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REVIEW ARTICLE

Effects of Silicon Application on Crop Growth and Productivity under Stressful Environments: A Mini Review

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ABSTRACT

Silicon (Si) being the second most abundant natural element in the soil after oxygen, many research reports ostensibly confirm its effective application confer imminent tolerance to various abiotic and biotic stress such as drought, acidity induced edaphic constraints, heavy metal toxicity and disease pests in agricultural and horticultural crops.Optimized Si nutrition witnessed significant positive effect on improved plant growth, photosynthetic activity and thereby enhances the overall productivity under stressful environment. Si majorly involved in the reduced formation of toxic reactive oxygen species (ROS) and act as primary factor in decreasing relentless lipid peroxidation and membrane damage while increasing the activity of ROS sequestering enzymes viz., superoxide dismutase(SOD), ascorbate peroxidase (APX), glutathione reductase (GdH), catalase which are vital to regulate and sustain optimal metabolic capacity and normalized growth under stressful environment. Si is also known to impart biotic stress tolerance like disease and pest resistance in several agricultural crops. In this backdrop, this review mainly discuss and deliberate on the major effects of silicon application on the crop growth, physiology and other associated aspects of plant growth and development especially by alleviation role of silicon under acid soil induced edaphic stresses.

***Keywords**: Detoxification, Elemental toxicity, Photosynthesis, Silicon nutrition,Disease resistant*

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INTRODUCTION

Plants known to accumulate silicon (Si) are unprecedently benefitted from its nutrition. It is ideally considered as beneficial element for increasing plant growth and development as it critically required by some plant species under specified conditions [1, 2]. Potential beneficial effects of Si are tacitly reported by various researchers with enhancement the tolerance of plants to various abiotic and biotic stresses. Various experiments conducted in the laboratory, greenhouse, and field conditions have clearly demonstrated the benefits of silicon fertilizers for crops substantiating the importance of such fertilizers as aintegral component in sustainable agriculture. However, to benefit from SiO_2, the plant must be able to acquire this element in high concentrations particularly by altering and modifying the basic cellular metabolic events such as controlling cell wall and cytosolic properties [1, 3]. An estimated need of silica as soil amendment was 1-100 kg ha^{-1} in range for monocots plants [4] and the degree of Si solubility is depends on soil physical and chemical properties. Applied silicon apparently interacts favourably with other nutrients and offers to improve their agronomic performance efficiency and yield response. The silicon transport using metal salts of silicic acid needs their hydrolysis before their uptake, which affects ionic balance of the soil and plant system [5]. Si application also alleviated metal toxicity and enhances resistance against fungi, bacteria and pest disease attack on crop plants. In this background, this review comprehensively bring out and illustrates the role of silicon on crop growth and physiology with special reference to acid soil condition which is predominantly present across North East Hill region of India.

SILICON ON PLANT GROWTH AND DEVELOPMENT

Silicon absorbed in the form of orthosilicic acid and applied Si has direct and indirect beneficial effects on plant growth largely due to its unique physiological role. It promotes growth attributes, photosynthetic activity, improved leaf and stalk erectness to avoid lodging in rice. As absorbed silica is present in leaves and stalks, it enhances photosynthesis and transpiration rate [6]. Numerous researchers reported that the plants grown without Si or under low Si have shown malformation of young leaves, bears chlorosis of mature leaves and witnesses leaf senescence, leaf tracking, yellowing and browning of lower leaves. Necrotic spots, poor tillering and dried leaf tips, small panicles with high sterility is also evident. To avoid this, silicon can be applied through various means viz., foliar application, soil application, hydroponics, seed priming and even use as seedling root dip techniques. Foliar application of Si @ 0.50% was produced maximum grain diameter and grain protein while silicon @ 1.00 % found the maximum number of productive tillers, straw yield, spike per panicle, 1000 grain weight, paddy yield and grain starch of Basmati rice on loamy soil [7] and it also increased the root and total length of white oat seedlings[8]. Si application also increased the internode diameter, internode wall thickness, filled grain ratio, silicon accumulation in rice shoot and husk [9]. Moreover, a pot experiment in wheat under silty loam soil has revealed that application of 0.25%-0.50% silicic acid increased the rate of germination while overdose was found harmful which consequently reduced the germination rate and also affected the total crop stand and yield [10].

