ASSESSMENT OF BIOEFFICACY OF SILIXOL GRANULES ON GROWTH AND YIELD IN RICE (*Oryza sativa L)*

A thesis submitted to the School of Agriculture and Food Science in partial fulfillment of the requirements for the award of the Degree of Masters of Sciences in Crop Science, university of Rwanda

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DECLARATION

I, Jean Claude ABAYISENGA student at University of Rwanda, Masters of Science in Crop Sciences hereby declare that my research work titled as "**Assessment of bioefficacy of Silixol granules on growth and yield in rice"** under supervision of **Dr. Saidi Rumanzi Mbaraka** is my original work and has not been submitted or published for any other degree award to any degree or any other award in any other university.

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I, **Dr. Saidi Rumanzi Mbaraka**, hereby confirm that this work was carried out by the candidate under my supervision.

Supervisor's Signature: ………………………………… Date……/……/ 2019

DEDICATION

This thesis is dedicated to my beloved parents for their parent love, care and for shaping me into the person I am today. They helped me and provided an example of hard work, the time they spent, the opportunities of being student they provided and the instruction they gave continue to help me in my life.

I dedicate it also to my brothers and sisters for their unlimited love and for being my source of motivation and encouragement. This work is also dedicated to my classmates, colleagues and friends for their encouragement during my studies.

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LIST OF ABBREVIATIONS AND ACRONYMS

°C: Degree Celsius

CIP: Crop Intensification Program

ICT: Information Communication Technology

IRRI: International Rice Research Institute

ISAR: Institut des Sciences Agronomique au Rwanda

MINAGRI: Ministry of Agriculture and Animal Resources

NISR: National Institute of Statistics of Rwanda

NRDS: National Rice Development Strategy

pH: Potential of Hydrogen

PRC: People’s Republic of China

RAB: Rwanda Agriculture Board

USD: United State Dollars

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ABSTRACT

Rice is one of the leading food crops in the world and greatly contributes to the agricultural sector in Rwanda. However, its yield is reduced due to fertilizer use imbalances and degradation of soil. Silicon is known as important for rice growth and yield and is commonly utilized in form of Silixol fertilizers. However, the use of Silixol fertilizers to enhance crop production has not been evaluated in Rwanda. This study therefore aimed at assessing the Silixol granules bioefficacy on rice growth and yield when used as an additional fertilizer to the recommended dose fertilizer (RDF).

The study was conducted in Rwagitima Marshland, Gatsibo district, in the Eastern province of Rwanda. To examine theSilixol effect on rice growth and yield, we used different combinations of 100 % (200 kg/ha NPK and 100 kg/ha Urea) and 75% (150 kg/ha NPK and 75 kg/ha Urea) of RDF and additional applications of 10, 15 and 20 kg/ha of Silixol granules. Eight treatments were replicated three times in a randomized complete block design.

The results showed that Silixol granules have a highly significant effect on growth characters (number of tillers, height of plant, root length and plant dry matter) of rice. The treatments where 20kg of Silixol granules were used resulted in a high level of growth . Yield and yield related characters (number of panicles, weight of panicles, weight of grain per panicle, harvest index and rice yield) increased from the control .However, the harvest index for 75% RDF+20kg of Silixol granules was lower than the control. Therefore, to conclude, 20 kg/ha of Silixol granules applied as additional fertilizer to100 % RDF has the potential to increase the rice productivity.

Key words: Rice, growth, yield, Silixol granules, fertilizer dose

CHAPTER I. INTRODUCTION

1.1. Introduction

Rice (*Oryzasativa L*) was domesticated approximately 9000 years ago (Diamond, 2002) and ranks the second most cultivated cereal after wheat. Rice is among the major staple food crops and feeds over half of the world's population, mostly in Asia. It contains 20% of the per capita energy, and 13% of the protein consumed worldwide (Juliano, 1994). Rice was introduced in Rwanda in the 1960s by various missionaries from South Korea, Taiwan and PRC. Since then, rice has begun to be one of the major food crops grown in Rwanda (NRDS, 2011).

Since the 1980s, Rwanda has been unable to meet its domestic food needs from national production (Okoboi et al., 2003).The food deficit has been filled in import and to a large extent by food aid.In order to create a more self-reliant food balance in the country, the government has developed a strategy regarding a number of food crops including maize, beans, rice, maracuja and sweet potatoes. The reason for focusing on these crops is that they are crops which offer a better trade and value added prospects than the traditional food staples (Okoboi et al., 2003).

Rice production has become a vital component in Rwandan agricultural sector. The area under rice cultivation was expected to increase in order to raise the rice production from 66,000 Metric Tons (MT) of paddy to 369,000 MT/year in 2018 (NRDS, 2011). However, rice yield is either constant or decreasing in the post green revolution period mainly due to degradation of soil,fertilizer use imbalance, cropping system practices and lack of suitable genotypes of rice that are adapted to low moisture and disease resistant (Prakash, 2010).

Silicon is important for a proper growth and a stable production of rice. In addition, the rice plant accumulates great amounts of silicon. Silicon ranks the second most available element on the earth surface and has important role in conveying resistance to abiotic and biotic stresses and in increasing crop productivity (Savantet al., 1997). Silicon is mostly present in the amorphous form in which it is impossible for the plants to assimilate. Plants utilize silicon from the soil in the form of monosilicic acid, also known as orthosilicic acid (H_4SiO_4) (Lewin and Reimann, 1969).

Orthosilicic acid is more unstable and is easily converted into non-available forms like polymeric silicic acid or is connected with other compounds to form metasilicates. Silicon in the form available to plants is not common in fertilizers available at the market but can be found as calcium or potassium silicates. However, silicon in this form is not readily absorbed by plants. Privi Life Sciences, India has stabilized the orthosilicic acid (OSA) through a patented technology and are now marketing the product with the commercial name Silixol (Jawahar et al., 2015). Silixol is a newly introduced fertilizer in Rwanda, to be used as additional fertilizer and has not been used before. The influence of Silixol on rice growth and yield in Rwanda was assessed in the present study.

1.2. Problem statement

In general rice production is constrained by different factors such as inadequate application of agricultural inputs (Nguyen et al 2006). Additional supply of fertilizers containing necessary mineral nutrients is required to increase the productivity. The mineral nutrients include both macro and micronutrients. The normally used fertilizers used in rice cultivation contain mainly the macronutrients. Silicon is a micronutrient that increases the yield in rice cultivation. Soil nutrients deficiency in Rwanda are depleted through erosion leading to poor soil fertility. Organic soils and highly weathered soils in rainfed lowland and upland areas might have lower Si reserves (IRRI, 2016). Silixol granules might be used as additional fertilizer in rice cultivation to increase the silicon availability to the plant ; however, the use of these Silixol fertilizers to increase the crop production has not been reported in Rwanda. Silixol granules fertilizer affects rice growth and productivity. In this study different rate of Silixol granules were used to assess its bioefficacy on rice growth and yield when added as an additional fertilizer

1.3. Justification of the study

In Rwanda, rice is among the crops under the Crop Intensification Program (CIP) and is increasingly becoming a staple cereal crop. Through the promotion of rice intensification by the government, there has been an increase in rice cultivation. The production of rice has been given a high priority and the government is seeking to extend productivity from the flood prone marshlands that are favorable for rice growing. It has also been observed that rice is capable of giving very high yields of over 7 MT per ha per growth cycle (Okoboi et al., 2003). Rwanda produces about 3,532 kg/ha (NISR, 2018).However, the production in other areas is still low mainly due to limited availability and use of inorganic fertilizers on poor soil.

