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Influence of Nano-silica foliar application on growth and yield of Maize (Zea mays L.) under drought stress condition

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Abstract

Nano-silica and micro silica powders were tested on maize plants. Silicate nanoparticles (SNPs) were applied by foliar application at different concentrations under field conditions. The basic parameters such as stem height, stem width, grain yield, and grain nutrient content were determined. SNPs enhanced all aspects. Since SNPs achieved significant values of morphological, grain yield and grain component higher than other treatments especially low levels of foliar application of SNPs. Different plant characteristics measured wasn't affected by the ration of irrigation water when treated with foliar application of SNPs. We recommend to useing foliar application of SNPs especially when plant was suffering from stress condition of drought.

Keywords: Nano-silica, water stress, Maize, foliar application, drought.

Introduction

Plants generally require silica to control biotic and abiotic stress (Ma , 2004). The presence of silicon reduces toxic metal elevation, increases water-use efficiency and photosynthesis rate in plants. Silicon also acts as a bioprotectant against fungal attack (Datnoff et al., 1997). Different sources of silica are used as fertiliser for crops, but their effect on soil biological properties is still not clear. These sources are routinely applied to the growth of crops such as sugarcane and rice (Ayres, 1966; Anderson, 1991; Epstein, 1999). Silicon is abundant in soil. It constitutes the second most common element on earth after oxygen . The Freely available form of silicon requires a biological weathering of rocks, to solubilize chemically inert silicate (Wainwright, 1997). Some bacteria use silicon-based autotrophy as a source of energy to support CO_2 fixation (Das et al., 1992) . Silicic acid stimulates growth of both aerobic and facultative anaerobic soil bacteria in ultra-pure water under strict oligotrophic conditions. It is proposed that there is a possibility of the first bacteria having evolved on earth because of silicon (Wainwright et al., 2003). Therefore, it is an essential element for plants because continuous cropping reduces available forms of silicon, leading to poor growth and yield of crops. To improve growth and crop yield, different sources of silica fertilizers are used. Plants normally absorb silicon in the form of monosilicic and polysilicic acids. The absorbed silica and silicates are polymerized in roots and then deposited in stems and leaves. Nano silica is an important metal oxide that covers all major fields of science and technology including industrial, electronics and biomedical applications (Paulkumar et al., 2011; Dinda et al., 2012 and Cheng et al., 2008). It has gained greater attention because of its highly reactive surface-to-volume ratio property. Agricultural application of nanoparticles is currently a promising area of interest. The introduction of nanoparticles into plants may have significant impact and thus can be used for agricultural applications to obtain better growth and yield. Several studies are made on toxicity of nanoparticles and seed germination which are based on germination rates (Josko et al., 2013 and Lin et al., 2007). Addition of nano-silicate soil enhances growth of maize (Zea mays L.) (Yuvakkumar et al., 2011). Even though different sources of silica are used as silicon fertilizers, eco-toxicological properties and the risks of silicon fertilizers in terms of soil microbial health and soil nutrient values are scanty. Plant growth promoting rhizobacteria (PGPR) plays a key role in recycling and maintenance of soil health which improves plant growth (Supanjani et al., 2006; Khakipour et al., 2008; Ortíz-Castro et al., 2008 and Gholami et al., 2009).

Silica nanoparticles (SNPs) would be required in small quantities to improve crop protection. Silicon (Si)-deficient plants are often structurally weaker with abnormal growth and are more susceptible to biotic and abiotic stresses compared with Si-rich plants (Rafi et al., 1997). Maize (Zea mays. L) ranks third in global cereal production and is used as food, feed, and fodder (Mahmood et al., 2005). Developing sustainable maize cultivation is necessary for enhanced yield potential. Also, there is a possibility that abundant Si is absorbed and significantly in different plant species (Hossain et al., 2002). Si-deficiency in soil is fulfilled by the SiO_2 fertilizers. However, the effect of Si on plants relies on the kind of source used as a fertilizer, which can be studied using different types of silica sources. Although silicon-based fertilizers are widely used in poaceae family, their role in nutrient availability to plants and their influence on ionic exchanges between the environment and plants are scarce. Hence, it is essential to find appropriate silica source with small particle size for effective uptake. In on-farm seed priming, there is a possibility of deterioration of seeds while sowing in dry soil and highly prone to mechanical damage and pests (Clark et al., 2001). To avoid these aspects, seeds pre-incubated with silica contribute to plant erectness and increase seed vigor, leading to early growth before weed emergence . These benefits are due to the differences in the initial state of Si in plants (Hodson and Evans, 1995). However, the absorption levels of silica and its influence on other nutrients are also necessary to regulate the quantity of SiO2 applications. Rapid germination and seed emergence are key determinants of successful establishment of plants. The toxic effects of SNPs have been found to be highly effective against grain pests (Debnath et al., 2011). However, the effect of nanoparticles differs among various plant species. Scant research has been reported on the study of SNPs for maize growth as well as on their interactions (Yuvakkumar et al., 2011). For effective practical applications, it is Affordable sources of Si and methods application to maize were studied (Datnoff and Rodrigues, 2005). Attention to appropriate experimental design and interpretation is required to provide a strong scientific understanding of the biological effects of nanoparticles (Murashov, 2006). Although reports are available on the interaction between salinity and silicon in higher plants (Miao et al., 2010; Haghighi et al., 2012), there is less information about the possible beneficial effects of metal/metal oxide application to reduce abiotic stress damages under hydroponic conditions (Yang et al., 2008; Romero-Aranda et al., 2006). The purpose of the current investigation is to assess the effect of SNPs on growth and yield of maize using foliar application silica sources under stress condition of drought.

