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Research Article

Silicon Fertilization Improves Growth Attributes, Root Traits, Water Relations and Photosynthetic Activity of Maize (*Zea mays* L.) Genotypes

Varsha[1], T. Chitdeshwari[1*], D. Jegadeeswari[1] and T. Srinivasan[2]

[1]Department of Soil Science and Agricultural Chemistry

[2]Department of Millets

Tamil Nadu Agricultural University, Coimbatore-641003, Tamil Nadu

*Corresponding Author E-mail: chithukesh@gmail.com

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ABSTRACT

A forty day long pot culture experiment was conducted to study the impact of silicon fertilization on the growth and root traits of various hybrid maize genotypes. Ten different maize genotypes were selected and tested with three levels (0, 75 kg ha^{-1} and 150 kg ha^{-1}) of silicon as calcium silicate. The genotypes were imposed with recommended fertilizers (250:75:75kg NPK ha^{-1}) and grown up to 40 days by following necessary plant protection and production measures. At the end of 40 days, growth parameters viz., plant height, leaf area, leaf width, SPAD and relative water content and root traits like root length, lateral root length and root volume were recorded. Results indicated that with an increase in Silicon application, there is a remarkable increase in the overall development of hybrid maize genotypes. A linear increase in growth attributes of maize genotypes was observed with increasing levels of Si application upto 150 kg Si ha^{-1}. The genotype CO (H) M 8 was found to be the most responsive genotype to Si application among all the ten genotypes followed by CMH12-586 and VaMH12014. Lesser response to Si application was noticed with NK 6240 and CMH 15-005. Inclusion of silicon in the fertilizer schedule showed positive impact on growth and root attributes of hybrid maize genotypes which was evident in better photosynthetic parameters, leaf area and width, and relative water content observed in the plants. Relationship studies also confirmed the positive correlation exists among various growth and root parameters for silicon fertilisation.

Keywords: *Chlorophyll, Growth attributes, Maize genotypes, Root traits, Silicon levels, RWC*

INTRODUCTION

Intensive agriculture to satisfy the consistently expanding demand for food has resulted in overwhelming exhaustion of applied as well as native nutrient reserves within the soil. Silicon is one such element which is although considered as a plant nutritional non-entity, it is being depleted from soil due to plant uptake and several pedological processes like weathering, and leaching.

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In spite of being viewed as a beneficial nutrient (IPNI, 2015), Silicon is considered to be non-essential for plant growth. But, recent research studies revealed that Si manifests its effects on plant growth as like any other non-essential plant nutrients (Detmann et al., 2012). It plays a key role in plant growth, by conferring mechanical strength to crops and resistance against pathogens and herbivory. Silicon additionally infleuences plant chlorophyll content and enhances the photosynthetic capabilities of crops by improving their light-receiving posture (Balakhnina, & Borkowska, 2013; Tubana et al., 2016).

Silicon fertilizers have been used since 1995 in crops like paddy in Japan and due to its increasing popularity these fertilizers are now being used for wheat, maize and soybean in increasing the productivity and to sustain crop production. In general, most monocotyledon plants such as ryegrass, wheat, sorghum, and barley are known as Si-accumulating species (Guntzer et al., 2012; Ma & Takahashi, 2002). Maize (*Zea mays* L.) is also known as Si-accumulator grown widely as important cereal in India. It is known to actively take up and accumulate Si in its organs (Coskun et al., 2019; Liang et al., 2007) and is highly responsive to Si fertilization (Liu et al., 2011). Application of Si improves growth of maize and increases its yield in arid or semi-arid areas under water-stress conditions.The benefits of Si on maize are manifold like improving the population, quality, photosynthetic efficiency, increasing leaf area, yield, etc (Covshoff & Hibberd, 2012; Meena et al., 2014). Thus, a short term experiment was carried out with different genotypes of hybrid maize to assess the effectiveness of various levels of Silicon applied as calcium silicate on growth and root traits of hybrid maize.

