 15.37 dm^2 respectively) at 30 DAS, 60 DAS and at harvest (Table 2).

This might be due to the role of Zn in auxin metabolism which helps in cell division and cell elongation resulting in increased leaf area (Anand (2007), Saleh and Maftoun (2008), Dore (2016) and Potanna (2017).

Table.1 Effect of Zn biofortification on phenological traits in bajra

Treatments	Flag leaf initiation (days)	50 % flowering (days)	Milk stage (days)	Physiological maturity (days)
T_1: RDF (Control)	39.00^{ab}	51.33^{ab}	61.67^{a}	79.00^{ab}
T_2:RDF + Basal application of $ZnSO_4.7H_2O$ @ 5 kg ha^{-1}	40.67^{a}	53.00^{ab}	59.33^{ab}	76.00^{b}
T_3: RDF + Basal application of $ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	37.33^{ab}	51.33^{ab}	56.67^{ab}	79.00^{ab}
T_4: RDF + Basal application of $ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	36.67^{b}	52.00^{ab}	56.67^{ab}	80.00^{ab}
T_5: RDF + Basal application of $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	37.00^{ab}	51.33^{ab}	56.67^{ab}	83.33^{ab}
T_6: RDF + Basal application of Zn EDTA @ 5 kg ha^{-1}	37.00^{ab}	52.00^{ab}	57.67^{ab}	80.67^{ab}
T_7: RDF + Basal application of Zn EDTA @ 10 kg ha^{-1}	36.67^{b}	54.67^{a}	57.67^{ab}	80.00^{ab}
T_8: RDF + Basal application of Zn EDTA @ 15 kg ha^{-1}	37.33^{ab}	51.33^{ab}	57.33^{ab}	83.00^{ab}
T_9: RDF + Basal application of Zn EDTA @ 20 kg ha^{-1}	36.67^{b}	49.00^{b}	55.33^{b}	84.33^{a}
Mean	**37.59**	**51.78**	**57.74**	**80.59**
S.Em. ±	**1.17**	**1.50**	**1.71**	**2.39**
L.S.D. @ 5 %	**3.51**	**4.51**	**5.12**	**7.15**

RDF: Recommended dose of fertilizer
Means within a column followed by the same letter(s) are not significantly different according to DMRT (P = 0.05)

Table.2 Effect of Zn biofortification on leaf area and leaf Zn content in bajra

Treatments	Leaf area $plant^{-1}$ (dm^2)			Leaf Zn content (mg kg^{-1})	
	30 DAS	**60 DAS**	**At harvest**	**At 50 % flowering**	**At harvest**
T_1: RDF (Control)	4.82^{d}	22.78^{c}	15.37^{d}	29.87^{d}	26.19^{d}
T_2:RDF + Basal application of $ZnSO_4.7H_2O$ @ 5 kg ha^{-1}	5.31^{b-d}	23.67^{bc}	15.43^{d}	30.51^{d}	27.26^{cd}
T_3: RDF + Basal application of $ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	5.57^{b-d}	26.33^{ab}	17.18^{b-d}	31.12^{cd}	28.42^{cd}
T_4: RDF + Basal application of $ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	5.85^{a-d}	27.02^{ab}	18.18^{a-c}	33.28^{b-d}	31.69^{ab}
T_5: RDF + Basal application of $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	6.67^{ab}	28.68^{a}	19.66^{a}	37.04^{b}	32.92^{a}
T_6: RDF + Basal application of Zn EDTA @ 5 kg ha^{-1}	5.04^{cd}	25.27^{a-c}	16.29^{cd}	30.96^{d}	27.92^{cd}
T_7: RDF + Basal application of Zn EDTA @ 10 kg ha^{-1}	5.73^{a-d}	27.02^{ab}	18.07^{a-c}	31.94^{cd}	29.74^{bc}
T_8: RDF + Basal application of Zn EDTA @ 15 kg ha^{-1}	6.52^{a-c}	28.38^{a}	19.22^{ab}	35.06^{bc}	32.03^{ab}
T_9: RDF + Basal application of Zn EDTA @ 20 kg ha^{-1}	7.13^{a}	28.70^{a}	19.87^{a}	40.82^{a}	34.01^{a}
Mean	**5.85**	**26.43**	**17.70**	**33.40**	**30.02**
S.Em. ±	**0.45**	**1.09**	**0.70**	**1.22**	**0.93**
L.S.D. @ 5 %	**1.36**	**3.26**	**2.09**	**3.65**	**2.79**

