IMPACT OF PRIVI-SILIXOL FOLIAR FERTILIZER IN COMBINATION WITH DI-AMMONIUM PHOSPHATE AND MYCORRHIZA ON PERFORMANCE, NPK UPTAKE, DISEASE AND PEST RESISTANCE ON SELECTED CROPS IN A GREENHOUSE EXPERIMENT†

[IMPACTO DEL FERTILIZANTE FOLIAR PRIVI-SILIXOL EN COMBINACIÓN CON FOSFATO DI-AMONIO Y MYCORRHIZA SOBRE EL RENDIMIENTO, ABSORCIÓN DE NPK Y RESISTENCIA A ENFERMEDADES Y PLAGAS EN CULTIVOS SELECCIONADOS EN UN EXPERIMENTO DE INVERNADERO]

G.N. Karuku[1]* and M. Maobe[2]

[1]*Department of Land Resources and Agricultural Technology, University of Nairobi; Email, karuku_g@yahoo.com*
[2]*Department of Plant Science and Crop Protection, University of Nairobi. Email: gmoe54321@gmail.com*
[*]*Corresponding author*

SUMMARY

Despite silicon not considered an essential nutrient, it is typically abundant in soils and is known to have beneficial effects when added to rice crops and several other plants. These beneficial effects include disease and pest resistance, structural fortification, and regulation of the uptake of other ions. In this study, the effect of silicic acid fertilization (Privi-Silixol) on the increased biomass, economic yields, pest and disease tolerance or resistance, NPK uptake and chlorophyll content for five crop plants (Cowpea, common beans, cabbage, maize, and rice) was evaluated. The approach was executed through a controlled greenhouse experiment using Acid Washed Sand as a neutral medium. Crops planted with Privi-Silixol alone or in combination with full or half rates of recommended inorganic fertilizer performed significantly ($P \leq 0.05$) better compared to all other treatments. Plants treated with Privi-Silixol had higher dry matter yield (DMY), chlorophyll content and NPK uptake. Maize, common bean, cowpea, cabbage and rice had better disease and pest resistance compared to the control plants. Collectively, these results indicate beneficial effects of silicon in DMY, chlorophyll content, pest and disease resistance, but additional studies are needed under farmers' conditions to conclusively understand the interactions of silicon with other interacting factors in the field.
Key words: silicon; biomass; yield; chlorophyll content; draught tolerance.

RESUMEN

A pesar de que el silicio no se considera un nutriente esencial, por lo general abunda en los suelos y se sabe que tiene efectos benéficos cuando se agrega a los cultivos de arroz y a muchas otras plantas. Estos efectos beneficiosos incluyen resistencia a enfermedades y plagas, fortificación estructural y regulación de la absorción de otros iones. En este estudio se evaluó el efecto de la fertilización con ácido silícico (Privi-Silixol) sobre el aumento de biomasa, rendimiento económico, tolerancia / resistencia a plagas y enfermedades, absorción de NPK y contenido de clorofila para cinco plantas de cultivo (caupí, frijol común, repollo, maíz, y arroz). El enfoque se ejecutó a través de un experimento de invernadero controlado usando arena acidificada como medio neutral. Los cultivos plantados con Privi-Silixol solo o en combinación con dosis completas o medias de fertilizante inorgánico recomendado tuvieron un rendimiento significativamente mejor ($P \leq 0.05$) en comparación con todos los otros tratamientos. Las plantas tratadas con Privi-Silixol tuvieron mayor rendimiento de materia seca (DMY), contenido de clorofila y absorción de NPK. El maíz, el frijol común, el caupí, el repollo y el arroz tuvieron mejor resistencia a enfermedades y plagas en comparación con las plantas control. Colectivamente, estos resultados indican efectos benéficos del silicio en el rendimiento, contenido de clorofila, plagas y resistencia a enfermedades, pero se necesitan estudios adicionales bajo las condiciones de los agricultores para comprender de manera concluyente las interacciones del silicio con otros factores que interactúan en el campo.
Palabras clave: Silicio; biomasa; rendimiento; contenido de clorofila; tolerancia a sequía.

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INTRODUCTION

Weathering is the main factor in the availability of silicon in soils (Song et al., 2012). As weathering increases, available silicon is generally depleted (Narayan et al., 1999). This phenomenon occurs mostly in tropical regions of the earth. At a lower pH which is common in the tropics, silicic acid (H_4SiO_4) is more soluble and less likely to dissociate (Tubaña and Heckman. 2015) and is in equilibrium with soil SiO_2 at pH 3.1 and at a concentration of 0.794mM.

Silicon amendments can be important for optimal crop yields (Alvarez *et al.,* 1988; Korndörfer and Lepsch, 2001).The essentiality of silicon for plant growth has long been a question of interest to plant nutrition researchers. Uptake of silicon from soil increases with increasing soil water content (Hemmi, 1933; Williams and Shapter, 1955) and varies by species and by plant group (Jones and Handreck 1967; Ma *et al.*, 2001; Richmond and Sussman, 2003). Rice plants appear to perform active uptake of silicon (Ma and Yamaji, 2006; Van Soest, 2006), at least in hydroponic solutions. Ma and Yamaji (2006) suggest that there is a gene that encodes a Si uptake transporter in rice while Cornelis *et al.* (2010) suggest that uptake is passive in forest trees.

