Comparison of Silicon Status in Rice Grown Under the System of Rice Intensification and Flooding Regime in Mkindo Irrigation Scheme, Morogoro, Tanzania

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Abstract
Silicon (Si) is the second most abundant element available in the earth's crust, and is considered as a beneficial element for crop growth especially rice. A study was conducted in Mkindo irrigation scheme, Mvomero District, Morogoro, Tanzania to assess the Silicon status in rice grown under the System of Rice Intensification and continuous flooding at various growth stages. The experiment was laid out in a randomized complete block design (RCBD) with two treatments which were two water application regimes: T_1 was alternate wetting and drying using SRI technology and T_2 was continuous flooding. The treatments were replicated three times and the rice variety used was SARO 5 (TXD 306). The experiment was conducted in two seasons from October 2019 to January 2020 and from March 2020 to June 2020. Si status in rice seeds and grains as well as rice plant leaves at various growth stages were evaluated according to elemental analysis based on Energy Dispersive X- Ray Fluorescence and results were analyzed using GENSTAT software. Si content in rice seeds observed prior to the experiment was 6.76%. Si content in rice grains was gradually increasing during reproductive stage and later drops during harvest. Si content in rice plant leaves increased significantly from vegetative to ripening stage whereby the highest Si content was recorded in T_1 (12.37%) while T_2 recorded the lowest value (10.15%). It was concluded that, the alternate wetting and drying field conditions enhances adequate uptake of Si compared to continuous flooding practices.

Keywords: Silicon, alternate wetting and drying, System of Rice Intensification, continuous flooding, growth stages.

Introduction

About half of the world's population depends on rice (*Oryza sativa* L.) as their staple food (FAO, 2008; Rajamani, 2012; Ricepedia, 2015; Kangile *et al.,* 2018). In Tanzania, rice is the second most popular cultivated, commercial and staple food crop after maize (Katambara *et al.,* 2013; Kahimba *et al.,* 2014; SRI-Rice, 2015). It is cultivated over an area of about 681 000 ha which represents 18% of the cultivated land. Nearly half of the country's rice is grown by 230 000 smallholder farmers in Tabora, Shinyanga, and Morogoro Regions (SRI-Rice, 2015). Other major rice producing Regions include Mwanza, Manyara, Mbeya and Kilimanjaro. Most of the rice producers in developing countries such as Tanzania are subsistence farmers who produce rice under traditional methods. Most commonly is the continuous flooding, a technique that uses large amount of water and results in low yields, low water productivity and low water use efficiency (Katambara *et al.,* 2013; Kangile *et al.,* 2018).

Smallholder farmers have realized average rice yields of about 1 to 2 tons/ha under continuous flooding practices in improved irrigation schemes (URT, 2009; MAFSC, 2009, SRI-Rice, 2015). Low yields of rice under this practice are attributed to various factors including low nutrients uptake, low soil fertility status and inadequate nutrients management practices used by many farmers (MAFSC, 2009; Amuri *et al.,* 2013). These factors in combination to continuous flooding practices for rice production are inefficient thus calling for adoption of modern water saving technologies such as the System of Rice Intensification (SRI).

System of Rice Intensification (SRI) is a modern technology for rice production that was introduced in Tanzania in 2009 by various researchers to increase the yield of rice and country's food security, improve water productivity and water use efficiency (SRI-Rice, 2015). The SRI technology involves applying small amount of water regularly by alternating wetting and drying field conditions to maintain a mix of aerobic and anaerobic soil conditions (Uphoff, 2007). Various researchers have reported increase in rice yield for about 6 to 8 tons/ha with subsequent water saving of 25% to 50% after using SRI practice (Katambara *et al.,* 2013; SRI-Rice, 2015). For instance, in Mkindo Irrigation Scheme, rice yield of up to 9.91 tons/ha were realized by Mkindo farmers under SRI practices in a spacing of 25 cm × 25 cm (Katambara *et al.,* 2013; SRI-Rice, 2015). Improved performance of SRI practices has been attributed to many factors including more uptakes of nutrients and proper management of water and nutrients (Masawe *et al.,* 2017).