Application of NPK fertilizer together with silicon significantly increased total uptake of N, P and K in rice (Chanchareonsooket al., 2002). The efficient use of nutrients increased the yield leading to an increased income generation and improved people livelihood. The study provided the the farmers with information on the bioefficacy of Silixol granules rates on rice growth and yield.

1.4. Objectives

1. 4.1. General objective

- To determine the bioefficacy of different rates of Silixol granules on rice crop growth and yield when added as additional fertilizer compared to the rates of fertilizer normally used in rice production.

1.4.2. Specific objectives

- To determine the bioefficacy of different rates of Silixol granules on the growth of rice .
- To determine the bioefficacy of different rates of Silixol granules on the yield of rice.

1.5. Hypotheses

- There are significant differences in bioefficacy between use of recommended dose of fertilizer and the additional application of Silixol granules to recommended dose fertilizer.
- There are significant differences in bioefficacy between different amounts of added Silixol granules.

CHAPTER II LITERATURE REVIEW

2.1. Rice nutrient requirement

Nutrient uptake by rice is influenced by the range, season, nature and composition of the soil and the yield level. In order to produce 1 ton of paddy (rough rice), the rice crop absorbs an average of 20 kg N, 11 kg P_2O_5, 30 kg K_2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo and 52 kg Si. About 50 percent of N, 55 percent of K and 65 percent of P are absorbed during the early panicle initiation stage. About 80 percent of N, 60 percent of K and 95 percent of P uptake is completed by the heading stage. The uptake of N and P is higher in grain than in straw (3:1) whereas larger proportions of K, Ca, Mg, Si, Fe, Mn and B can be found in the straw. Absorbed Zn, Cu and S are distributed equally in straw and grain (Yoshida, 1981)

2.2. Need of new fertilizer in Rwanda for rice production

Most Rwandan soils undergo soil erosion which leads to low fertility. The soils thus require high-levels of investment in soil amendments (Rutunga et al., 2006). With such soil types, it is not enough to control erosion, as productivity is already very low; they often produce zero yields of cereals (Rutunga et al., 1998).The rice subsector is important for the Rwandan national economy (MINAGRI, 2014). Rice is produced by an estimated 94,275 households and it accounts for 18 % of per capita energy derived from cereals (NISR, 2014).

Despite rice natural endowments, Rwanda remains a net importer of rice, and in 2013 spent USD 27.6 million on imported rice, making rice the largest contributor to import values across all agriculture, forestry, and fishery products (ICT, 2014) Rwanda produces about 55,946 MT of paddy from 15,842 hectares, which is translated to 3,532 kg/ha (NISR, 2018). However, as high levelsas 8-10 tons/ha are frequently reported by model farmers who invest in high levels of production inputs such as fertilizers (300kg of NPK/ha) and pesticides (ISAR, 2009).

2.3. Importance of silicon for rice production

Silicon ranks the second most available element on the surface of earth and has an important role in conveying resistance to abiotic and biotic stress and increasing crop productivity (Jawahar and Vaiyapuri, 2010). It is also important in preventing or reducing lodging in cereal crops which is the major problem in agricultural productivity.Silicon increases the leaferectness in rice, and strengthens the air canal, leading to highefficiencyof oxygen supply to the roots and reduced water loss by evapotranspiration. Silicon is a diatomic element in structure and a cell wall constituent in rice and other grasses. Generally, older plant parts contain greater amountsof Si than younger parts. Silicon contributes to the plant compression resistance and cell wall rigidity which in turn improve photosynthetic efficiency, light interception and drought resistance (Epstein, 1999).

Silicon has a major function in root formation, as formation of secondary and tertiary roots are controlled by monosilicic acid in the soil. The rice plant obviously requires Si to maintain a healthy growth and high productivity. Silica increases resistance to leaf and neck blast, sheath blight, brown spot, leaf scald and stem rot (Datnoff and Rodrigues, 2005). Silicon also alleviates many abiotic stresses including chemical stress such as high salt, metal toxicity, nutrient imbalance and lodging, drought, radiation, high temperature and freezing. (Ma andYamaji, 2006).

2. 4. Influence of silicon on nutrient uptake

Increased silicon levels increase phosphorus content due to a increased solubility of phosphorus and a decreased retention capacity of soil resulting in an increased efficiency of phosphotic fertilizers (Subramanian and Gopalswamy, 1990). Application of NPK fertilizer together with silicon significantly increased the total uptake of N, P and K in rice (Chanchareonsooket al. 2002). Silicon also favorably influenced the sulphur uptake. The increased Si uptake with the application of Si-rich fertilizers might be due to the increased availability of silicon in the soil and an improved root system, which in turn might stimulate the plant to take up more Si from the soil (Pati et al., 2016).

Moreover, the application of Si significantly improved the uptake of N, P and K in above-ground rice biomass (Pati et al., 2016). Singh et al. (2005) reported that Si application has the potential to enhance the availability of N in the soil, resulting in an enhanced N uptake due to ample N availability. Si application also increases the K uptake by the rice plant (Pati et al., 2016).

2.4.1. Effect of Silixol granule on height of rice plants

The increase in plant height could be due to deposition of silicon in the plant tissues causing leaf and stem erectness (Yavarzadeh et al.,2008).Silicon causes cell division, elongation and expansion resulting in an increased height of the plant (Jawahar et al., 2015). The more erect leaves and stem lead to a decreased mutual shading which otherwise can be caused by a high density of plants, and hence a better light interception and a higher photosynthetic rate (Jawahar, 2011 and Yoshida et al., 1969).

2.4.2. Effect of Silixol granules on number of tillers

Tillering is the production of extending axillary buds in relation to the mother clumps. Tillers obtain nutrients and carbohydrates from the mother clump during the early growth period and the process is clearly enhanced by application of Silixol (Liang et al., 1994). Application of NPK fertilizer in combination with Si increased the total number of tillers in rice (Chanchareonsooket al., 2002).The tillering of rice increased with increased amounts of silicon in the nutrient solution (Malavet al.,2015).Application of Silixol granules according to the recommended dose resulted in a higher number of tillers per hill of rice (Jawahar et al., 2015). Silixol granules have beneficial effects which appear to be the result of a low initial content of silicon in the soil. Silixol granules applied according to the recommended dose might be favorable for abundant root and shoot growth, thereby enhancing NPK and Si absorption from the soil leading to an increased plant metabolic activity (Jawahar, 2011).

2.4.3. Influence of Silixol granule on rice dry matter production

Silixol granules application resulted in higher dry matter production due to efficient utilization of light ,maintenance of high photosynthetic activity and translocation of assimilated products to the sink (Rani et al., 1997).In addition, silicon improved the interception of sunlight by leaves due to leaf erectness by stimulating canopy photosynthesis in rice (Singh et al., 2005). The balanced supply of silicon might favourably influence the carbohydrate metabolism, energy transformation, activation of carbon fixing enzymes and synthesis of auxin which in turn favourably influence the dry matter production of rice (Dhanasekara, 2010).High chlorophyll content and a larger leaf area might result in the plant accumulating more photosynthates and thereby producing higher plant dry matter (Jawaharet al., 2015).