In addition, Si application at 300 kg Si ha^{-1} increased the plant growth parameters like plant height and shoot dry matter However, these growth parameters were statistically par across 150, 300 and 600 kg Si ha^{-1} doses[11]. Similarly, there was no significant difference on growth parameters with different levels of foliar silicic acid alone and along with half dose of pesticide at hilly zone while it was significant at coastal zone. The plant growth parameters like plant height, panicle length and no of tillers were found higher with the foliar spray of silicic acid at 4 ml L^{-1}alone and along with half dose of pesticides over control and other treatments[12]. On the other hand, seed priming with silicon in the form of silica gel with 1.5% silicon concentration has increased the grain yield of wheat with maximum spike length (14.3 cm) and enhanced biological yield (7.63 g pot^{-1}), hundred grain weight (3.97 g pot^{-1}) and grain yield (2.46 g pot^{-1}) [13]. Further, Si application has increased the germination or vigor of wheat seeds.

SILICON ON CROP PHYSIOLOGY

Silicon distribution and accumulation depended with the respective age and parts of the plant. The mature leaf of forage grass *Brachiariabrizantha*content Si content in the decreasing order of mature leaf blades > recently expanded leaf blades > non expanded leaf blades. Grass leaf blades exhibit a non-uniform distribution pattern of Si on the adaxial leaf surface, which reflects the silica deposition exclusively on the cell wall of bulliform cells[14]. In rice plant, Si was firstly lignified and silicified in the cell wall and then deposited gradually in silica cells as leaves aged until the leaf was fully matured [15].Extensive research about the Si application in rice was significantly increased the leaf chlorophyll content and reduced lipid peroxidation compares to non-Si treated plants. In addition, Si application regulated the wound-related stress to plants [16].The Si application (2mM) promoted the accumulation of photosynthetic pigments and stability of the cell membrane in maize plants. but didn't show significant changes in hydrogen peroxide, glutathione, electrolyte leakage and melondialdehyde in leaf and root tissues of the plant[17]. However, the increasing grain yield of maize by increasing photosynthesis (maximum quantum yield of photosystem II, an effective quantum efficiency of PS-II, photochemical quenching of PS-II) and antioxidant enzyme activity was recorded[18]. In addition, foliar application of Si on Sugar beet showed the positive correlation with leaf area index (LAI) and photosynthetic active radiation (PAR) and yield of roots and technological sugar [19].The combined effect of Si, N and P nutrition improved the growth, photosynthetic rate, and concentration of chlorophyll and soluble sugar of rice after flood overcast and consequent recovery [20]. Moreover, the fertilization with Si has improved the architecture of upland rice plants by reducing the leaf angle and increasing the chlorophyll content[21].

The Si application reduced the decline of physiological and biochemical activities like excessive respiration, melondialdehyde (MDA), production upon reduced lipid peroxidation, electrolyte leakage by increasing the plasma membrane stability, root antioxidant defense capacity in rice seedling roots under water stress plants[22]. The foliar application of sodium and calcium silicate increased the activity of catalase (CAT), ascorbate peroxidase (APX), guaiacol peroxidase (GPX) and MDA content while proline and H_2O_2 concentration of chrysanthemum was decreased[23]. Similarly, Si addition also increased in antioxidant enzymes such as CAT, superoxide dismutase (SOD), APX and metabolites like methionine, proline in alfalfa plants and reduced H_2O_2 providing antioxidant defense against Cd stress in alfalfa plants [24] and its application on maize seedling (2mM) accelerated amylase activity, decreased abscisic acid increased indole acetic acid and gibberellic acid contents. [25]. Si application in the form of potassium silicate also reduced the fruit respiration and ethylene evolution rate and maintained the fruit quality of Avocado[26]. The rate of transpiration (E) under field conditions was also reduced by silicon application resulting from increased stomatal sensitivity and cuticular resistance which was the main reason for maintaining photosynthetic activity, and thus increased dry matter production in Si treated plants[27].Si application (foliar and Soil) was also improved the quality of Banana fruits in terms of days taken for full ripening of the fruits, acidity, total soluble solid, shelf life, reducing sugar, non reducing sugars and pulp peel ration of the fruit over control[28].The edaphic factors affecting silicon availability to roots was shown in Figure 1.