The presence of Si in plants has been found to alleviate many abiotic and biotic stresses, leading to the incorporation of silicates into many fertilizers. The deposition of silica as a physical barrier to penetration and reduction in the susceptibility to enzymatic degradation by fungal pathogens has been examined (Yoshida *et al*., 1962). However, there is debate as to whether this increased strength is sufficient to explain the protective effects observed (Fauteux *et al*., 2005). Investigations on defense mechanisms by Belanger *et al*. (2003) and Rodriguez *et al*. (2003), studying wheat and rice blast, respectively indicated that these species were capable of inducing biologically active defense agents, including increased production of glycosylated phenolics and antimicrobial products such as diterpenoid and phytoalexins in the presence of silica. Experiments performed on cucumber leaves following fungal infection showed that further resistance to infection is acquired by expression of a proline-rich protein together with the presence of silica at the site of attempted penetration (Kauss *et al*., 2003).

Metal toxicity (e.g. Mn, Cd, Al and Zn), salinity, drought and temperature stresses can be alleviated by Si application (Liang *et al*., 2007).Drought tolerance brought about by the application of 'Si' may result from decreased transpiration (Epstein, 1999) and the presence of silicified structures in plants suggest a reduction of leaf heat-load, providing an effective cooling mechanism and thereby improving plant tolerance to high temperatures (Wang *et al*., 2005). Resistance to salt stress is associated with the enhancement of enzymes such as superoxide dismutase (SOD) and catalase, preventing membrane oxidative damage (Zhu *et al*., 2004; Moussa, 2006).

Shubhodaya Mycorrhiza on the other hand is a commercial root fungi manufactured by Cosme Biotech PVT Ltd India, that enhances efficient utilization of nutrients and water in low fertility soils and under draught conditions, respectively. It contains 10^5 ineffective propagules per kilogram. It is applied in nurseries for transplanted crops while in field crops like maize, it can also be applied or injected into the soils at sowing or seeds maybe coated using juggery syrup and Shubhodaya Mycorrhiza sprinkled on them. In field and greenhouse trials conducted by Karuku *et al*. (2014c) in five agro-ecological zones in Kenya, Shubhodaya mycorrhiza was shown to increase root and shoot biomass, yields of field crops and branching of rose flowers. The French beans' root mass, pod weight, Stover and seed weight increased by 27.9, 43.5, 40.8 and 55.7%, respectively and were all significantly different at ($p \leq 0.05$) compared to the control. Plots treated with Shubhodaya Mycorrhiza gave higher yields in beans, maize, collianda while tomatoes recorded highest number of fruits at 99.1% increment above control. Flowering and fruiting was observed to occur earlier than in the other plots not treated with the root fungi.

Use of fertilizers such as K_4SiO_4 have a potential of making the crop resistant to attack by pests while improving nutrient status and not interfering much with the biodiversity is bound to give positive results. Si strengthens tissues and acts as an insecticide and a fungicide (Datnoff and Rodrigues, 2005). Chen *et al*. (2011) also found that silicon increased photosynthetic rate on a per-leaf basis. According to Lee *et al.* (2010), the addition of 2.5 mM Si to soybean plants "is beneficial in hydroponically grown plants as it significantly improves growth attributes and effectively mitigates the adverse effects of NaCl induced salt stress". According to Shen *et al.* (2010), the addition of 1.7 mM Si significantly increased soybean dry mass by 26% when subjected to -0.5 MPa of polyethylene glycol stress (PEG) stress. Sonobe *et al.* (2010) reported that 1.78 mM Si (SiO_2) in a 15% PEG 6000 (v/v) solution (to create -0.6 MPa) at 23 days increased shoot dry weight and second-nodal root diameter of Sorghum plants in hydroponic culture, even with decreased osmotic potential of roots. Also of interest is that Bakhat *et al.* (2009) found that corn supplied with 0.8 mM Na_2SiO_3 in solution culture under no stress conditions accumulated more leaf area and biomass than corn supplied with no silicon under the same conditions.

Shubhodaya Mycorrhiza ameliorates soil conditions as it interacts with the rhizosphere hence solubilizing fixed nutrients thus increasing their efficiency use. Finally, Shubhodaya Mycorrhiza harnesses and enhances acquisition of micro-nutrients such as Zn, Cu and Fe from low fertility soils, improves water use efficiency at low matric potential and generally improves the wellbeing of plant through proper photosynthetic activity (Karuku *et al*., 2014c).

Specific objectives of the study were (i) Conduct trials to evaluate effectiveness of Privi-Silixol foliar fertilizer in comparison and interactively with conventional fertilizers and Shubhodaya mycorrhiza on economic yield, biomass and chlorophyll production of Cowpea, Common beans, Cabbage, Maize, and rice(ii)Evaluate effectiveness of Privi-Silixol fertilizer on improving plants immunity/ resistance to attack by pest and diseases and (iii) Determine N, P, K uptake of selected crops treated with Privi-Silixol.