2.4.4. Impact of Silixol granules application on rice root length

Silixol granules, when applied to the recommended dose of fertilizer, highly affect the root length of rice (Jawahar et al., 2015). The maximum root length and volume at tillering and flowering stages of rice might be affected by silicon fertilization, as there was an increase in the development of secondary and tertiary cells of endodermis, thus allowing a better root penetration in soils and a faster root growth (Hattori et al., 2005)

2.4.5. Effect of Silixol granules application on rice panicle initiation

Application of Silixol granules according to the recommended dose resulted in a higher number of panicles per plant. This might be due to readily available silicon in the form of orthosilicic acid and high photosynthetic activity arising from its synergistic effect with other nutrients. Panicle formation is directly associated with the number of productive tillers per unit area (Jawahar et al, 2015; Rani and Narayanan, 1994).

2.4.6. Influence of Silixol granules on rice yield and yield components

Higher nitrogen levels along with added silicon gave a significant increase in yield and yield attributes of rice (Singh et al., 2005). The higher grain yield was due to synergistic effects between silicon and nitrogen, phosphorous and potassium, which in turn resulted in a better photosynthetic activity leading to increased yield attributes and yield (Sudhakar et al., 2004). The increase in grain yield may be due to the positive effect of silicon on pollen viability and photosynthetic activity (Patiet al., 2016).

The increase in grain yield could also be due to an increased production of number of panicles per m^2, number of grains per panicle, and weight of grains (Rani and Narayanan, 1994). The application of readily available forms of silicon (orthosilicic acid) to the crop and its synergistic effect with other nutrients results in higher photosynthetic activity and higher yield (Singh et al., 2006). Application of silicon increased the amount of spikelets per panicle particularly when it was applied during the reproductive stage(Anand and Sreekanth, 2018).

Higher grain weight is attributed to a better availability and translocation of nutrients as well as transport of photosynthates from source to sink. A sufficient silicon supply might improve the photosynthetic activity that enables the rice plant to accumulate sufficient photosynthates, resulting in an increased dry matter production. These factors in combination with an efficient translocation of photosynthates might result in a higher number of filled grains and an increased weight of grain (Jawahar et al., 2015). Grain yield of rice is dependent on the tillering capacity as it is closely associated with panicle number per unit area (Efisue et al., 2014)

CHAPTER III MATERIALS AND METHODS

3.1. Study area

The study was conducted at Rwagitima site, Gatsibo district in the Eastern province of Rwanda. The area where this research was carried out was 750 m^2. The field was located at 1364 m of altitude. The district is characterised by the granite low valley whose average altitude is 1550 m.a.s.l. spread on the plateau and the savannah of the Eastern part of the country. Gatsibo district has a low precipitation, ranging from 800-1000mm per annum and an average temperature between 25.3^o C and 27.7^{o}C (Ruboneza, 2013).

3.2. Experimental design

The experimental design was a randomized complete block design. The field layout was composed by one factor rate of Silixol applied in 8 different treatments replicated 3 times (Figure 1). Each treatment was applied to a plot of 6 x 5 m with a total area of 30 m^2.Each treatment appeared once within each block and 24 plots covered 720 m^2 within the field of 750 m^2. The distance between plots was 0.8 m

3.3 Fertilizer application for each treatment

During the experiment different treatments were used according to the recommended dose of fertilizer and additional applications of Silixol (Table1).Treatment one (T1) consisted of a full dose (100%) of Recommended Dose of Fertilizer (RDF) while treatment two (T2) comprised a 75% dose of RDF. Treatment three (T3) was 100% RDF and 10 kg of Silixol. Treatment four (T4) was 100% RDF and15 kg of Silixol granules. Treatment five (T5) was 100% RDF and 20kg of Silixol granules. Treatment six (T6) was 75% RDF and 10kg of Silixol granules. Treatment seven (T7) was 75% RDF and 15kg of Silixol granules, while treatment eight (T8) was 75% RDF and 20 kg of Silixol granules.

BLOCK 1	**T2**	**T4**	**T3**	**T1**	**T8**	**T6**	**T7**	**T5**
BLOCK 2	**T8**	**T7**	**T4**	**T5**	**T2**	**T3**	**T6**	**T1**
BLOCK 3	**T3**	**T2**	**T6**	**T4**	**T5**	**T7**	**T1**	**T8**

Figure 1. Field layout used in this study.

Table1. List of fertilizers applied and fertilizer application rates to each treatment.

Treatments	Fertilizer applied	Basal application		2nd Application		3rdApplication
		Kg/ha				
		NPK	Silixol granules	Urea	Silixol granules	Urea
T1	100% of RDF	200	0	50	0	50
T2	75% RDF	150	0	37	0	37
T3	RDF +10 Kg/ha of Silixol granules	200	10	50	10	50
T4	RDF +15 Kg/ha of Silixol granules	200	15	50	15	50
T5	100%RDF+20 Kg/ha of Silixol granules	200	20	50	20	50
T6	75%RDF +10 Kg/ha of Silixol granules	150	10	37	10	37
T7	75%RDF +15 Kg/ha of Silixol granules	150	15	37	15	37
T8	75% RDF+20 Kg/ha of Silixol granules	150	20	37	20	37

3.4. Source of plant material

The rice variety used was "Yun yin 4" which has a life cycle of 170 days. "Yun yin 4" is a short grain Chinese type of rice variety commonly grown in Rwanda and it is currently grown in Rwagitima site. Seeds of "Yun yin 4" were obtained from Rwanda Agriculture board (RAB)

3.5 Field operations

3.5.1. Nursery preparation

The seed was sown in the raised bed for seedling preparation where 1.5 kg of rice seed was sown within the same seedbed. Proper irrigation, weeding and pest and disease control were ensured to obtain healthy seedlings for transplanting. Sowing was done on 18th February 2019.

3.5.2. Land preparation

The primary tillage was done on 20th February 2019 by using hand hoes. After two weeks, on 6thMarch 2019, it was followed by the second tillage to break large clods and to do puddling in preparation for transplanting. The field was marked out into three blocks and each block was divided into 8 plots.

3.5.3. Transplanting

Transplanting was done on 7 March 2019,at 17 days from seeds sowing, one day after puddling and one seedling was planted in each hole using a spacing of 20 cm x 20cm.Therefore 750 seedlings were planted during transplanting

3.5.4. Paddy field water management

After planting, the water in the field had to be removed to ensure root growth and allow an efficient fertilizer use. After one week, a 3 day interval was used to remove old water and add new water to the field. When adding water to the field it is important to remove the old water to prevent pests and diseases prevalence. Water was completely removed from the field within 2 weeks before harvesting to ensure reduced water content

3.5.5. Fertilizer application

Fertilizer application was done at three occasions; NPK 17-17-17and Silixol granules were used as basal fertilizer at planting, urea and Silixol granules were used for top dressing at the second occasion after first weeding and the third application of urea was done after the second weeding.

3.5.6. Weeding

Weeding was done by hand hoes at 3 weeks after planting, the second and third weeding was done at 4 weeks interval to prevent the competition between rice and weeds.

3.5.7. Pest and disease control

Pest and disease control was done in nursery for proper seedling growth and in the field after transplanting at tillering stage and at panicle initiation to harvesting stage. Cypermethrin for insect pest control, Dethane and Beam for fungal like blast and sheath blight disease prevention was used. The birds were controlled by using human power to prevent the yield loss.

