# Silicon Status in Soil and its Effect on Growth and Yield of Rice under the System of Rice Intensification and Continuous Flooding in Mkindo Irrigation Scheme, Morogoro, Tanzania

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## Abstract

*Silicon (Si) improves physical, chemical and biological properties of soil, enhances growth and rice yield. Hence, Si deficiency in the soil may lead to decline in rice yields. A study was undertaken to assess Si status in soils and its relation to growth and yield parameters of rice plant grown under the system of rice intensification (SRI) and continuous flooding regime in Mkindo Irrigation Scheme, Morogoro, Tanzania. A randomized complete block design (RCBD) with two treatments replicated three times was employed for the experiment. The treatments were two water application regimes (T1 and T2). T1 was alternate wetting and drying using SRI technology and T2 was continuous flooding. Rice variety SARO 5 (TXD 306) was used as a test crop. The experiment was conducted for two consecutive seasons from October 2019 to January 2020 and from March 2020 to June 2020. The objectives of the study were to assess the Si status in soils of the experimental site and to examine growth (in terms of plant height, number of tillers, number of productive tillers and number of panicles per hill) and grain yield in relation to soil Si status. Results showed that the soils of the study area had sufficient amount of available Si content (235.5 mg kg$^{-1}$). Plots under SRI technology recorded higher plant height (147 cm), number of tillers per hill (54), number of productive tillers per hill (46), number of panicles per hill (31) and grain yield (8 tons ha$^{-1}$). On the other hand plots under continuous flooding gave lower plant height (129 cm), number of tillers per hill (27), number of productive tillers per hill (22), number of panicles per hill (27) and grain yield (3 tons ha$^{-1}$). It was thus concluded that, SRI enhanced higher uptake of soil Si which in turn improved significantly crop growth and rice yield.*

***Keywords:*** Rice, Silicon deficiency, Silicon status, soil, growth, rice yield

## Introduction

Silicon (Si) is the second most abundant element available in the earth's crust next to Oxygen and is known to have numerous benefits to rice growth (Jinger *et al.,* 2017; Rao *et al.,* 2017; Gowele *et al.,* 2020). Si is available in the soil in form of monosilicic acid and polysilicic acid as well as complexes with organic and inorganic compounds such as Al oxides and hydroxides (Rajamani, 2012; Rao *et al.,* 2017). Soluble Si may be introduced in the soil by either runoff, weathering of silicate minerals, deposition of silicate materials at the soil surface or by capillary ascension from the water table (Rajamani, 2012). The solubility of silicate minerals varies under different soils and environmental conditions however, its concentration in soils ranges from 0.1 to 0.6 mM (Ma and Takahashi 2002; Joseph, 2009).

Moreover, the solubility of Si in the soils may be altered by different processes occurring in the soil such as particle size of the Si fertilizer, soil acidity (pH), organic complexes, the presence of Al, Fe and phosphate ions, dissolution reactions and soil moisture content (Rao *et al.,* 2017). Tubana *et al.* (2016) reported that soils that are less weathered or geologically young have higher ability to supply higher amounts of plant available Si (PAS) than highly weathered soils. PAS is taken up by rice plants and it has a direct influence on growth (Berthlesen et al., 2003; Rao *et al.,* 2017). The presence of PAS in the soil facilitates the improvement of physical, chemical and biological properties of soil as well as increased rice yields (Rao *et al.,* 2017).

The availability of Si in the soil is associated with the rate of replenishment of Si and the rate of Si uptake during the plant growth (Marschner, 1995). The critical level of Si in soil is 40 mg kg$^{-1}$ (40 ppm) whereas in rice it is <5% of whole plant dry matter (Shivay and Denish, 2009; Rao *et al.,* 2017). Si deficiency is common in areas with poor soil fertility, in old and degraded soils, in organic soils with small mineral Si reserves, in highly weathered soils and leached tropical soils, in rain-fed lowland and upland areas (IRRI, 2018). Si depletion may also occur in traditional soils due to continuous mono-cropping and intensive cultivation of cereal crops such as rice and this could be one of the factors leading to reduced rice yields (Miyake, 1993; Savant *et al.,* 1997; Mali *et al.,* 2008; Meena *et al.,* 2014).

Low base saturation soils and low pH soils such as Oxisols and Ultisols are among the soils with low Si contents (Datnoff *et al.,* 2005). Moreover, Si can be depleted from the soil due to drainage, severe and frequent soil erosion, sediment transportation, desilication process, leaching process and plant uptakes if it is not replenished (Rajamani, 2012; Meena *et al.,* 2014; Jinger *et al.,* 2017). Si deficiency may affect the development of strong leaves, stems, roots and the formation of thick silica layer in the epidermal cells hence making the rice plants susceptible to fungal, bacterial diseases and insect pests infestation (IRRI, 2018).