RDF: Recommended dose of fertilizer
DAS: Days after sowing
Means within a column followed by the same letter(s) are not significantly different according to DMRT (P = 0.05)

Table.3 Effect of Zn biofortification on relative chlorophyll content (SPAD value) and chlorophyll content in bajra at 30 DAS and 60 DAS

Treatments	Relative chlorophyll content (SPAD value)		Chlorophyll-a (mg g^{-1} fresh weight)		Chlorophyll-b (mg g^{-1} fresh weight)		Total chlorophyll (mg g^{-1} fresh weight)	
	30 DAS	**60 DAS**	**30 DAS**	**60 DAS**	**30 DAS**	**60 DAS**	**30 DAS**	**60 DAS**
T_1: RDF (Control)	35.24^{c}	45.20^{c}	1.05^{d}	1.54^{c}	0.29^{c}	0.45^{c}	1.34^{e}	1.99^{e}
T_2:RDF + Basal application of $ZnSO_4.7H_2O$ @ 5 kg ha^{-1}	36.02^{bc}	48.46^{bc}	1.21^{b-d}	1.56^{c}	0.35^{bc}	0.45^{c}	1.56^{c-e}	2.01^{e}
T_3: RDF + Basal application of $ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	38.94^{a-c}	51.84^{a-c}	1.42^{a-c}	1.80^{bc}	0.39^{a-c}	0.53^{a-c}	1.82^{a-c}	2.33^{cd}
T_4: RDF + Basal application of $ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	41.14^{a}	55.67^{ab}	1.49^{ab}	1.90^{ab}	0.42^{ab}	0.59^{a-c}	1.91^{a-c}	2.49^{a-d}
T_5: RDF + Basal application of $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	42.30^{a}	56.39^{ab}	1.58^{a}	2.03^{ab}	0.47^{a}	0.67^{ab}	2.05^{ab}	2.70^{ab}
T_6: RDF + Basal application of Zn EDTA @ 5 kg ha^{-1}	38.21^{a-c}	50.63^{a-c}	1.10^{cd}	1.76^{bc}	0.30^{c}	0.48^{bc}	1.40^{de}	2.24^{de}
T_7: RDF + Basal application of Zn EDTA @ 10 kg ha^{-1}	40.21^{ab}	53.67^{ab}	1.36^{a-d}	1.83^{ab}	0.38^{a-c}	0.55^{a-c}	1.73^{b-d}	2.38^{b-d}
T_8: RDF + Basal application of Zn EDTA @ 15 kg ha^{-1}	41.97^{a}	56.20^{ab}	1.58^{a}	1.98^{ab}	0.46^{a}	0.63^{a-c}	2.04^{ab}	2.61^{a-c}
T_9: RDF + Basal application of Zn EDTA @ 20 kg ha^{-1}	42.47^{a}	56.91^{a}	1.65^{a}	2.08^{a}	0.47^{a}	0.71^{a}	2.12^{a}	2.79^{a}
Mean	**39.61**	**52.78**	**1.38**	**1.83**	**0.39**	**0.56**	**1.77**	**2.39**
S.Em. ±	**1.40**	**2.48**	**0.09**	**0.08**	**0.03**	**0.05**	**0.12**	**0.11**
L.S.D. @ 5 %	**4.20**	**7.43**	**0.30**	**0.24**	**0.09**	**0.17**	**0.35**	**0.30**

DF: Recommended dose of fertilizer
DAS: Days after sowing
Means within a column followed by the same letter(s) are not significantly different according to DMRT (P = 0.05)

Table.4 Effect of Zn biofortification on photosynthetic rate, stomatal conductance and transpiration rate in bajra at different growth stages