MATERIALS AND METHODS

Study Site

The study was conducted at the University of Nairobi, Upper Kabete Field Station farm located at 1°15' S and 36° 44' E at an altitude of 1940 m asl. The area is representative, in terms of soils and climate, of large areas of the Central Kenya highlands. According to the Kenya Soil Survey agro climatic zonation methodology (Sombroek *et al*., 1982), the climate of the study area can be characterized as semi-humid. The area experiences a bimodal rainfall distribution with long rains in March–May and the short rains in October – December with mean annual rainfall of 1006 mm (Karuku *et al.,* 2012, Karuku *et al*., 2014a,b). The ratio of annual average rainfall to annual potential evaporation, r/Eo is 58% (Karuku *et al.,* 2012, Karuku *et al.,* 2014a&b). The geology of the area is composed of the Nairobi Trachyte of the Tertiary age while the soils are well-drained, very deep (> 180 cm), dark red to dark reddish brown, friable clay (Gachene, 1989) and are classified as humic Nitisol (FAO, 1990; WRB, 2015). The land is cultivated for horticultural crops such as kales (*Brassica oleracea*), tomatoes (*Lycopersicon esculentum*), cabbage (*Brassica oleracea*), carrots, (*Daucus carota*), onions (*Allium fistulosum*), fruit trees such as avocadoes (*Persea americana*) and coffee (*Coffea arabica*).

Privi-Silixol as a nutrient

Privi-silixol is manufactured by Privi-Pharma in Mumbai-India. It is an Orthosilicic acid measured as silica (Si w/v) which is 0.8%v/v with 48% (v/v) stabilizers. The chemistry of formulation is well guarded by the manufacturers with only specifications being 500ml Privi-Silixol per hectare per application and the crop should be given 3 applications at 15 days interval.

Characterization Privi-silixol product

Laboratory tests were conducted on Privi-Silixol fertilizer which is a new product in Kenya to ascertain chemical constitution of the product and whether it contains the various chemical nutrients stated on the package by the manufacturers. Purity of the product was assessed to ascertain presence/absence of pollutants such as heavy metals in the Privi-Silixol fertilizer as follows: (a) Lead and Cadmium Graphite Furnace Atomic Absorption Spectrometry (Schlemmer and Radziuk, 1999) and Mercury Cold Vapour Atomic Absorption Spectrometry (Shrader and Hobbins, 2010).This is a major requirement by Kenya Plant Health Inspectorate Service (KEPHIS) for new products entering the Kenyan market.

The bioassay of Privi-Silixol showed the content of heavy metals was very low as to affect the soil or bio-accumulate in plant tissues (Lead = 0.10, Cadmiun = 0.004, Mercury = 0.15 and Zinc = 0.85 ppm). NIOSH at CDC has set a Recommended Exposure Limit (REL) of 50µg/m^3 to be maintained so that worker blood lead remains <60µg/dL of whole blood (*http://www.cdc.gov/niosh/npg/npgd0368.html, 2017*). Uncontaminated soil contains lead concentrations less than 50 ppm but soil lead levels in many urban areas exceed 200 ppm (*http://www.cdc.gov/niosh/npg/npgd0368.html, 2017*). The allowable levels of lead in fertilizers are 5ppm according to Washington State Standards for Metals. *(http://www.ecy.wa.gov/programs/hwtr/dangermat/fert_standards.html, 2017*). Plant uptake factors are low ranging from 0.01-0.1 hence amount in these bio-fertilizers are negligible.

Privi-Silixol fertilizer trials

Trials evaluated the response of Rice, Maize, Cowpea, Common bean and Cabbages to Privi-Silixol alone; di ammonium phosphate (DAP) fertilizer in combination Privi-Silixol at full and at half recommended rates of the study site and Shubhodaya Mycorrhiza in combination with Privi-silixol comprising seven treatments replicated four times under a neutral media of acid washed sand. Parameters assessed included N, P and K uptake, chlorophyll content in leaves, above and below ground biomass and economic yield at harvest. In addition, disease and pest resistance, lodging incidences (falling on the side as in wheat, rice and maize especially with a slight wind) and draught tolerance were also evaluated.

Experimental layout and design for greenhouse trial

The experimental design was a Completely Randomized Design (CRD).The test crops used in the trials were Maize (*Zea mays)*, Common beans *(Phaseolus vulgaris),* Cabbages *(Brassica oleracea var. capitata),* Cowpeas *(Vigna unguiculata)* and Rice *(Oryza sativa).* The experiment consisted of 7 treatments (T) replicated (R) four times in pots containing 5kg soil and the design was as in Table 1.