2. Materials and Methods

2.1 Synthesis and characterization of nano-silica

Nano Silica was prepared according to the methodology described by Premaratne et al. (2013). Briefly, Rice husk (RH) were washed by deionized water and oven dried at 105 ºC then calcinated at 700 ºC for 6 hours to produce silica. Ten grams of calcinated RH was stirred in 80 mL of 3.0 M NaOH solution then boiled for 3 hours. The solution was filtered, and the residue was washed with 20 mL deionized water. The filtrate was allowed to cool to room temperature and 2.5 M H_2SO_4 acid were added until the pH of the solution reached 2 and followed by addition of NH_4OH until pH 8.5. The filtrate was then dried at 120 ºC for 12 hours. After cooling the material was powdered and the pure silica was extracted by refluxing with 6 M HCl for 4 hours. Then the silica was washed repeatedly with deionized water until the solution become acid free. Precipitate was separated by centrifugation, and the purified silica sample was dried at 105 ºC for 2 hours. Pure silica extracted from RH was then dissolved in 3.0 M NaOH by continuous stirring for 10 hours on a magnetic stirrer. Afterward, 0.5 M H_2SO_4 was added dropwise to adjust the pH in the range of 7.5 to 8.5. The precipitated silica was washed repeatedly with warm deionized water until the filtrate became alkali free. The precipitate was separated by centrifugation (3500 rpm for 1 hour). The resultant material was dried at 50 ºC for 48 hours to obtain nano-silica.

The surface morphology of the synthesized materials was investigated by an SEM (Jeol, JSM-6360LA, Japan) at low magnification. The powder of synthesized materials was fixed onto the specimen holder and was covered by gold coated layers using the sputtering method. The SEM images were taken at a magnification of 1000× using a 10 kV accelerating voltage.

Functional groups initiated onto synthesized materials surfaces were tested using Fourier transform infrared spectroscopy (FTIR), and the data were generated from the diffused reflectance style by employing Bruker Vertex 80 joined with Ram-FT module (RAM II) spectrometer.

2.2 Field study

A field maize was carried out at the Research Station of Moshtohor Faculty of Agriculture, Benha University, Kalyobiya Governorate, Egypt during the two summer successive seasons 2020 and 2021to investigate the effect of irrigation regimes and foliar application with silicon grown on a clayey soil using the flood irrigation method. Main chemical properties are shown in Table 1.

Table (1) Physical and chemical properties of the experimental soil before corn sowing as average of two seasons.

Physical property		Chemical property	
Sand (%)	25.0	Organic matter (%)g/kg	21.0
Silt (%)	19.9	Available K (mg/kg)	129.5
Clay (%)	55.1	Available P (mg/kg)	4.5
Texture	Clay	Available N (mg/kg)	155.5
		Available Si (mg/kg)	5.2
		Total carbonate (%)(g/kg)	12.8
		pH (1:2.5)	7.1
		EC (ds/m)	6.575

2.2.1. Layout of the experiment:

The phosphorus fertilization was applied at 17 kg P / ha to all plots during soil preparation in form of ordinary calcium superphosphate (6.8% P) at the standard. Seeds of maize grains (Zea mays L.) cultivar (Solitary Hybrid 168 'Yellow') were obtained from Almadina company, Egypt and sown on May 10 and 15 in the first and second season, respectively (2020 and 2021) on one side of ridge. Two grains were sown per hill and 25 cm apart within the row. Immediately after the corn sowing, the experimental plots were surface irrigated with Nile water. twenty days after seedling (before the second irrigation), plants were thinned to one plant/hill.

The nitrogen and potassium fertilization were applied to the soil as urea (460 g/kg N) and potassium sulphate (400%g k/kg), at the rate of 250 kg N/ha.

