THE EFFECT OF SILICON AND HIGH RATE OF NITROGEN FERTILIZERS ON THE GROWTH AND YIELD OF TQR-2 PADDY VARIETY

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

CROP PRODUCTION PROGRAMME
SCHOOL OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2011

PUMS 99:1

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: THE EFFECT OF SILICON AND HIGH RATE OF NITROGEN FERTILIZERS ON THE GROWTH AND YIELD OF TQR-2 PADDY VARIETY

IJAZAH: DEGREE OF BACHELOR OF AGRICULTURE SCIENCE WITH HONOURS

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ACKNOWLEDGEMENT

I would like to take this opportunity to express my utmost appreciation to Tn. Hj. Mohd Dandan @ Ame Bin Hj. Alidin, my supervisor. Thanks for giving me opportunity to gain the invaluable experience in conducting my final year project. I am truly grateful for his patience, encouragement, advice, support and effort in guiding me to accomplish my dissertation.

I owe my indebtedness to Dr. Mohamadu Boyie Jalloh and Ms. Chee Fong Tyng, lecturers of School of Sustainable Agriculture, Universiti Malaysia Sabah for the productive discussions and valuable teaching on the statistical analysis and helpful suggestions for my final year project. In addition, my gratitude also extends to the field laboratory assistants who provided their technical support in making my study a smooth one and their cooperation.

I also wish to express my appreciations to my friends and course mates who have assisted me during the soil preparation, helping me in the laboratory work and through all the challenges in this study and during the progression of my dissertation writing. I am very thankful for their patience and tolerance.

Furthermore, I would like to take this opportunity to dedicate my heartfelt thanks to my beloved parents, brother and other relatives who gave me moral support and endless love in encouraging me to keep going. Special thanks to my father, Mr. Chan Pai Hey who constantly encouraged and provided financial support on completing this study.

Last but not least, I would also like to express my sincere thanks to Mr. Alle Go, Chief Executive Officer of Goodearth Resources Sdn. Bhd. for supplying the silicon fertilizer for my study.

ABSTRACT

This study was carried out from August 2010 to December 2010 at the School of Sustainable Agriculture Field Laboratory in Universiti Malaysia Sabah (UMS) to evaluate the effects of different levels of silicon fertilizer treatments and high nitrogen fertilizer application on the growth and yield of TQR-2 paddy variety and its effect on reducing the lodging effect on the paddy. Silicon Premium 2 (SP2) fertilizer was used for the six treatments at the rate of 0, 250, 300, 350, 400, 450 kg ha^{-1}. The urea was applied as basal fertilizer before transplant, 15 DAT and panicle initiation and the silicon fertilizer at 15 DAT and panicle initiation. Urea was used as nitrogen source at 120 kg ha^{-1}. A completely randomized design (CRD) was used in this study and consisted of six treatments with three replicates each. In addition, the parameters on plant vegetative growth, yield components and strength of paddy stem were recorded and the data was analysed using one way ANOVA at 0.05% significant level. The high rate of silicon fertilizer (450 kg ha^{-1}) increased the plant height up to 72.33 cm at tillering stage and 92.33 cm at panicle initiation stage. Moreover, 450 Si kg ha^{-1} resulted in significantly higher culm height (64.33 cm) during harvest, 1000 grains weight (27.53 g) and stem diameter (2.52 cm) compared to all other treatments. The extrapolated yield of TQR-2 paddy variety had increased significantly up to 7.6 ton ha^{-1} per season by the high application rate (450 kg ha^{-1}) of silicon fertilizer. However, the length of basal internode was decreased to 0.98 cm as one of the prominent factors that increase the strength of paddy stalk and lodging tolerance of TQR-2 paddy variety. The application of silicon fertilizer on the TQR-2 paddy variety with high nitrogen fertilization is recommended to reduce the lodging effect and achieve high yield.