MATERIALS AND METHODS

A pot culture study was conducted in the glass house of Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. The soil chosen for the study was sandy loam in texture having deficient Si content (36.5 mg kg^{-1}). It was neutral in soil reaction (7.50), non saline (0.09 dS m^{-1}), non calcareous and having low organic carbon content (1.18 g kg^{-1}). The available N (86.8 kg ha^{-1}) and K (123 kg ha^{-1}) was low but high in available P (23.1 kg ha^{-1}). Each pot was filled with 4.50 kg of processed soil and three seeds per pot were sown. The basal recommended dose of N, P_2O_5 and K_2O was applied (250:75:75 kg NPK ha^{-1}). The silicon was applied as calcium silicate at three levels 0, 75 and 150 kg ha^{-1}. Ten different hybrid maize genotypes were chosen for the study, out of which eight were TNAU hybrids (CO 6, CO(H)M 8, CO(H)M9, VaMH2014) and cultures (CMH12- 586, CMH2-686, CMH14-716, CMH15-005) and two private hybrids (NK6240 and 900M Gold). All the plants were grown and harvested at 40 days after sowing for recording growth parameters such as plant height, SPAD value, leaf area, leaf width and relative water content. Besides the root traits *viz.,* root length, lateral root length and root volume were also recorded.

A chlorophyll meter (SPAD 502) designed by the Plant Analysis Development (SPAD 502) section, Minolta Camera Co. Ltd., Japan was used to record the SPAD readings at a wavelength of 940 nm (Yuan et al., 2016). Measurements were taken from upper most fully expanded leaf (3^{rd} or 4^{th} leaf from the apex) and five readings were taken in each replicate to represent the mean SPAD 502 value of each treatment. Leaf area was measured in the third leaf from top on 40^{th} day after sowing by non-destructive method after sunrise using a Leaf area meter (model CI-202) which calculates the length and width to provide leaf area measurements. The plant height was determined by measuring the length of plant from collor region of shoot to meristem and expressed in centimeter. The leaf width was measured using a ruler at most expanded area of the leaf and was expressed in cm. The relative water content (RWC) was determined in the fully expanded leaf wherein firstly, the fresh weight of the sample leaf was recorded following which they were immersed in distilled water for two hours subsequent to smudging off the surplus water and the turgid weight was recorded. Then, the samples were oven dried at 70ºC until getting the constant weight and the dry weight was recorded. Using the given equation RWC was calculated (Pirzad et al., 2011).

$$RWC\ (\%) = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Root length was determined by measuring the length of root from the base of the stem to the tip of the lengthiest root and expressed in centimeter (cm). Forceps were used to straighten the roots in order to avoid any overlapping and glass plates were used to hold them in position to measure the lengths of roots to the nearest millimeter by eye inspection (Bohm, 1979; Loades et al., 2010). Lateral roots are those which initiate from the primary roots and were determined by measuring the length from primary root to the tip and expressed in cm. The root volume was measured using water displacement technique by immersing the root in water filled measuring cylinder. The water displaced is measured using a graduated cylinder and is expressed in cm (Amin et al., 2016; Balakhnina & Borkowska, 2013; Thakur et al., 2011).

The data obtained from the investigations were subjected to analysis of variance to find out the significance (Panse & Sukhatme, 1978). Wherever the treatment differences were found significant critical differences (CD) were worked out at 5% level with a mean separation by least significant difference and denoted by symbol (* ,** for 5% and 1% respectively). Non significant comparisons were indicated as NS. Simple correlation was worked out between different parameters to know the positive or negative relationships existing between them.

RESULTS

Plant height

Data pertaining to plant height of different maize genotypes measured on 40th day has been given in table 1 which showed a linear increase in plant height with increasing levels of Silicon application. The highest plant height (90.2cm) was recorded with the application of 150 kg Si ha^{-1} and the lowest plant height was recorded in NPK control (60.7cm). The genotype CO(H)M 8 showed better performance with the application of Si @ 150 kg ha^{-1} as there was a remarkable increase in plant height from 79.0 cm in NPK control to 90.2 cm at 150 kg Si ha^{-1} followed by the genotype CMH12- 586 (77.0 to 85.7cm) and VaMH12014 (74.0 to 83.0cm). Lesser plant height was noted with the hybrids viz., NK 6240 (63.1 cm) and CMH 115-005 (64.9 cm).

