BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF CROP SCIENCE

Evaluating the influence of silicon on the growth and yield of maize *(zea mays* l) under limited water condition.

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BINDURA UNIVERSITY OF SCIENCE EDUCATION
FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE
DEPARTMENT OF CROP SCIENCE
RESEARCH PROJECT

DECLARATION

I, Martin M Mawire do hereby declare that this research project is a result of my original research work undertaken by myself except where clearly and specifically acknowledged. It is being submitted for the fulfilment of the Bachelor of Agricultural Science Honours Degree (Crop Science). It has not been submitted before for any degree or examination at any other University.

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I have supervised the research project for the above mentioned and I am convinced that the research project:

a) Can be submitted

Project Supervisors: i) ______________________________

Signature____________________

Date: 27/06/22

ii) ______________________________Signature_____________________

I certify that I have checked the Research project and I am satisfied that it conforms to the Department of Crop Science guidelines for project preparation and presentation. I therefore authorize the student to submit this dissertation for marking.

Quality controller____________________________Signature____________________________

Date: 27/06/22

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DEDICATION

I dedicate this project to my parents and my 2 brothers.

ACKNOWLEDGEMENTS

The grace of the Almighty God brought me to the doors of Bindura University in the dawn of 2018 which was the beginning of a deeply valued educational journey and a rich experience. I would like to appreciate the unending sacrifices and overflowing love and support of my parents and my 2 brothers Milton and Isheanopa. I am forever indebted to the Crop Science department for affording me a chance to develop and mold a habit of concentration acquired over the years of great mentorship and supervision of Ms. Kamota, Dr Zenda the cheerful teachings of Elder Daniel, Trymore and Ethel, the meticulous teachings my friends Bancho, Walla, Scatter and Tafadzwa and with the continuous motivation from Patience. I would like to express gratitude to the ever-smiling colleagues and the supportiveness of my school colleagues. Most of all I’m thankful to the Lord Almighty for sustaining me throughout my life, for paving the way for me and granting me the capacity to understand that which I was being taught.

ABSTRACT

Abiotic stressors reduce crop yields by around 70% each year worldwide, and severe drought affects about 30% of farmed land. An open-field experiment on effects of Si was conducted at Braford Farming to evaluate the influence of silicon under limited water conditions on the growth and yield of maize using the randomised complete block design arranged in a factorial manner replicated three times. The treatments were randomly assigned to the experimental units using the hat system and the variation in slope was the blocking factor. The experiments consisted of five SiO_2 treatments which included a control named M1 with SiO2 0 Lt/ha and four treatments named M2, M3, M4, and M5 with SiO2 5 L/ha, 7 L/ha, 9 L/ha, and 10 L/ha, respectively. All silicon, phosphate, and potassium fertilizers were applied as basal applications. All treatments where exposed to limited water supply of 40 % moisture content. The parameter used to monitor the growth and yield of maize under Si treated treatments were plant height, stem diameter, LAI, number of leaves, cob length and cob weight. The results showed that there was a significant difference in plant height, LAI, stem diameter, number of leaves, cob length and cob weight and treatment 10L/Ha recorded the highest in all parameters with means 195.1, 70.83, 5.94, 17.67, 23.50 and 700.3 respectively, biggest cob and LAI whilst treatment 0L/Ha had the lowest of all these parameters. In conclusion 10L/Ha showed the highest growth rate and highest yield whilst 0L/Ha showed the lowest growth and yield.

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LIST OF ACRONYMS AND ABBREVIATION

L/Ha	Litres per hectare
N	Nitrogen
Si	Silicon
SiO2	Silicon Oxide
cm	Centimeters
g	Grams
FAO	Food Agricultural Organisation
AN	Ammonium Nitrate
Zn	Zinc
ANOVA	Analysis of variance
Fe	Iron
RCBD	Randomised Complete Block Design

CHAPTER 1 INTRODUCTION

1.1 Background information

Drought, salt, metals, severe temperatures, raised CO_2, unbalanced nutritional status, herbicides, and increased UV-B irradiation are all common environmental restrictions faced by crop plants in agricultural settings (Taiz and Zeiger, 2006). Abiotic stress conditions in the environment have a significant impact on crop management and result in significant losses in crop returns around the world (Bechtold and Field, 2018). Abiotic stressors reduce crop yields by around 70% each year worldwide, and severe drought affects about 30% of farmed land (Etesami and Jeong, 2018)]. Drought stress has a variety of negative consequences on agricultural productivity, including limiting plant morphological, physio-biochemical, and molecular processes, as well as damaging photosynthetic mechanisms and lowering crop yields (Abd El Mageed et al, 2016).

Exogenous use of organic and inorganic chemicals to minimize various abiotic stresses in plants has been studied extensively in recent years (Abd El Mageed et al, 2012). Silicon (Si) is one of these compounds that can aid plant growth by reducing biotic and abiotic stressors (Liang et al, 2005). Si is the second most abundant mineral element on the earth's surface, after oxygen, and makes up around a quarter of the crust (Liang et al, 2015). Despite the fact that Si is an important nutrient for the bulk of higher plants, its importance has not been well recognized until recently (Kaya and Tuna, 2006).

Several recent investigations have clarified that Si is necessary as a beneficial element for monocotyledons under biotic and abiotic stressors (Gong & Chen, 2012). Si plays a protective role against a variety of environmental stresses in a variety of crops, including maize (Da Cunha KPV et al, 2008). Si can improve plant performance and tolerance to both abiotic and biotic stresses, according to agronomists (MaJF and Yamaji, 2006). Through the strengthening of the plant cell wall and cuticle characteristics, Si plays a critical role in sustaining plant tolerance to abiotic and biotic stressors (Sonobe et al, 2009). Previous research has shown that Si has a variety of physiological benefits in plants, including improving water absorption by roots and thus increasing nutrient absorption (Ming et al, 2012), lowering transpiration moisture loss from leaves due to Si deposition on cell walls (Gong et al, 2003), organizing plant water relations under stress (Chen et al, 2011), and promoting photosynthetic operation (Ming et al, 2012 &Tuna AL et al, 2008).