Gowele *et al.* (2020) reported on higher Si content in grains and leaves of rice plants grown under SRI compared to continuous flooding regime. However, little has been done to assess Si status in paddy soils and its relation to growth and yield parameters of rice under different water regimes. It is necessary to assess Si status in agricultural soils in order to develop nutrient management systems that will include Si during rice growth. This study was therefore designed to assess Si status in soils of the experimental site and its relation to growth and yield parameters of rice under SRI and continuous flooding regime in Mkindo Irrigation Scheme, Tanzania. The specific objectives of the study were to assess Si status in soils of the experimental site at different rice growth stages and to examine growth (in terms of plant height, number of tillers, number of productive tillers and number of panicles per hill) and grain yield of rice under SRI and continuous flooding.

## Materials and methods

### Study location and climate

The experiment was carried out in 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 at an altitude ranging from 345 to 365 meters above mean sea level. It is about 85 km from Morogoro Municipality (Fig. 1).

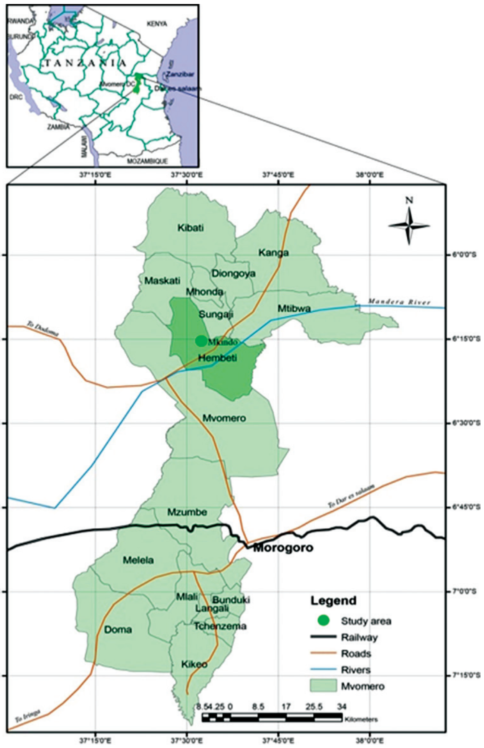

**Figure 1: Location map of Mkindo village in Mvomero District, Morogoro, Tanzania**

***Source:*** Gowele et al., 2020

The rainfall pattern of the study area is bimodal with short rains starting from October to December (OND) and long rains starting from March to May (MAM). The average annual rainfall for Mkindo area is 1088.9 mm (Table 1). The average monthly maximum temperature at the experimental site varies between 35.1°C and 28.5°C for February and June, respectively whereas the average monthly minimum temperature ranges between 20.4°C and 15.8°C for March and July, respectively (Table 1, Fig. 3).

**Soils**

The soil of the study area is sandy loam with 82.3% sand, 13.8% clay and 3.9% silt. The experimental soil has also the following properties: medium acidic soils with pH of 5.85, very low (0.04%) total nitrogen content, medium extractable phosphorus (P) =14.06 mg kg$^{-1}$, sufficient available Silicon content (Si) = 235.5 mg kg$^{-1}$, low potassium content (K) = 0.16 cmol (+) K kg$^{-1}$ and low organic carbon content (OC) = 1.04%.

**Table 1: Average weather data at Mkindo Village collected at Mtibwa Sugar Meteorological Station year 1999-2019**

| Month | Average rainfall (mm) | Max temp (°C) | Min temp (°C) |
|---|---|---|---|
| January | 106.9 | 33.8 | 20.1 |
| February | 83.2 | 35.1 | 20.1 |
| March | 208.2 | 32.9 | 20.4 |
| April | 250.3 | 30.6 | 20.1 |
| May | 112.6 | 29.1 | 18.7 |
| June | 25.4 | 28.5 | 16.7 |
| July | 9.9 | 28.7 | 15.8 |
| August | 18.0 | 29.3 | 16.4 |
| September | 19.9 | 30.8 | 16.9 |
| October | 52.6 | 32.2 | 19.1 |
| November | 85.9 | 32.3 | 19.5 |
| December | 116 | 33.7 | 20.0 |
| Average | 1088.9 | 31.4 | 18.7 |