KESAN RAWATAN BAJA SILIKON DAN PEMBAJAAN NITROGEN KADAR TINGGI PADA PERTUMBUHAN DAN HASIL VARIATI PADI TQR-2

ABSTRAK

Kajian ini dilaksanakan dari bulan Ogos 2010 hingga Disember 2010 di Makmal Ladang Sekolah Pertanian Lestari, Universiti Malaysia Sabah (UMS) untuk mengkaji kesan rawatan baja silikon dan penggunaan nitrogen pada kadar yang tinggi terhadap pertumbuhan dan hasil variati padi TQR-2 serta kesannya untuk mengurangkan kesan rebah padi. Baja Silicon Premium 2 (SP2) digunakan dalam kadar 0, 250, 300, 350, 400, 450 kg ha^{-1}. Urea dibajakan sebagai baja asas sebelum pindah tanam, 15 hari selepas mengubah dan semasa tahap pembentukan malai. Baja urea sebagai sumber nitrogen dalam kadar 120 kg ha^{-1}. Reka bentuk uji kaji rawak lengkap digunakan dalam kajian ini dan kajian ini terdiri daripada enam rawatan yang setiap daripadanya mengandungi tiga replikasi. Selain itu, parameter pertumbuhan vegetatif tanaman, komponen hasil dan kekuatan batang padi direkodkan dan data dianalisis dengan menggunakan ANAVA satu hala pada 0.05% tahap yang signifikan. Pembajaan silikon kadar tinggi (450 kg ha^{-1}) telah meningkatkan ketinggian tanaman sehingga 72.33 cm pada tahap pembentukan anakan dan 92.33 cm pada tahap pembentukan malai. Tambahan pula, 450 Si kg ha^{-1} meningkatkan ketinggian batang padi (64.33 cm) semasa menuai, berat 1000 butir (27.53 g) dan diameter batang (2.52 cm) secara signifikan berbanding dengan rawatan silikon yang lain. Unjuran hasil variati padi TQR-2 ditingkatkan secara signifikan sehingga 7.6 tan ha^{-1} dalam satu musim dengan kadar aplikasi baja silikon yang tinggi (450 kg ha^{-1}). Walau bagaimanapun, panjang ruas asas telah dikurangkan kepada 0.98 cm, ia merupakan salah satu faktor yang penting untuk meningkatkan kekuatan batang padi dan rebah toleransi pada padi variati TQR-2. Penggunaan baja silikon pada variati padi TQR-2 dengan kadar aplikasi baja nitrogen yang tinggi disyorkan untuk mengurangkan kesan rebah dan memperoleh hasil yang tinggi.

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LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CRD	Complete Randomized Design
BRRI	Bangladesh Rice Research Institute
DAS	Days after sowing
DAT	Days after transplant
DBT	Days before transplant
DMRT	Duncan Multiple Range Test
N	Nitrogen
P	Phosphorus
K	Potassium
MOP	Muriate of Potash (fertilizer)
Si	Silicon
SP2	Silicon Premium 2 (fertilizer)
SPSS	Statistical Package for Social Science
TQR-2	Tuaran Quality Rice 2
TSP	Triple Super Phosphate (fertilizer)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rice is a staple crop and mainly for human consumption especially in Asian countries. The total area of land used for rice cultivation is the second largest in the world. The sufficient supply of rice ensures the global food security. The self-sufficiency of rice of Malaysia was 78% in 2008 (Malaysia Agricultural Directory and Index, 2007/2008). Therefore, it is important to improve the yield of paddy to fulfil the self sufficient supply of rice.

Normally farmers tend to add more Nitrogen (N) fertilizer to their paddy crop in order to improve the growth and increase the yield. The high application of N fertilizer leads to the excessive growth of paddy crop and thus causing weaker stems to support the crop. The over dose of N fertilizer is another factor which causes lodging in plants. Apart from lodging, the excessive application of N fertilizer contributes to several problems to the paddy crop. High incidence of pest and disease could also happen and it may lead to other nutritional disorders (Dobermann and Fairhust, 2000).