Table 1: Experimental design and layout

RI	RII	RIII	RIV
T7	T3	T5	T2
T2	T4	T1	T3
T5	T6	T7	T4
T1	T2	T6	T5
T6	T7	T4	T1
T4	T1	T3	T6
T3	T5	T2	T7

Legend: T1: Plant alone (0F 0PS)-Control; T2: Plant + Privi-Silixol only (0F PS); T3: Plant + ½ recommended DAP dose + Privi-Silixol (1/2F PS); T4: Plant + Full recommended DAP rate + Privi-Silixol (F PS); T5: Plant + Full recommended DAP dose (200 DAP kg/ha);T6: Plant + ½ recommended DAP dose (100 DAP kg/ha); T7: Plant + Shubhodaya Mycorrhizae (SM) alone; R: Replicates I-IV

River sand was obtained and then acid washed, rinsed with deionized water to remove any nutrients before being used as the neutral medium for the trials. This allowed for the proper administration of nutrients in the treatments.

Chlorophyll content

Chlorophyll content of the fully expanded leaf on the plant was measured with a Minolta SPAD-502 chlorophyll meter. SPAD chlorophyll readings were taken on each leaf, avoiding the midrib, and then averaged per plant. SPAD reading was done when the plant had four fully developed leaves.

Application rates

Each acre requires an application rate of 1 liter of Privi-Silixol dissolved in 1000 liters of water per application. The whole growing cycle required 3 applications hence 3 liters per hectare per season. And taking a furrow slice at 15cm depth, an acre is assumed to have $1x10^6$ kg of soils. Using this relationship and the bulk density of the sand/soil, the amount of Privi-Silixol or DAP fertilizer to add was calculated using the weight of the 10 kg sand in the pot. The parameters assessed were Stover residue biomass and Economic Yield at harvest; NPK uptake; Chlorophyll content and Disease and pest tolerance for plants.

Efficacy of privi-silixol in disease management

Maize. Leaves with *Exserohilum turcicum* which causes northern leave blight were collected from the university farm and inoculum was prepared using Muiru *et al.* (2010) procedure. Disease scoring was done on a scale of 1-5 where 1: Light infection, moderate number of lesions on lower leaves only, 2: Moderate infection, abundant lesions are on lower leaves, few on middle leaves. 3: Heavy infection, lesions are abundant on lower and middle leaves, extending to upper leaves. 4: Very heavy infection, lesions abundant on almost all leaves plants prematurely dry or killed by the disease.

Common beans. Isolation and inoculation of common beans with *Colletotrichum lindemuthianum* which causes bean anthracnose was using a method described by Wahome *et al.* (2011). The bean plants were inoculated by spraying at the sixth week using an atomizer. The plants were covered with plastic bags, and incubated under cool conditions overnight. A 1 to 5 severity scale, based on visual observation of the percentage of the organ presenting symptoms, was adopted. A score of 1 represented no observed symptoms while 5 corresponded to 100% of the organ covered by brown typical lesions of anthracnose

Cowpea. *Colletotrichum destructivum* was obtained from anthracnose lesions on the leaves of cowpea plants in the University of Nairobi farm. Inoculum preparation followed the procedure outlined by Sun and Zhang (2009). The cowpea plants were inoculated by spraying at the sixth week using an atomizer. The plants were covered with plastic bags; they were incubated under cool conditions overnight. A 1 to 5 severity scale, based on visual observation of the percentage of the organ presenting symptoms, was adopted. A score of 1 represented no observed symptoms while 5 corresponded to 100% of the organ covered by brown typical lesions of anthracnose.

Cabbage. *Xanthomonas campestris* pv campestris which causes black rot in brassica family was isolated, purified and then multiplied on nutrient agar. After 24 hours in the incubation chamber at 25 ºC, the colonies were harvested using a spatula into a one liter beaker containing 200 ml of sterile distilled water. The bacterial cell suspension was adjusted using hemacytometer to $1x10^4$ colony forming units. The suspension was sprayed on two months old cabbage plants in the green house using a hand atomizer. The plants were monitored for the rate of establishment and progress of the necrotic lesions typical to black rot for two weeks. Disease reactions were rated from 10 days after inoculation with a 0 to 5 scale: 0 = disease free, 1 = trace infection, 2 = 0.5 to 0.9, 3 = 1.4, 4 = 1.5 to 1.9, and 5 = more than 2 cm 2 of leaf diseased.

Early blight inoculum preparation and inoculation. Tomato leaves showing *Alternaria solani* lesions were used to prepare *Alternaria inoculums* using Reni et al. (2007) procedure. The same procedure was followed for inoculation.

Rice. Blast infected rice tissues were used to prepare the inoculum in the laboratory. The tissues were surface sterilized and cultured in 9mm petri dish containing Potato dextrose agar (PDA). The spores were harvested and the suspension adjusted to 1×10^6 and then rice at three leave stage was inoculated using a hand atomizer. Inoculated seedlings were incubated overnight at 16°C in a humid chamber and subsequently transferred to the glasshouse for the disease development. The plants were monitored for three weeks. Based on the spots scoring were rated on the basis of severity as: 0-10% neck infection as resistant (1), 11- 25% infection as moderately resistant (2), 26–40% infection as mildly susceptible (3), 41-70% infection as moderately susceptible (4) and 71-100% as susceptible (5)

Privi-silixol in Pest management

Mite resistance experiment for maize, common bean, cabbages and rice crops. The trial to ascertain the efficacy of Privi-Silixol was carried out using the procedure described by Gatarayiha et al. (2010).