After wheat and rice, maize (Zea mays L.) is the world's third most cultivated crop (Malcovska et al, 2014), and has become the most important staple cereal and feed crop in many nations, including Zimbabwe (FAO, 2017). Abiotic variables such as salinity, water scarcity, high temperatures, low soil fertility, metal ions, and pest infestation have a significant impact on maize productivity in Zimbabwe (Abdel latef et al, 2016). Therefore, the objective of this study was to evaluate the influence of Silicon on the growth and yield of maize under a limited water supply. The results could prove useful for developing sustainable management strategies for maize production with reduced irrigation water.

1.2 Problem statement

Drought in recent years has been a major challenge Zimbabwe has been facing especially in maize production. Maize production is seriously reduced by abiotic factors such as salinity, water scarcity, high temperature, low soil fertility, metal ions, and pest infestation. However, there is very little understanding about the effect of Si in a large-scale field study under deficit irrigation and Si′s possible role in drought stress mitigation in maize. Although some research had been done in previous years on the effects of silicon on maize, but the effects of Si on growth and yield and under limited water supply remained undefined especially here in Zimbabwe. The use of Si fertilizers is not yet well adopted here in Zimbabwe because people have little knowledge on its benefits and use hence this study is being carried out to address the problem of growth and yield in maize due to water shortage (drought) using silicon fertilizers.

1.3 Justification

Zimbabwe recent years has been facing droughts due to climate change which reduces maize production in Zimbabwe. The study is going help improve maize production to farmers by increasing the growth rate and yield under abiotic stresses like drought.

1.4 Aim

The major objective is to evaluate the influence of silicon under limited water conditions on the growth and yield of maize.

1.4.1 The specific objectives

- To determine the influence of different silicon application rates on the growth of maize under limited water conditions.
- To determine the influence of different silicon application rates on the yield of maize under limited water conditions.

1.4.2 Hypothesis

H_1: There is a significant difference in maize growth under different Silicon application rates and limited water conditions.

H_1: There is significant difference in the yield of maize under different Silicon application rates and limited water conditions.

H_1: Differentiation of silicon application rate has a significant effect on maize growth and yield under limited water conditions

CHAPTER 2 LITRATURE REVIEW

2.1 Maize background

Maize is a domesticated grass that originated approximately 7000 years ago in what is now Mexico (Kage et al, 2013). It is also referred to as corn, depending on the source of data or references consulted. Maize was spread across the world shortly after the European discovery of the Americas. Regardless of origin, maize has proven to be one of the most adaptable crops (Ren et al, 2002). Its evolution apparently occurred mainly under domestication and resulted in biotypes with adaptation ranging from the tropics to the north temperate zone, from sea level to 12,000 feet altitude, and growing periods (planting to maturity) extending from 6 weeks to 13 months (Kage et al, 2013). Currently, the United States, Brazil, Mexico, Argentina, India, France, Indonesia, South Africa, and Italy produce 79% of the world's maize production (Ren et al, 2002). Between 1990 and 2011, number of millions of maize hectares harvested ranged from 129.1 to 163.9. During the same period, the production of maize in metric tons per hectare increased from 3.7 to 5.1, and total maize production increased from 482.0 to 832.5 million metric tons. Worldwide, 60–70% of maize production is used domestically as livestock feed, and the remaining 30–40% is used for the production of items for human consumption (Xing et al, 1998).

2.1.1 Maize production in Zimbabwe

Maize is the most important cereal crop grown in Zimbabwe. It ranks first in the number of producers, area, and total production. The maize industry is one of the mainstays of agriculture and of the Zimbabwean economy (Mushunje, 2005). Over 70% of the hectarage in smallholder agriculture is planted with maize. Prior to independence in 1980, the large-scale commercial farmers produced over 80% of the maize marketed through the Grain Marketing Board (GMB) (Mushunje, 2005). Currently, small-scale farmers are contributing over 90% of the GMB’s maize intake. This post-independence sharp increase was a result of growth in area planted to maize, an increase in yields, and increased support services (extension, credit, and marketing). Maize is commonly known as “chibage” in Shona and “umumbu” in Ndebele (Kapuya, 2010).

2.1.2 Abiotic factors affecting maize production in Zimbabwe

Crop production in Zimbabwe is primarily rain-fed; as a result, productivity is associated with the quality of the rain season; as a result, the country's food security is affected by seasonal quality. Maize output varies from year to year depending on rainfall patterns, according to Mashingaidze, (2006). Droughts result in a considerable drop in maize yield. The observed association between maize performance and seasonal quality clearly refers to a lack of strategic planning for droughts.

To maximize the production of any crop, it is important to understand how environmental factors affect plant growth and development. All environmental factors such as climatic, edaphic, biotic, physiographic, and anthropic (socio-economic) factors interact with one another to influence crop growth and development (Kang et al, 2013). The major environmental factor (drought, high salinity, cold, and heat) negatively influence the survival, biomass production, and yields of maize up to 70% hence, threatening food security worldwide.

Maize development is controlled by soil temperature, humidity and other environmental conditions. Consequently, factors that reduce soil temperature will retard crop development for up to 25% of the crop's life, and this may reduce yield. It is widely understood that temperature has a major influence on crop development (Warrington and Kanemasu, 1983), and it is usually implicitly assumed that crop development rate is driven by air temperature because the latter is a good guide to meristem temperature.

Dehydration stress imparted by drought, salinity, and temperature severity is the most prevalent abiotic stress that limits plant growth and development. In the last decade, significant progress has been made in understanding of the complex mechanisms governing environmental factors stress tolerance in crop plants (Liang et al, 2015). However, researchers are still far from pinning the exact battery of gene activation responsible for tolerance to a particular abiotic stress condition. This situation is complicated when one considers plants have to simultaneously cope with numerous biotic stresses along with various abiotic stresses (Kaya and Tuna, 2006).