Leaf area and width

From the data given in table 1, it was evident that silicon application significantly increased the leaf area of all the maize genotypes and varied from 110 cm^2 in NK6240 to 147 cm^2 in CO (H)M 8. Application of Silicon at 150 kg ha^{-1} considerably increased the leaf area of all maize genotypes and maximum leaf area of > 140 cm^2 was registered with CO(H)M 8 and CMH 12-586. The lowest leaf area was observed in NPK control in NK 6240 and CMH15-005.

From the Fig.1 it was quite evident that there was a slight increase in the width of all maize genotypes with increasing levels of silicon applied which varied from 4.43 cm in CMH15-005 to 6.07cm in CO (H) M8.

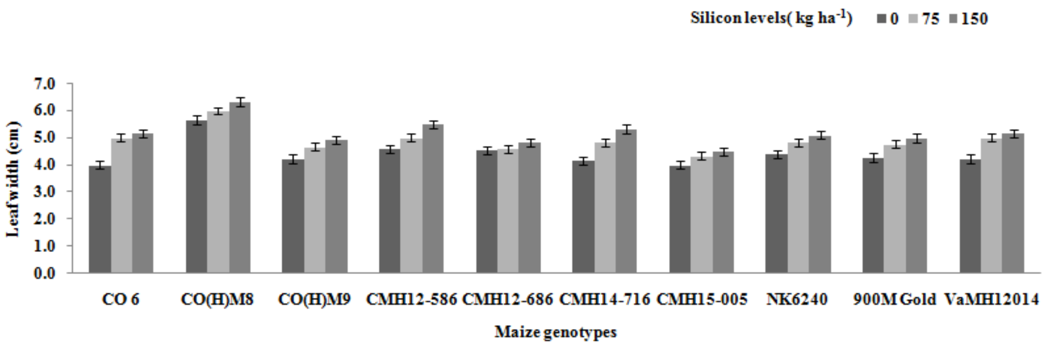

Fig. 1: Effect of silicon levels on the leaf width of hybrid maize genotypes

Better results was registered with CO (H) M8 as compared to all other genotypes and varied from 5.67cm in NPK control to 6.33 cm in 150 kg Si ha^{-1} followed by CMH12-586 and VaMH12014.

Chlorophyll content (SPAD)

Similarly, chlorophyll content was measured using the SPAD meter for all the maize genotypes which also increased with increasing levels of Si application. Highest SPAD value was observed in the genotype CO(H)M8 (40.2) followed by CMH12-586 (37.6) whereas lesser SPAD values was found in the genotypes NK6240 (35.0) and CMH5-005 (35.3, Fig.2)

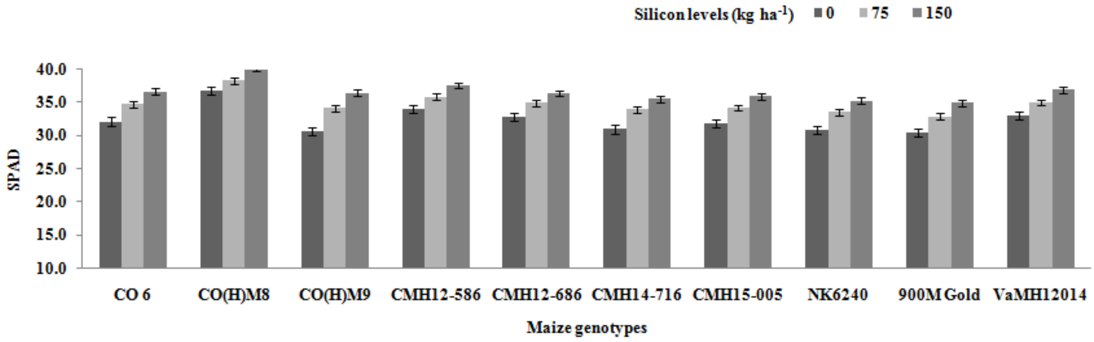

Fig. 2: Effect of silicon on the SPAD (chlorophyll content) value of hybrid maize genotypes

Relative water content (RWC)

As expected, increasing levels of silicon increased the relative water content in the leaves of maize genotypes and the mean values varied from 81.4 to 90.9%. Increasing levels of Silicon increased the RWC in leaves and the highest value was recorded with the application of 150 kg Si ha^{-1} in the genotype CO (H) M8 (93.3%). Lesser RWC was observed with NK6240 (83.3%, Table 1) in NPK control treatment.