The experimental design was as split-plot with four replicates. The factors were:

Main plots : Water regime (W), two regimes as follows:

W_1: 100% of irrigation water.

W_2: 60% of irrigation water.

Sub plots: silica application six as follows:

Si 0 : No silica.

Si 1: Micro silicon 50% (0.35 g/L).

Si 2: Micro silicon 100% (0.70 g/L).

Si 3: Nano silicon 50% (0.25 g/L).

Si 4: Nano silicon 100% (0.50 g/L) .

Si 5: Micro silicon (0.35 g/L) + Nano (0.25 g/L).

The two irrigation treatments were allocated to the main plots and the six treatments were assigned the sub-plots. Thus there were 12 combinations considering 4 replications, the overall number of plots was 48. The size of each plot was 42 m^2 (8.57 × 4.9 m). Each plot consisted of 7 rows. Row spacing in each plot was 70.0 cm. The plots were isolated by ditches of 1.5 m in width to avoid lateral movement of water. The spray treatments were applied three times during the growing period at 21, 35 and 50 days after sowing.

2.2.3. Measurements:

2.2.3.1. Soil measurements:

Soil samples were taken air dried, crushed and sieved through a 2- mm sieve. Physical and chemical analyses of the investigated soils were conducted as follows using methods cited by **Page *et al* (1982)** and **Klute (1986).**

1. Particle size distribution was carried out using the pipette method and sodium hexametaphosphate as a dispersing agent.
2. Soil moisture retention curve carried out using the pressure cooker and the pressure membrane .
3. Electrical conductivity (EC) measured in soil paste extract using electrical conductivity bridge.
4. Soil pH measured in 1: 2.5 soil water suspension using a pH meter.
5. Organic matter content using the Walkley and Black method.
6. Calcium carbonate was determined using the calcimeter.
7. Soluble cations and anions in the soil paste extract.
8. Soluble sulphate (SO_4^{-2}) was calculated by the difference between the sum of determined soluble cations and sum of determined soluble anions.
9. Available Fe, Mn, Zn, Co, Ni and Pb were extracted by NH_4HCO_3- DTPA according to **Sultanpour (1985)** and determined using Atomic Absorption spectrophotometer (Perlein- Elmer, Model 2308).
10. Available nitrogen was extracted with 1% potassium sulphate solution and determined by steam-distillation procedure using Devarda alloy method according to Bremner and Keeney (1962).
11. Available phosphorous was extracted according to Olsen *et al.,* (1954).
12. Available potassium was extracted using neutral 1 M ammonium acetate and determined by the flame photometer, (Dewis and Freitas, 1970).

2.2.3.2. Plant measurements

The maize plants were harvested at maturity on the 2^{nd} of October 2020 and on the 6 the of October 2021.

Plant samples were washed thoroughly with tap water, rinsed three times with distilled water, then dried at 70°C for 24 h. Oven-dry samples were finely ground for analysis. 0.5g dry sample was digested using a mixture of concentrated perchloric and sulfuric acids (1:1) as reported by Chapman and Pratt (1961) and plant nutrients were determined as follows:

- Nitrogen was determined by Kjeldahl method according to the procedure described by Jackson (1973).
- Phosphorus was determined colorimetrically using the ascorbic acid method, Jackson (1973).
- Potassium was determined by flame photometer.
- Fe, Zn and Mn were determined in plant extract using the Atomic Absorption spectrophotometer (Perlein- Elmer, Model 2308). pb, Ni and Co were determined using Inductively Coupled Plasma Emission Spectrometer (ICP- 400).

At harvest, plants of the three middle rows of each plot were harvested and threshed to determine the corn yield and yield components. The dry weight of the grains and stover was recorded. The grain yield was adjusted to be at 15.5% moisture content. The 15.5% moisture content in the grain yield represents the Egyptian standard criteria of the corn grain yield. The stover yield was calculated as Mg/ha. The weight of 1.0 ardab of the corn grains = 140 kg. The 100-grain weight of maize was recorded by weighing.

2.3 Statistical Analysis

The collected data were undergone to analysis of variance based on RCBD where statistical procedures were performed using WASP software. Least significant difference (LSD) was utilized to compare mean differences (Hoshmand, 2006).