3.5.8. Harvesting

Harvesting was done when the rice had reached full physiological maturity and the grains from each plot were put in separate plastic bags. Each sample was dried separately until they got fully dried at 14 % moisture content.

3.5.9. Threshing and winnowing

The fully dried rice was threshed separately for each treatment and replication. Each sample was winnowed and packed to measure the paddy.

3.6. Data collection

3.6.1. Plant height

Plant height was measured from to the soil to the top of the upper leaf using tape measure. Ten randomly selected plants per treatment in each block were measured and the mean was calculated to get the average height per plot expressed in cm (Rukhsana et al., 2018).The data were collected at mid tillering and panicle initiation stages.

3.6.2. Number of tillers per m^2

Ten plants per treatment within each block were randomly selected in different part of plots and used to determine the number tillers per hill (Malav et al.,2015).They were collected at mid tillering and panicle initiation stage. The counting were expressed in number of tillers per m^2.

3.6.3. Root length of the rice plant

Ten plants per plot randomly selected and uprooted after harvesting and their roots were washed and measured in centimeter from bottom to its extremity using a tape measure (Jawahar et al., 2015).

3.6.4. Plant dry matter per treatment

Ten plants per plot were randomly selected in the centre of the plot at harvesting stage. These samples were dried in an oven at 70^0C until constant weight was attained and measured using electronic balance (Singh et al., 2006). Dry matter was expressed into kg per ha.

3.6.5. Number of panicles per m^2

Ten hills were selected randomly and used to measure the number of panicle produced by each hill for each plot and was expressed as number of panicles per m^2 (Aveshik et al., 2017).

3.6.6 .Weight of panicle

Tens panicles were randomly selected in each plot at harvesting stage after plants being dried (Mosaad, 2012).The average weight of panicles was done and the results were expressed in gram

3.6.7. Harvest index per treatment

The rice plants were harvested and the harvest index was obtained from the ratio between grain yields to biological yield (Elkheir et al., 2018).

3.6.8. Grain yield per treatment

The grains were collected from each treatment within each block after harvesting and were dried until 14 percent moisture content (Singh et al., 2006).The grain yield was expressed as tons per hectare.

3.7. Data analysis

The experimental data were analyzed using the method used by Gomez and Gomez (1994). Treatment effects were significant at $P<0.05$ and means was separated using standard error of the difference. The tables and figures were used to present the results.

CHAPTER IV: RESULTS

The results show the effects of each treatment on the growth, yield components and yield. In this study we evaluated the effect of different treatments on number of tillers per plant, plant height per plot, root height per plant, dry matter production per treatment, number of panicle per hill, weight of panicle, harvest index and yield per treatment.

4.1. Effect of Silixol granules on plant height at mid tillering and panicle initiation stages

There was a highly significant difference in plant height per treatment at panicle initiation stage but no significant difference at mid tillering stage (Table 2). At both the mid tillering and the panicle initiation stage, the plant height increased as the Silixol dose increased. At 100% RDF and 20kg/ha of Silixol granules (T5), the plant height increased 16 % at mid tillering and 10% at panicle initiation stage compared to the control (T1). An application of 75 % RDF and 20kg/ha of Silixol granules (T8) increased the plant height 10 % at mid tillering and 8.6% at panicle initiation compared to the control (T2). Plants treated with 100% RDF and 20kg/ha of Silixol granules were in general taller than plants treated with 75% RDF and 20kg/ha of Silixol granules.

4.2. Effect of Silixol granules on number of tillers at mid tillering and panicle initiation stages

Application of Silixol granules resulted in highly significant differences in number of tillers ($P<0.05$) at panicle initiation stage but did not show any significant difference at mid tillering stage (Figure 2). However all plants exhibited an increase in number of tillers at all both mid tillering and panicle initiation stage. The usage of 100% RDF and 20kg/ha of Silixol granules (T5) increased the number of tillers by 30.6% mid tillering and 33.5% at panicle initiation stages compared to the control (T1). At 75 % RDF and 20kg/ha of Silixol granules (T8) there was an increase in the number of tillers by 14.1 % at mid tillering and 26.4% at panicle initiation stage when compared to the control (T2). The treatment where 100%RDF and 20kg/ha of Silixol granules was used resulted in a higher number of tillers than the treatment with 75%RDF and 20kg of Silixol granules.

4.3. Effect of Silixol granules on root length

There was a significant difference in root length at $p<0.05$ among treatments (Table 3). The root length increased with a higher dose of fertilizer (RDF) and Silixol granules.100% RDF and 20 kg/ha of Silixol granules gave longer roots compared to 75% RDF and 20 kg/ha of Silixol granules. At 100% RDF and 20kg/ha of Silixol granules (T5) root length increased 41%while 75 % RDF and 20kg/ha of Silixol granules (T8) increased the root length with14.7%compared to the controls.

4.4. Effect of Silixol granules on weight of dry matter production

Silixol granules application on rice led to a significant difference in the weight of dry matter production ($p <0.05$) (Figure 3). Weight of dry matter produced increased 30.58% for 100 % RDF and 20kg/ha of Silixol granules (T5). For 75% RDF and 20kg/ha of Silixol granules (T8) there was an increase of 4 % compared to the control. In addition, 100% RDF and 20kg of Silixol granules gave a higher amount of plant dry matter than 75% RDF and 20kg of Silixol granules.

4.5. Effect of Silixol granules on number of panicles

There was a significant effect of Silixol granules on the number of panicles per m^2 ($p< 0.05$) (Figure 4), as an increase in the amount of fertilizer resulted in an increase in the number of panicles per m^2. At 100% RDF and 20kg/ha of Silixol granules (T5), the number of panicles increased 31.4% while 75 % RDF and 20kg/ha of Silixol granules (T8) increased by 30.1% compared to their controls. 100% RDF and 20 kg/ha of Silixol granules resulted in a higher number of tillers compared to 75% RDF and 20 kg/ha of Silixol granules.

Table2. Effect of Silixol granules on plant height and number of tillers at mid tillering and flowering stages

Treatment	Recommended dose of fertilizer (RDF) kg/ha		Silixol granules kg/ha	Plant height per hill (cm)		Number of tillers per m^2	
	NPK	Urea		MT	PI	MD	PI
T1	200	100	0	80.29	90.75^{ab}	196	221^{ab}
T2	150	75	0	80.89	89.38^{b}	192	186^{b}
T3	200	100	10	82.19	93.01^{ab}	218	226^{ab}
T4	200	100	15	88.29	94.71^{ab}	236	244^{ab}
T5	200	100	20	93.12	99.88^{a}	256	295^{a}
T6	150	75	10	87.24	93.61^{ab}	193	218^{ab}
T7	150	75	15	83.62	94.58^{ab}	195	220^{ab}
T8	150	75	20	89.23	97.11^{ab}	219	235^{ab}
P Value				0.269 ns	0.004**	0.07ns	0.008**

**shows that the treatment effect is highly significant at $p < 0.01$, ns shows that the treatment effect is not significant at $p<0.05$ MT: Mid Tillering, PI: Panicle Initiation

Table 3 Effect of Silixol granules on root length per treatment

Treatment	Recommended dose of fertilizer (RDF) kg/ha		Silixol granules kg/ha	root length per treatment (cm)
	NPK	Urea		
T1	200	100	0	11.07^{ab}
T2	150	75	0	10.87^{b}
T3	200	100	10	11.87ab
T4	200	100	15	12.67ab
T5	200	100	20	15.63^{a}
T6	150	75	10	11.53^{ab}
T7	150	75	15	12.2ab
T8	150	75	20	12.47^{ab}
P Value				0.049*