Silicon (Si) is the second most abundant element available in the earth's crust, and is considered as a beneficial element for crop growth especially rice (Aarekar, 2012; Rajamani, 2012; Jinger *et al.,* 2017; Rao *et al.,* 2017). All plants contain Si in their tissues at concentrations similar to those of the macro nutrients such as N, P and K however, the concentration of Si in plant tissues varies with the plant species ranges from 0.1 to more than 10.0 Si% of whole plant dry matter (Aarekar, 2012; Rajamani, 2012; Jinger *et al.,* 2017; Rao *et al.,* 2017). Si can enhance the growth of plant under a water-stressed condition than in a non-stressed condition. Furthermore, Si can alleviate water stress by decreasing transpiration of leaves through the stomata and cuticle (Ma and Takahashi, 2002). Rice plant which is grown under SRI stands a chance of enhanced uptake of Si due to stress induced through alternate wetting and drying.

The availability of Si to plant mainly depends on the weathering rate of silicate minerals and release of Si to soil (Aarekar, 2012). The plant absorbs Si from the soil in the form of monosilicic acid then deposits it in the cell walls near the cuticle forming silica-cuticle double layer and silica-cellulose double layer on the surfaces of leaves and stem in the form of silicic acid (Raven, 2001; Rao *et al.,* 2017). Si is the only element that does not damage plants when accumulated in excess amounts and reduces the concentration of toxic elements like Fe, Mn and other heavy metals (Ma *et al.,* 2001; Ma *et al.,* 2006; Rajamani, 2012). When plant absorbs more silica than requirements, tend to deposit it on tissues as it cannot be excreted (Jinger *et al.,* 2017). Moreover, when Silica is deposited in leaf epidermal cells become immobile and it cannot be translocated to new growing leaves (Tubana *et al.,* 2016).

Si uptake by rice roots is governed by two genes (transporters) known as Lsi 1 and Lsi 2 (Ma *et al.,* 2006; Ma *et al.,* 2007; Ma and Yamaji, 2008; Rao *et al.,* 2017). Lsi1 is an influx transporter accountable for transporting Si from the soil to the root cells, whereas Lsi 2 is an efflux transporter accountable for transporting Si from the inside to the outside of the root cells (Ma *et al.,* 2006; Ma *et al.,* 2007; Ma and Yamaji, 2008). Suppression of Lsi 1 expression resulted in reduced Si uptake meanwhile expression of Lsi 1 enhances uptake of Si in rice roots (Ma and Yamaji, 2008). Lsi1 and Lsi2 must work together to facilitate the efficient uptake of Si in rice roots (Ma and Yamaji, 2008). Other three Si transporters known as Lsi 2, Lsi 3 and Lsi6 were identified in rice node, and they are responsible for the intervascular transfer of Si for the preferential distribution of Si to the leaves and grains (Yamaji *et al.,* 2015). Ma *et al.* (2001) investigated the role of root hairs and lateral roots in the Si uptake using two rice mutants, whereby one was defective in the formation of root hairs (RH-2) while another in the formation of lateral roots (RM-109). Results have indicated that the lateral roots contributed to the Si uptake in rice plant whereas root hairs do not.

Among all wetland plants, rice is a highly Si accumulating plant and it can uptake an average of 150 to 300 kg of Si per ha (Jinger *et al.,* 2017). Furthermore, it was estimated that the production of 5 t/ha of rice removes about 230 to 470 kg ha^{-1} of Si from soil depending upon soil and plant factors (Rajamani, 2012; Rao *et al.,* 2017). The availability of Si in rice plants facilitates efficiency of sunlight use and increase in photosynthetic activity (Shivay and Dinesh, 2009). Furthermore, Si increases the mechanical strength of cells, decreases lodging due to wind and water and increases resistance to certain insects and diseases (Ma and Yamaji, 2008; Jinger *et al.,* 2017). Consequently, it is imperative to consider Si as an essential element for increasing and sustaining rice productivity (Sudhakar *et al.,* 2006; Rao *et al.,* 2017).