Silicon (Si) is one of the most abundant elements on earth (Belanger *et al.*, 1995) and this element exists as silica or silicon dioxide or silicates in nature. As much as 60% of earth's crust is silicon dioxide and it is a compound that combines with various metals. Silicon has been reported to have beneficial effects on agriculture and horticulture which helps in plant growth and crop quality, stimulates photosynthesis (Ma and Takahashi, 2002), and protects against fungal diseases such as powdery mildew (Belanger *et al.*, 1995). In addition, silicon enhances the strength of stalk and resistance to lodging by contributing to the strength of the structure of cell walls. Si fills the epidermal walls and vascular tissues where it appears to strengthen the tissues, retard fungal infection, and reduce water loss (Tisdale *et al.*, 1993).

Lodging is defined as the permanent displacement of the stem of a free-standing crop plant from the vertical position (Pinthus, 1973; Berry *et al.*, 2004). Lodging is a serious problem in paddy thus lodging contributed 41% loss paddy crop in Muda Agriculture Development Authority (MADA) in 1992 (Soon, 1992). The plants prone to lodging are those exposed to strong winds and heavy rainfall during heading (Watanabe, 1997; Kaack and Schwarz, 2001). This commonly happens in cereal plants like paddy, wheat and oat. Lodging of plants affects the mechanical harvesting efficiency, quality of paddy production and lowers its yield. However, there is less lodging problem in improved short paddy varieties.

1.2 Justification

TQR-2 paddy variety is widely grown in Sabah due to its high yielding and good quality. In order to attain higher yield, farmer tend to apply high rate of nitrogen fertilizer on the paddy plants. This is because nitrogen fertilizer application helps plants grow vigorously, produce more green leaves, increase number of tillers and panicles and thus increase yield (Pande, 1994). However, the problems occurred in heavily fertilised paddy is lodging. Lodging of paddy causes the plant not able to stand in a proper vertical position and easily destroyed by moderate wind blow. High nitrogen fertilization contributes to heavy top during heading to maturity.

Lodging is more severe problem with high level of nitrogen fertilizer application. Due to the heavy filled panicles, the strength of crop stem is reduced. The weaker paddy stalk cannot support the plant to stand vertically and tend to bend towards the ground when there is heavy rainfall and strong wind. When the paddy crop cannot stand vertically, it will affect the growth and yield of paddy.

In addition, paddy plants with high rate of nitrogen lodging also due to over shaded by big number of tillers. It may cause great losses in both grains yield and quality, and presents extreme problems in harvest operations (Cooper, 1971; Weibel and Pendleton, 1964). The proper physiological pathway like growth and filling of grains in paddy plant cannot be carried out properly. This can directly affect the grains quality by contributing more percentage of empty grains and decreased farm profits. The application of silicon fertilizer is believed can reduce lodging problem in paddy crop. Silicon enhances the strength of paddy stalk and resistance to lodging by strengthening the structure of stem cell walls. Moreover, silicon improves the leaf morphology to reduce self-shading especially under high input of Nitrogen fertilizer (Yoshida *et al.*, 1969).

1.3 Objectives

The objectives of this study were

a) To determine the effect of silicon fertilizer in the high nitrogen fertilizer rate application on the growth and yield of TQR-2 paddy variety.
b) To evaluate the effect of silicon in reducing the lodging effect due to high rate of Nitrogen application on TQR-2 paddy variety.

1.4 Hypothesis

H_o: There is no significant difference in the effect of different levels of silicon on the growth and yield of paddy.

H_a: There is significant difference in the effect of different levels of silicon on the growth and yield of paddy.

CHAPTER 2

LITERATURE REVIEW

2.1 Paddy

2.1.1 Classification of Paddy

Paddy belongs to the genus of *Oryza* in the grass family *Gramineae* or *Poaceae*. There are 25 different species included in this genus in the world and spread in the tropical and sub-tropical region of Asia, Africa, Central America, Southern America and Australia (Grist, 1986). However, there are two species *Oryza sativa* L. and *Oryza glaberrima* Steud that are widely cultivated. *Oryza sativa* is commonly known as Asian rice and it is indigenous to Asia, while, *Oryza glaberrima* is commonly known as African rice and it is indigenous to Africa. *Oryza sativa* is easily found in almost all tropical and sub-tropical regions having of sufficient water and optimum temperature for cultivation (Nanda and Agrawal, 2006).