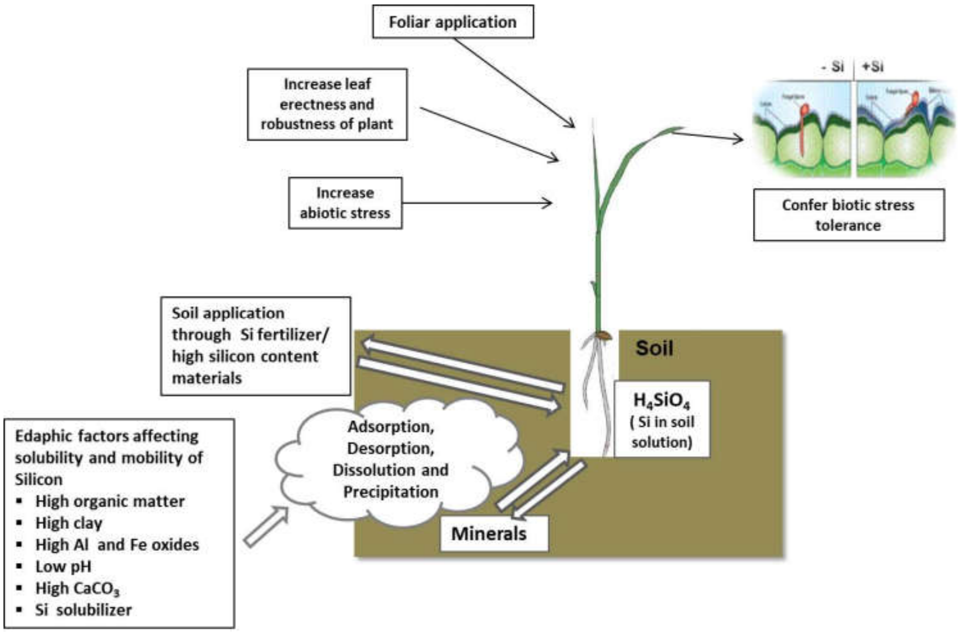

Figure 1Major soil physical and chemical properties affecting silicon availability to roots

Table 1: Common plant diseases caused by different microorganism known to reduce upon Si application.

Host	**Disease**	**Micro organism**	**Causal organism**	**Reference**
Rice	Blast	Fungi	*Magnaportheoryzae*	Gao *et al.* [58]
	Blast	Fungi	*Pyriculariaoryzae*	Cacique *et al*. [59]
	Brown spot	Fungi	*Bipolarisoryzae*	Rezende *et al*. [60]
	Striped Stem Borer	Insect	*Chilosuppressalis*	Hosseini *et al* [61]
Avocado	Black root rot	Fungi	*Calonectriailicicola*	Dann and Le [62]
Cucumber	Powdery mildew	Fungi	*Podosphaeraxanthii*	Liang et al. [6]
Pumpkin	Powdery mildew	Fungi	*Sphaerothecafuliginea*	Mohaghegh *et al.* [63]
Sugarcane	Borer	Insect	*Diatraeasaccharalis*	Vilela et al. [64]

SILICON ON SOIL ACIDITY TOLERANCE

Under widespread and unprecedented soil acidity, high concentration of aluminum (Al) directly affects the growth and yield of crop especially in vast tracts of sub-Himalayan Northeast India. The effect of Al toxicity on crop growth and yield mainly occurred when the soil pH ≤ 5.5 [29] as the solubility of Al increased to manifolds which primarily targeted to inhibit root tip growth and thereby affects uptake of essential nutrients [30]. As result of this, many physiological and biochemical processes of plants are impaired significantly affecting overall plant metabolism and growth which consequently reduce their performing productivity [31]. Al toxicity unwarrantedly increases the production of reactive oxygen species (ROS) causing improper root growth, proliferation with engrained damage on plant membranes and cell organelles. In addition, Si also increased the antioxidant activity and thereby decreases the efficacy of photosynthetic machinery [29].

Beneficial effect of Si nutrition in ameliorating the harmful effects of Al and Fe toxicities in cereals has been widely reported [32].The Si-decreased Mn accumulation in rice is a consequence of both reduced root-to-shoot translocation of Mn, probably by formation of Mn-Si complex in the root cytosol, and decreased Mn uptake due to down-regulation of *OsNramp5* gene in rice [33]. A field experiment conducted in acidic soil of Karnataka showed that the silicon application @ 8 ml L^{-1} as foliar application in the form of potassium silicate has increased the utilisation of macronutrients and resulted more yield and quality of Sapota, [34]. Addition of silicon significantly increased plants biomass of seedling in both root and shoot. Silicon has antagonistic effect with Zn concentration in soil and silicate supply has increased the cell-bound fraction of Zn up to 10% [35]. Si uptake is correlated with the presence of lateral roots and that the gene controlling formation of lateral roots [36]. Ammonical fertilizers such as $(NH_4)_2SO_4$ and urea, have increased dissolution of applied Ca_2SiO_4 and subsequent uptake of Si by sugarcane [37].