Pest resistance in cowpea. The experiment was laid out in a completely randomized design in green house. The seeds were sown in ten pots, 2 seeds per two liter plastic pot containing sterile (sand). At 5 weeks after germination, aphids were artificially introduced. An assessment for aphid population was carried out and on the 6 week and before treatments was applied to establish the infestation and stabilization levels. Visual examination on the degree of infestation was done. The cow pea aphid, *Aphis fabae*, numbers were rated using a categorical index due to the fact that their numbers are usually exceptionally high, thus a challenge to enumerate, where 0 = None; 1 = few scattered individuals; 2 = few isolated colonies; 3 = Several isolated colonies; 4 = Large isolated colonies; and 5 = Large continuous colonies. The same key was used to assess the aphid population after folia spray. Aphid damage was classified as wilted. The control experiments both the negative and positive controls were carried out in nearby greenhouses independently. After application of potassium silicate, the Aphid population was monitored weekly for three weeks. Data on the aphid population was recorded using the above key.

RESULTS AND DISCUSSION

Table 2 shows chlorophyll content in bean, cabbage, maize and rice crops under different fertility treatments. Generally the plots treated with Privi-Silixol alone or in combination with diammonium phosphate showed higher chlorophyll content than those not treated with Privi-Silixol in all crop species. Chlorophyll is an indicator of photosynthetic activity and currently it’s being linked to high N content in plant tissues.

Table 3 shows dry biomass of selected crops at harvest under different treatments. At harvest, rice biomass with full DAP recommended rate + Privi-Silixol treatment performed better compared to all other treatments. Plots treated with Privi-Silixol + ½DAP had 99 % more biomass than control and 46% more than ½DAP treated plots alone while Privi-Silixol + full DAP had 138% and 57% above control and full DAP alone, respectively in cowpeas. In rice crop, Privi-Silixol + ½DAP had 150% more biomass weight above control and 79.8% more than ½DAP recommended treated plots alone while Privi-Silixol + full DAP recommended rate had 199.2% and 84.1 % more biomass above control and full DAP recommended rate alone, respectively.

Table 2: Chlorophyll content on selected crops under different fertility level treatments and with Privi-Silixol

Treatment	1	2	3	4	5	6	7	mean	F-value	LSD	SED
Bean	12.18	26.38	20.75	22.25	19.48	25.63	12.40	19.86	$P \leq 0.001$	3.14	1.50
Cabbage	17.83	30.53	31.93	33.00	28.08	29.03	29.90	28.18	$P \leq 0.001$	2.81	1.34
Rice	27.92	23.70	32.02	33.35	28.30	27.72	25.02	28.29	$P \leq 0.001$	2.38	1.13
Maize	16.95	24.88	32.97	34.00	24.22	25.30	15.50	24.83	$P \leq 0.001$	3.62	1.73

Legend: Crop + the following treatments:1: Control, 2: Privi-Silixol only, 3: Silixol + 100 kg/ha di ammonium phosphate (DAP), 4: Privi-Silixol +200 kg/ha DAP recommended rate, 5: 200 kg/ha DAP recommended rate, 6: 100 kg/ha DAP half recommended rate, 7: Mycorrhiza only; GM: general mean, LSD: least square difference; SED: standard error

Table 3: Dry biomass at harvest of selected crops under different fertility treatments (g/Pot)

Treatment/crop	1	2	3	4	5	6	7	Mean	F-value	LSD	SED
Cowpea	2.05	2.63	4.08	4.88	3.10	2.80	2.40	3.13	P ≤0.004	1.36	0.65
Rice	1.28	1.70	3.20	3.83	2.08	1.78	1.53	2.20	P ≤0.001	1.05	0.50
Maize	5.30	5.47	12.35	13.95	9.40	8.35	5.22	8.58	P ≤0.004	3.65	1.74

Legend: Crop + the following treatments: - 1: Control 2: Privi-Silixol only 3: Privi-Silixol + 100 kg/ha DAP 4: Silixol +200 kg/ha DAP recommended rate: 5: 200 kg/ha DAP recommended rate 6: 100 kg/ha DAP half recommended rate 7: Mycorrhiza only; Lsd least square difference; Sed standard error

The same trend was observed in maize crop where, Privi-Silixol + ½DAP recommended had 94.5% more biomass above control and 30.3 % more than ½DAP recommended alone. Privi-Silixol + full DAP recommended had 100.6 % and 40.4 % more biomass above control and full DAP recommended rate alone, respectively and the data was significantly different at (p≤0.00)1 in all cases. These results are in agreement with those obtained by Kaerlek (2012) who, when investigating the effect of Silicon on plant growth and drought stress tolerance observed that the total corn plant mass increased by over 20% and the effect was statistically significant (p<0.05).Similar results were observed by Jawahar *et al.* (2015) at Annamalai University Experimental Farm, Annamalai Nagar, Tamil Nadu, India when studying the effect of silixol granules on growth and yield of rice. Among the different treatment imposed, 100 % recommended dose of fertilizers + silixol granules @ 37.5kgha^{-1} recorded higher values for growth (plant height, number of tillers plant^{-1}, root length, root volume, leaf area index and dry matter production), yield attributing (number of panicles m^{-2}, number of grains panicle^{-1} and test weight) characters and yield (grain and straw) of rice, respectively. Thus, it is concluded that soil application of silixol granules along with 100 % recommended dose of fertilizers holds immense potentiality to boost the productivity and profitability of rice. This was well articulated in this study where full recommended DAP rate plus Privi-silixol gave the highest performance in all parameters investigated.