Kangile *et al.* (2018) predicted that there would be a need for additional milled rice of about fifty-nine million tons by 2020 above the 2007 consumption of 422 million tons. This demand can be met by ensuring a right balance of mineral nutrients in soils to increase rice productivity. Studies done by Mbaga, (2015) and Masawe *et al.* (2017) in Tanzania investigated the effects of some nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K) and Sulfur (S) on the yield of rice cultivated under SRI and continuous flooding. Results have indicated increased rice yields due to the interaction between nutrients and water applied in the field under study. However, little has been done to assess Si uptake by rice plant grown under SRI and continuous flooding regime. Therefore, this study was designed to compare the Silicon status in rice grown under SRI and continuous flooding regime in Mkindo Irrigation Scheme, Mvomero District, Morogoro Region, Tanzania. The specific objectives of this study were to: i) Assess Silicon status in rice seeds at the beginning of the experiment and rice grains at the reproductive stage and at harvest and ii) determine Silicon status in rice plant leaves at different growth stages.

Materials and methods

Study location and climate

The study was conducted at Mkindo Farmer Managed Irrigation Scheme located at Mkindo Village, Mvomero District in Morogoro Region, Tanzania. The scheme is situated between latitude 6°16’ and 6°18’ South and longitude 37°32’ and 37°36’ East and an altitude between 345 and 365 meters above mean sea level. It is about 85 km from Morogoro Municipality (Fig. 1). The Mkindo Irrigation Scheme was constructed between 1980 and 1983 and started producing rice in 1985 with only 17 ha under cultivation. The irrigation water used in the scheme is drawn from Mkindo Perennial River through a well-organized irrigation infrastructure with lined main canal and unlined secondary, tertiary and drainage canals (Reuben *et al.,* 2016). According to Mkindo farmers, rice is the only crop produced in the scheme which serves as food and income generation. Currently the scheme has an arable area of 740 ha with only 300 ha under rice cultivation.

Figure 1: Location map of Mkindo village in Mvomero district, Morogoro, Tanzania

The rainfall distribution of the study area is bimodal with short rains starts from October to December (OND) and long rains starts from March to May (MAM). In Mkindo area, the long rains (*masika*) receives more rains which ranges between 112.6 to 250.3 mm with a total rainfall of 571.1 mm compared to the short rains (*vuli)* which receives fewer rains which varies between

52.6 to 116 mm with a total rainfall of 254.5 mm, respectively. The average annual rainfall ranges between 716.5 to 1503.5 mm (Fig. 2). The average monthly maximum temperature at the experimental site ranges between 35.1°C to 28.5°C for February and June while the average monthly minimum temperature ranges between 20.4°C to 15.8°C for January, March and July, respectively (Fig. 3).

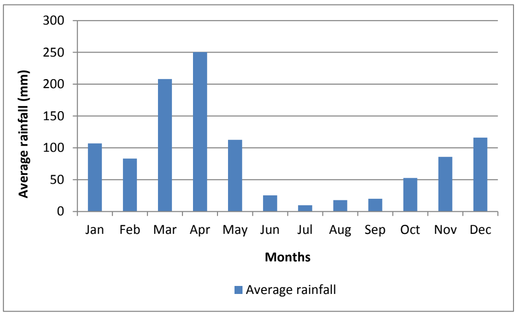

Figure 2: Average monthly rainfall (mm) at Mkindo Irrigation Scheme (1999 to 2019)

Source: Mtibwa Sugar Metrological Station, 2020

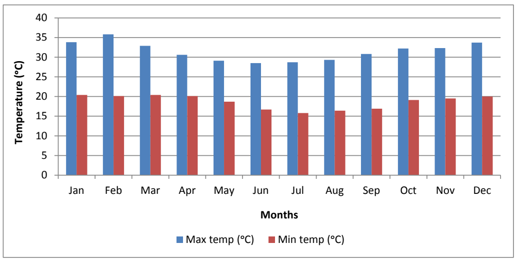

Figure 3: Average maximum and minimum monthly temperature at Mkindo Irrigation Scheme (1999 to 2019)