2.2 Effects of drought on the photosynthetic characteristics of maize

Field crops are subjected to numerous inconsiderate climatic hazards that negatively affect physiological processes, growth, and yield. Droughts are one of the major abiotic factors that limit agricultural productivity especially here in Zimbabwe. The physiological drought-responding morphological structures of plants under drought stress and the molecular regulations have been extensively studied, and it has been found that drought stress cannot only reduce photosynthesis (Liu et al., 2016; Zhang et al., 2011) and damage metabolic pathways (Zhou et al., 2010), but also changes ultrastructures of tissues and organs are mainly manifested as damage to cytoplasmic and chloroplast membranes, deformations of chloroplast and mitochondrion ultrastructures (Xu et al., 2010), the disordered arrangement of stroma lamella, expanded granum thylakoids, and the appearance of starch grains in chloroplasts. Chloroplasts are most sensitive to, and more damaged by, drought stress than mitochondria, whereas the nucleus is less affected (Zhang et al., 2011). However, all these challenges can be minimized by the use of Silicon fertilizers which is BARIKAT one of the protectors which are readily available on the market.

2.3 Silicon fertilizers

BARIKAT is a plant-tissue fortifier that contains calcium and silicon which allows the strengthening of the cell wall through the production of chitinases (Cosmocel manual, 2021). The plants have a greater tolerance capacity to sudden changes in humidity and temperature. BARIKAT improves shelf life and minimizes mechanical damage. It is a natural product that does not generate resistance. Plants that are under an inadequate nutritional status have fewer stress pests, diseases, and/ or climatic tolerance. Calcium and Silicon detonate different mechanisms that increase the expression of defence proteins in the plant (chitinases, peroxidases, protease, etc). These defence proteins are also directly responsible for the stiffness of the cell wall (Cosmocel manual 2021).

2.3.1 Recommendations of using BARIKAT and its application rates

BARIKAT should be applied preferably from the early stages of crop development, or when environmental conditions favour the establishment of pests and diseases (Cosmocel manual, 2021). During silking, BARIKAT should be applied to improve shelf life. BARIKAT can also be applied as a ground spray, fertigation, or aerial application. BARIKAT is not phytotoxic, when used as recommended, and can be combined with most agrochemicals and fertilizers of common use, except those formulated with phosphorus (Cosmocel manual, 2021). Its chemical composition includes calcium 10%, silicon (SiO_2) 15%, and conditioners and thinners 66%.

2.3.2 Effects of silicon on seed germination rate of maize.

The present results from studies carried out showed that exogenous Si can improve the seed germination rate, germination potential, germination index, and vigor index; promote seedling growth; and increased chlorophyll contents (Badal et al, 2013). In addition, Si could improve the antioxidant defense ability of maize plants and increase the contents of osmotic substances, thereby increasing the ability to remove ROS and maintain the integrity of the membrane system. Some studies' findings indicate that the appropriate concentration of Si can promote maize seed germination and seedling growth laying a good foundation for subsequent growth (FAO, 2017).

2.3.4 Benefits of using Si in maize

In trying to cope up with these effects of drought and other environmental impacts, many experiments have been carried to find the solution to these drought problems. Most of the experiments were done in eastern part of the world in areas like China, India. Some of the experiments include the one carried by Abd El Mageed et al, (2017) who carried an experiment to see the Silicon Defensive Role in Maize (Zea mays L.) against Drought Stress and Metals-Contaminated Irrigation Water and he found out that Exogenous application of Si increased drought stress tolerance in maize by enhancing photosynthetic efficiency, stomatal conductance (gs) and cell membrane integrity as evaluated by membrane stability index. These results were positively reflected in improving plant growth, WUE, and productivity along with decreasing accumulation of Ni^{+2}, Cd^{+2}, and Cr^{+3} in leaves and grains under drought stress by metals-contaminated irrigation water.Silicon is a naturally occurring beneficial nutrient that modulates plant growth and development events that have been known to improve crop tolerance to abiotic stresses. Although Si is not generally included in the list of essential elements, it is considered one of the important beneficial nutrients for plant growth (Kage et al, 2013). The amount of Si in soil may vary considerably from 1 % to 45 % (Orhun, 2013). However, Si is present in the soil in different forms, but plants can easily absorb silicic acid Si (OH)4from soil. Silicic acid is generally found in the range of 0.1-0.6 mM in soils (Ren et al, 2002). Although Si is beneficial for plant growth it plays a vital role as a physio- mechanical barrier in most plants. Despite its deposition on cell walls, its active involvement in a multitude of physiological and metabolic processes is also evident (Xing and Zhang, 1998).

Silicon's viable strategy of overcoming the drought-induced injurious effect on plant growth is the exogenous application of inorganic nutrients (Marafen and Endres, 2013). By adopting this strategy, studies (Xiang et al, 2012) have recommended the supplements of Si to plants subjected to salt-affected soils. The ameliorative role of Si to adverse effects of drought has been examined in different crops e.g., rice, sugarcane, wheat, tomato, sorghum, and soybean.

When the drought becomes severe, the water potential of the plant decreases. However, when transpiration is suppressed by stomatal closure, diurnal changes in water potential can be reduced, which adversely affects CO 2 fixation (Savant et al., 1999). Under these circumstances, the application of Si reduces transpiration (Gao et al, 2004), improves root hydraulic conductivity, and increases aquaporin protein expression and xylem potassium concentration (Covshoff and Hibbert). In addition, the potential impact of Silicon application on potassium uptake and distribution may be involved in the regulation of plant water status only under potassium deficient conditions.

Silicon can modify water transport by adjusting the osmotic potential of cells through a higher accumulation of osmolytes. Within these osmolytes are sugars and amino acids such as proline, which improve cell turgor and water absorption (Ren et al, 2002) and increase the tolerance of plants to stress conditions (Karmollochaab et al, 2013).

According to Amin et al, (2015) on the experiment they carried on the influence of silicon fertilization on maize performance under limited water supply they evaluated growth of two maize hybrids P-33H25 and FH-810 under well watered and water deficit situations as affected by Si application and they found out that silicon application to drought stressed maize plants improved the growth and yield which could be attributed to improved photosynthetic rate and lowered transpiration. According to the research project carried out by Janisplampi, (2012) he identified that silicon increased dry mass of all four crops in the study (corn, wheat, soybean, and rice). This increase occurred in unstressed as well as stressed plants, although there was no effect on dry mass in unstressed plants. An increase in visible plant size was also observed at times. Hattori et al. (2005) appear to be the only researchers to report that silicon increased the visible size of a plant.