Root traits

The data on the root traits such as root length, lateral root length and root volume of various maize genotypes were recorded and given in table 2. The results envisaged that application of Silicon as calcium silicate had a positive influence on all the root traits of hybrid maize genotypes. The highest root length was measured with the genotype CO(H)M8 and the values varied from 24.2 cm in NPK control to 29.6 cm in 150 kg Si ha^{-1}. This was closely followed by CMH12-586 with 21.1cm in control and 28.0 cm in 150 kg Si ha^{-1}.

The lateral root length was also increased with the application of silicate fertilizer and higher mean lateral root length was recorded with the addition of 150 kg Si ha^{-1} which varied from 11.4 cm in genotype CMH15-005 to 13.9 cm in CO(H)M 8. The order of higher lateral root length was noted as: CO(H)M 8 > CMH12-586 > VaMH12014. Lesser values were noticed in NPK control with the genotypes CMH 15-005 (5.0 cm) and NK 6240 (5.67 cm).

Similarly positive effect of silicon application on root volume (Table 2) was also observed which differs widely with all the maize genotypes and varied from 6.06cc in CMH15-005 to 13.7cc in CO(H)M8. Higher root volume (16.3cc) was recorded with the application of 150 kg Si ha^{-1} in the genotype CO(H)M 8, followed by CMH12-586 (14.7cc) and VaMH12014 (13.7cc). Lesser root volume observed with NK 6240 and CMH 15-005 was well correlated with poor growth and root attributes of these genotypes.

An attempt was made to understand the relationship between root traits viz., root volume and root length with growth attributes like plant height and relative water content. It was observed that the plant height and relative water content are positively correlated with root volume (r = 0.982**, 0.953** respectively, Fig. 3 and Fig.4). Also, from Fig.4 it was clear that there was a linear relationship between root length and relative water content (r = 0.943**). Again, a linear association of plant height and relative water content (r= 0.955**) was also observed among the maize genotypes fertilized with silicon (Fig.3).