Source: Mtibwa Sugar Metrological Station, 2020

Soils

The soil of the study area is sandy loam with 82.32% sand, 13.8% clay and 3.92% silt. The Mkindo soils have also the following properties: pH = 5.85 (medium acidic soils), total nitrogen content (TN) = 0.04% (very low), extractable phosphorus (P) = 14.06 mg kg^{-1} (medium), potassium content (K) = 0.16 cmol (+) K kg^{-1} (low), organic carbon content (OC) = 1.04% (low) and available Silicon content (Si) = 235.5 mg kg^{-1} (sufficient).

Experimental design and layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments were two water application regimes: T_1 was alternate wetting and drying using SRI technology and T_2 was continuous flooding. The experiment was conducted in two seasons from October 2019 to January 2020 and from March 2020 to June 2020. In SRI plots, one seedling per hill was transplanted in a square pattern of 25 cm × 25 cm using 10 days old seedlings while in continuous flooding plots, two seedlings per hill were transplanted in a square pattern of 20 cm×20 cm using 21 days old seedlings. Again in SRI plots, irrigation water was applied by alternating wetting and drying field conditions whereas in continuous flooding plots, 5 cm depth of water was maintained from transplanting to harvest. The individual plot size was 5 m×10 m (50 m^2) each separated from the other by 1 m buffer zone. Table 1 and Figure 4 show the details and layout of the treatments.

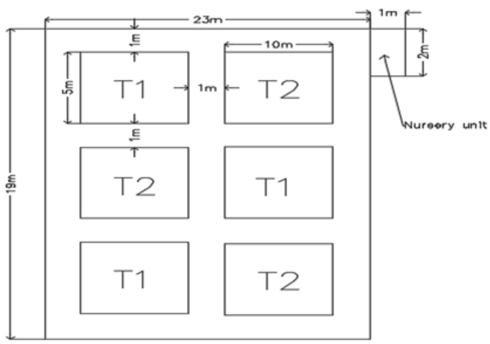

Figure 4: Layout of experimental plots showing treatments

Table 1: Treatments

Treatments	Water application regimes	Transplanting age (days)	Seedling per hill	Spacing (cm)
T1	Alternate Wetting and Drying	10	1	25 × 25
T2	Continuous Flooding	21	2	20 × 20

Assessing Si status in rice seeds and grains

First, seed samples (SARO 5; TXD 306) were taken from Agricultural Seed Agency (ASA) at the beginning of experiment then a portion of it weighing 500 gm was stored in a labelled bag and taken to Tanzania veterinary laboratory agency (TVLA) for Si analysis. Second, grain samples were randomly collected during reproductive (85 DAT) and ripening phase (115 DAT). From each field plot a randomly selected area of 1 m^2 was demarcated then grain samples were collected, air dried, stored in a labelled bag and taken to Tanzania Veterinary Laboratory Agency (TVLA) for analysis. In the laboratory seeds and grains samples were placed in a labelled plastic bottle then introduced in the EDXRF machine for analysis to determine the Si status according to elemental analysis based on Energy Dispersive X-Ray Fluorescence (EDXRF) as described by Yao *et al.* (2015).

Determining Si status in rice plant leaves

Samples for rice plant leaves were collected randomly at vegetative (55 DAT), reproductive (85 DAT), and ripening phase (115 DAT). From each field plot, a randomly selected area of 1 m^2 was demarcated then leaf samples i.e. 3rd or 4th leaves from the top of the plant were collected randomly. The collected plant samples were air dried, chopped into small pieces and placed in a labelled bag then taken to Tanzania Veterinary Laboratory Agency (TVLA) for analysis. In the laboratory plant samples were placed in a labelled plastic bottle then introduced in the EDXRF machine for analysis to determine the Si status according to elemental analysis based on Energy Dispersive X-Ray Fluorescence (EDXRF) as described by Yao *et al.* (2015).