Table 4 shows NPK content in maize tissues under different treatments. Highest NPK uptake was observed in plots treated with Privi-Silixol + ½DAP and Privi-Silixol + full DAP recommended rates in maize crop. Plots treated with Privi-Silixol + ½DAP had 183, 928.5 and 1364% more NPK uptake, respectively above control and 7.9, 27.4 and 4.0% above that of ½DAP alone treated plots, respectively while Privi-Silixol + full DAP recommended plots had 202, 1002 and 1561% and 16.9, 7.7 and 6.4% more NPK uptake above control and full DAP alone treated plots, respectively. Similar findings were reported by Datnoff and Rodrigues (2005) where silicon alone was associated with a gain in grain weight over the control, 37% (N at 50kgha^{-1}) to 40% (N at 75kgha^{-1}). The beneficial effects of Si to plants under biotic and/or abiotic stresses have been reported to occur in a wide variety of crops such as rice, oat, barley, wheat, cucumber, and sugarcane. Leaves, stems, and culms of plants, especially rice grown in the presence of Si, show an erect growth thereby the distribution of light within the canopy is greatly improved (Alvarez and Datnoff, 2001; Elawad and Green, 1979; Epstein, 1991; Ma and Takahashi, 1991 and Savant et al., 1997). Silicon increases rice resistance to lodging and drought and dry matter accumulation in cucumber and rice (Adatia and Besford, 1986, Epstein, 1991; Lee et al., 1981). Silicon can positively affect the activity of some enzymes involved in the photosynthesis in rice and turf grass (Savant, et al., 1997; Schmidt et al., 1999) as well as reduce the senescence of rice leaves (Kang, 1980) hence the increased biomass. Silicon also lowers the electrolyte leakage from rice leaves and, therefore promotes greater photosynthetic activity in plants grown under water deficit or heat stress (Agarie et al., 1998) thus increasing biomass and yields of the crop.

Generally, Si-fertilization was shown to improve drought and salt stress tolerance, but the effects were inconsistent among crops. Silicon increased total maize plant biomass by up to 20% and the effect was statistically significant (p<0.05) (Kaerlek, 2012). Silicon increased water use efficiency (plant biomass accumulated divided by mass of water used) in corn by up to 36% and the effect was statistically significant (p<0.05) in one out of four trials. Collectively, these results indicate an effect of silicon in drought and salinity stress tolerance, but additional studies on the rate and onset of drought are needed to determine interacting factors and better understand the inconsistent results (Kaerlek, 2012).

Eneji *et al.* (2008) found that 1000 mg kg^{-1} potassium silicate (K_2SiO_3) application to the soil of four grass species under deficit irrigation (half of field capacity) “produced the greatest biomass yield responses across species,” as compared to calcium silicate ($CaSiO_3$) or silica gel. According to Gunes *et al.* (2008), sodium silicate applied to the soil mitigated the adverse dry mass reduction effects of drought in 6 of 12 sunflower cultivars. Pulz *et al.* (2008) found that using calcium and magnesium silicates in the place of dolomitic limestone (in areas with acidic soil) increased potato plant height, decreased stem lodging (weak lower stems), and increased the yield of marketable tubers in drought conditions (soil Ψ = -0.05 MPa). In addition to observations of reduced occurrence of stalk lodging and an increase of mean tuber mass in potatoes, Crusciol *et al.* (2009) found that the application of 284.4 mg dm^{-3}Ca and Mg silicate to the soil increased proline concentrations under drought conditions. Sonobe *et al.* (2009) found no effect of silicon on unstressed hydroponic sorghum, but found that 50 ppm (approximately 0.8 mM) silicon ameliorated dry mass reduction in hydroponic sorghum exposed to polyethylene glycol water stress. Chen *et al.* (2011) found that applying 1.5 mM silicon to drought stressed rice significantly ($P<0.05$) increased total root length, surface area, volume, and root activity, even to the extent that these parameters were equivalent to those observed in non-stressed plants in many cases.

Table 5 shows NPK content in bean tissues under different treatments. Highest uptake was observed in treatments of Silixol +200 kg/ha DAP recommended rates in bean crop just like in maize. Silixol + 100 kg/ha DAP also had high N and P uptake though K was slightly lower than 100 kg/ha DAP, 200 kg/ha DAP recommended rate and Mycorrhiza only. The same trend observed with maize above is replicated with common beans.