3. Results and Discussion

3.1 Characterization of Synthesized Nanomaterials

The Nano-SiO_2 was characterized by SEM (Figuer. 1) which shows that the pure SiO_2 Nano-particles were uniform, loose and without reunion, and their grain size ranges from 5nm to 100nm. The nano-silica particles do not show clear boundaries as they are in agglomerate and amorphous form. Figure 2 shows the FTIR spectrum of nano silica powder. Figure 2 shows strong absorption peaks absorbed at 463, 621 and 791 cm^{-1} that correspond to Si–O–Si bending, Si–H and symmetric, and Si–O–Si stretching modes of vibrations, respectively (Yuvakkumar et al., 2014). This confirms that a highly pure nano silica powder can be produced from RHA using 2.5N NaOH purification treatment. Figure 2 shows a peak at 1069 cm^{-1} which can be assigned to Si-O-Si asymmetric stretching vibration (Premaratne et al., 2013) In general, the FT-IR spectrum of nano-silica synthesized from PHA clearly indicates that they are in amorphous form.

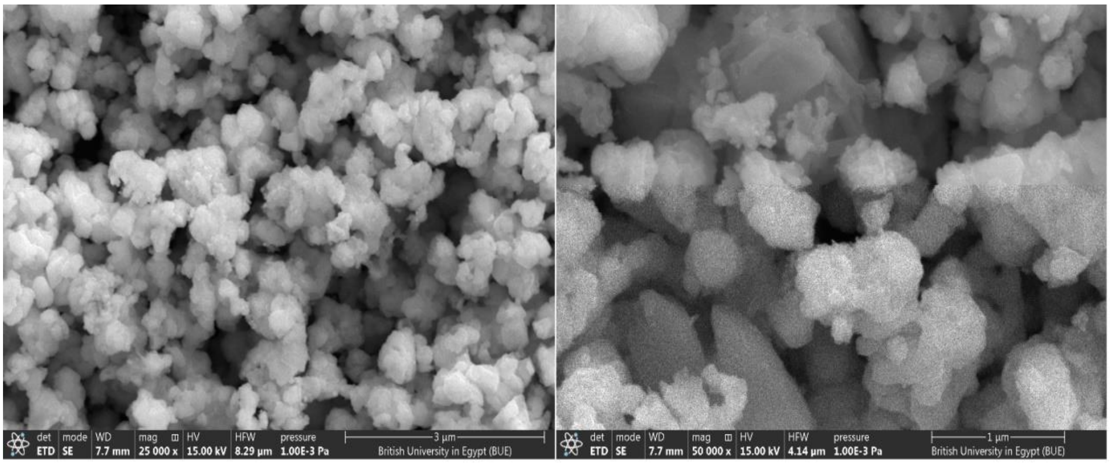

Fig (1) Scanning electron microscopy (SEM) images of SNPs

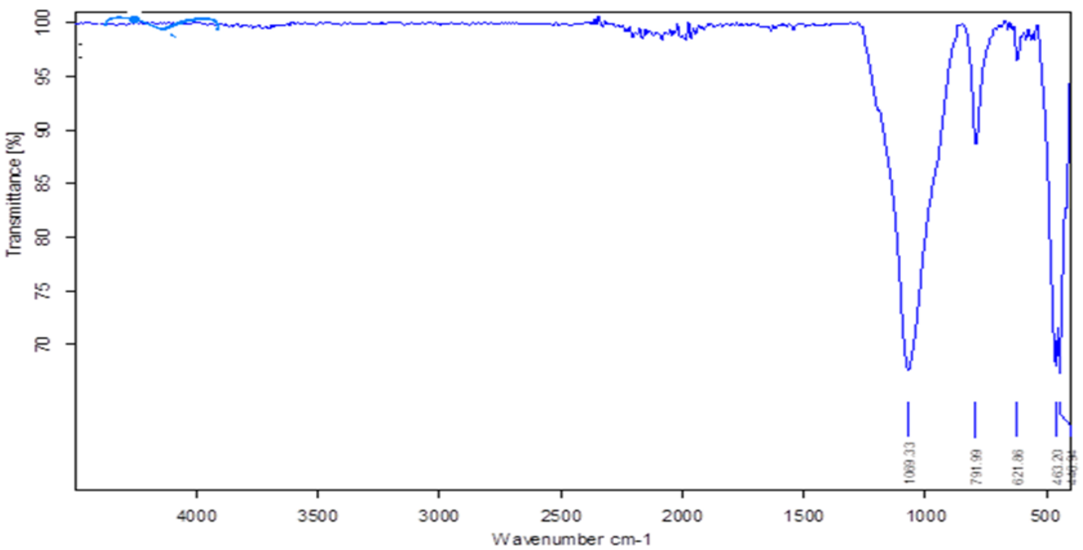

Fig (2) FTIR spectra of SNPs

3.2 Effect of silica source on morphological properties of Maize.

The effects of SNPs, and Micro silica on plant growth were determined by measuring morphological parameters, such as plant height and plant diameter. In addition to crop yield parameters such as number of corn cup and grains number of maize cup and number of per grains cup.