Treatments	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})		Stomatal conductance (µmol m^{-2} s^{-1})		Transpiration rate (µmol H_2O m^{-2} s^{-1})	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1: RDF (Control)	21.79^{c}	32.95^{b}	0.10^{c}	0.22^{d}	1.39^{c}	4.00^{c}
T_2:RDF + Basal application of $ZnSO_4.7H_2O$ @ 5 kg ha^{-1}	22.76^{bc}	32.98^{b}	0.11^{c}	0.23^{cd}	1.41^{c}	4.18^{c}
T_3: RDF + Basal application of $ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	23.46^{bc}	36.92^{ab}	0.11^{c}	0.26^{cd}	1.80^{bc}	4.72^{a-c}
T_4: RDF + Basal application of $ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	24.39^{a-c}	37.80^{a}	0.15^{ab}	0.33^{ab}	2.01^{ab}	5.24^{a-c}
T_5: RDF + Basal application of $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	25.70^{ab}	38.59^{a}	0.17^{a}	0.36^{a}	2.38^{a}	5.81^{a}
T_6: RDF + Basal application of Zn EDTA @ 5 kg ha^{-1}	22.84^{bc}	34.56^{ab}	0.11^{c}	0.24^{cd}	1.42^{c}	4.27^{bc}
T_7: RDF + Basal application of Zn EDTA @ 10 kg ha^{-1}	23.73^{bc}	37.03^{ab}	0.13^{bc}	0.29^{bc}	1.86^{a-c}	4.96^{a-c}
T_8: RDF + Basal application of Zn EDTA @ 15 kg ha^{-1}	25.03^{ab}	38.26^{a}	0.17^{a}	0.35^{a}	2.31^{ab}	5.74^{ab}
T_9: RDF + Basal application of Zn EDTA @ 20 kg ha^{-1}	26.76^{a}	38.96^{a}	0.18^{a}	0.38^{a}	2.41^{a}	5.91^{a}
Mean	**24.05**	**36.45**	**0.14**	**0.30**	**1.89**	**4.98**
S.Em. ±	**0.92**	**1.32**	**0.01**	**0.02**	**0.17**	**0.46**
L.S.D. @ 5 %	**2.75**	**3.97**	**0.03**	**0.05**	**0.51**	**1.37**

DF: Recommended dose of fertilizer
DAS: Days after sowing
Means within a column followed by the same letter(s) are not significantly different according to DMRT (P = 0.05)

Table.5 Effect of Zn biofortification on yield attributes in bajra

Treatments	Grain yield plant^{-1} (g)	Grain yield (kg ha^{-1})	Test weight (g)	Harvest index
T_1: RDF (Control)	21.10^{b}	3276^{c}	10.43^{b}	30.63^{b}
T_2:RDF + Basal application of $ZnSO_4.7H_2O$ @ 5 kg ha^{-1}	21.82^{b}	3379^{bc}	10.97^{ab}	30.76^{b}
T_3: RDF + Basal application of $ZnSO_4.7H_2O$ @ 10 kg ha^{-1}	22.44^{ab}	3563^{a-c}	11.50^{ab}	30.98^{ab}
T_4: RDF + Basal application of $ZnSO_4.7H_2O$ @ 15 kg ha^{-1}	24.57^{ab}	3983^{ab}	11.90^{ab}	31.78^{ab}
T_5: RDF + Basal application of $ZnSO_4.7H_2O$ @ 20 kg ha^{-1}	25.55^{ab}	4095^{a}	12.37^{a}	33.14^{ab}
T_6: RDF + Basal application of Zn EDTA @ 5 kg ha^{-1}	22.37^{ab}	3549^{a-c}	11.17^{ab}	31.41^{ab}
T_7: RDF + Basal application of Zn EDTA @ 10 kg ha^{-1}	23.42^{ab}	3763^{a-c}	11.73^{ab}	30.76^{b}
T_8: RDF + Basal application of Zn EDTA @ 15 kg ha^{-1}	25.35^{ab}	4066^{a}	12.23^{ab}	32.17^{ab}
T_9: RDF + Basal application of Zn EDTA @ 20 kg ha^{-1}	26.65^{a}	4153^{a}	12.77^{a}	34.32^{a}
Mean	**23.70**	**3758**	**11.67**	**31.77**
S.Em. ±	**1.31**	**195.6**	**0.547**	**1.05**
L.S.D. @ 5 %	**3.93**	**586.4**	**1.64**	**3.11**

F: Recommended dose of fertilizer
Means within a column followed by the same letter(s) are not significantly different according to DMRT (P = 0.05)

Fig.1 Correlation between leaf Zn content at 50% flowering and SPAD value at 60 DAS