Table 6 shows NPK content in rice tissues under different treatments. Highest uptake observed in treatments of Privi-Silixol +200 kg/ha DAP recommended rates in bean crop just like in maize. Privi-Silixol + 100 kg/ha DAP also had high N and P uptake though K was slightly lower than 200 kg/ha DAP recommended rate and Mycorrhiza only. The same trend observed with maize and beans above is observed with Rice crop. Similar reports were recorded by Sajal et al. (2016) in a field experiment conducted to study the effect of silicon (diatomaceous earth, DE) fertilization on growth, yield, and nutrient uptake of rice during the kharif season of 2012 and 2013 in the new alluvial zone of West Bengal, India.

Results showed that application of silicon significantly increased grain and straw yield as well as yield attributing parameters such as plant height (cm), number of tillers m−2, number of panicle m−2, and 1000-grain weight (g) of rice.

Table 4: NPK content in maize tissue under different fertility treatments six weeks after emergence

Treatment/crop	1	2	3	4	5	6	7	Mean	F-value	LSD	SED
% N	0.600	0.600	1.700	1.812	1.550	1.575	1.000	3.13	P ≤0.001	0.19	0.09
K ppm	508	708	5225	5600	5200	4100	4525	2.20	P ≤0.001	1032	496
P ppm	29.2	46.0	427.5	485.0	455.8	411.2	184.5	8.58	P ≤0.004	73.8	35.5

Legend: Crop + the following treatments:-1: Control 2: Privi-Silixol only 3: Privi-Silixol + 100 kg/ha DAP 4: Silixol +200 kg/ha DAP recommended rate; 5:200 kg/ha DAP recommended rate 6:100 kg/ha DAP half recommended rate 7: Mycorrhiza only; Lsd least square difference; Sed standard error

Table 5: NPK content in common bean tissues under different fertility six weeks after emergence

Treatment/crop	1	2	3	4	5	6	7	Mean	F-value	LSD	SED
% N	0.500	0.718	2.150	3.025	2.550	1.700	1.475	1.731	P ≤0.001	0.60	0.27
K ppm	396	531	2775	4300	3775	3050	4275	2729	P ≤0.001	1168	562
P ppm	62	52	448	562	505	418	304	336	P ≤0.004	91.3	43.9

Legend: Crop + the following treatments:-1: Control 2: Privi-Silixol only 3: Privi-Silixol + 100 kg/ha DAP 4: Silixol +200 kg/ha DAP recommended rate; 5: 200 kg/ha DAP recommended rate 6: 100 kg/ha DAP half recommended rate 7: Mycorrhiza only, Lsd least square difference; Sed standard error

Table 6: NPK content in rice tissues under different fertility treatments six weeks after emergence

Treatment/crop	1	2	3	4	5	6	7	Mean	F-value	LSD	SED
% N	0.625	0.525	2.425	3.350	2.375	1.675	1.200	1.739	P ≤ 0.001	0.69	0.33
K ppm	452	598	3625	5100	3925	2775	4025	2929	P ≤ 0.001	1038	499
P ppm	62	49	550	630	490	405	322	358	P ≤ 0.001	123.4	59.3

Legend: Crop + the following treatments:-1: Control 2: Privi-Silixol only 3: Privi-Silixol+ 100 kg/ha DAP 4: Silixol +200 kg/ha DAP recommended rate; 5: 200 kg/ha DAP recommended rate 6: 100 kg/ha DAP half recommended rate 7: Mycorrhiza only, Lsd least square difference; Sed standard error

The greatest grain and straw yields were observed in the treatment T6 (DE at 600kgha−1 in combination with standard fertilizer practice (SFP). The concentration and uptake of silicon, nitrogen (N), phosphorus (P), and potassium (K) in grain and straw were also greater under this treatment compared to others. It was concluded that application of DE at 600kgha−1 along with SFP resulted increased grain, straw, and uptake of NPK.

Table 7 shows pest and disease resistance in maize crop under various treatments. Privi-Silixol alone, Privi-Silixol + 100kg and 200 $kgha^{-1}$ DAP had highest pest and disease resistance ratings of slightly infested or diseased.

Table 7: Pest and disease resistance ratings in maize under different fertility treatments.

Treatment/ Disease or Pest	Average ratings	
	Mites	Blight
Control	4	5
Privi-Silixol only	2	2
Privi-Silixol + 100$kgha^{-1}$ DAP	2	2
Privi-Silixol + 200$kgha^{-1}$ DAP	3	2
200$kgha^{-1}$ DAP	3	2
100$kgha^{-1}$ DAP	3	3
Mycorrhiza only	4	4

Legend 1: Pest and disease free- not infested/diseased; 2: Slightly infested or diseased; 3: Moderately infested /diseased; 4: Fairly infested /diseased and 5: Fully infested/diseased

Table 8 shows pest and disease resistance in rice crop under various treatments. Privi-Silixol alone, Privi-silixol + 100kg and 200 $kgha^{-1}$ DAP had higher pest and disease resistance ratings of moderately and slightly infested or diseased, respectively (3 & 2 ratings). Onodera (1917) compared the chemical composition of the rice plants infected with blast with that of healthy ones grown in the same paddy field. He observed that diseased plants always contained less Si in comparison to healthy ones obtained from the same field, and that the natural Si content found in rice tissue depended on the paddy field in which the plants had been grown. His finding did not necessarily mean that blast infection was reduced by the Si content of the rice plants or that plants with less Si content were more susceptible. His results did show that there was a relationship between Si content and blast susceptibility.