3.2.1Plant height of Maize

Table 2 shows the effect of irrigation regime and foliar application of silica (Micro & Nano) as well as the interaction between them on plant height of maize. Maize plant height was observed to be high in SNPs treated plots while it is found to be reduced under micro silica treatments. No significant difference is observed between SNPs treatments. The plant height was not significantly affected by irrigation regimes. In contrast, there is a considerable increase in plant length when using SNPs and micro-SiO_2 treated plants. Baoshan et al. (2004) studied Larix olgensis by treating chemically synthesized SNPs and observed the promoted seedling growth. In another study, a mixture of SNPs and nano-TiO2 resulted in enhanced seed germination and plant enzyme activity (Lu et al., 2002) which agrees with the current results. Suriyaprabha et al.,(2012) found a considerable increase in the root length of SNPs and micro-SiO_2 treated plants. These results might explain the role of silica in maize plant growth.

Table (2) Effect of irrigation regimes and foliar application of silica (Micro & Nano) on plant height of maize (cm).

Foliar application	First season			Second season		
	Irrigation regime					
	100%	60%	Mean	100%	60%	Mean
No Silica	175.3c	278.0a	226.7C	276.0bc	275.3c	275.7BC
Micro Silica (0.35 g/L)	250.0b	274.0a	262.0B	290.0a	286.0ab	288.0A
Micro Silica (0.70 g/L)	276.0a	286.0a	281.0A	280.0ac	290.0a	285.0A
Nano silica (0.25 g/L)	280.0a	286.0a	283.0A	276.0bc	275.0c	275.5BC
Nano silica (0.50 g/L)	278.0a	288.0a	283.0A	280.0ac	285.7ab	282.8AB
Micro + Nano (0.35 g/L) + Nano (0.25 g/L)	278.0a	288.0a	283.0A	264.0d	281.5ac	272.8C
Mean	256.2B	283.3A		277.7A	282.3A	

3.2.2. Stem width of maize

The effect of irrigation regimes and foliar application of silica as well as on stem width of maize is presented in Table 3. Results reveal that the maize stem width was affected by silica addition to plant. Combination between SNPs and micro silica showed significant increase in the stem width. The increase in stem width in the plots treated with SNPs may be due to accumulation and enlargement of phloem element due to application of nano-silica (Yuvakkumar et al., 2011).

No significant difference was observed between different concentrations of SNPs or between different irrigation regimes. This was attributed to the effect of silica which makes a considerable increase in the root length enhance the ability of plant for water absorption from soil (Suriyaprabha et al., 2012). Overall, plant growth parameters in plots treated by SNPs and micro silica at a concentration of 50% with foliar application were significantly greater than other treatments. Despite the differences in the effect among the used materials (Table 2, 3), there was virtually no difference in plant performance during the two seasons.

3.3 Effect of SNPs on grain yield of maize.

Different parameters were used to assess the effect of silica fertilization on grain yield of maize such as rows and grain number of maize cop. effect of studied materials with interaction with different water regimes on the number of maize cobs are shown in Table 4. The results reveal that addition of SNPs (50%) produced higher yield than the other treatments especially when using 100 % from irrigation water. These results agree with those reported by Miao et al., (2010) and Yang et al., (2008) who concluded that nano-SiO_2 has an advantage for improving plant yield.

Table (5) shows the effect of silica materials and water regimes on grain yield of maize. Plots treated in combination with micro and Nano silica showed higher grain yield than other treatments especially with those irrigated with 100% water demand. It was reported that silica has an important role in plant growth, since silica enhances growth and yield of all annual and vegetable crops, promotes upright growth, which prevents lodging, promotes favorable exposure of leaves to the light, provides resistance to diseases and decrease abiotic stress.

Table (3) Effect of irrigation regimes and foliar application of silica on plant diameter of maize (cm).

Si Foliar application	First season			Second season		
	Irrigation regimes					
	100%	60%	Mean	100%	60%	Mean
No Silica	1.65bc	2.24ac	1.94AB	2.8a	2.9a	2.8A
Micro Silica (0.35 g/L)	2.80a	1.30c	2.05AB	3.0a	3.2a	3.1A
Micro Silica (0.70 g/L)	2.14ac	1.94ac	2.04AB	2.9a	3.1a	3.0A
Nano silica (0.25 g/L)	2.06ac	2.68ab	2.37AB	2.9a	3.0a	3.0A
Nano silica (0.50 g/L)	2.10ac	1.24c	1.67B	2.7a	3.1a	2.9A
Micro + Nano (0.35 g/L) + Nano (0.25 g/L)	2.66ab	2.62ab	2.64A	2.8a	3.2a	3.0A
Mean	2.23A	2.00A		2.8B	3.1A	

Table (4) Effect of irrigation regimes and foliar application of silica on rows number of maize cob.