*shows that the treatment effect is significant at $p<0.05$

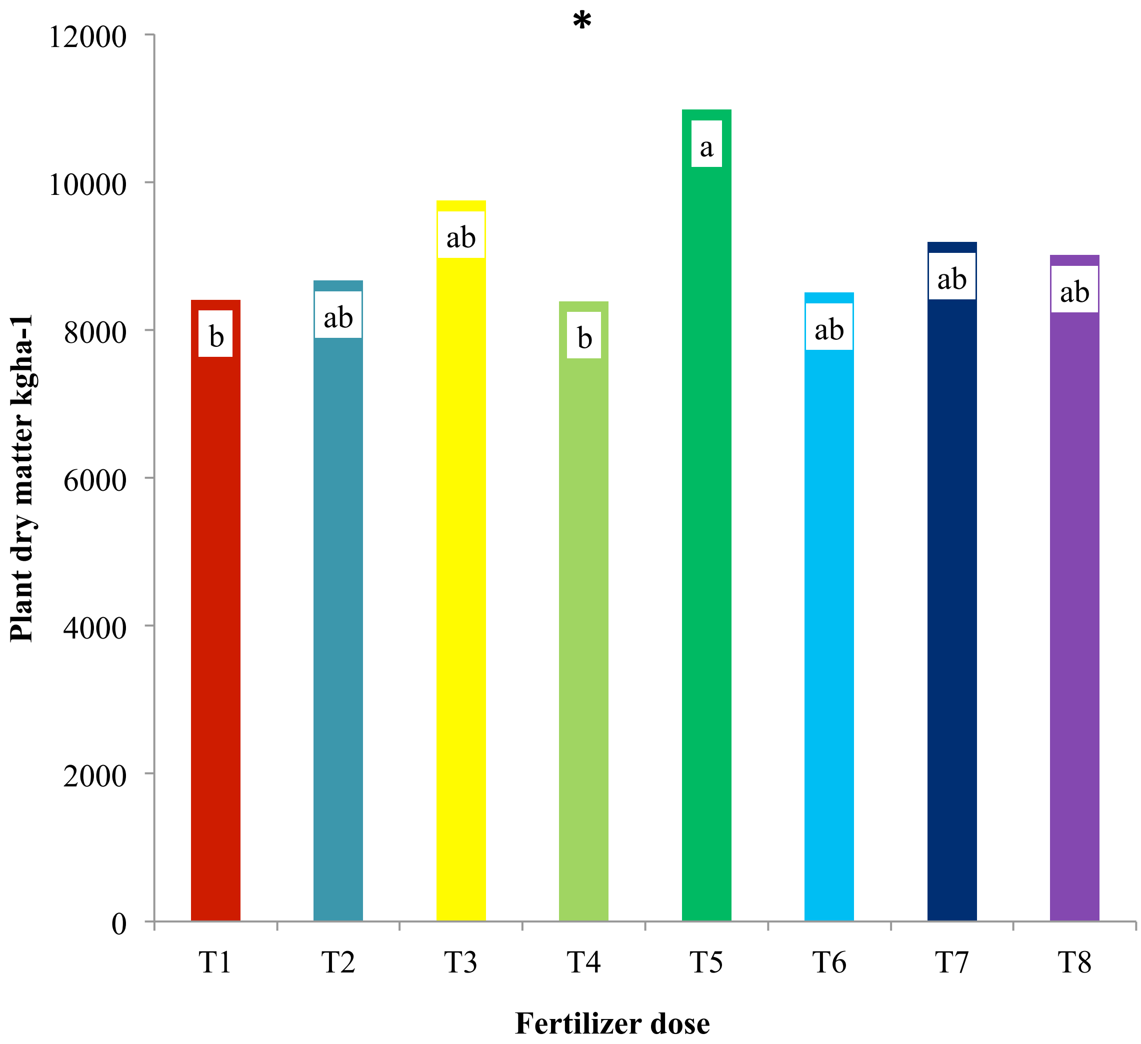

Figure2. Effect of Silixol granules on weight of dry matter production

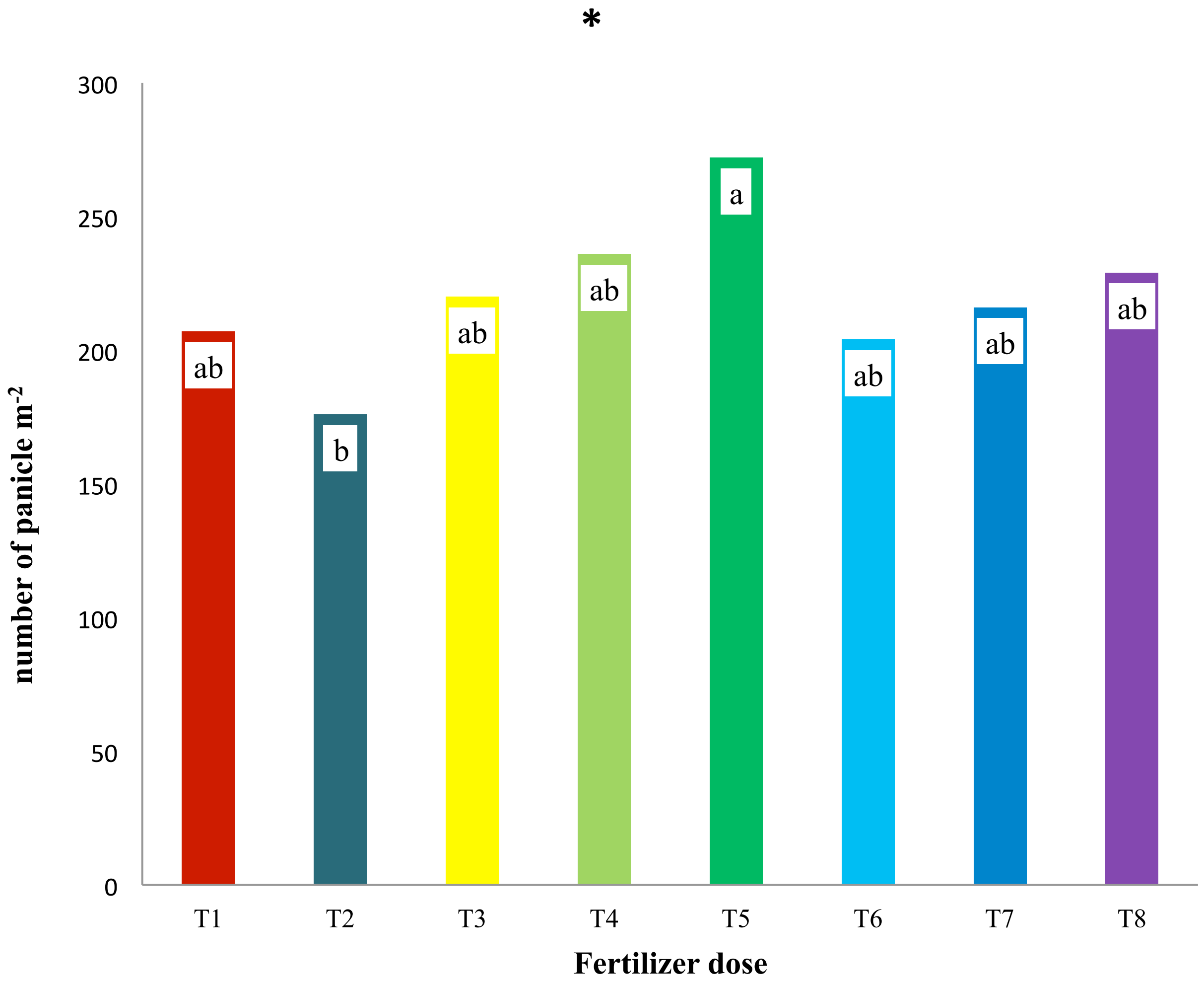

Figure 3. Effect of Silixol granules on number of panicles

4.6 Effect of Silixol granules on weight of panicle

There was no significant effect of Silixol granules on the weight of panicles (Figure 5).However there was an increase in weight of panicles per hill. The increase in weight of panicles was 11.32% at 100% RDF and 20Kg/ha Silixol granules and 8.7% for 75% RDF and 20kg/ha of Silixol granules compared to their controls .An increased amount of Silixol granules seems to increase the weight of panicles. 100% RDF and 20 kg/ha of Silixol granules produced a higher panicle weight compared to 75% RDF and 20 kg/ha of Silixol granules.

4.7. Effect of Silixol on weight of grains per panicle

There was a significant difference between treatments in weight of grains per panicle ($p< 0.05$) (Figure 6). The increase in weight of grains per panicle was 21.53%at 100% RDF and 20Kg/ha of Silixol granules and 26% at 75% RDF and 20kg/ha of Silixol granules. An increased amount of Silixol granules increased the weight of grains per panicle but not for 75% RDF because where 20 kg of Silixol was used owned less weight to treatment 15 kg of Silixol granules was applied. The treatment treated with 100%RDF and 20 kg of Silixol granules exhibit more weight per panicle compare to the treatment treated with 75% RDF and 20kg of Silixol granules.

4.8. Effect of Silixol granules on harvest index

There was no significant difference of Silixol granules on harvest index (Table 4). However there was an increase of 6.5% in harvest index when using 100% RDF and 20 kg /ha of Silixol granules compared to the control. The treatment with 100% RDF and and10kg /ha of Silixol resulted however in a lower harvest index .At 75% RDF and 20 kg/ha of Silixol granules there was a decrease of 1.33% of the harvest index compared to the control.