Paddy consists of two major subspecies which are *japonica* and *indica* varieties. *Japonica* variety is short grained and sticky while *indica* variety is long grained and non-sticky. *Japonica* is usually cultivated in dry fields, in temperate East Asia, upland areas of Southeast Asia and high elevations in South Asia. *Indica* is mainly grown in lowland and mostly submerged in areas of tropical Asia (Oka, 1988).

2.1.2 TQR-2 Paddy Variety

Tuaran Quality Rice 2 (TQR-2) is a new paddy variety released by the Department of Agriculture Sabah. This paddy variety can grow up to 80-105 cm high and the maturity period is 120-125 days and it is a short term variety. TQR-2 is a high yielding variety and with a potential yield of 7.5 metric ton per hectare per season. It has a very good eating quality too (Jabatan Pertanian Sabah, 2007).

TQR-2 is also resistant to 'Rice Tungro' disease (caused by Rice Tungro Bacilliform Virus or Rice Tungro Spherical Virus) that commonly attacks paddy crops. However, TQR-2 is not recommended to be grown with high N fertilizer application rate (Jabatan Pertanian Sabah, 2007). In addition, TQR-2 experiences lodging problems due to strong wind and heavy rainfall. The cultivation of TQR-2 also depends on the weather and drainage conditions in the fields.

2.2 Morphology of the Vegetative Parts of a Paddy Plant

The vegetative parts of a paddy plant consist of roots, culm and leaves. The branch bearing the roots, culm and leaves with or without panicle is known as tiller (Appendix Aa). The roots of paddy plants are fibrous and possess rootlets and root hairs. The adventitious roots grow from nodes above the soil and the secondary adventitious roots are produced from the underground nodes of the young culm. The coarse adventitious roots often form in whorls from the nodes above the ground level and these adventitious roots are freely branched. This provides a good anchorage for the vertical standing plants (Chang and Bardenas, 1965).

The stem of a paddy plant is known as the culm and it consist of a series of nodes and internodes. The internodes are elongated in vary dimensional way. The lower internodes having larger diameter and grow thicker than the upper ones. The primary tillers are arising from the lowermost nodes and give rise to the secondary tillers. The leaf consist of sheath and blade and borne on the culm. The leaf sheath is important in supporting the culm. It envelops the culm above the node in varying forms, length and tightness (Chang and Bardenas, 1965). The morphology of these vegetative parts of paddy plants is shown in appendix A.

In the cross section of stem, the internode has a large hollow space called the medullary cavity, whose diameter is the inner diameter of the internode. Many large vascular bundles are found in the middle portion of the internode tissue. In addition, many small vascular bundles are located near the epidermis. In the lower elongated internodes, fourth or fifth from the top, many air spaces may be found between the vascular bundles (Yoshida, 1981).

2.3 Nutrient Management in Paddy Plant

Paddy and other plants need more than 16 essential elements for plant growth and yield. Nutrients like nitrogen, phosphate, potassium, calcium, magnesium, sulphur and silicon are required relatively large amounts by the plants. Paddy yield and quality depend highly on soil nitrogen fertility (Murayama, 1979). Macronutrients like nitrogen, phosphorus and potassium are playing crucial role. Nitrogen fertilizer helps plants to grow vigorously, produce more green leaves, increase number of tillers and panicles and thus increase yield (Pande, 1994). Potassium fertilizer application to paddy plant provides higher tolerance to pests and diseases in the plants and may helps in reducing lodging potential. Application of phosphorus fertilizer can enhance root development, promote tillering at the early stage and assist in the ripening of plants (Dobermann and Fairhust, 2000).

There are many varieties of paddy crops being bred for high yield performance. High yielding crop requires and removes more nutrients from the soil to sustain economically viable outputs. This causes the soil is lacking of both major and minor elements hence weakening the crops and become more vulnerable to numerous pests and diseases. Moreover, there are symptoms of growth stunted and lower yield caused by nutrient deficiency and improper nutrient management.

Various cereals remove 100 to 300 kg Si ha^{-1} (Bazilevich *et al.*, 1975). Rice plants take up large amount of nutrients from paddy soil every year. The average amount of nutrients taken up for the production of 100 kg brown rice per hectare estimated by Central Agricultural Experiment Station in Japan is shown on Table 2.1.