Si Foliar application	First season			Second season		
	Irrigation regimes					
	100%	60%	Mean	100%	60%	Mean
No Silica	9.9f	17.6b	13.8C	14.9a	13.7bc	14.3A
Micro Silica (0.35 g/L)	14.4de	16.6bc	15.5B	13.6bc	13.6bc	13.6A
Micro Silica (0.70 g/L)	15.4ce	17.2bc	16.3B	12.4d	13.0cd	12.7B
Nano silica (0.25 g/L)	20.4a	16.0bd	18.2A	13.4bd	14.0ac	13.7A
Nano silica (0.50 g/L)	17.9b	14.0de	16.0B	13.6bc	13.4bd	13.5AB
Micro + Nano (0.35 g/L) + Nano (0.25 g/L)	16.8bc	13.4e	15.1BC	14.4ab	13.4bd	13.9A
Mean	15.8A	15.8A		13.7A	13.5A	

Table (5) Effect of irrigation regimes and foliar application of silica on the grain yield of maize (Mg/ha).

Si Foliar application	First season			Second season		
	Irrigation regimes					
	100%	60%	Mean	100%	60%	Mean
No Silica	341.0e	566.0bc	453.5C	506.4ab	537.1ab	521.8AB
Micro Silica (0.35 g/L)	505.0cd	643.2b	574.1B	539.6ab	588.8a	564.2A
Micro Silica (0.70 g/L)	518.0cd	570.4bc	544.2B	485.8a	445.2b	465.5B
Nano silica (0.25 g/L)	459.0d	552.8c	505.9BC	497.6ab	581.0a	539.3AB
Nano silica (0.50 g/L)	488.5cd	561.0bc	524.8B	536.4ab	532.7ab	534.5AB
Micro + Nano (0.35 g/L) + Nano (0.25 g/L)	798.6a	512.2cd	655.4A	584.0ab	519.6ab	551.8A
Mean	518.4B	567.6A		525.0A	534.1A	

3.4 effect of SNPs on yield components.

The carbohydrate and lipids in grains were measured to assess the efficiency of SNPs and silica on maize (Tables 6,and 7). The ratio of carbohydrate was significantly increased using micro, nano silica, and their combination**.** SNPs achieved higher contents of carbohydrate under 60% of irrigation demand, which proves that using SNPs might be useful under stress conditions of drought. In the second season SNPs (50%) achieved significant carbohydrate than other treatments. These results may be attributed to high concentration of potassium in leaves of plants treated with SNPs (50%), which are responsible for transferring carbohydrates from leaves to grains. Potassium ions were adsorbed onto SNPs by ionic bond with negative functional groups functionalized on the surface of SNPs. The results show that SNPs (50%) and Micro silica (100%) achieved higher ratio of lipids than other treatments (Table 7). These results indicated that using low amounts of nanomaterials achieve the same benefits of high amounts of micronutrients. In general,the values of carbohydrate and lipids were lower in second season than the first season. This may be attributed to lower mineral contents in the soil of the second season and its light texture which lead to loss of nutrients by leaching.

Table (6) Effect of irrigation regimes and foliar application of silica on carbohydrates % of grains**.**

Si Foliar application	First season			Second season		
	Irrigation regimes					
	100%	60%	Mean	100%	60%	Mean
No Silica	71.52e	71.67d	71.60C	38.32	61.35	49.83
Micro Silica (0.35 g/L)	71.94a	71.91ab	71.93A	27.38	5.48	16.43
Micro Silica (0.70 g/L)	71.45e	71.29f	71.37E	120.45	32.85	76.65
Nano silica (0.25 g/L)	71.25f	71.86ac	71.56CD	304.01	27.40	165.71
Nano silica (0.50 g/L)	71.20f	71.75cd	71.47D	27.38	39.57	33.47
Micro + Nano (0.35 g/L) + Nano (0.25 g/L)	71.85ac	71.78bd	71.82B	26.48	52.56	39.52
Mean	71.54B	71.71A		90.67A	36.54B	

Table (7) Effect of irrigation regimes and foliar application of silica on Lipids % of grains**.**