Data analysis

Data for Si status in rice seeds and grains as well as rice plant leaves gathered from the experiment at different growth stages were analyzed using GenStat 15th Edition statistical software and the significant differences between means were separated using the Least Significance Difference (LSD) based on the p-value of 0.05.

Results and discussion

Si status in rice seeds at the beginning of the experiment

The available Si content in rice seeds observed at the beginning of the experiment was 6.76% (Table 2). This value is within the

Table 2: Si content in rice seeds and grains at different growth stages

REP	Season	Treatments	Si content (%) start	Si content (%) reproductive stage	Average Si content (%) reproductive stage	Si content (%) ripening stage	Average Si content (%) ripening stage
1	S1	T1	6.76	12.1	12.7	8.09	8.78
2	S1	T1		12.8		8.39	
3	S1	T1		13.3		9.86	
1	S1	T2		7.59	9.45	6.24	7.1
2	S1	T2		9.86		7.13	
3	S1	T2		10.9		7.93	
1	S2	T1		13.3	13.7	7.83	8.6
2	S2	T1		13.9		8.28	
3	S2	T1		13.9		9.83	
1	S2	T2		8.23	10.1	6.73	7.1
2	S2	T2		10.6		6.97	
3	S2	T2		11.6		7.73	

S1: Season 1 (*vuli* season), S2: Season 2 (*masika* season)
T1: Treatment 1 using SRI technology and T2: Treatment 2 under continuous flooding

acceptable range (4-20%) of Si content in rice plants as suggested by Shivay and Dinesh, (2009) and Rao *et al.* (2017).

Table 3: Statistical results for Si content in rice grains at various growth stages

Treatments	Si content (%) reproductive stage	Si content (%) ripening stage
T1	13.2	8.7
T2	9.8	7.1
SE±	0.3	0.5
p-value	<0.001	0.022
LSD (0.05)	1.0	1.8

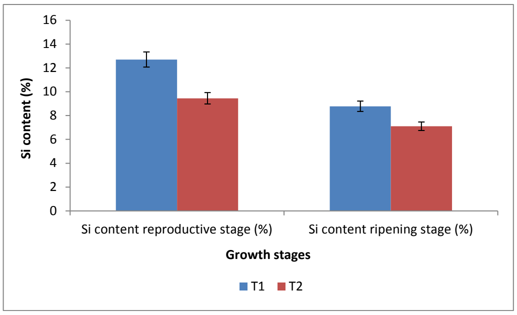

Figure 5: Si content (%) in rice grains during *vuli* season

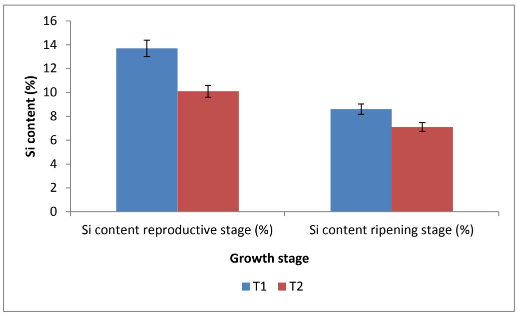

Figure 6: Si content (%) in rice grains during *masika* season

Si status in rice grains during reproductive stage

For the two growing seasons, Si content in rice grains in treatment T_1 was significantly different at P<0.05 from treatment T_2. There was also significant increase in Si content in rice grains in both treatments during the two seasons. The significant increase in Si content might be due to higher uptake of Si by rice plant for establishment of rice grains. The highest Si content in rice grains was recorded in treatment T1 (13.2%) while the lowest value was observed in treatment T2 (9.8%) (Table 2, Table 3, Figure 5 and Figure 6). The highest values observed in treatment T1 might be attributed to intermittent water application and weeding process which facilitates improved oxygen supply in rice roots thereby causing stronger and healthier root system which ensures higher Si uptake from the soil as suggested by Katambara *et al.* (2013) and Reuben *et al.* (2016).

