Nutritional roles of Silicon in Rice for Yield Enhancement

Silicon (Si) is next to oxygen (O) in quantity on earth's crust. Silicon in combination with oxygen forms silicon dioxide (SiO_2) which is also known as silica. About 87% of the earth's surface is made up of silica. There are 200 over types of silicated rocks in nature. These include quartz and mica. The white mica is made up of silicon, potassium and aluminium whereas the black mica contains iron and magnesium.

Soil minerals on earth's surface are the result of weathering of rocks over time. They contain approximately 47% oxygen, 28% silicon, 8% aluminium, and 5% iron. The remaining 90 over types of elements together constitute only 12% of the mass of soil minerals. Glass contains silica as well as sodium carbonate and calcium carbonate.

The original soil minerals are predominantly silicated compounds. For example, sand and silt contain 70-90% of silica. The other major elements in the soil minerals are potassium, sodium, calcium, magnesium, and anhydrous aluminium salt. In the process of soil formation, clay is formed by the combination of silicon tetrahedral layers and aluminium octahedral layers. The silicon in sand, silt, and clay is extremely insoluble and difficult to be absorbed by plant. However, under the reaction of soil microorganism and a process called hydration, a small portion of silicon in the form of Silicic acids (H_4SiO_4) is weakly soluble and thus become available to plants.

Differential Absorption of Silicon by Plants

Plants vary in their ability to absorb silicon. Plants that can absorb and accumulate silicon in their tissues are known as silicon accumulators, e.g. horsetail and wetland grasses. These plants can accumulate up to 4-7% of silicon in their foliage. In contrary, the silicon non-accumulators can only absorb and store 0.5-1.5% of silicon. In general, dicot plants contain low quantity of silicon.

Rice exhibits the greatest uptake of silicic acid in the grass family. With the application of large quantity of silicon fertilizers, rice can accumulate silicon in the stem and leaves up to 10-15% of its dry weight. Rice depends mainly on its root system to absorb moisture and most of the minerals. The root system exhibits differential absorption of minerals, e.g. rice root can absorb ammonium and silicon more efficiently than tomato. The passive absorption of minerals is through diffusion where no biological energy is used by the cells. Whereas in the case of active absorption, energy arising from metabolism is used. In the process of active absorption, silicated salts can suppress the absorption of sulphate but not phosphate and nitrate. This indicates that salts of silicon and sulphur share common ionic carriers. In the case of phosphates and nitrates, the carriers are different. This implied that silicon can facilitate the absorption of phosphorous.

Research findings from China reveal that rice yield of 7.5 ton/ha require 750-1,500 kg of silica. On average, 1,125 kg of silica is required to achieve that yield. This far exceeds the absorption of the three macro elements namely nitrogen, phosphorous, and potassium.

Physiological Functions of Silica on Rice Crop

1. Increasing canopy photosynthetic efficiency by keeping leaves erect and compact.

Rice uses chlorophyll to fix atmospheric carbon dioxide and water to form carbohydrate. Rice yield is directly proportional to the accumulation of photosynthates formed in the process of photosynthesis. The manufacturing of photosynthates are closely related to leaf surface and leaf’s efficiency in trapping solar energy. Appropriate plant density and fertilizer management are essential for achieving optimal leaf area index for photosynthesis.

Ideal plant type such as semi-dwarf stature, compact tillers, erect leaves, thick and narrow leaf surface would ensure better penetration of light through the plant canopy. The application of silica fertilizer enhances the mechanical strength of epidermal cells on rice leaf surface, keeping the rice leaves erect and avoiding mutual shading.

2. Increasing resistance to Fungi, Bacteria, and Insect Pests.

Silicon helps to strengthen cells of rice leaf, stem, and roots. Epidermal cells accumulate the most amount of silicon absorbed from the soil. In the intercellular spaces, silicon is oxidized to form silicon dioxide (silica gel). Silicon can also exist as amorphous silicon dioxide in the plant tissues. Their presence enhances the plant's resistance towards insect pests and disease pathogens.

Japanese plant nutritionists I. Onodera in 1917 revealed that plants infected by blast disease contain less silicon in their foliage compared with healthy rice plant. In 1927, R. Kawashima discovered that application of silicon fertilizer enhances rice plant's resistance to rice blast. Subsequently many Japanese researchers demonstrated that application of 1.5-2.0 tons per hectare of various silicon sources in silicon deficient soil dramatically reduced the intensity of blast.

In 2002, Chinese researcher, S J Chang revealed that silicon fertilizer can shorten the leaf lesion caused by bacterial leaf blight by 5-22%. Reducing the size of lesions is directly proportional to the reduction of soluble sugar in leaves caused by the presence of silicon.

Application of 200 kg silica (SiO_2) per hectare can reduce the infection of dirty panicle (grain discoloration) by as much as 18%. Correspondingly rice yield increases by 20% after silica application.

Chinese scientists also reported that when the available SiO_2 in soil is increased from 60 ppm to 220 ppm, the silicon content in flag leaf increased correspondingly from 7.4% to 18.7%. Meanwhile the neck rot infection was observed to reduce from 8.6% to 1.5% while pink stem borer infection was reduced from 33.6% to 6.6 %. The reduction in disease infection and pests infestation is principally due to the fact that silicon promotes ammonium assimilation. This chemical process inhibits the accumulation of unstable amino acids and amides in cells which provide nutrients to pests and pathogens.

3. Reducing the Toxicity of Heavy metals

Rice plant is often affected by adverse environmental factors such as acidity, salinity, and toxicity resulting from pesticides and fertilizers residues. Prolonged submergence of rice field will result in increased activities of anaerobic microorganisms especially under the conditions of excessive organic matters. This will reduce the redox potential in soil causing the formation of toxic-reduced substance.