2.4 The research gap

Looking at all the benefits and studies carried out to minimise drought there is a research gap in the study of how different Si application rates can affect maize growth rate and yield especially here in Zimbabwe where we have different environmental conditions from most of the studied areas in the above literature. The effects of Si on growth and yield under limited water supply remained undefined especially here in Zimbabwe. The use of Si fertilizers is not yet well adopted here in Zimbabwe because people have little knowledge on its benefits and use hence this study is going to determine the effects of different Si application rates on growth and yield of maize. Some work has been done by on different cereal crops on the effects of silicon.

CHAPTER 3 METHODOLOGY

3.1 Experimental Site

The field trials were conducted in Braford Farming in Mashonaland West Zimbabwe from September to December 2021 when there was no rainfall. This research site lies in region 2b, and lies on an altitude of 1100m and a latitude 13º 19´ South and 33º 06´ East with a mean annual temperature of about 34ºC in the hottest and 14ºC in the coldest, and annual average precipitation of 600-800 mm. The basic properties of the red soils are from 0 to 20 cm deep. (any references?)

3.2 Experimental design

The experiment consisted of 5 treatments each replicated 3 times in a Randomised complete random block design. The treatments were randomly assigned to the experimental units using the hat system and the variation in slope was the blocking factor. The experiments consisted of five SiO2 treatments which included a control named M1 with SiO2 0 Lt/ha and four treatments named M2, M3, M4, and M5 with SiO2 5 L/ha, 7 L/ha, 9 L/ha, and 10 L/ha, respectively. There were 4 different rates of Silicon application plus standard fertilizer application. All silicon, phosphate, and potassium fertilizers were applied as basal applications. All treatments where exposed to limited water supply of 40 % moisture content and was applied 2 weeks interval up to week 14.

3.2.1 Table 3:1 Showing treatments and Si application rates

Treatments	M1	M2	M3	M4	M5
Silicon application rates in L/Ha	0L/Ha	5L/Ha	7L/Ha	9L/Ha	10L/Ha

3.3 Land preparation

The land was prepared using the conventional tillage method which uses both primary and secondary tillage implements. The land was tilled using a ripper to break plow pans followed by plowing with a disk plow, disk harrow, and a roller to break clods and come up with a fine soil tilt**.** The treatments were allocated in beds. The treatments were assigned using the hat system. The plot sizes were 6m by 8m and each bed has a population of 240 plants.

3.3.1 Planting

Prior to sowing which was done in the first week of September, Compound D (7:14:7) Windmill fertilizer was applied at 200kg per hectare to all treatments. Si was applied as ground spray just after germination. Ammonium nitrate was split and applied at 100kg, 75kg, and 50 kg respectively. Planting of maize SC 513 was done with an in-row spacing of 30cm and interrow spacing of 65cm.

3.3.2 Spraying and weeding

Spraying of Spear was done to control armyworms and termites since the area is associated with a termite infestation. Weeding was done using hoes and it was done in 3 weeks intervals.

3.3.3 Data collection

- Plant height was measured at 2 weeks interval after germination up to week 10. The plant height of 5 randomly selected plants shall be used to deduce the growth rate of the plants by subtracting the second measurement from the first measurement, then divide that number by the number of days between the two measurements. The randomly selected plants will be tagged so that they will be easily identified.
- Stem diameter (cm) was measured using a ruler, at 2 weeks interval up to week 10 after germination.
- Leaf area shall be measured at weekly intervals using graph paper method from the day of harvest. The leaf area shall be used to determine Leaf Area Index using the formula LAI = *.The number of leaves of 5 tagged randomly selected plants was counted at 2 weeks interval after germination up to week 10 using physical methods and was recorded in a notebook.
- The Cob length of 5 randomly selected plants was measured using a ruler at week 17 during harvest.
- The weight of cobs was used to estimate yield. The weight of 5 randomly selected cobs from each treatment were measured using a digital scale to determine yield.

3.3.4 Data Analysis

Data collected during the experiment was subjected to statistical analysis of variance using Genstat package 16th Edition version and LSD at 5% level. The Graphs and tables was used for presentation of the results.

CHAPTER 4 RESULTS

4.1 Effects of different Si application rate on plant height and yield on maize under limited water supply.

Table 4.1: showing effects of different Si application rate on plant height.

Silicon treatments	Means for weekly interval collection				
	week 2	week 4	week 6	week 8	week 10
10L/Ha	11.00a	31.95a	62.85a	124.0a	195.1a
9L/Ha	10.97b	31.91a	62.82a	123.9a	195.0a
7L/Ha	10.80c	30.74b	61.15b	122.6b	180.3b
5L/Ha	10.70d	30.69b	61.04bc	122.1b	171.0c
0L/Ha	10.16e	30.32c	60.64c	121.6d	170.4c
P value	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
C.V%	**0.1**	**0.2**	**0.4**	**0.2**	**0.2**
L.S.D	**0.01575**	**0.2537**	**0.4744**	**0.4544**	**0.6565**

Week 2 showed that there was a significant difference in plant height among treatment means ($P<0.05$) with the highest plant height was recorded in treatment 10L/Ha. Treatment which was the control with 0L/Ha of silicon showed the lowest plant height. In week 4 there was no significant difference in plant height between treatment 10L/Ha and 9L/Ha and also in treatment 7L/Ha and 5L/Ha.

Different Si application rates in week 6 showed that there was a significant difference in plant height between treatment means in treatment 10L/Ha and treatment 7L/Ha, 5L/Ha, and 0L/Ha respectively. Treatment 10L/Ha showed the highest plant height whilst treatment 0L/Ha had the lowest plant height. In week 8 treatment 10L/Ha and treatment 9L/Ha had statistically similar height and these were different from the other treatments with the control recording the least plant height. Week 10 showed that different Si application rates in treatment 7L/Ha, 5L/Ha and 0L/Ha had statistically different heights in their means ($p<0.05$). Treatment 10L/Ha recorded the highest plant height with a mean of 195.1 and treatment 0L/Ha had the lowest plant height with a mean of 170.4.