Si Foliar application	First season			Second season		
	Irrigation regimes					
	100%	60%	Mean	100%	60%	Mean
No Silica	9.59b	9.57b	9.58	3.28d	3.30c	3.29C
Micro Silica (0.35 g/L)	9.09e	9.56b	9.33	3.32b	3.31bc	3.315
Micro Silica (0.70 g/L)	9.88a	9.28d	9.58	3.3c	3.24e	3.27D
Nano silica (0.25 g/L)	9.83a	9.55b	9.69	3.31bc	3.30c	3.305B
Nano silica (0.50 g/L)	9.61b	9.38cd	9.49	3.32b	3.35a	3.337A
Micro + Nano (0.35 g/L) + Nano (0.25 g/L)	9.03e	9.52bc	9.27	3.36a	3.25e	3.305B
Mean	9.51A	9.48A		3.32	3.29	

Conclusion

Silicon nano particles . SNPs enhanced in all plant aspects**.** Since SNPs achieved significant values of morphological, grain yield and grain component higher than other treatments especially low levels of foliar application of SNPs. Different plant characteristics measured were not affected by irrigation water when treated with foliar application of SNPs. The use foliar application of SNPs is recommended especially when plant was suffering from stress condition of drought.

References

[1] Anderson, D.L.: 1991.‘Soil and leaf nutrient interactions following application of calcium silicate slag to sugarcane’, Fertilizer Res., 30, 9–18

[2] Ayres, A.S.: 1966.‘Calcium silicate slag as a growth stimulator for sugarcane on low silicon soils’, Soil Sci., 101, 216–227

[3] Bao-shan, L.; Shao-qi, D.; Chun-hui, L.; Li-jun, F.; Shu-chun, Q.; Min, Y. Effects of TMS (nanostructured silicon dioxide) on growth of Changbai larch seedlings. J. Forestry Res., 2004, 15, 138-140.

[4] Chapman H.D. and Pratt P.F, 1978. methods of analysis for soils plants and waters unit. California Di. Agric Sci Public. CA. USA.Cheng, L., Zheng, L., Li, G., Yao, Z., Yin, Q., Jiang, K.: ‘Manufacture of epoxy-silica nanoparticle composites and characterisation of their dielectric behavior’, Int. J. Nanoparticles, 2008, 1, pp. 3–13

[5] Clark, L.J.; Whalley, W.E.; Ellis-Jones, J.; Dent, K.; Rowse, H.R.; FinchSavage, W.E.; Gatsai, T.; Jasi, L.; Kaseke, N.E.; Murungu, F.S.; Riches, C.R.; Chiduza, C. On farm seed priming in maize: A physiological evaluation. Proceedings of the 7th eastern and South africa regional maize conference Kenya, 2001; pp. 268-273.

[6] Das, S., Mandai, S., Chakrabarty, A.N., Dastidar, S.G.: ‘Metabolism of silicon as a probable pathogenicity factor for Mycobacterium’, Indian J. Med. Res., 1992, 95, pp. 59–65.

[7] Datnoff, E.L., Deren, C.W., Snyder, G.H.: ‘Silicon fertilization for disease management of rice in Florida’, Crop Prot., 1997, 16, pp. 525–531

[8] Datnoff, L.E.;and Rodrigues, F.A. The role of silicon in suppressing rice diseases. APSnet feature story. Am. Phytopathol. Soc., 2005, 1-28.

[9] Debnath, N.; Das, S., Seth, D.; Chandra, R.; Bhattacharya, C.S.; Goswami, A. Entomotoxic effect of silica nanoparticles against Sitophilus oryzae (L.). J. Pest. Sci., 2011, 84, 99-105.

[10] Dinda, A.K., Prashant, C.K., Naqvi, S., Unnithan, J., Samim, M., Maitra, A.: ‘Curcumin loaded organically modified silica (ORMOSIL) nanoparticle; a novel agent for cancer therapy’, Int. J. Nanotechnol., 2012, 9, pp. 862–871

[11] Epstein, E.: ‘Silicon’, Annu. Rev. Plant Physiol. Plant Mol. Biol., 1999, 50, pp. 641–664