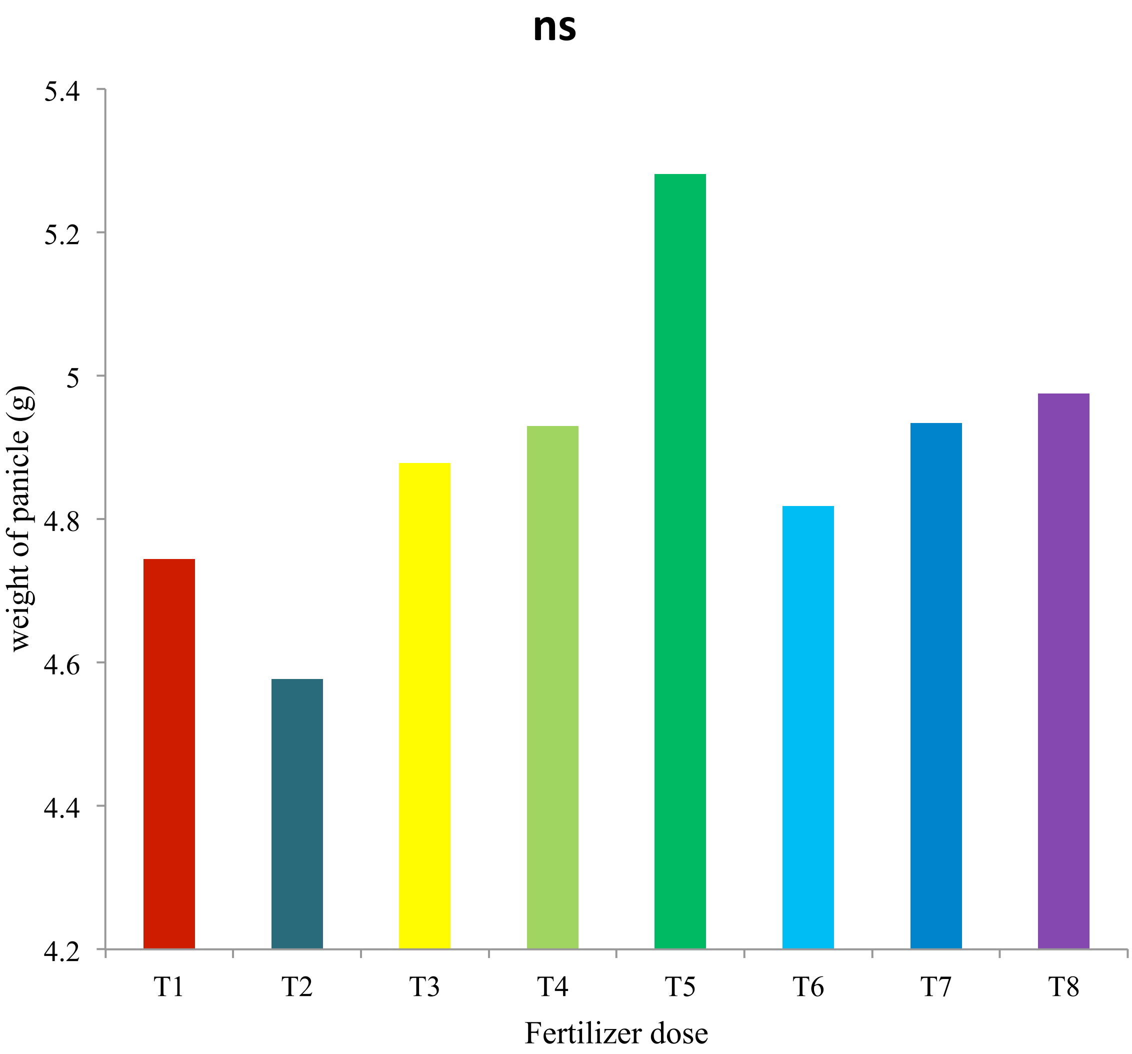

Figure 4. Effect of Silixol granules on weight of panicles

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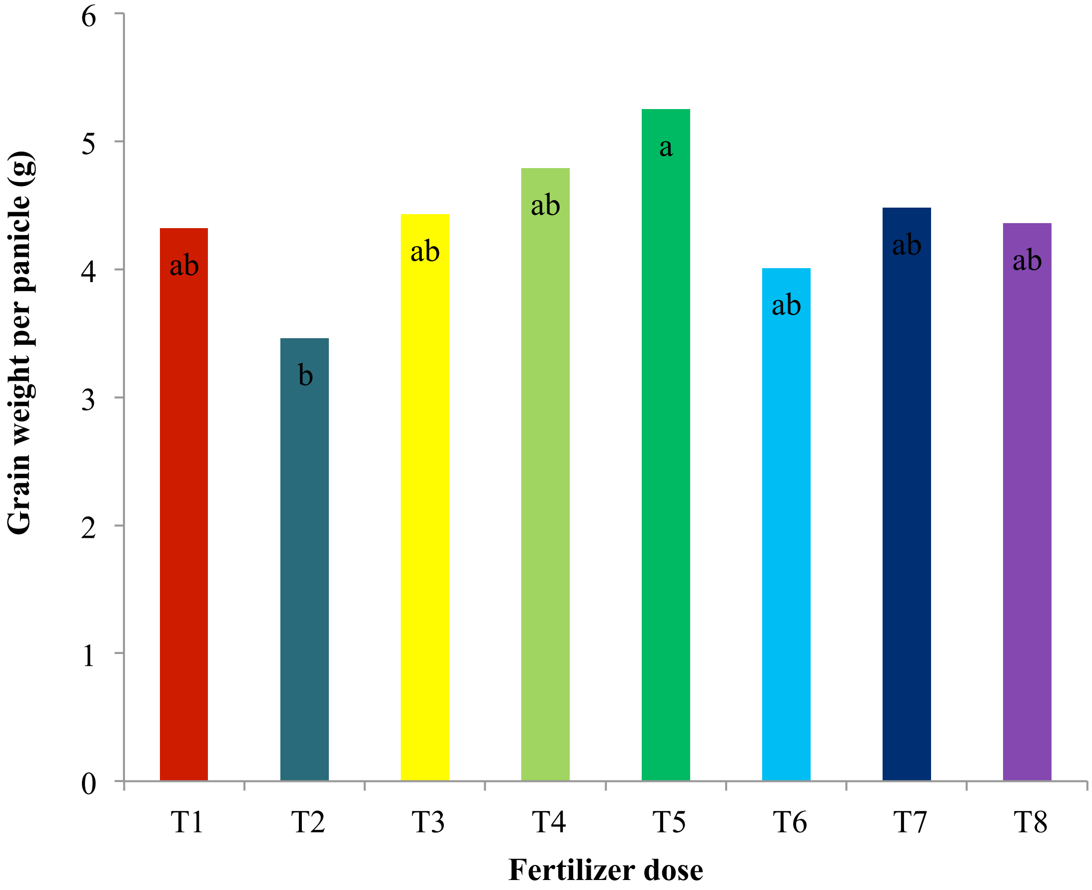
Grain weight per panicle (g)
0
1
2
3
4
5
6
ab
b
ab
ab
a
ab
ab
ab
T1
T2
T3
T4
T5
T6
T7
T8
Fertilizer dose

Figure 5. Effect of Silixol granules on grain weight per panicle

Table4. Effect of Silixol granules on harvest index

Treatment	Recommended dose of fertilizer (RDF) kg/ha		Silixol granules kg/ha	harvest index %
	NPK	Urea		
T1	200	100	0	47.7
T2	150	75	0	52.6
T3	200	100	10	45.1
T4	200	100	15	49.1
T5	200	100	20	50.8
T6	150	75	10	49.2
T7	150	75	15	50.7
T8	150	75	20	51.9
P value				0.8 ns

4.9. Effect of Silixol granules on rice grain yield

There was no significant difference of treatment on grain yield (Figure 7).There was an increase with 25.3% in grain yield at 100% RDF and 20kg of Silixol granules and an increase of 3.7% at 75% RDF and 20 kg/ha of Silixol granules. However the grain yield produced for 100% and 75% for RDF in combination with10 or 15kg Silixol granules was lower compared to their controls.