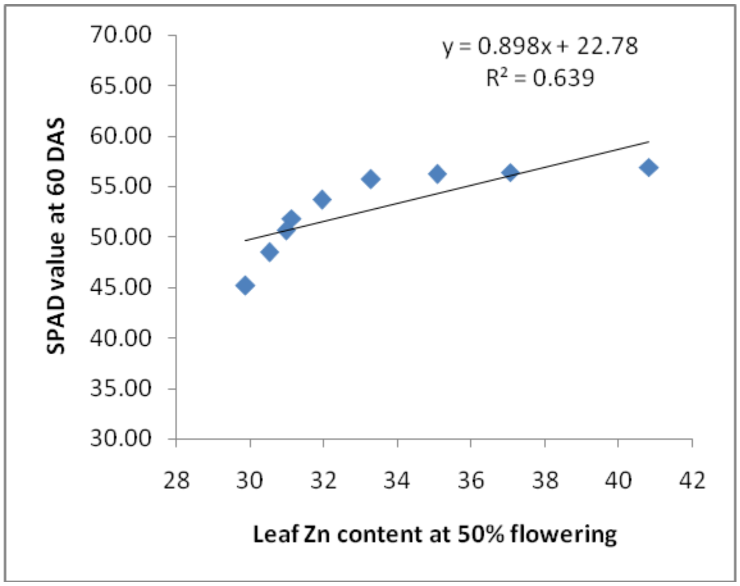
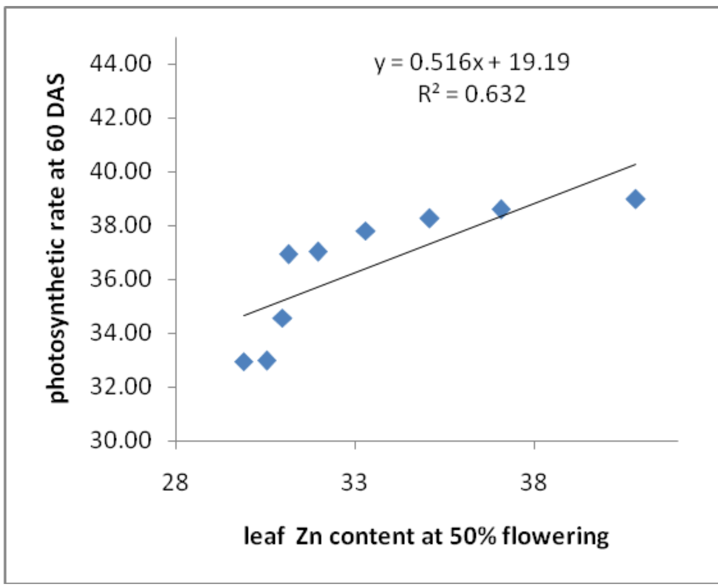


Fig.2 Correlation between leaf Zn content at 50 % flowering and photosynthetic rate at 60 DAS



Leaf Zn content with soil Zn application

Leaf Zn content increased with increase in Zn fertilizer dose and recorded highest in 20 kg ha^{-1} Zn EDTA treated plot at both 50 % flowering and harvesting (40.82 and 34.01 mg kg^{-1} respectively) followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$ treated plot (37.04 and 32.92 mg kg^{-1} respectively) and lowest was observed in control (29.87 and 26.19 mg kg^{-1} respectively) (Table 2). Leaf Zn content decreased at the harvesting stage which might be ascribed to the remobilization of Zn to the grain after flowering for seed formation. Higher accumulation of Zn in Zn EDTA application might be due to its slow releasing nature and greater availability in the rhizosphere (Imtiaz *et al.*, (2003), Karak *et* *al.*, (2005), Raghavendra (2013), Rasul *et al.*, (2014), Prasad *et al.*, (2015) and Choudhary *et al.*, (2016)).

SPAD value to soil Zn application

The relative chlorophyll content (SPAD value) is the quantification of the greenness of the leaves. Earlier studies in rabi sorghum (Anand, 2007), rice (Kabeya and Shankar, 2013) and bread wheat (Raghavendra, 2013) showed that an increase in relative chlorophyll content due to Zn application. This might be attributed to the fact that application of Zn enhanced the chlorophyll content of the leaf. In the present study also, 20 kg ha^{-1} Zn EDTA application (42.47 and 56.91 respectively) significantly increased the relative chlorophyll content over control (35.24 and 45.20 respectively) and this is immediately followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$ (42.30 and 56.39 respectively) at 30 and 60 DAS (Table 3).