4.2 Effects of different Si application rates on leaf area index (LAI) under limited water supply.

Silicon treatments	Means for weekly interval collection				
	week 2	week 4	week 6	week 8	week 10
10L/Ha	37.75a	48.79a	61.98a	65.57a	70.83a
9L/Ha	37.73a	48.75b	61.78b	65.17b	69.50b
7L/Ha	37.56b	48.43c	58.09c	63.78c	69.12b
5L/Ha	33.55c	46.15d	56.03d	63.06d	68.26c
0L/Ha	22.13d`	44.02e	53.12e	55.20e	57.36d
P value	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
C.V %	**0.1**	**0.0**	**0.0**	**0.1**	**0.4**
L.S.D	**0.04934**	**0.01914**	**0.02254**	**0.0848**	**0.49** .

In week 2 there was a significant difference in leaf area index between treatment means ($p<0.05$) 7L/Ha, 5L/Ha, and 0L/Ha. Treatment 10L/Ha recorded the highest LAI with a mean of 37.75and treatment 0L/Ha had the lowest LAI with a mean of 33.55. Week 4 showed that different Si application rates had caused a significant difference in LAI between treatment means ($P<0.05$) with the highest LAI recorded in the treatment 10L/Ha and the least in treatment 0L/Ha which was the control. In week 6 all treatments showed a significant difference with treatment 10L/Ha having the highest LAI of mean of 62.

and treatment 0L/Ha showed the lowest LAI with a mean of 53.1. In week 8 the effects of different Si application rates showed a significant difference in LAI between treatments means ($p<0.05$). Treatment 10L/Ha showed having the highest LAI of mean 65.57 and treatment 0L/Ha showed the lowest LAI with a mean of 55.20. The results showed that means for LAI as influenced by different Si application in all treatments differed significantly ($p<0.05$) at week 10 after germination. Treatment 10L/Ha produced the highest LAI with a mean of 70.83 and the lowest was recorded in 0L/Ha with a mean of 57.36.

4.3 Effects of different Si application rates on stem diameter of maize under limited water supply.

Silicon treatments	Means for weekly interval collection				
	Week 2	week 4	week 6	week 8	week 10
10L/Ha	1.620a	2.497a	3.553a	4.507a	5.490a
9L/Ha	1.597b	2.427b	3.503a	4.307b	5.207b
7L/Ha	1.510c	2.307c	3.010b	4.017c	4.813c
5L/Ha	1.213d	2.003d	2.887b	3.697d	4.503d
0L/Ha	0.707e	1.413e	2.097c	2.797e	3.987e
P value	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
C.V %	**0.9**	**0.8**	**2.4**	**0.3**	**0.2**
L.S.D	**0.02254**	**0.03368**	**0.1346**	**0.01835**	**0.02254**

Table 4.3: showing the effects of different Si application rates on stem diameter.

In week 2 there was a significant difference in stem diameter between treatment means ($p<0.05$). Treatment 10L/Ha showed the highest stem diameter of mean of 1.620 and treatment 0L/Ha showed the lowest stem diameter with a mean of 0.707. The means for stem diameter as influenced by different treatments differed significantly ($P<0.05$) at 4 weeks after germination. During this period 10L/Ha maintained the highest stem diameter with a mean of 2.497and 0L/Ha had the lowest stem diameter with a mean of 1.413. In week 6 the effects of different Si application rates statistically had similar stem diameter in treatments 10L/Ha and 9l/Ha also in treatment 7L/Ha and 5L/Ha had no significant difference. There was a significant difference between the treatment mean of 0L/Ha and the remaining treatments ($p<0.05$) with treatment 10L/Ha showing the highest stem diameter with a mean of 3.553 and treatment 0L/Ha has the lowest plant height with a mean height of 2.097.

There was a significant difference in stem diameter between treatment means ($p<0.05$) in week 8. All treatments showed a significant difference with treatment 10L/Ha having the highest stem diameter of mean of 4.507 and 0L/Ha the lowest stem diameter with a mean of 2.797. In week 8 the results showed that there was high stem diameter growth compared to all other weeks. In week 10 the means for stem diameter as influenced by different Si application rate differed significantly ($P<0.05$). Treatment 9L/Ha and 10L/Ha are among the highest with means 5.940 and 5.503cm respectively. Treatment 0L/Ha recorded the lowest stem diameter with a mean of 4.503.

4.4 Effects of different Si application rates on number of leaves of maize under limited water supply in week 2, 4, 6, 8 and 10