[12] Gholami, A., Shahsavani, S., Nezarat, S.: 'The effect of plant growth promoting rhizobacteria (PGPR) on germination, seedling growth and yield of maize', Int. J. Biol. Life Sci., 2009, 1, pp. 35–40
[13] Haghighi, M.; Afifipour, Z.; Mozafarian, M. The effect of N-Si on tomato seed germination under salinity levels. J. Biol. Environ. Sci., 2012, 6, 87-90.
[14] Hodson, M.J.; Evans, D.E. Aluminium/silicon interactions in higher plants. J. Exp. Bot., 1995, 46, 161-171.
[15] Hossain, M.T.; Mori, R.; Soga, K,; Wakabayashi, K.; Kamisaka, S.; Fujii, S.; Yamamoto, R.; Hoson, T. Growth promotion and an increase in cell wall extensibility by silicon in rice and some other Poaceae seedlings. J. Plant. Res., 2002, 115, 23-27.
[16] Josko, I., Oleszczuk, P.: 'Influence of soil type and environmental conditions on ZnO, TiO2 and Ni nanoparticles phytotoxicity', Chemosphere, 2013, 92, pp. 91–99
[17] Khakipour, N., Khavazi, K., Mojallali, H., Pazira, E., Asadirahmani, H.: 'Production of auxin hormone by fluorescent Pseudomonads', American-Eurasian J. Agric. Environ. Sci., 2008, 4, pp. 687–692
[18] Lin, D., Xing, B.: 'Phytotoxicity of nanoparticles: inhibition of seed germination and root growth', Environ. Pollut., 2007, 150, pp. 243–250
[19] Lu, C.M.; Zhang, C.Y.; Wen, J.Q.; Wu, G.R.; Tao, M.X. Research of the effect of nanometer materials on germination and growth enhancement of Glycine max and its mechanism. Soybean Sci., 2002, 21, 168-172.
[20] Ma, J.F.: 'Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses', Soil Sci. Plant Nutr., 2004, 50, pp. 11–18
[21] Mahmood, S.; Hussain, A.; Saeed, Z.; Athar, M. Germination and seedling growth of corn (Zea mays L.) under varying levels of copper and zinc. Int. J. Environ. Sci. Tech., 2005, 2, 269-274.
[22] Miao, B.H.; Han, X.G.; Zhang, W.H. The ameliorative effect of silicon on soybean seedlings grown in potassium-deficient medium. Ann. Bot., 2010, 105, 967-973.
[23] Murashov, V. Comments on particle surface characteristics may play an important role in phytotoxicity of alumina nanoparticles by Yang, L.; Watts, D.J. Toxicol. Lett., 2005, 158, 122-132. Toxicol. Lett., 2006, 164, 185-187.
[24] Ortíz-Castro, R., Valencia-Cantero, E., López-Bucio, J.: 'Plant growth promotion by Bacillus megaterium involves cytokinin signalling', Plant Signal Behav., 2008, 3, pp. 263–265
[25] Paulkumar, K., Arunachalam, R., Annadurai, G.: 'Biomedical applications of organically modified bioconjugated silica nanoparticles', Int. J. Nanotechnol., 2011, 8, pp. 653–663
[26] Premaratne, W.A.P.J., Priyadarshana, W.M.G.I., Gunawardena, S.H.P. and De Alwis, A.A.P. (2013). Synthesis of Nanosilica from Paddy Husk Ash and Their Surface Functionalization, Journal of Science, University of Kelaniya, 8: 33-48.
[27] Rafi, M.M.; Epstein, E.; Falk, R.H. Silicon deprivation causes abnormalities in wheat (Triticum aestivum L.). J. Plant Physiol., 1997, 152, 497-501.
[28] Romero-Aranda, M.R.; Jurado, O.; Cuartero, J. Silicon alleviates the deleterious salt effect on tomato plant growth by improving plant water status. J. Plant. Physiol., 2006, 163, 847-855.
[29] Savant, N.K., Korndorfer, G.H., Datnoff, L.E., Snyder, G.H.: 'Silicon nutrition and sugarcane production: a review', J. Plant Nutr., 1999, 22, pp. 1853–1903
[30] Supanjani, Han, H.S., Jung, J.S., Lee, K.D.: 'Rock phosphate-potassium and rock-solubilising bacteria as alternative, sustainable fertilisers', Agron. Sust. Dev., 2006, 26, pp. 233–240
[31] Wainwright, M., Al-Wajeeh, K., Wickramasinghe, N.C., Narlikar, J.V.: 'Did silicon aid in the establishment of the first bacterium?', Int. J. Astrobiol., 2003, 2, pp. 227–229
[32] Wainwright, M.: 'The neglected microbiology of silicon', Soc. Gen. Microbiol. Q., 1997, 24, pp. 83–85
[33] Yang, Y.; Li, J.; Shi, H.; Ke, Y.; Yuan, J.; Tang, Z. Alleviation of silicon on low-P stressed maize (Zea mays L.) seedlings under hydroponic culture conditions. World J. Agri. Sci., 2008, 4, 168-172 .
[34] Yuvakkumar, R., Elango, V., Rajendran, V., Kannan, N. 2014. High-purity nano silica powder from rice husk using a simple chemical method. J. of Experimental Nanoscience. 9, 3. 272 -281 .
[35] Yuvakkumar, R., Elango, V., Rajendran, V., Kannan, N.S., Prabu, P.: 'Influence of nanosilica powder on the growth of maize crop (Zea mays L.)', Int. J. Green Nanotechnol., 2011, 3, pp. 180–190