***Source:*** Mtibwa Sugar Meteorological Station, 2020

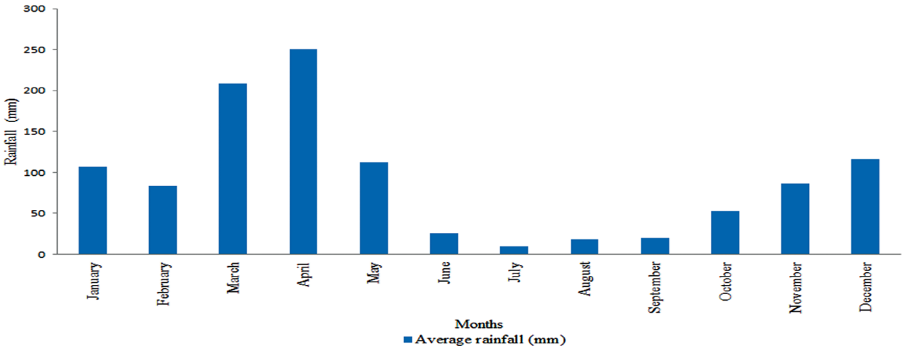

**Figure 2: Average monthly rainfall (mm) at Mkindo Irrigation Scheme (1999 to 2019)**
***Source:*** Mtibwa Sugar Meteorological Station, 2020

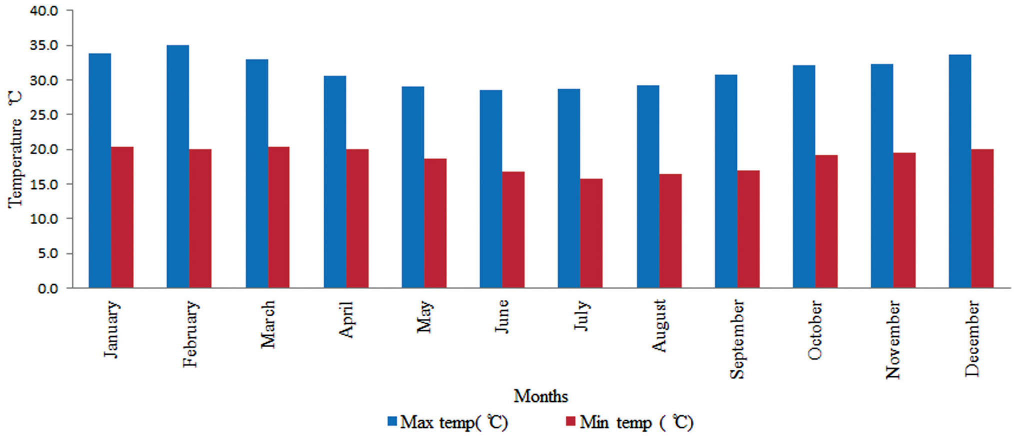

**Figure 3: Average maximum and minimum monthly temperatures (°C) at Mkindo Irrigation Scheme (1999 to 2019)**
***Source:*** Mtibwa Sugar Meteorological Station, 2020

### Experimental design and layout

The experiment was carried out in a randomized complete block design (RCBD) with two treatments replicated three times. The treatments were two water application regimes (T1 and T2). T1 was alternate wetting and drying using SRI technology and T2 was continuous flooding regime. The experiment was conducted for 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. Meanwhile, in continuous flooding plots, two seedlings per hill were transplanted in a square pattern of 20 cm × 20 cm using 21 days old seedlings. The age of seedling and spacing were adopted from the studies done by Kombe (2012) and Reuben *et al,* (2016). 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 at the surface from transplanting to harvest. Drainage channels were formed between plots for removal of excess water from the experimental plots. The individual plot size was 5 m × 10 m (50 m$^2$) each separated from the other by 1 m buffer zone. Table 2 and Fig. 4 show the details and layout of the treatments.