The ameliorative effect of Si on Al toxicity reduced the toxic Al^{3+} concentration in solution by forming Al-Si complexes [38]. The pre-treated plants with Si exhibited was higher root elongation rates than the not pretreated Si which is possibly due to the lower Al uptake in Si pretreated plants but it was clear that there was not a consequence of decreased Al availability in the bulk solution[39] and Si alleviated the phytotoxicity of Al at lower concentration (up to50 μmol L^{-1}) of Al, but exaggerated it at a higher concentration of Al in Barley. Thus effect of Si on Al toxicity depends upon the plant spa, Al and Si levels and the duration of plant exposed to Al stressed environment[40].Si application also decreased the translocation of Fe from roots to shoots[41].

Moreover, the significant role of Si extend to the ameliorative effects on metal toxicity including manganese (Mn), iron (Fe), cadmium (Cd), arsenic (As), chromium (Cr), copper (Cu), lead (Pb), zinc (Zn), and Al. The Si induced mitigation of Cd toxicity in maize plant was related to the development of apoplastic barriers and maturation of vascular tissue in roots. Alleviation of Cd toxicity by added Si might be attributed to enhanced binding of Cd to the apoplasmic fraction in maize shoots[42].Ca-silicates application reduced heavy metals content (Fe, Cu, Zn and Mn) in sugarcane leaf tissue and soil and it also improved the nutrient status (P, K, S, Ca and Mg) and CEC of soil [43]. The Si induced Cd tolerance in rice leaves was due to the changes in the rice leaf proteome. Around 60 protein spots were identified under this mechanism. Out of this, 50 were regulated by Si including protein associated with photosynthesis, redox homeostasis, regulation/protein synthesis, and pathogen response and chaperone activity.

SILICON UNDER DROUGHT CONDITIONS

Under unabated drought stress, Si application improved the key physiological response of plant like leaf transpiration rate, antioxidant processes and leaf conductance. It enhanced seed germination and improvement of photosynthetic quantum in tomato seedlings under imminent occurrence of environmental stress [44]. Si application increased plant growth and biomass of wheat under drought stress condition [45]. The silicon treated plant has increased cell-wall extensibility in the apical and subapical zones with concomitant decrease in elastic moduli (E) and viscocity coefficient (η). Siliconfertilization under water stress condition especially in upland rice has decreased the proline content in both the vegetative and reproductive stages while the peroxidase activity was increased in reproductive phase which clearly shows the stress tolerance of rice plant in presence of silicon fertilizer [46]. Foliar application of silicon at tillering and anthesis stages promotes draught resistance by maintaining cell membrane integrity, relative water content and increasing chlorophyll content[47] and Si increased the leaf water potential, leaf area index, SPAD chlorophyll, net assimilation and relative growth rate in sorghum which can help to resist in drought [48]. Si application increased the water use efficiency in maize which is due to reduction in transpiration rate through stomata and Si influenced the stomata movement. Water flow in xylem vessels with 2mmol L^{-1} was 20% lower than that of without Si [49]. Foliar Si application can ameliorate water stress induced damage in wheat seedlings and maintained the cell membrane integrity from membrane injury [50]. The pre-treated Hawthorn seedlings with Si nanoparticles (SNPs) decreased carbohydrate and proline content under drought stress. SNPs gave a positive role in maintaining critical physiological and biochemical functions in hawthorn seedlings under drought stress conditions[51].

In North-East India, the major drought occurs especially during the winter period [52]. According to the Indian Meteorological Department (IMD), altogether the eastern and north-eastern regions have received 31% less rainfall than the normal in this south-west monsoon season as on July 25, 2018 [53]. Such a way, the agricultural fields in North-East India fears the seasonal drought especially rabi crops. Besides the improving breeding and transgenic approaches, the application of Si is an alternative ways for improving plant growth under stressful conditions. However, the application of Sias drought improving methods in North East India is seldom reported. Therefore, the use of Silicon treatment is one of the most important methods to improve the plant growth under this continuous changing stressful environment and it is highly recommended for this region, the acidic rainfed area of North-eastern region India.

SILICON ON DISEASE TOLERANCE

Role of silicon fertilization is well established for imparting disease resistance by several researchers. The silicon fertilizer reduced the disease like blast it may be due to the following two hypothesis *i. e*. silicon function as mechanical barrier against appressorial penetration and another one is that silicon has some physiological roles in disease resistance[54]. The silicon application significantly ($\alpha = 0.05$) reduced the severity of disease with the highest reduction (75%) recorded in treatments receiving 120 g of silica gel[55]. However, the disease severity reduction was higher with silica gel (root) application than sodium silicate (foliar) treatment at all rates compared to the control treatment. Si application was significantly reduced leaf folder larval survival[56]. However, Si application alone could not change the defense related enzymes and melondialdehyde concentration in rice leaves. In addition, silicon reduced soluble protein content and cell silification of rice leaves. The management of sheath blight of rice was significantly effective by giving Si fertilization as compare with Cu and Zn applied treatments which result in several yield loss[57]. Some common plant disease which reported to be reduced by silicon application is listed and presented in table 1.