Chlorophyll content with soil Zn application

The indirect role of Zinc in chlorophyll biosynthesis by participating in the enzyme catalysis and protein functioning which are essential for chlorophyll synthesis and also in protecting the chloroplast membrane from disruption are well documented (Balashouri, 1995 and Hisamitsu *et al.*, 2001). The passive role of Zinc were also confirmed by Saleh and Maftoun (2008), Akay (2011), Rana and Kashif (2014) and Samreen *et al.*, (2017). In the present investigation also the role of Zinc in the chlorophyll a, chlorophyll b and total chlorophyll content significantly increased from 30 DAS (1.38, 0.39 and 1.77 mg g^{-1} fresh weight respectively) to 60 DAS (1.83, 0.56 and 2.39 mg g^{-1} fresh respectively) (Table 3). The chlorophyll content was maximum when treated with 20 kg ha^{-1} Zn EDTA, followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$ and the lowest was noted in the absolute control. There is an indirect influence of

Effect of soil Zn application on Photosynthetic traits

The rate of photosynthesis, stomatal conductance and transpiration rate increased with increase in the Zn supplementation reporting maximum in the treatment receiving 20 kg ha^{-1} Zn EDTA, followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$ and significantly lowest was reported in the control (Table 4). A significant increase of photosynthetic activity at 30 DAS (24.05 µmol CO_2 m^{-2} s^{-1}, 0.14 µmol m^{-2} s^{-1} and 1.89 µmol H_2O m^{-2} s^{-1}respectively) to 60 DAS (36.45 µmol CO_2 m^{-2} s^{-1}, 0.30 µmol m^{-2} s^{-1} and 4.98 µmol H_2O m^{-2} s^{-1}respectively) was evidenced due to Zn application. The role of Zn in regulating stomatal conductance, which is a function of density, size and degree of opening of stomata, causes greater photosynthesis is well established (Sharma *et al.*, 1995). The increase in the rate of photosynthesis in response to Zn application attributed to its role in carbonic anhydrase enzyme activity (Cakmak and Engels, 1999). In response to this transpiration rate also increased, as higher photosynthesis leads to rapid utilization of CO_2 resulting in greater uptake of CO_2 coupled with the expense of H_2O. Ahmed *et al.*, (2009) in cotton and Liu *et al.*, (2016) in summer maize observed similar results due to Zn application as obtained in the present investigation.

Correlation study

The increase in the SPAD value, chlorophyll content and photosynthetic rate mentioned above is attributed to the increase in the leaf Zn content when fertilized with $ZnSO_4.7H_2O$ and Zn EDTA. Leaf Zn content at 50 % flowering stage showed a significant and positive correlation with relative chlorophyll content (SPAD value) (r^2=0.639) (Fig 1) and the photosynthetic rate (r^2=0.632) at 60 DAS

(Fig 2), which increased lucidly with an increase in the leaf Zn content.

Effect of soil Zn application on Yield attributes

Increased photosynthetic rate resulted in greater biomass accumulation and mobilization of a major part of it to the grains which will reflect in the harvest index. So, increase in the grain yield plant^{-1}, grain yield ha^{-1}, test weight and harvest index were due to Zn application (Kumar *et al.,* (2015), Ghoneim (2016), Potanna (2017) and Singh and Pandey (2017)). Significant variation in yield to the Zinc application was recorded in the present study. At 20 kg ha^{-1} Zn EDTA (26.65 g plant^{-1}, 4153 kg ha^{-1}, 12.77 g and 34.32 respectively), followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$ (25.55 g plant^{-1}, 4095 kg ha^{-1} 12.37 g and 33.14 respectively) and significantly lowest was reported in the control (21.10 g plant^{-1}, 3276 kg ha^{-1}, 10.43 g and 30.63 respectively) (Table 5).

Relative efficiency of $ZnSO_4.7H_2O$ and Zn EDTA

It has been observed from the experiment that the use of Zn EDTA served the crop better in terms of chlorophyll content, photosynthetic rate and harvest index as compared to $ZnSO_4.7H_2O$. Higher water solubility (100%) and slow releasing character of Zn EDTA as it is chelated might be the reason for its higher efficiency than $ZnSO_4.7H_2O$.

It is concluded from the experiment that soil Zn application during sowing leads to the earlier attainment of growth stages viz. flag leaf initiation, 50 % flowering and milky stage whereas physiological maturity was late in Zn treated plot which led to higher grain filling. Leaf Zn content was also higher when supplied with Zn as compared to control due to which a significant increase in the leaf area, chlorophyll content, SPAD value and photosynthetic rate was observed. Ultimately increased photosynthetic rate resulted in higher grain yield plant^{-1}, grain yield ha^{-1}, test weight and harvest index in Zn treated plot. Plots receiving 20 kg ha^{-1} Zn EDTA showed the best result followed by 20 kg ha^{-1} $ZnSO_4.7H_2O$. So, Zn EDTA identified as a more efficient source for Zn nutrition than $ZnSO_4.7H_2O$.

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