**Table 2: Experimental treatments**

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

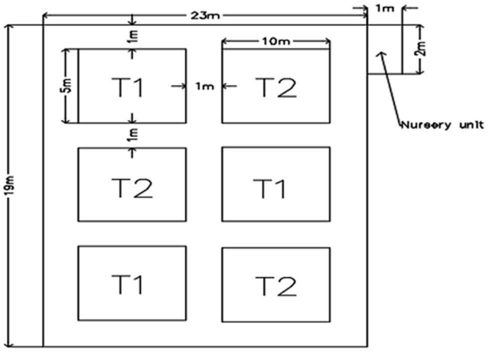

**Figure 4: Layout of experimental plots showing treatments**

### Assessing available Silicon status in soils of the experimental site

Representative soil samples were randomly collected from each field plot at the start of the experiment and during vegetative (55 days after transplanting (DAT)), reproductive (85 DAT) and ripening phase (115 DAT). Six soil samples were randomly collected from each field plot using an auger at depths of 0 to 30 cm below the soil surface. Then soil samples from each field plot were mixed thoroughly to form a total of six composite samples which were then air dried, hand pounded, passed through 2 mm sieve and placed in a labelled bag then taken to Tanzania veterinary laboratory agency (TVLA) for analysis. In the laboratory, each of the soil samples was placed in a labelled plastic bottle then introduced in the Energy Dispersive X- Ray Fluorescence (EDXRF) machine for analysis to determine the Si status according to elemental analysis based on EDXRF as described by Yao *et al.* (2015).

### Examining growth and yield parameters of rice

Growth and yield parameters examined per hill included total number of tillers, number of productive tillers and number of panicles as well as plant height and grain yield. For each of the field plots, a randomly selected area of 1 m$^2$ was demarcated from which data for the stated parameters were collected. Five plants within the demarcated area were randomly selected and data for plant height, total number of tillers per hill, number of productive tillers per hill and number of panicles per hill were taken during vegetative (55 DAT), reproductive (85 DAT) and ripening (115 DAT) phases. At harvest, the border rows on all sides of the demarcated area in individual plots were first harvested, then the plants within the demarcated area were cut and seeds separated from the straw followed by sun drying to 15% moisture content. Grain yield was measured using an electronic balance.

### Data analysis

Data for total number of tillers per hill, number of productive tillers per hill, number of panicles per hill, plant height and grain yield as well as Si status in soils were analyzed using GenStat 15th Edition statistical software and the differences between treatment means were compared with the least significant difference (LSD) at the 5 per cent level of significance.

## Results and discussion

### Available Si status in soils at different rice growth stages

The available Si content in Mkindo soils observed at various rice growth stages is presented in Table 3. There was significant difference ($p<0.05$) in Si content in soils at the experimental site in all rice growth stages for the two growing seasons.

**Table 3: Statistical results for Si content (mg kg$^{-1}$) in soils of the experimental site at different rice growth stages**

| Treatments | Si content vegetative stage | Si content reproductive stage | Si content ripening stage |
|---|---|---|---|
| T1 | 150.82a | 230.70a | 242.50a |
| T2 | 120.93b | 219.80b | 231.20b |
| SE± | 0.349 | 0.1399 | 0.0694 |
| p-value | 0.001 | 0.002 | <.001 |
| LSD (0.05) | 1.209 | 0.4843 | 0.2401 |

*T1: Treatment 1 using SRI technology and T2: Treatment 2 under continuous flooding.*
*Different letters within a column represent significant difference (p<0.05)*

### Available Si status in soils at the beginning of the experiment

The available Si content in Mkindo soils observed at the beginning of the experiment was 235.5 mg kg$^{-1}$ rated as sufficient for rice production (Shivay and Dinesh, 2009; Rao *et al.* 2017).

### Si status in soils during vegetative stage

At this stage, there was decrease in Si content in soils of the experimental site which ranged between 120.93 and 150.82 mg kg$^{-1}$ when compared to what was observed at the beginning of the experiment (235.5 mg kg$^{-1}$). The decrease in Si content in soils could be attributed to higher uptake of Si by rice plants for the development of the various parts of the plant such as roots, leaves and panicles. Higher Si content in soils was observed in treatment T1 (150.82 mg kg$^{-1}$) under SRI technology compared to treatment T2 (120.93 mg kg$^{-1}$) under continuous flooding regime (Table 3).

### Si status in soils during reproductive and ripening stages

There was increase in soil Si content in all treatments during reproductive and ripening stages. During these stages, all parts of the plant such as roots, leaves and panicles were fully developed as a result little Si was taken up by the rice plant from the soil to support crop growth, hence this attributed to a higher balance in Si content in soils of the experimental site. The increase in available soil Si content could also be associated with its release from ferrosilicon complexes under reducing soil conditions as reported by Savant *et al.* (1997).

For the two growing seasons, the average values observed were between 219.8 and 242.5 mg kg$^{-1}$ during reproductive and ripening stages (Table 3). However, T1 recorded higher values (230.7 and 242.5 mg kg$^{-1}$) compared to T2 (219.5 and 231.2 mg kg$^{-1}$) during the reproductive and ripening stage, respectively (Table 3). The higher values observed in T1 could be attributed to proper management of irrigation water, younger seedling used of ten days old and wider spacing used of 25 x 25cm in SRI plots. Regardless of the method of water application regime, Mkindo soils appear to have sufficient amount of Si (>40 mg kg$^{-1}$) in all rice growth stages hence could be judged as being suitable for rice cultivation.