In 1995 and 1996 experiments, Si was incorporated prior to seeding at 0 and 1000 $kgha^{-1}$ (80). Plots that were treated in 1995 (residual Si) were compared to plots receiving a fresh or current year application of Si in 1996 to study the residual effect. Two foliar applications of edifenfos, sprayed at 20 and 35 days after planting, were made and followed by three applications of tricyclazole. Leaf blast was evaluated as percent area of individual leaves and neck blast was rated as percent incidence of 100 panicles. In both 1995 and 1996, ratings of leaf blast for Si alone (residual and fresh applications) and Si plus edifenfos (residual and fresh applications) were 50 to 68% lower than those in the non-treated control plots (Datnoff and Rodrigues, 2005).

Table 9 shows resistance to mites and anthracnose by common beans and cowpeas treated with privy-silixol or in combination with fertilizers. Privi-Silixol alone, Privi-silixol + 100 kg and 200 kg/ha DAP had higher pest and disease resistance ratings of moderately and slightly infested or diseased, respectively (3 & 2 ratings).

Table 8: Pest and disease resistance ratings in Rice crop under different fertility treatments (materials and methods for rice).

Treatment/ Disease or Pest	Average ratings	
	Mites	Blast
Control	4	4
Privi-Silixol only	3	2
Privi-Silixol + 100 $kgha^{-1}$ DAP	3	2
Privi-Silixol + 200 $kgha^{-1}$ DAP	3	3
200 $kgha^{-1}$ DAP	4	3
100 $kgha^{-1}$ DAP	5	4
Mycorrhiza only	5	4

Legend: 1: Pest and disease free- not infested/diseased; 2: Slightly infested or diseased; 3: Moderately infested /diseased; 4: Fairly infested /diseased and 5: Fully infested/diseased

Table 9: Pest and disease resistance ratings in common bean crop under different fertility treatments.

Treatment/ Disease or Pest	Average ratings	
	Mites	Anthracnose
Control	3	4
Privi-Silixol only	2	2
Privi-Silixol + 100 $kgha^{-1}$ DAP	2	2
Privi-Silixol + 200 $kgha^{-1}$ DAP	2	2
200 $kgha^{-1}$ DAP	3	3
100 $kgha^{-1}$ DAP	3	3
Mycorrhiza only	4	4

Legend: 1: Pest and disease free- not infested/diseased; 2: Slightly infested or diseased; 3: Moderately infested /diseased; 4: Fairly infested /diseased and 5: Fully infested/diseased

Table 10 shows resistance to aphids and anthracnose by cowpeas treated with Privi-silixol or in combination with fertilizers. Privi-Silixol alone, Privi-silixol + 100 kg and 200 kg/ha DAP had higher pest and disease resistance ratings of moderately and slightly infested or diseased, respectively (3 and 2 ratings).

Under cabbages (Table 11) mites fairly infested the crop and black rot was moderate under privy-silixol treatments.

Table 10: Pest and disease resistance ratings in cowpea crop under different fertility treatments

Treatment/ Disease or Pest	Average ratings	
	Aphids	anthracnose
Control	3	4
Privi-Silixol only	2	2
Privi-Silixol + 100 $kgha^{-1}$ DAP	2	3
Privi-Silixol + 200 $kgha^{-1}$ DAP	2	2
200 $kgha^{-1}$ DAP	4	4
100 $kgha^{-1}$ DAP	3	4
Mycorrhiza only	4	4

Legend: 1: Pest and disease free- not infested/diseased; 2: Slightly infested or diseased; 3: Moderately infested /diseased; 4: Fairly infested /diseased and 5: Fully infested/diseased

Table 11: Mites and black rot resistance ratings in cabbages under different fertility treatments

Treatment/ Disease or Pest	Average ratings	
	Mites	Black rot
Control	5	5
Privi-Silixol only	3	3
Privi-Silixol + 100 $kgha^{-1}$ DAP	2	3
Privi-Silixol + 200 $kgha^{-1}$ DAP	3	3
200 $kgha^{-1}$ DAP	5	4
100 $kgha^{-1}$ DAP	5	5
Mycorrhiza only	5	5

Control Chart Ratings: 1: Pest and disease free- not infested/diseased; 2: Slightly infested or diseased; 3: Moderately infested /diseased; 4: Fairly infested /diseased and 5: Fully infested/diseased

CONCLUSIONS

Privi-Silixol increased efficiency utilization of conventional fertilizers. Where used with Diammonium Phosphate (DAP) at full or half recommended rates, there was increased biomass in all crops tested, increased NPK uptake and increased pest and disease resistance. There were few disease incidences and pest infestation in the crops treated with Privi-silixol alone or in combination with DAP fertilizer. The chlorophyll content was higher indicating better photosynthetic activity. It can therefore be concluded that there is potential in the use of Privi-Silixol in combination with other sources of nutrients for maximum efficiency utilization of nutrients. This will cut down on use of excessive fertilizers that has had a devastating effect on the health of our soils.

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