Table 2.1: The average amount of nutrients taken up for the production of 100 kg brown rice estimated by Central Agricultural Experiment Station in Japan

Elements	Kilogram (kg)
Nitrogen	2.1
Phosphorus	0.5
Potassium	3.3
Silicon dioxide	20.0
Calcium	0.7

Source: Ma and Takahashi (2002) and Yakabe (1987)

Soil fertility is crucial as both macronutrients and micronutrients are supplied in the soil to maintain the productivity. The regular fertilizing program which integrates the essential nutrients to increase the soil activities such as increasing biological activity, enhance rapid decomposition and mineralization of organic matter available in the soil. This also helps in preventing nutrient leaching (Dobermann and Fairhust, 2000).

2.4 Effect of High Nitrogen Application

Nitrogen is an essential constituent of amino acids, nucleic acids, nucleotides, and chlorophyll. It promotes rapid growth like increased plant height, tillers number, leaf size, spikelet number per panicle, percentage of filled spikelet and grain protein content. Leaf nitrogen concentration is closely related to the rate of photosynthesis and crop biomass production. The sufficient nitrogen application to the crop increased the demand of other macronutrients such as P and K (Dobermann and Fairhust, 2000). Thus, nitrogen is the most important nutrient for rice, and its deficiency occurs almost everywhere unless nitrogen is applied as a fertilizer (Yoshida, 1981).

The high input of nitrogen fertilizer improved the growth and yield of paddy plant. However, over dose of N fertilizer caused unfavourable condition like mutual shading and lodging to yielding (Barbosa Filho, 1987 and 1991). When the number of tillers and leaves increased by the high rate of N fertilizer decreased the photosynthetic performance in plant, thus affect the panicles production. Moreover, empty spikelets occurred by the high Nitrogen application (Dobermann and Fairhust, 2000).

According to Yoshida (1981), tall varieties of paddy fail to yield more in response to increased nitrogen applications mainly because they tend to lodge at high nitrogen levels. Furthermore, there was positive response of nitrogen fertilizer found and reported that elongation of the lower internodes caused by heavy nitrogen application, which are essential for high yield, make the plant more susceptible to lodging.

The high input of Nitrogen (N) fertilizer is also causing lodging in plants. The over dose of N fertilizer leads to over growth of paddy plant and thus weaken the stem to support the plant. Culm of rice plants also becomes weak under heavy application of nitrogenous fertilizers, deep submergence and sunlight deficiency (Kono 1995). Apart from lodging, the excessive N fertilizer application caused several problems such as high incidence of pest and diseases that leads to other nutritional disorders.

2.5 Lodging Effect on Paddy Plant

Lodging is defined as the permanent displacement of the stem of a freestanding crop plant from the vertical (Pinthus, 1973; Berry *et al.*, 2004) (Appendix Ab). Lodging has been a major constraint in cereal production (Pinthus, 1973). It may causes great losses in both grains yield and quality, and presents extreme problems in harvest operations (Cooper, 1971; Weibel and Pendleton, 1964). Thus, it is a common problem in most cereal like wheat, barley and paddy.

Over 70 years ago (Ramaiah and Mudaliar, 1934), it was shown that the more lodging-resistant types of rice had stems with a thicker band of sclerenchyma at the periphery of the stem than lodging-susceptible strains. More recently, Chaturvedi *et al.* (1995) showed that lodging-tolerant submerged lowland rice varieties had more vascular bundles, both peripheral and in the inner section of the outer layers, than susceptible varieties. Lodging can occur at three parts in rice plants, from the base, in mid-tiller and as result of heavy panicles (Bhiah *et al.*, 2010).

Lodging depends on three paddy features that are stalk strength, stalk height and weight of panicles. By analysing the basis of lodging, studies show that the susceptibility of a variety to lodging will depend on three factors which are the size and dynamics of the forces to which it is subjected (Pinthus, 1973), the bending strength of the stem and its resistance to lodging (Neenan and Spencer-Smith, 1975), and the anchorage strength of the root system. Lodging of paddy depends on the angle of bushing-out between the lateral shoot and the main one, where the most favourable angle is 30°-35°. There is a direct correlation between the stalk strength and roots strength (Cherepanov, 1995).