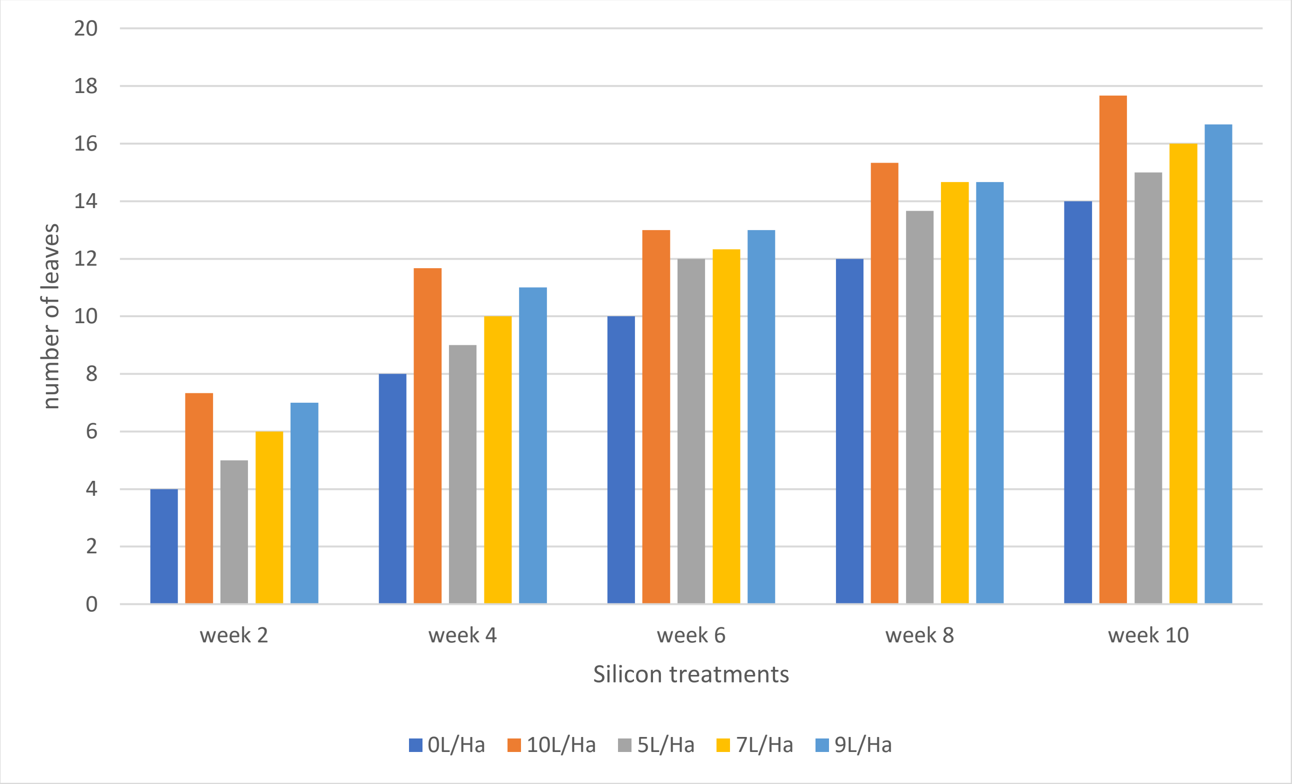

Fig 4.1 graph showing number of leaves of maize measured in 2 weeks interval.

In week 2 there was a significant difference on number of leaves between treatment means ($P<0.05$). The highest number of leaves was recorded in treatment 10L/Ha with a mean of 7.333 and the lowest was noted in treatment 0L/Ha with a mean of 4.00. In week 4 there was a significant difference on number of leaves between treatment mean ($P<0.05$) with treatment 10L/Ha recording the highest number of leaves. The lowest number of leaves was recorded in treatment 0L/Ha. In week 6 treatment 10L/Ha and treatment 9L/Ha had statistically similar number of leaves and these were different from the other treatment with the control recording the least number of leaves.

Week 8 showed that the effects of different Si application rates on the number of leaves has caused a significant difference to all treatments ($P<0.05$). Treatment 10L/Ha recorded the highest number of leaves and the lowest was recorded in 0L/Ha

In week 10 the graph showed that there was a significant different on number of leaves between treatments means ($p<0.05$) 10L/Ha and other remaining treatments. There is no significant difference on number of leaves in treatments 9L/Ha and 7L/Ha. Treatment 10L/Ha showed the highest number of leaves with a mean of 17.67 whilst treatment 0L/Ha showed the lowest number of leaves with mean 14.00.

4.5 Effects of different silicon application rates on cob length under limited water supply.

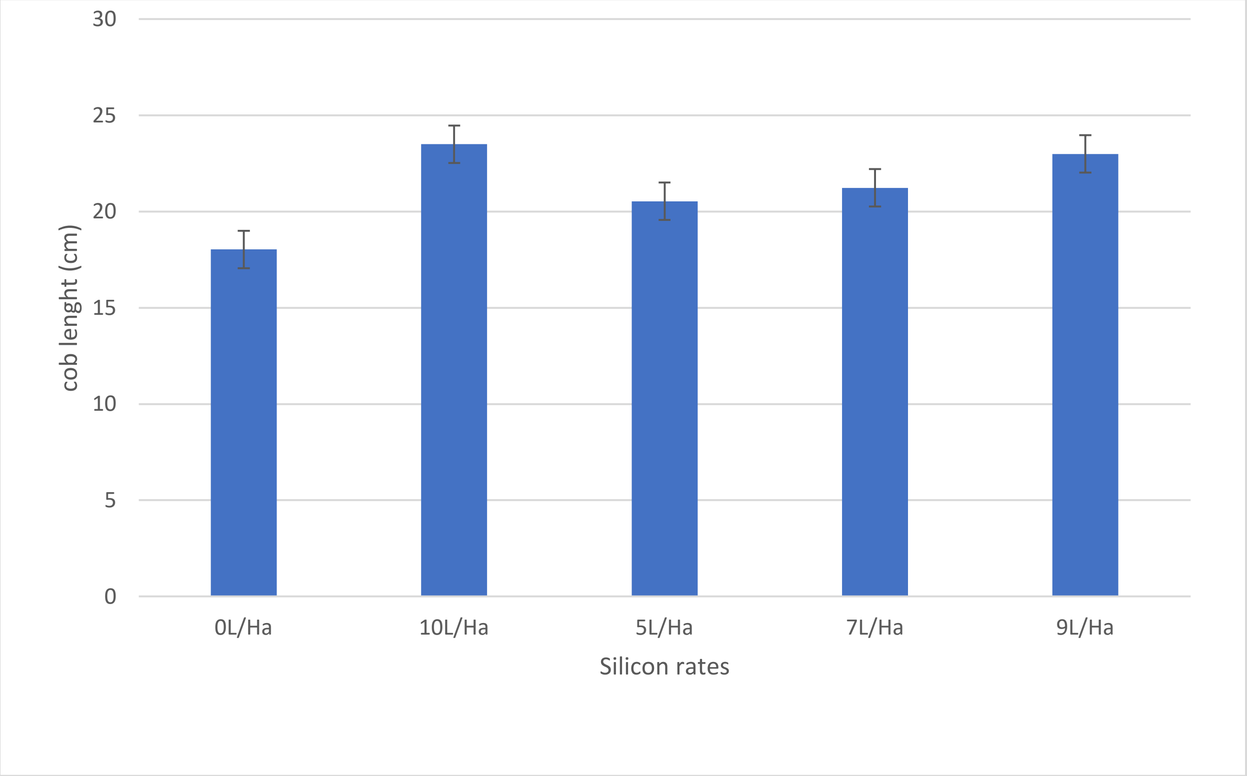

Fig 4.2 graph shows cob length of maize.