SILICON AS HARVIBORE REPELLENT

The silicon application is also responsible for increased plant defenses from herbivore in *Cucumissativa* which is primarily due to increase accumulation of defence volatile emissions. However there was no major change in physical defences of lignin and leaf-trichomes[65] and priming of jasmonate (JA) with Si result the defence mechanism against insect herbivore and the promotion of Si by JA[66].

CONCLUSION

Silicon has a significant positive impact on plant growth and development especially by altering several crop physiological processes and also by imparting abiotic and biotic stress tolerance which thereby improves and sustain the crop productivity under stress conditions. Al toxicity in acid soil and heavy metal toxicity can be reduced by Si application in the soil to a great extent. The application of Si also increased the drought tolerance under stressful conditions. Moreover, application of Si has clearly increased the resistance against the pests and diseases and even increased repellent power against herbivore. Si promotes and maintains all basic plant processes like the photosynthetic parameters, plant hormones and enzyme activities even under stress prevailing condition.

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REFERENCES

1. Epstein, E. (1999). Silicon. Annual Review of Plant Biology, 50:641–664
2. Ma, J.F. &Yamaji, N. (2015). A cooperative system of silicon transport inplants. Trends in Plant Science,20:435–442.
3. Ma, J.F. &Yamaji, N. (2006). Silicon uptake and accumulation in higher plants.Trends in Plant Science, 11:392–397.
4. Matichenkov, V.V. &Bocharnikova, E.A. (2001). The relationship between silicon and soil physical and chemical properties. *In*: Silicon in Agriculture, Vol. 8, Studies in Plant Science. Datnoff, L.E., Snyder, G.H., Korndorfer, G.H. (eds). Amesterdam, The Netherlands: Elsevier, 209-219.
5. Ranganathan, S., Suvarchala, V., Rajesh, Y.B.R.D., Srinivasa Prasad, M., Padmakumari, A.P. &Voleti, S.R. (2006). Effects of silicon sources on its deposition, chlorophyll content, and disease and pest resistance in rice. BiologiaPlantarum, 50(4):713-716.
6. Singh, K.K., Singh, K., Singh, R.S., Singh, R. &Chandel, R.S. (2005). Silicon nutrition in rice – A review. Agric. Rev., 26(3): 223-228.
7. Ahmad, A.Afzal, M., Ahmad, A.U.H. &Tahir, M. (2013). Effect of foliar application of silicon on yield and quality of rice (*Orizasativa* L.). CercetariAgronomice in Moldova,XLVI(3): 21-28.