Si status in rice grains at harvest

There was significance different at P<0.05 in Si content in rice grains between the treatments. The highest Si content in rice grains was recorded in treatment T_1 (8.7%) while the lowest value was observed in treatment T_2 (7.1%) (Table 2, Table 3, Figure 5 and Figure 6). There was also reduction in Si content in rice grains at this stage when compared to what observed at the reproductive stage. This might be attributed to loss of moisture content as most of the rice grains dry at harvest hence the whole plant dry matter and the percentage Si content in grains get reduced. However, the values observed at this stage were higher than what observed in rice seeds at the beginning of the experiment (6.76%). The lower value of Si content observed in rice seeds may be due to loss of moisture content due to storage of rice seeds. Similar results were observed by Paye (2016) who reported increase in Si content in rice straw and panicles during harvest stage after Si application in soils under the study at the beginning of the experiment.

Silicon status in rice plant leaves at different growth stages

Similarly to Si content in rice seeds and grains, Si content in rice plant leaves were also within acceptable range (4-20%) for proper rice growth as suggested by Shivay and Dinesh (2009) and Rao *et al.* (2017). They reported that Si content of < 5% as critical level in rice plants. In all rice growth stages, there were significant differences at P<0.05 in Si contents in rice plant leaves among the treatments during vuli and masika seasons. Moreover, there was significant increase in Si content in rice plant leaves from vegetative to ripening stage due to higher uptake of Si from the soil (Table 4, Table 5, Figure 7 and Figure 8).

Silicon status in rice plant leaves at vegetative stage

The highest Si content in rice plant leaves

Table 4: Si content in rice plant leaves at different growth stages

REP	Season	Treatments	Si content (%) vegetative stage	Average Si content (%) vegetative stage	Si content (%) reproductive stage	Average Si content (%) reproductive stage	Si content (%) ripening stage	Average Si content (%) ripening stage
1	S1	T1	8.2	8.2	9.48	10.2	11.3	12.2
2	S1	T1	7.35		10.4		12.5	
3	S1	T1	8.99		10.6		12.8	
1	S1	T2	4.68	5.9	6.81	7.5	10.3	10.7
2	S1	T2	6.85		7.01		10.6	
3	S1	T2	6.06		8.79		11.1	
1	S2	T1	8.07	8.6	9.54	10.4	11.3	12.5
2	S2	T1	8.92		9.87		13.1	
3	S2	T1	8.74		11.7		13.2	
1	S2	T2	6.85	7.3	6.98	7.5	8.46	9.6
2	S2	T2	7.15		7.11		9.02	
3	S2	T2	7.99		8.51		11.4	

Table 5: Statistical results for Si content in rice plant leaves at various growth stages

Treatments	Si content (%) vegetative stage	Si content (%) reproductive stage	Si content (%) ripening stage
T1	8.38	10.27	12.37
T2	6.6	7.54	10.15
SE±	0.281	0.16	0.256
p-value	0.004	<.001	<.001
LSD $_{(0.05)}$	0.972	0.555	0.886