In week 17 treatment 9L/Ha was statistically similar to 10L/Ha ($p<0.05$). The biggest cob was found in treatment at 10L/Ha meaning it had the highest cob length of mean 23.50 cm. The lowest cob length was found in treatment 0L/Ha with a mean of 18.03. Treatment 9L/Ha and 10L/Ha had the highest cob length with means 23.50 and 22.99. Fig 4.11.

4.6 Effects of different silicon application rates on cob weight under limited water supply.

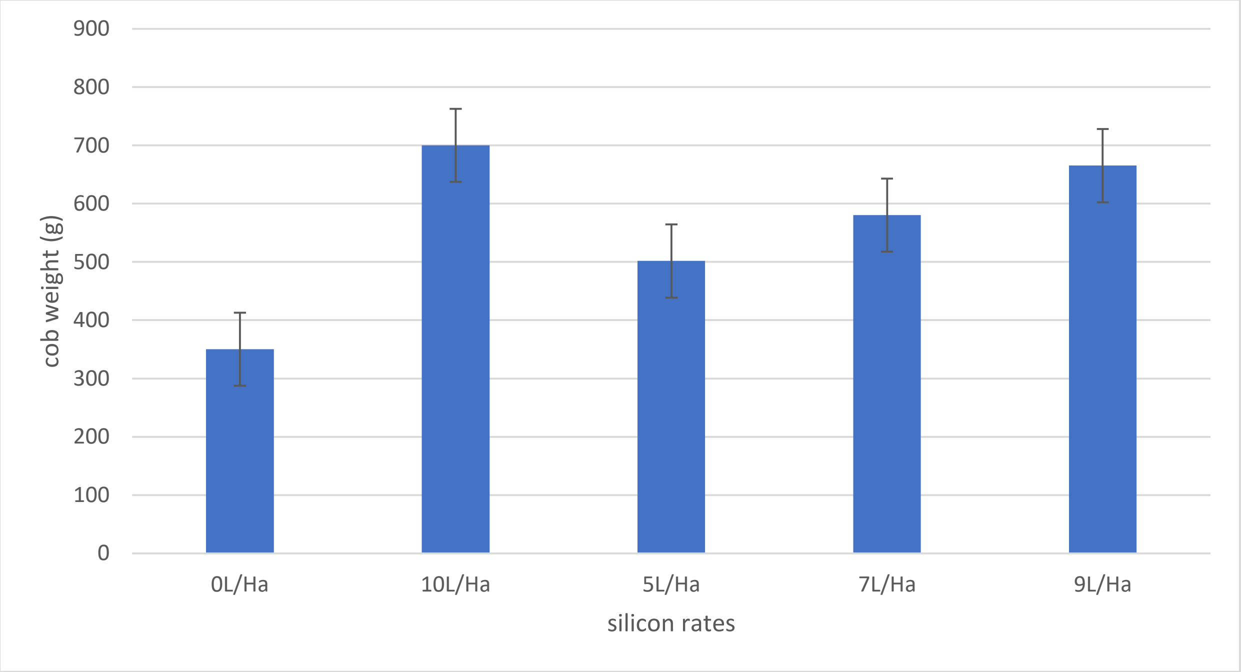

Fig 4.3: graph showing cob weight of maize.

In week 17 all treatments were statistically similar in weight of the cobs to all 5 treatments means ($p<0.05$). Treatment 10L/Ha with mean 700.3g has the highest weight followed by treatments 9L/Ha, 7L/Ha,5L/Ha and 0L/Ha respectively. Treatment 0L/Ha has the lowest cob weight of mean 350.3g. Fig 4.3.

CHAPTER 5 DISCUSSION OF RESULTS

5.1 Plant height

Different Si application rates under limited water supply showed that there was a significant difference in plant height between treatment means ($P<0.05$). This occurred because some treatments grew more quickly than others due to germination rates. The highest plant height was recorded in treatment 10L/Ha maybe because it had the highest Si application rate which made it germinate faster than other treatments. Ahmad et al. (1992) declared that the "addition of silicon caused significant recovery from salt stress" in wheat at different growth stages, including germination. An increase in plant height can also be due to the fact that Si strengthens the physiological attributes of the maize (Kaya et al., 2006; Amin et al., 2016), and also addition of Si in the form of calcium silicate reduced Na+ uptake, resulting in an increase of height in maize (Ashraf et al., 2015). Si application rates to limited watered plants enhance their performance which is plant growth due to photosynthetic rate improvement, higher osmotic adjustment, increased water status, and lowered transpiration. This may also be attributed to the fact that silicon helps in increasing the erectness of leaves thereby increasing photosynthetic capacity which results in higher plant height. Similar findings were also reported by Fallah, (2012).

5.2 Leaf area index

Different Si application rates influenced the LAIs of maize at 4, 6, 8, and 10 weeks after germination. Increasing the Si application rates resulted in an increase in LAIs. This might be due to the significant role of Si that it affects the uptake, distribution, and functionality of several mineral nutrients in plants. Gong et al. (2003) found that 7.14 mmol of Na2SiO3 per 8 kg of soil contributed in an increase in wheat leaf area index of 8.3 cm2 per plant, an increase in dry mass of 45.3 mg per plant, and an increase in leaf thickness. Silicon influences Zn uptake where Zn plays an important role in functions like photosynthesis, protein, and chlorophyll synthesis, and these processes aid to an increase in LAI of maize (Cakmak, 2008). The influence of different Si application rates increases LAI this is also supported by the works of Singh et al, (2012) who reported that Si application enhances Nitrogen availability by modifying physiochemical for example soil exchange capacity and biological properties of soil and leads to an increase in Nitrogen uptake by plants and this leads to high leaf area index as more nitrogen increases vegetative growth of maize. In this regard, Si application could affect N availability to plants and enhance nutrient use efficiency also known as agronomic efficiency.