8. Tolido, M.Z., Castro, G.S.A., Crusciols, C.A.C.,Soratto, R.P., Cavarianis, C., Ishizuka, M.S. &Picoli, L.B. (2012). Silicon leaf application and physiological quality of white oat and wheat seeds. DOI: 10.5433/1679-0359.2012v33n5p1693.
9. Nhan, P.P., Dong, N.T., Nhan, H.T. & Chi, N.T.M. (2012). Effects of OryMax^{SL} and Siliysol^{MS} on growth and yield of MIL560 rice. World Applied Science Journal, 19(5):704-709.
10. Abro, S.A., Qureshi, R., Soomro, F., Mirbahar , A.A. &Jakhar, G.S. (2009). Effects of silicon levels on growth and yield of wheat in silty loam soil. Pak. J. Bot., 41(3): 1385-1390.
11. Ullah, H., Luc, P.D., Gautam, A. &Datta, A. (2017). Growth, yield and silicon uptake of rice (*Oryza sativa*) as influenced by dose and timing of silicon application under water-deficit stress. Archives of Agronomy and Soil Science, DOI:10.1080/03650340.2017.1350782.
12. Prakash, N.B., Chandrashekar, N., Mahendra, C., Patil, S.U., Thippeshappa, G.N. &Laane, H.M. (2011). Effect of foliar spray of soluble silicic acid on growth and yield parameters of wetland rice in hilly and coastal zone soils of Karnataka, South India. Journal of Plant Nutrition, 34(12):1883-1893.
13. Ahmed, M., Qadeer, U., Ahmed, Z.I. & Hassan, F.U. (2015). Improvement of wheat (*Triticumaestivum*) drought tolerance by seed priming with silicon. Archieves of Agronomy and Soil Science, doi:10.1080/03650340.2015.1048235.
14. Melo, S.P.D., Monteiro, F.A. & Bona, F.D.D. (2010). Silicon distribution and accumulation in shoot tissue of the tropical forest grass *Brachiariabrizantha*. Plant Soil, 336:241-249.
15. Zhang, C., Wang, L., Zhang, W. & Zhang, F. (2013). Do lignifications and silicification of the cell wall precede silicon deposition in the silica cell of the rice (*Orizasativa* L.) leaf epidermis? Plant Soil, 372:137-149.
16. Kim, Y.H., Khan, A.L., Waqas, M., Shahzad, R. & Lee, I.J. (2016). Silicon-mediated mitigation of wounding stress acts by up-regulating the rice antioxidant system. Cereal Research Communication 44(1):111-121.
17. Barbosa, M.A.M., Silva, M.H.L.D., Viana, G.D.M., Ferreira, T.R., Souza, C.L.F.D.C., Lobato, E.M.S.G. &Lobato, A.K.D.S. (2015). Beneficial repercussion of silicon (Si) application on photosynthetic pigments in maize plants. Australian Journal of Crop Science, 9(11):1113-1118.
18. Xu, H., Lu, Y. &Xie, Z. (2016). Effects of silicon on maize photosynthesis and grain yield in black soils. EmiratesJournal of Food and Agriculture, 28(11):779-785.
19. Artyszak, A., Gozdowski, D. &Kucinska, K. (2016). Effect of foliar fertilization with silicon on the chosen physiological features and yield of sugar beet. Fragm. Agron., 33(2): 7-14.
20. Lal, B., Gautam, P., Mohanty, S., Raja, R., Tripathi, R., Shahid, M., Panda, B.B., Baig, M.J., Rath, L., Bhattacharyya, P. &Nayak, A.K. (2015). Combined application of silica, nitrogen alleviates the damage of flooding stress in rice. Crop and Pasture Science, 66:679-688.
21. Oliveira, J.R.D., Koetz, M., Bonfim-Silva, E.M. & Silva, J.A.D. (2016). Production and accumulation of silicon (Si) in rice plants under silicate fertilization and soil water tensions. Australian Journal of Crop Science, 10(2): 244-250.
22. Dong-feng, M., Hong-mei, Y., Yu-hai, W., Hai-jun, G. & Wei-jun, Z. (2012). Effects of silicon on the physiological and biochemical characteristics of roots of rice seedlings under water stress. ScientiaAgriculturaSinica,45(12):2510-2519. doi: 10.3864/j.issn.0578-1752.2012.12.021.
23. Hajipour, H. &Jabbarzadeh, Z. (2016). Effect of foliar application of silicon on physiological responses of Chrysanthemum (*Dendranthema* x *grandiflorum*) at two different growth stages. Journal of Ornamental Plants, 6(1):39-47.
24. Kabir, A.H., Hossain, M.M., Khatun, M.A., Mandal, A. &Haider, S.A. (2016). Role of silicon counteracting cadmium toxicity in Alfalfa (*Medicago sativa* L.). Frontiers in Plant Science, DOI: 10.3389/fpls.2016.01117.
25. Delavar, K., Ghanati, F., Zare-Maivan, H. &Behmanesh, M. (2017). Effects of silicon on the growth of maize seedlings under normal, aluminium and salinity stress conditions. Journal of Plant Nutrition, DOI:10.1080/01904167.2016.1269344.
26. Kaluwa, K., Bertling, I., Bower, J.P. &Testay, S.Z. (2010). Silicon application effects on 'Hass' avocado fruit physiology. South African Avocado Growers' Assocciation Yearbook, 33:44-47.
27. Agarie, S., Uchida, H., Agata, W., Kuboto, F. & Kaufman, P.B. (1998). Effect of silicon on transpiration and leaf conductance in rice plants (*Oryza sativa* L.). Plant Prod. Sci., 1(2): 89-95.
28. Hanumanthaiah, M.R., Kulapatihipparagi, R.C., Vijendrakumar, R.C., Renuka, D.M., Kirankumar, K. &Santhosha, K.V. (2015). Effect of soil and foliar application of silicon on fruit quality parameters of banana cv. Neypoovan under Hill zone. Plant Archives, 15(1):221-224.
29. Merino-Gergichevich, C., Alberdi, M., Ivanov, A.G. & Reyes-Diaz, M. (2010). Al^{3+} - Ca^{2+} interaction in palnts growing in acid soils: Al-phytotoxicity response to calcareous amendments. J. Soil Sc. Plant Nutr., 10(3):217-243.
30. Ma, J.F., Ryan, P.R. & Delhaize, E. (2001b). Aluminium tolerance in plants and the complexing role of organic acids. Trends Plant Science, 6:273-278.
31. Mora, M.L., Alfaro, M.L., Jarvis, S.C, Demanet, R. &Cartes, P. (2006). Soil aluminium availability in Andisols of Southern Chile and its effect on forage production and animal metabolism. Soil Use Manage, 22:95-101.
32. Sistani, K.R., Savant, N.K. & Reddy, K.C. (2008). Effect of rice hull ash silicon on rice seedling growth. Journal of Plant Nutrition, 20(1):195-201 DOI: 10.1080/01904169709365242.
33. Che, J., Yamaji, N., Shao, J.F., Ma, J.F. &Shen, R.F. (2016). Silicon decreases both uptake and root-to-shoot translocation of manganese in rice. Journal of Experimental Botany, 67(5):1535-1544.
34. Lalithya, K.A., Bhagya, H.P., Taj, A., Bharati, K. &Hipparagi, K. (2014). Response of soil and foliar application of silicon and micronutrients on soil nutrient availability of sapota. The bioscan, 9(1):171-174.