These results are in agreement with those obtained by Paye (2016) who conducted a study to determine the critical soil Si level for rice production in Louisiana using different extraction procedures. The experimental sites were observed to have low to high initial soil Si content which ranged between 11 and 164 mg kg$^{-1}$ at the beginning of the experiment. At harvest stage plots which had high initial soil Si observed to have sufficient Si contents.

### Plant height

There was significant difference ($p<0.05$) in plant height between treatments. It was observed that plant height increased as soil Si content increased from vegetative to ripening stage. At harvest, treatment T1 with higher Si content in soils (242.5 mg kg$^{-1}$) recorded higher plant height (147 cm) compared to treatment T2 (129 cm) with lower soil Si content (231.2 mg kg$^{-1}$) (Table 4).

**Table 4: Statistical results for growth and yield parameters of rice under SRI and continuous flooding**

| Treatments | Plant height (cm) | Number of tillers/hill | Number of productive tillers/hill | Number of panicles/hill | Grain yield (tons/ha) |
|---|---|---|---|---|---|
| T1 | 147$^{a}$ | 54$^{a}$ | 46$^{a}$ | 31$^{a}$ | 8$^{a}$ |
| T2 | 129$^{b}$ | 27$^{b}$ | 22$^{b}$ | 27$^{b}$ | 3$^{b}$ |
| SE± | 2.49 | 1.34 | 1.56 | 0.57 | 0.57 |
| p-value | <.001 | <.001 | <.001 | 0.003 | <.001 |
| LSD (0.05) | 7.98 | 4.28 | 5 | 1.82 | 1.83 |

*T1: Treatment 1 using SRI technology and T2: Treatment 2 under continuous flooding*
*Different letters within a column means significant difference (p<0.05)*

### Number of tillers per hill

As observed in plant height, the number of tillers per hill also increased with the age of plants after two weeks of transplanting till ripening stage. Also there was significant difference ($p<0.05$) in number of tillers per hill between treatments (Table 4). Plots with higher soil Si contents (242.5 mg kg$^{-1}$) were observed to have a higher number of tillers per hill (54)

(Table 4).

### Number of productive tillers per hill

There was significant variation ($p<0.05$) in number of productive tillers per hill between treatments. Similar to number of tillers per hill, treatment T1 with higher soil Si content (242.5 mg $kg^{-1}$) recorded a higher number of productive tillers per hill (46) compared to treatment T2 (22) with lower soil Si content (231.2 mg $kg^{-1}$) (Table 4). The higher number of tillers and productive tillers per hill observed in rice plants grown under SRI could also be attributed to proper management of water through alternate wetting and drying field conditions as reported by Gowele *et al.* 2020.

### Number of panicles per hill

There was significant variation ($p<0.05$) in number of panicles per hill between treatments. A higher number of panicles per hill was observed in treatment T1 (31) with higher soil Si content (242.5 mg $kg^{-1}$) compared to treatment T2 (27) with lower soil Si content (231.2 mg $kg^{-1}$) (Table 4).

### Grain yield

There was significant difference ($p<0.05$) in grain yield between the treatments. Higher grain yield was recorded in treatment T1 (8 tons $ha^{-1}$) with higher soil Si content (242.5 mg $kg^{-1}$) compared to treatment T2 (3 tons $ha^{-1}$) with lower soil Si content (231.2 mg $kg^{-1}$) (Table 4).
These results concur with the findings by Jawahar and Vaiyapuri (2010) who reported higher plant height, number of tillers per hill, number of panicles per hill and grain yield in plots with higher Sulphur and Si content. These results are also in conformity with those observed by Rajaman (2012) who reported significantly higher mean grain yield (6779 kg $ha^{-1}$) in rice genotype JGL-3855 with higher Si content compared to rice genotype RNR-235(46460 kg $ha^{-1}$) with lower Si content.

## Summary and conclusion

Si content in the experimental soils in both treatments was found to be sufficient for rice growth. Water management through alternate wetting and drying field conditions (SRI) appeared to have a significant influence on its evolution and consequent uptake by rice plants as observed by Gowele *et al.* (2020). Treatment T1 under SRI technology showed higher growth and yield parameters compared to treatment T2 under continuous flooding regime. Further studies should be conducted to assess Si status in soils under different environmental conditions around the country.

## Acknowledgement

The authors wish to acknowledge Mr. Erasto Gowele for the financial support.

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