Under reduced condition i.e. oxygen depleted condition in the rice field, the insoluble Manganate (Mn^{+4}) is converted to soluble Manganous (Mn^{+2}). The insoluble ferric iron (Fe^{+3}) is reduced to soluble ferrous iron (Fe^{+2}). At the same time the sulphate radical (SO_4^{-2}) is reduced to form hydrogen sulphide (H_2S). The soluble manganous and ferrous cations as well as hydrogen sulphide are toxic to rice roots. Manganous toxicity causes brown spots to occur on older leaves and chlorosis on young leaves. Iron toxicity causes rusty leaf spots. Hydrogen sulphide causes root rot and reduced tillers.

The application of silicon fertilizer can enhance the transportation of oxygen to rice roots which increases root oxidative capacity so that the toxic manganous and ferrous ions will be oxidized and precipitated on root surface. This chemical reaction reduced the absorption of toxic metals by rice roots.

Silicon can also regulate soil acidity and reduce the availability of heavy metals. The application of silicon will precipitate the soluble toxic aluminium, cadmium, and mercury forming insoluble aluminium silicate, cadmium silicate, and mercuric silicate. The precipitation of these harmful heavy metals can prevent their entry into the food chain and make our food safer.

4. Improving Water Use efficiency by Reducing Cuticular Transpiration

Rice leaf surface is covered by epidermal cells which have a cuticular layer. Gaseous exchange between the atmosphere and the leaf is through stomata. On both sides of the leaf veins, there are bulliform cells which are arranged in a fan form. Under dry weather conditions, excessive water loss through transpiration will cause the bulliform cells to shrink and the leaf will roll up in order to reduce transpiration loss. When the atmosphere is well laden with moisture, the bulliform cells will absorb moisture and expand. The leaf will re-open.

The cuticle on the leaf surface plays an important role in reducing transpiration loss and also prevents pests and diseases attack.

Accumulation of silicon will form a thick silicated layer on the leaf surface and this will effectively reduce cuticular transpiration. The findings from Japanese researchers revealed that the application of silica will reduce transpiration loss by as much as 30%.

5. Silicon Enhances Rice plant's Resistance to Lodging.

Lodging is one of he major causes of yield loss. Lodged plants stack upon one another reduces photosynthetic efficiency. The snapped culm will hinder the translocation of nutrients which are essential for grain filling. Under flooded conditions, panicles soaked in water may cause the grains to germinate prematurely and become rotten.

Imbalance between nitrogen, phosphorous, and potassium in rice plant is one of the causes of lodging. Excessive application of Nitrogen will cause the leaves to grow luxuriantly and the whole canopy becomes too heavy for the culms to support. Excessive Nitrogen in plant tissues reduces the accumulation of starch, and affects adversely cellulose formation. As cellulose is important for culm strengthening, decrease in cellulose content lowers the resistance of rice plant towards lodging.

Excessive Nitrogen reduces Calcium uptake which is essential for the formation of Calcium pectates. These compounds are essential constituents of cell wall and play an important role in strengthening rice culm against lodging.

Under normal condition, Phosphorous is usually adsorbed by clay particles and not readily available to the plant. With the help of silicon, more phosphorous become available to be absorbed by the plants. Phosphorous is essential for root formation, thereby strengthening the root system. A stronger and more extensive root system will lead to better anchorage and reduce lodging.

In addition, phosphorous is an essential elements in the generation and storage of energy in plant cells. Increased absorption of phosphorous due to the presence of silica will provide more energy for the plant to absorb other elements such as Calcium and Potassium. These elements help to strengthen the rice plant against lodging and reduce pest and disease attacks.

Symptoms of Silicon Deficiency

Rice leaves become soft and droopy. Droopy leaves will cause mutual shading and reduce photosynthetic efficiency. This will lead to reduced starch formation and affect grain filling. Lowering of starch formation and accumulation will lead to yield reduction. In addition, occurrences of diseases such as blast and brown spots become more widespread in silicon deficient soils. As excessive Nitrogen fertilizer always tends to produce flaccid leaves, the application of silica will help to rectify this problem by making the leaves erect. Studies by IRRI indicate that silicon deficiency always reduces the number of panicles per square meter and percentage of filled grains. Silicon deficient plants are particularly susceptible to lodging.

Causes of Silicon Deficiency

Silicon deficiency can be due one of the following factors:

- Soil parent materials contain inadequate quantity of available silicon.
- Soluble Silicon is continuously leached out in strongly weathered soils.
- Long period of intensive crop cultivation (double or triple cropping) depletes the available soil Silicon. This problem is further aggravated by the removal of rice straw from the field.

Common sources of Silicon Fertilizer include blast furnace slag (Calcium Silicate, Magnesium Silicate), Silico-Manganese Slag (Calcium Silicate and Manganese Silicate), Fused Magnesium phosphate, Calcium silicate, and Potassium silicate.

In recent years, the application of nano-technology has led to the production of granulated and liquid silicon fertilizer with high bio-availability. This new silicon fertilizer can easily penetrate the leaf and form a thick silicated layer on leaf surface. IRRI research indicates that Silicon deficiency can be rectified by the application of Calcium silicate slag at the rate of 120-200 kg per hectare or Potassium silicate at 40-60 kg per hectare. As rice leaf and stem generally contain 5-6% (ranges from 2-10%) Silicon, and rice husk contains 10%, thus returning the crop residues back to the soil will help to replenish Silicon in the soil. The most suitable time of silicon application in rice is about 60 days before harvesting.

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