Lodging-tolerant submerged lowland rice varieties had more vascular bundles, both peripheral and in the inner section of the outer layers, than susceptible varieties (Chaturvedi *et al.,* 1995). The differences in the degree of lodging and the lodging index were largely dependent on variation in the breaking strength of the basal internodes (Ooawa *et al.*, 1993). These physical characteristics of culms associated with lodging resistance in paddy rice.

2.5.1 The Causes of Lodging on Paddy Plants

Agronomic factors affecting lodging are nitrogen (N) supply (and timing) and potassium (K) and silicon nutrition. Increased and timely nitrogen supply, promoting vigorous vegetative growth and increased panicle size and weight, may result in lodging (Bhiah *et al.*, 2010).

According to Yoshida (1981), lodging usually results from the bending or buckling of the two lowest internodes, which have elongated more than 4 cm and the leaf sheath enclosing these internodes must be stiff. The strength of elongated internodes is affected by mechanical strength, chemical composition, and plant nutritional status. The mechanical strength is related to culm thickness and tissue strength. Lodging decreases grain yield drastically, particularly when it occurs right after heading and when panicles are brought in contact with standing water. The beneficial and ill effects of heavy applications of nitrogen present a serious dilemma.

Several factors make the paddy plants prone to lodging. The lodging effect on the plant is depended to the different varieties of paddy plants. The tall varieties are usually more prone to lodging and it is rarely in short varieties of paddy (Chang, 1964). In spite of work done on lodging resistance, the only successful approach to increasing lodging resistance has been to develop short varieties. Short varieties, however, are not always lodging resistant (Chandler 1969) because other characteristics such as culm thickness, tissue strength, and rate of senescence of lower leaves modify the breaking strength of the shoot (Yoshida, 1981). Meanwhile, lodging is more severe problem in the high level of Nitrogen fertilizer application practice due to the over shaded of tillers and heavy panicles in paddy plants. In addition, the shallow roots that are weak in anchorage provide a poor stand establishment to support the plant (Ariff, 2007).

In addition, lodging is characterised by stem bending, stem breakage, and root lodging (Kono, 1995). Lodging can be determined in term of bending moment and the breaking strength of the culm and sheath (Chang, 1964). The bending moment of stem is caused by the weight of supportive stem and the height of the main axis. The panicle weight will increase as the grains grow after the heading, when ripening progresses and panicles drop. Therefore, the bending moment on the paddy plant will occurs more vigorously after heading. While the length of the upper internode affects the bending strength of the paddy culm, the stiffness of the elongated internode and strength and tightness of the leaf sheath (Yoshida, 1981).

2.5.2 The Characteristics of Paddy Plant Resistant to Lodging

Paddy plant with weaker stalk strength makes the plants more prone to lodging caused by the unfavourable weather condition like strong wind and heavy rainfall during heading (Watanabe, 1997; Kaack and Schwarz, 2001). Lodging of plants affects the mechanical harvesting efficiency, quality of paddy production and lowers its yield (Kono, 1995). However, there is less lodging problem in the shorter paddy varieties.

The characteristics of paddy plant which resistant to lodging can be measured using the third and the fourth internodes at 35-40 days after heading. The bending moments calculated from the length and weight of shoot above the third and the fourth internodes under the heavily fertilization and lightly fertilization. The application of rice chaff was able to improve the strength of the stalk by its Si adsorption (Khandaker, *et al.*, 1999).

In addition, basal internode elongation with low internode thickness is the most important character for lodging. Moment, culm strength and nature of wrapping of the leaf sheath are also important for lodging. Paddy plant with lower moment, higher culm strength and tightly wrapping of the leaf sheath make a variety tolerant to lodging. Consequently, these characters are greatly influenced by nitrogen application which is more remarkable for lodging susceptible varieties (Mahbub *et al.*, 2006).