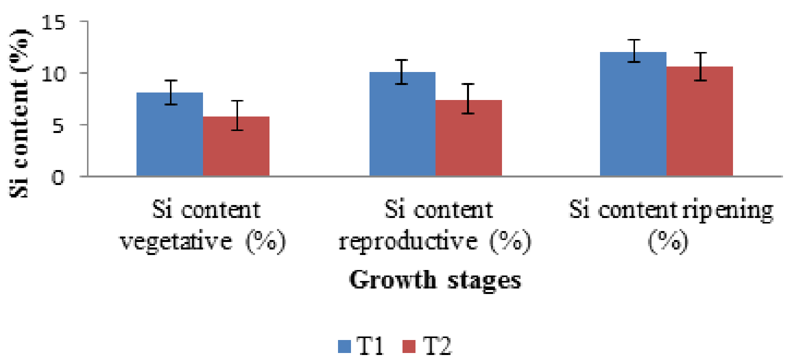

Figure 7: Si content (%) in rice plant leaves during vuli season

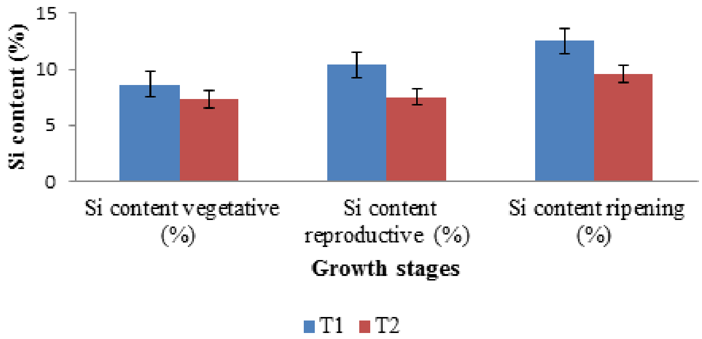

Figure 8: Si content (%) in rice plant leaves during masika season

was observed in treatment T1 (8.38%) whereas the lowest value was observed in treatment T2 (6.6%) (Table 4, Table 5, Figure 7 and Figure 8). The highest Si content in rice plants grown under SRI was mainly attributed to alternating wetting and drying field conditions which enhance adequate supply of oxygen, water and higher uptake of nutrients especially Si from the soil. This situation contributed much to the strength of plants to withstand stresses due to wind and water.

Si content in plant leaves at reproductive stage

There was increase in Si content in rice plant leaves due to higher uptake of Si from the soil which results into the formation of thick cuticle double layer in the epidermal layer around cell walls of leaves and stems as suggested by Raven (2001) and Rao *et al.* (2017). Treatment T1 recorded the highest Si content (10.27%) in rice plant leaves. In comparison, the lowest Si content was observed in treatment T2 (7.54%) (Table 4, Table 5, Figure 7 and Figure 8).

Si content in plant leaves at ripening stage

Similarly, at the ripening stage there was increase in Si content in rice plant leaves whereby treatment T1 recorded the highest Si content (12.37%). Meanwhile, the lowest Si content was observed in treatment T2 (10.15%) (Table 4, Table 5, Figure 7 and Figure 8). The higher value of Si content in rice plant leaves which was observed in treatment T1 were attributed to higher uptake of Si from the soil. This was also attributed to proper maintenance of water applied in the rice field under SRI practices.

Similar observations were reported way back by Nayar *et al.* (1982). It was reported that the Si content in rice plant (the leaf blade, culm and whole plant) increases with the age of the plant from transplanting to harvest. The lower values were observed during vegetative growth stage while the higher values were observed after flowering stage.

These results agree with those observed by Rajamani (2012) in India who conducted a study to evaluate Si content in index leaves of various rice genotypes. It was reported that the Si content in index leaves were increasing from tillering to harvest stage with values being 2.76, 3.09 and 3.56% rated as critical value considering Si content of < 5% as critical level in rice plant as suggested by Shivay and Dinesh (2009) and Rao *et al.* (2017). This might be attributed to leaching of nutrients including Si above the root zone of the plant due to water flowing into the rice fields (Datnoff *et al.,* 2005).

Summary and conclusion

Rice variety SARO 5 (TXD 306) used in this experiment had an acceptable range of Si content (6.76%), which was observed prior to the experiment. Also this variety showed higher ability to take up more Si from the soil. At harvest, it was seen that the produced rice grains had an optimum level of Si which ranged from 10.15% to 12.37. Si content in rice plant leaves was increasing significantly from vegetative to ripening stage, and it was within an acceptable range for proper rice growth ranges between 4-20%. Moreover, SRI plants recorded the highest Si content in rice grains and rice plant leaves compared to continuous flooding. This indicates that the alternating wetting and drying field conditions enhances plants to take up more Si from the soil.

This study should be conducted in other places for the purpose of assessing Si content in different soils and environmental conditions around the country. Further studies should be conducted to assess the effect of different Si sources on yield and water productivity of rice. Further studies should also be undertaken to assess the available Si content of other rice varieties produced in Mkindo and other areas around the country for instance *mbawambili*, *cherehani* and *kula na bwana.*

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