35. Hai-Hong, G., Shu-Shun, Z., Shi-Zhong, W., Ye-Tao, T., Channey, R.L., Xiao-Hang, F., Xin-De&Rong-Linag, Q. (2012). Silicon-mediated amelioration of zinc toxicity in rice (*Oryza sativa* L.) seedlings. Plant Soil, 350:193-204.
36. Ma, J.F., Goto, S., Tamai, K. &Ichii, M. (2001). Role of root hairs and lateral roots in silicon uptake by rice. Plant Physiol, 127:1773-1780.
37. Keeping, M.G., Rutherford, R.S., Sewpersad, C. & Miles, N. (2014). Provision of nitrogen as ammonium rather than nitrate increases silicon uptake in sugarcane. AoB PLANTS,www.aobplants.oxfordjournals.org pp.1-14.
38. Ma, J.F., Sasaki, M. & Matsumoto, H. (1997). Al-induced inhibition of root elongation in com, *Zea mays* L. is overcome by Si addition. Plant Soil, 188:171-176.
39. Corrales, I., Poschenriede,r C. &Barcelo, J. (1997). Influence of silicon pre-treatment on aluminium toxicity in maize roots. Plant and soil, 190:203-209.
40. Liang, Y., Yang, C. & Shi, H. (2001). Effects of silicon on growth and mineral composition of barley grown under toxic levels of aluminium. Journal of Plant Nutrition, 24(2):229-243.
41. Junior, L.A.Z., Fontes, R.L.F., Avila, V.T.D. &Korndorfer, G.H. (2010). Iron and calcium, uptake by rice plants cultivated in nutritional solution with manganese and silicon doses. *ScientiaAgraria* Curitiba,11(3):263-269. 41
42. Vaculik, M., Landberg, T., Greger, M., Luxova, M., Rikova, M.S. & Lux, A. (2012). Silicon modifies root antomy, and uptake and subcellular distribution of cadmium in young maize plants. Annals of Botany, 110:433-443.
43. Bokhtiar, S.M., Hai-Ronghuang& Yang-Ruili. (2012). Response of sugarcane to calcium silicate on yield, gas exchange characteristics, leaf nutrient concentrations and soil properties in two different soils. Communication in Soil Science and Plant Analysis, 43:1363-1381.
44. Almutairi, Z.M. (2016). Effect of nano-silicon application on the expression of salt tolerance genes in germinating tomato (*Solanumlycopersicum* L.) seedlings under salt stress. Plant Omics Journal, 9(1): 106-114.
45. Gong, H., Chen, K., Chen, G., Wang, S. & Zhang, C. (2003). Effect of silicon on growth of wheat under drought. Journal of Plant Nutrition, 26:1055-1063.
46. Mauad, M., Crusciol, C.A.C., Nascente, A.S., Filho, H.G. & Lima, G.P.P. (2016). Effects of silicon and drought stress on biochemical characteristics of leaves of upland rice cultivars. RevistaCiencia Agronomics, 47(3):532-539.
47. Maghsoudi, K., Emam, Y. & Ashraf, M. (2015). Foliar application of silicon at different growth stages alters growth and yield of selected wheat cultivars. Journal of Plant Nutrition, DOI: 10.1080/01904167.2015.1115876.
48. Ahmed, M., Fayyaz-Ul-Hassan &Asif, M. (2014). Amelioration of drought in sorghum (*Sorghum bicolor* L.) by silicon. Communication in Soil Science and Plant Analysis, 45:470-486.
49. Gao, X., Zou, C., Wang, L. & Zhang, F. (2004). Silicon improves water use efficiency in maize plants. Journal of Plant Nutrition, 27(8):1457-1470.
50. Sapre, S.S. &Vakharia, D.N. (2017). Silicon induced physiological and biochemical changes under polyethylene glycol-6000 water deficit stress in wheat seedlings. Journal of Environmental Biology, 38:313-319.
51. Ashkavand, P., Tabari, M., Zarafshar, M., Tomaskova, I. & Struve, D. (2015). Effect of SiO_2 nanoparticles on drought resistance in hawthorn seedlings. LesnePraceBadawcze, 78(4): 350-359. DOI: 10.1515/frp-2015-0034.