According to Mahbub *et al.* (2006), internode thickness or thickness of culm is one of the most important characters of a rice variety for lodging resistance. The thickness of internode gradually decreased with the increase in internode number except 2nd internode in BR 11 (BRRI variety). It might be due to the increase in outer diameter of culm accompanied by a larger increment in inner diameter when high level of nitrogen fertilizer were added, resulting in thinner culm, smaller culm areas. As a result, plants are lodged at high level of nitrogen fertilizer. Chang (1964) also found similar results and reported that the culm becomes thin and slenderness ratio becomes large at high nitrogen level.

2.6 Silicon

Silicon (Si) is one of the most abundant elements on earth (Belanger *et al.*, 1995) and this element exists as silica or silicon dioxide (SiO_2) or silicates in nature. There are about 200 over types of silicate rocks in nature included quartz and mica. There is 60% of earth crust consists of silicon dioxide and it is a compound that combined with various metals. It occupies more than 50% of the soil and the concentration of Si in soil solution in the form of silicic acid is between 3.5 and 40 mg Si L^{-1} (Marschner, 1995). Silicic acid (H_4SiO_4) is a product of silicon rich mineral dissolution (Lindsay, 1979). The soluble and weakly adsorbed silicic acids (H_4SiO_4) are absorbed by plants and microorganisms (Yoshida, 1975). Silicic acid (H_4SiO_4) is significantly superior and advantageous for Si uptake by paddy (Takahashi *et al.*, 1990).

Silicon has been reported to have beneficial effect on agriculture and horticulture which helps in plant growth and crop quality, stimulate photosynthesis (Ma and Takahashi, 2002), and protect against fungal diseases such as powdery mildew (Belanger *et al.*, 1995). Besides, silicon enhances the strength of stalk and resistance to lodging by contributing to the structure of cell walls. Si filled the epidermal walls and vascular tissues where it appears to strengthen the tissues, retard fungal infection, and reduce water loss (Tisdale *et al.*, 1993). Consequently, silicon is important element for a large number of plants such as rice, bamboo, horsetails, ferns, gymnosperms and angiosperms (Sangster and Hodson, 1986).

Silicon is beneficial nutrient for *Graminaceous* plants but not an essential element for plant growing (Marschner, 1988). However, it still a very important element for cropping and it required for the development of strong leaves, stems, and roots (Dobermann and Fairhust, 2000). Although all the main nutrients in plants are supplied by application of NPK fertilizer, silicon fertilizer is an important element to restore major soil deficiencies. Long period of intensive crops cultivation depletes the available silicon in soil. Effective fertilization programs are essential for ensuring high crop performance but a well-balanced fertilizers are the most important to correct soil deficiencies and sustain high crop productivity. Paddy plants adequately supplied with Si have erect leaves and growth habit. This contributes to efficient light use, and thus N use efficiency (Dobermann and Fairhust, 2000). However, silicon application is usually ignored in the past.

2.6.1 Silicon Uptake

The silicon exists in form of silicic acids (H_4SiO_4) soluble in soil and for plant and microorganisms adsorption (Yoshida, 1975). Paddy roots have high ability to take up Si (Okuda and Takahashi, 1961). Silicon uptake modes in plants as observed in plants like paddy, barley and tomato are active, passive and rejective uptakes (Okuda and Takahashi, 1965). Theses uptakes modes are respond to the high, medium and low Si accumulation respectively.

Silicon absorbed by roots is in the form of silicic acid as an undissociated molecule (Takahashi and Hino, 1978). Si is then immediately transported to the shoot, together with the transpiration stream then polymerized and accumulated on the cell surface of the rice leaf (Yoshida, 1965). Silicon localization in rice tissues is related to transpiration, and heavy deposits of silica are often observed where water movement terminates (Yoshida *et al.*, 1962).

In general, the silicon adsorbed and accumulated in the epidermal cells of plants and it will increase leaf chlorophyll content and increase crop yield when it is properly applied. Silicon is assimilated by plant roots as silicic acids where it accumulates in leaves and other plant tissue primarily as amorphous silicates or phytolithic opal. Once deposited in this form, Si is immobile and is not redistributed within the plant (Epstein, 1994). Hydrated, amorphous silica is deposited in cell lumens, cell walls, intercellular spaces and accumulates in external layers below and above the

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