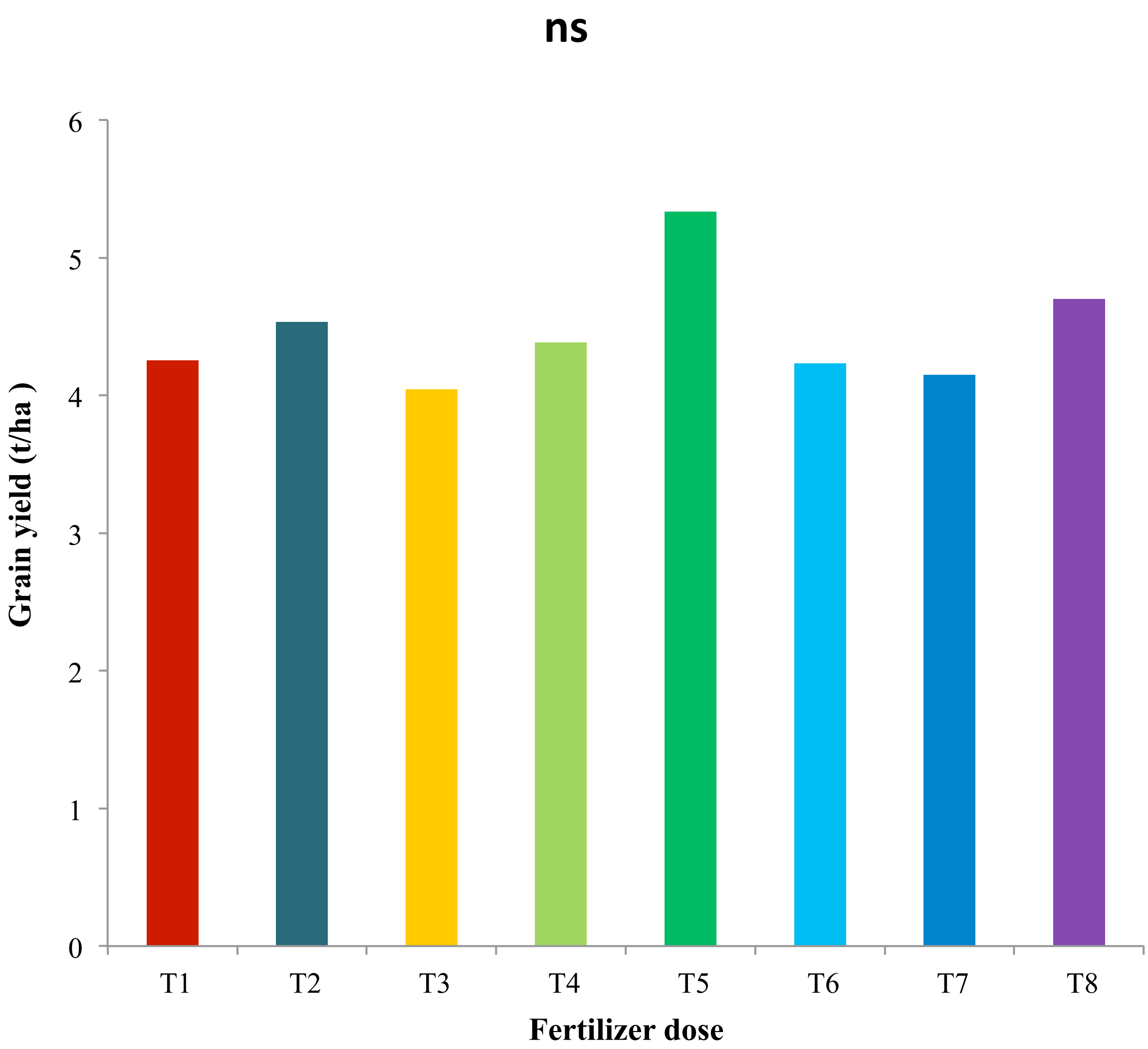

Figure6. Effect of Silixol granules on rice grain yield

CHAPTER V DISCUSSION

CHAPTER V DISCUSSION

5.1. Plant height

There was a highly significant difference in plant height per treatment at panicle initiation stage but no significant difference at the mid tillering stage. However at both stages, the plant height increased with an increased recommended fertilizer dose in combination with an increased dose of Silixol granules. The results at the panicle initiation stage are in conformity with that of Yavarzadeh et al.(2008) who reported that the increase in plant height could be due to deposition of silicon in the plant tissues causing leaf and stem erectness. Yoshida et al.(1969) came to the same conclusion, arguing that a decrease of mutual shading caused by a high plant density increases the photosynthetic rate of the plant due to a higher light interception.These findings are also in agreement with that of Jawahar et al.(2015) and Jawahar (2011).