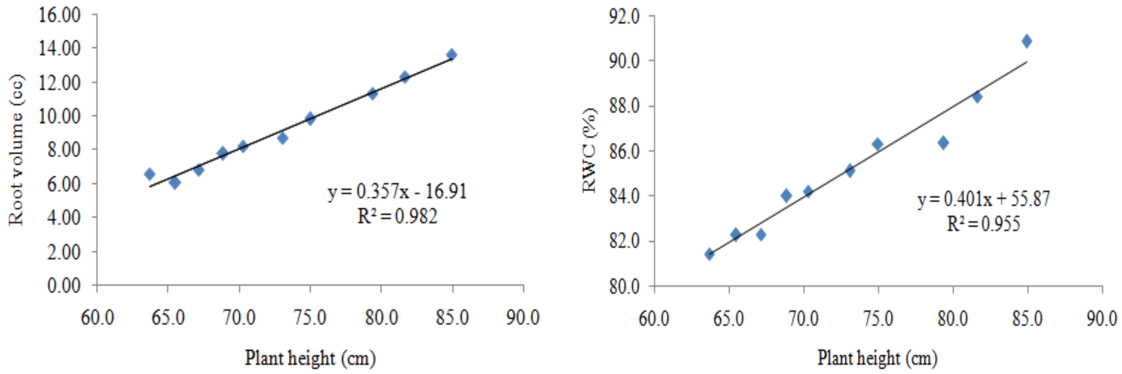

Fig. 3: Relationship of plant height with root volume and RWC

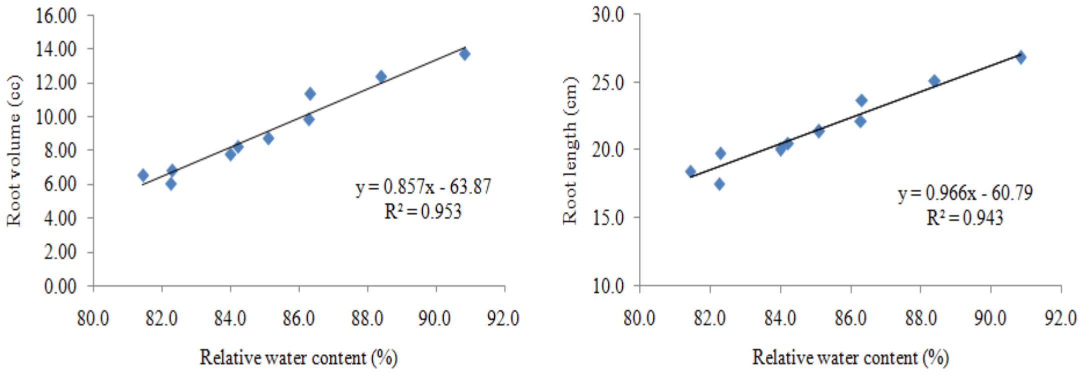

Fig. 4: Correlation of relative water content with root volume and root length

DISCUSSION

The results of this study clearly indicated that application of silicon fertilizers indeed helps in increasing the growth and overall development of maize genotypes. There have been various studies shown that Si application affects the growth of many crops positively[1], rice in particular (Gascho & Korndorfer, 1999; Li, 2018; Meena et al., 2014). Maize hybrids treated with silicon exhibited better growth characteristics as compared to the ones without Si fertilization (Greger et al., 2018; Vaculík et al., 2009). The data given in Table 1 shows that added Si increased the plant height of the maize genotypes and the results are in corroborations with the findings indicating that maize grown in the absence of silicon were shorter than those grown with Si (Venkataraju, 2013). The applied Silicon promotes water stauts and increases the photosynthetic rate of plants, consequently making the crop long and firm (Ahmed et al., 2013; Yuan et al., 2016).

Leaf characteristics like leaf area, leaf width and SPAD values enhanced with Si fertilization might be due to the fact that Si regulates stomatal activity, photosynthesis and water use efficiency which eventually resulted in better vegetative growth (Shedeed, 2018). Silicon is known to increase leaf area which enhances photosynthetic rate and prevents the destruction of chlorophyll (Gerami et al., 2012). Relative water content indicates the water status of crops which in turn implies the metabolism of plant tissues (Haynes, 2017; Kaya et al., 2006). In this study it was observed that increasing dosage of silicon fertilizers helped the maize hybrids to increase their leaf water content. This is well in conformity with the report that suggested that increase in relative water content due to Si fertilization might be attributable to the formation of double layer Si cuticle in leaf which decreased the cuticular transpiration due to increased thickness of the leaves (Ahmed et al., 2013; Rohanipoor et al., 2013).

From the data given in table 2 it is quite clear that incorporation of Si significantly increased the root demographics of all the maize genotypes. In a study it was observed that Si nutrition improved the volume of roots which further increased the absorbing capacity of roots (Amin et al., 2016; Snyder et al., 2016). The development of roots by silicon was perhaps due to the improved cell wall extensibility and root plasticity which were controlled by silicon mediated increment in polyamine levels and diminished ethylene levels. The improved root traits can enhance water absorption which further helps the crops in coping up with different abiotic stresses (Amin et al., 2016; Yin et al., 2016).