52. Saikia, J., Sarma, R.K., Dhandia, R., Yadav, A., Bharali, R., Gupta, V.K. &Saikia, R. (2018). Alleviation of drought stress in pulse crops with ACC deaminase producing rhizobacteria isolated from acidic soil of Northeast India. Scientific Reports, DOI:10.1038/s41598-018-21921-w
53. Sangomla, A. (2018). North-eastern states live in fear of drought https://www.downtoearth.org.in/author/akshit-sangomla-112269
54. Ashtiani, F.A., Kadir, J., Nasehi, A., Rahaghi, S.R.H. &Sajili, H. (2012). Effect of silicon on rice blast disease. Pertanika J. Trop.Agric.Sci., 35(S):1-12.
55. Abed-Ashtiani, F., Kadir, J.B., Selamat, A.B., Hanif, A.H.B.M. &Nasehi, A. (2012). Effect of foliar and root application of silicon against rice blast fungus in MR 219 rice variety. Plant Pathol. J.,28(2): 164-171.
56. Han, Y., Li, P., Gong, S., Yang, L., Wen, L. &Hou, M. (2016).Defense responses in rice induced by silicon amendment against infestation by the leaf folder Cnaphalocrocismedinalis. PLOS ONE | DOI:10.1371/journal.pone.0153918.
57. Khaing, E.E., Ahmad, Z.A.M., Mui-Yun, W. & Ismail, M.R. (2014). Effects of silicon, copper and zinc application on sheath blight disease severity on rice. World Journal of Agricultural Research, 2(6):309-314.
58. Gao, D., Cai, K., Chen, J., Luo, S., Zeng, R., Yang, J. & Zhu, X. (2011). Silicon enhances photochemical efficiency and adjusts mineral absorption in Magnaportheoryzae infected rice plants. Acta physiol. Plant, 33:675-682.
59. Cacique, I.S., Domiciano, G.P., Moreira, W.R., Rodrigues, F.A., Cruz, M.F.A., Serra, N.S. &Catala, A.B. (2013). Effect of root and leaf applications of soluble silicon on blast development in rice. Bragantia Campinas, 72(3):304-309.
60. Rezende, D.C., Rodrigues, F.A., Carre-Missio, V., Schurt, D.A., Kawamura, I.K. &Korndorfers, G.H. (2009). Effect of root and foliar applications of silicon on brown spot develepement in rice. Australian Plant Pathology,38:67-73.
61. Hosseini, S.Z., Jelodar, N.B. &Bagheri, N. (2012). Study of silicon effects on plant growth and resistance to stem borer in rice. Communication in Soil Science and Plant Analysis, 43:2744-2751.
62. Dann, E.K. & Le, D.P. (2017). Effects of silicon amendment on soilborne and fruit diseases of Avocado. Plants, 51: DOI: 10.3390/plants6040051.www.mdpi.com/journal/plants
63. Mohaghegh, P., Mohammadkhani, A. &Tehrani, A.F. (2015). Effects of silicon on the growth, ion distribution and physiological mechanisms that alleviate oxidative stress induced by powdery mildew infection in pumpkin (*Cucurbitapepo*, var. styriac). J. Crop Prot., 4(3):419-429.
64. Vilela, M., Moraes, J.C., Alves, E., Santos-Cividanes, T.M. & Santos, F.A. (2014). Induced resistance to *Diatraeasaccharalis* (Lepidoptera: Crambidae) via silicon application in sugarcane. RevistaColombiana de Entomologia, 40(1):44-48.

65. Callis-Duehl, K.L., McAuslane, H.J., Duehl, A.J. &Levey, D.J. (2017). The effects of silica fertilizer as an anti-herbivore defense in cucumber. Journal of Horticultural Research, 25(1):89-98.
66. Ye, M., Song, Y., Long, J., Wang, R., Baerson, S.R., Pan, Z., Zhu-Salzman, K., Xie, J., Cai, K., Luo, S. &Zeng, R. (2013). Priming of Jasmonate-mediated antiherbivore defense responses in rice by silicon. www.pnas .org/cgi/doi/10.1073/pnas.1305848110 PNAS