5.2. Number of tillers

Silixol granules have a highly significant effect on the number of tillers at panicle initiation stage but no significant effect at mid tillering stage. However all treatments resulted in an increment in number of tillers. Similar findings were reported by Jawahar (2011) who stated that application of Silixol granules according to the recommended dose resulted in a higher number of tillers per hill. Liang et al., (1994) reported that tillering is the production of axillary buds associated to the nutritional condition of the mother clumps. Tillers obtain nutrients and carbohydrates from the mother clump during the early growth period and the process is clearly enhanced by application of Silixol. The same findings were reported by Jawahar (2015).

5.3. Root length per treatment

Silixol granules have a significant effect on root length. The root length increased as the rate of recommended dose of fertilizer increased. These findings are similar to those of Hattori et al.,(2005) who reported that the maximum root length at flowering stage of rice might be affected by silicon fertilization, as there was an increase in the development of secondary and tertiary cells of endodermis, thus allowing better root penetration of soils and a faster growth of roots.

5.4. Plant dry matter production

There was a significant effect of Silixol granules on the weight of dry matter production. The results are in agreement with that of Rani et al., (1997) who reported that application of Silixol granules resulted in higher plant dry matter production which could be due to the maintenance of high photosynthetic activity, efficient utilization of light and translocation of assimilated products to the sink. In addition, Singh et al., (2005) reported that silicon improved the interception of sunlight by leaves due to leaf erectness by stimulating canopy photosynthesis in rice.

5.5. Number of panicles per m^2

There was a significant difference between treatments in number of panicles. The increase in the number of panicles per m^2cooccurred with an increased fertilizer recommended dose and an increased amount of Silixol granules. The results are similar to those obtained by Jawahar et al., (2015) who stated that application of Silixol granules according to the recommended dose resulted in a higher number of panicles per plant. This might be due to readily available silicon in the form of orthosilicic acid and a high photosynthetic activity arising from its synergistic effect with other nutrients. Panicle formation is directly associated with the number of productive tillers.similar findings has been reported by Rani and Narayanan (1994).

5.6. Weight of panicle

Silixol granules application increased the weight of panicles as the rate of additional Silixol granules increase which is a yield related attribute. This is in conformity with the results of Singh et al., (2005) who reported that the higher nitrogen level along with added silicon gave a significant increase in growth, and yield attributes of rice. Higher grain weight is attributed to a better availability and translocation of nutrients as well as the transport of photosynthates from source to sink.

5.7. Weight of grains per panicles

Silixol granules application significantly affected the grain yield per panicle. These findings are the same as those of Anand and Sreekanth (2018) who reported that silicon increases the rice grain yield per panicle compared to the controls. Application of silicon increased the number of spikelets per panicle of rice mainly when it was applied during the reproductive stage. Grain yield per panicle was significantly affected by Silixol application due to an increased synthesis of carbohydrates and that might have increased the sink size and capacity.

The same results were obtained by Jawahar et al.,(2015) who outlined that silicon is able to regulate stomatal activity, water use efficiency and photosynthesis ,resulting in a better vegetative and reproductive growth which in the end increase the panicle weight.

5.7. Harvest index

There was increase in harvest index from control to 100% RDF added 20kg/ha Silixol granules. These findings are in agreement with those reported by Jawahar et al. (2015) who stated that a sufficient silicon supply might improve the photosynthetic activity that enables the rice plant to accumulate a higher amount of photosynthates, resulting in an increased dry matter production. These factors link to an efficient translocation of photosynthates which might result in a higher number of filled grains and an increased weight of grains. Harvest index is determined from the ratio between grain yields to biological yield by Martin et. al.2017

5.8. Grain yield

There were increase in weight of grain yield from control to 20kg/ha Silixol granules applied to each recommended fertilizer dose . The findings are same as those those of Singh et al., (2006) who reported that the application of readily available forms of silicon to the crop and its synergistic effect with other nutrients resulted in a higher photosynthetic activity and a higher yield. Also Rani and Narayanan (1994) reported of higher yields and stated that the increase in grain yield could be due to an increased production of number of panicles per m^{-2}, number of grains per panicle, and grain weight whereas the increase in straw yield could be due to an increased plant height, number of tillers per hill, leaf area index, chlorophyll content and dry matter production. Rice grain yield is dependent on tillering capacity as it is closely associated with panicle number per unit area (Efisue et al., 2014).

CHAPTER VI CONCLUSION AND RECOMMENDATION

According to the results obtained in this study, 100% recommended dose of fertilizer applied together with 20 kg of Silixol granules resulted in a good performance in growth parameters like number of tillers per m^2, plant height and root length and plant dry matter produced. 100% and 75% recommended dose of fertilizer in combination with 20kg/ha of Silixol granules gave good results compare to the control. The application of 100 % RDF and 20kg/ha of Silixol resulted in a higher yield (5.3 tons per ha) compared to the treatment of 75% RDF and 20kg/ha of Silixol granules, which gave 4.7 tons per ha.

We recommend that this study is repeated for another season and across additional agro-ecological areas to generate more reliable results that can be transformed into recommendations for rice farmers. Further studies are needed to compare the application of Silixol granules with current recommended dose fertilizer. However, the findings of this study indicate the potential of Silixol to increase the productivity and yield of rice cultivation in Rwanda. This is the first report on the use of Silixol fertilizer in Rwanda, and will thus form the basis for further exploration of the need for silicon application in crop production.

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APPENDICES

Appendix 1: Growth related attributes

Treatment	Number of tillers per m^2 at MT	Number of tillers per m^2 at PI	Plant height per treatment at MT(cm)	Plant height per treatment at PI (cm)	Root length (cm)	Plant dry matter (kg/ha)
T1	196	221	80.29	90.75	11.07	8408
T2	192	186	80.89	89.38	10.87	8667
T3	218	226	82.19	93.01	11.87	9750
T4	236	244	88.29	94.71	12.67	8388
T5	256	295	93.12	99.88	15.63	10979
T6	193	218	87.24	93.61	11.53	8504
T7	195	220	83.62	94.58	12.2	9188
T8	219	235	89.23	97.11	12.47	9012
P =0.05	0.072	0.008	0.269	0.004	0.049	0.03

Appendix 2.Yield and yield related attributes

Treatment	Number of panicles per m^2	Panicle weight (g)	Harvest index (%)	Grain yield (t/ha)
T1	207	4.744	47.7	4.258
T2	176	4.577	52.6	4.533
T3	220	4.878	45.1	4.042
T4	236	4.93	49.1	4.383
T5	272	5.281	50.8	5.33
T6	204	4.818	49.2	4.233
T7	216	4.934	50.7	4.15
T8	229	4.975	51.9	4.7
P =0.05	0.04	0.924	0.8	0.598