Table 1: Effect of silicon on growth attributes of maize genotypes

Si levels (kg ha^{-1}) / Genotype	Plant height (cm)				Leaf area (cm^2)				RWC (%)			
	0	75	150	Mean	0	75	150	Mean	0	75	150	Mean
CO 6	68.0	72.0	77.3	72.0	120	124	130	125	83.0	85.0	86.7	85.1
COH (M)8	79.0	83.7	90.2	83.8	133	139	147	140	87.7	91.0	93.3	90.9
COH (M)9	63.2	66.6	70.3	66.4	114	126	133	124	80.7	82.0	84.3	82.3
CMH12-586	77.0	80.7	85.7	80.7	125	136	143	135	86.0	88.7	90.0	88.4
CMH12-686	69.4	74.0	80.0	74.0	118	129	134	127	83.7	86.0	88.0	86.3
CMH14-716	66.5	69.6	73.3	69.5	107	119	127	117	82.0	84.0	85.7	84.2
CMH15-005	62.2	65.2	68.0	64.9	97	115	119	110	80.0	81.3	84.7	82.3
NK6240	60.7	62.9	66.5	63.1	101	108	110	106	79.3	80.7	83.3	81.4
900M Gold	65.4	68.1	72.2	68.2	113	120	128	120	81.3	84.7	86.0	84.0
VaMH12014	74.0	79.3	83.0	78.4	125	133	137	132	84.7	86.3	88.0	86.3
Mean	68.5	72.2	76.7	72.1	115	125	131	124	82.8	85.0	87.0	85.1
	G	L	G×L		G	L	G×L		G	L	G×L	
SEd	0.489	0.268	0.846		1.160	0.635	2.009		0.703	0.385	1.217	
CD (P=0.05)	0.980	0.537	1.697		2.326	1.274	4.029		1.409	0.772	NS	

G - Maize genotypes L - Levels of silica NS - Non-significant

Table 2: Effect of silicon on root traits of maize genotypes

Si levels (kg ha^{-1}) / Genotypes	Root length (cm)				Lateral root length (cm)				Root volume (cc)			
	0	75	150	Mean	0	75	150	Mean	0	75	150	Mean
CO 6	18.5	20.8	23.8	21.3	11.9	12.3	12.7	12.3	7.50	8.50	10.2	8.72
COH (M)8	24.2	26.0	29.6	26.8	12.9	13.5	13.9	13.4	11.0	13.7	16.3	13.7
COH (M)9	17.2	19.4	22.1	19.8	11.0	11.8	12.6	11.8	6.00	7.00	7.50	6.83
CMH12-586	21.1	24.9	28.0	25.1	12.6	13.2	13.6	13.1	10.0	12.3	14.7	12.3
CMH12-686	19.0	21.5	24.7	22.1	12.0	12.6	13.0	12.5	8.50	9.50	11.5	9.83
CMH14-716	18.2	19.8	22.8	20.5	11.6	12.0	12.5	12.1	7.00	8.00	9.67	8.22
CMH15-005	15.1	17.3	19.0	17.5	10.7	11.0	11.4	11.0	5.00	6.17	7.00	6.06
NK6240	16.4	18.2	19.9	18.4	10.9	11.4	11.7	11.3	5.67	6.83	7.17	6.56
900M Gold	17.8	20.1	21.0	20.0	11.3	12.0	12.2	11.8	6.83	7.67	8.83	7.78
VaMH12014	20.2	23.0	26.9	23.6	12.3	13.1	13.5	13.0	9.00	11.3	13.7	11.3
Mean	18.8	21.1	23.8	21.5	11.7	12.3	12.7	12.2	7.65	9.10	10.65	9.13
	G	L	G×L		G	L	G×L		G	L	G×L	
SEd	0.330	0.181	0.572		0.065	0.036	0.113		0.493	0.270	0.853	
CD (P=0.05)	0.662	0.363	1.147		0.131	0.072	0.227		0.541	0.988	NS	

G -Maize genotypes L- Levels of silica NS - Non-significant

CONCLUSION

Silica fertilization to hybrid maize genotypes under unstressed conditions remains unexplored till date. This study was a small step towards finding the effects of silicon on maize under normal conditions. The positive effect of Si on maize under such circumstances clearly indicates that its influence is not just limited to stress conditions; rather, it is related to basic metabolic processes of crop also. From the study it was confirmed that Si indeed has a role in enhancing the efficiency of crops in absorbing more water and nutrients. The genotype CO (H) M8 was found to respond better to Si fertilization followed by CMH12-586 and VaMH12014. Moreover, it was found that a linear increase in growth and root traits was observed and application of 150 kg Silicon as calcium silicate ha^{-1} was better in increasing the growth and root traits of hybrids maize genotypes. However lesser growth and root attributes observed at NPK control in CMH15-005 and NK 6240 needs further investigations.

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