5.3 Stem diameter

The results indicated that the addition of different Si application rates under limited water supply enhanced stem diameter of maize. The highest application rate of 10L/ Ha performed very well with a stem diameter of mean 1.620. Amin et al, (2018) found maximum stem thickness in silicon-treated plots and he also said that Silicon nutrition not only increased plant height but also the stem thickness. Improvement in stem diameter with silicon treatment might be due to improved growth of drought-stressed plants which is initiated by the presence of Si. Previous studies (Ashraf et al, 2015) have shown that Si application increases the number of lateral roots in maize and this promotes stem diameter growth because of high nutrient absorption due to the increased number of lateral roots. These results can also be supported by the fact that Si moves to shoot parts, where it accumulates as silicon dioxide and enhances photosynthetic efficiency by increasing the production of photosynthates, which are essential for plant stem diameter and growth development (Amin et al, 2018). In addition, Si also regulates or stimulates phytohormone synthesis, followed by a series of molecular transcript accumulation in plants. Such biochemical, physiological, and molecular signalling cascades can lead to the activation of processes that ultimately improve root diameter and architecture (Gong et al, 2003). Generally root and the enhancement of secondary root traits contribute to plant fitness and increase in stem diameter under limited water conditions.

5.4 Number of leaves

Different Si application rates showed that Si has an influence on the number of leaves. Treatment 10L/Ha showed the highest number of leaves with a mean of 17.66 which proves that 10L/Ha had a great influence on the number of leaves compared to other application rates. This might be due to the fact that there was an abundant N nutrient supply in that treatment which rapidly increased vegetative growth which increased the number of leaves. This abundant nutrient supply might be due to the availability of Si which is known to increase N uptake in maize. Amin et al, (2018) in their experiment showed that silicon-treated water-stressed plants of hybrid FH-810 produced more leaves. Silicon is able to increase the soluble protein content of plants' leaves, which helps plants to overcome salt stress by replacing the lost soluble protein content under salinity stress (Zhu et al, 2004). A considerable enhancement in the antioxidant enzyme activities in leaves of water-stressed cucumber by additional Si treatment suggested that Si can be involved the in physiological or metabolic cycles of plants

(Zhu et al, 2006). The Si nutrition increased catalase activity significantly in all parts of plants and peroxidase activity in the cell wall of plant's leaves (Tahir et al, 2006). From the physical standpoint, Si is able to decrease the plasma membrane permeability in leaf cells of plants which resulted in reducing the lipid peroxidation levels in plant shoots. It was reported that application of Si in canola plants resulted in decreasing Si content in shoot parts of plants by formatting complexes of Si-polyphenol or substitution of Si and lignin (Maksimovic et al, 2007). These physical changes in plants' cell wall could facilitate the loosening process and promote cell extension, which results in plants' growth under salt stress (Hashemi et al, 2010). The Si protects plants from environmental stress, such as drought and heat, by providing more stable lipids involved in their cell membrane (Zhu et al, 2006).

5.5 Yield (Cob length and cob weight)

Effects of different Si application rates under limited water supply showed a significant difference ($p<0.05$) in all treatments. The biggest cob was found in treatment 10L/Ha this was due to the high concentration of Si. The lowest cob length was found in treatment 0L/Ha with a mean of 18.03 this was due to the fact that the treatment had no Si application. This can be supported by experiments done in China by Ahmad et al, (2015). Their results are in harmony with the findings of (Ghasemi & Chokan, 2013) who observed a greater number of spikelets per panicle by silicon application in rice. This could be due to the adequate silicon supply improving the photosynthetic activity (Gong et al, 2005) which enables maize plants to accumulate sufficient photosynthates. This in turn increases dry matter production and these together with efficient translocation results in greater numbers of filled grains with increased test weight and ultimately leads to higher cob weight and Karmollachaab et al, (2013).

Kaya et al, (2006); Amin et al, (2018) also supported that Si is closely related to plant growth and yield owing to strengthening the physiological attributes of the maize. Si has proved to enhance the photosynthesis process, improve the absorption of nutrients, and increase grain yield in maize (Xu et al., 2016). The increase in cob length and weight due to the use of Si, it had also been supported by Mabagala et al, (2020) who concluded that the use of silicon fertilizer can not only improve the N uptake and the N uptake rate of maize, but also promote the remobilization of nitrogen and the apparent contribution to grain weight, and ultimately improve the yield of maize.

CHAPTER 6 CONCLUSION

6.1 Conclusion

In conclusion, treatment 10L/Ha was able to withstand limited water conditions as compared to treatment 0L/Ha which was not treated with Si. Treatment 10L/Ha manages to maintain higher plant height, stem diameter, number of leaves, and leaf area index. It also maintained higher cob length and cob weight. On the other hand, 0L/Ha which was the control without Si came out at the end of the experiment with all parameters used for the determination of growth and yield having lower values compared to all other Si treated plots. Furthermore, treatment 10L/Ha with the highest rate proved to have the highest growth and yield. in conclusion it showed that Si increased growth and yield of maize under limited water conditions. It showed that 10L/Ha of Si increased growth rate and yield of maize under limited water conditions therefore proving to be the best application rate for increased growth and yield of maize.

6.2 Recommendations

Farmers are recommended, especially those leaving in areas where there is little rainfall to use silicon-based fertilizers. The one which is on the market right now is Barikat and can be found at FSG. Farmers are also recommended to use 9 to 10L/ha of Barikat because it showed that it increases growth and yield in maize production under limited water conditions.

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APPENDICES

Appendix 1 Analysis of Variance

Variate: Plant height at week_2

```
Stratum                          d.f.          s.e.          cv%
Replication                         2       0.00200          0.0
Replication.*Units*                 8       0.00837          0.1
```

Variate: Plant height at week_4

```
Source of variation          d.f.          s.s.          m.s.       v.r.     F pr.

Replication stratum             2    0.00028000    0.00014000       2.47

Replication.*Units* stratum
Silicon_rates                   4    6.07482667    1.51870667   26800.71     <.001
Residual                        8    0.00045333    0.00005667

Total                          14    6.07556000
```

Variate: Plant height at week_6

```
Source of variation          d.f.          s.s.          m.s.       v.r.     F pr.

Replication stratum             2     0.0032533     0.0016267       5.39

Replication.*Units* stratum
Silicon_rates                   4    11.4660667     2.8665167    9502.27     <.001
Residual                        8     0.0024133     0.0003017
```

```
Total                              14   11.4717333
```

Variate: Plant height at week_8

```
Source of variation              d.f.         s.s.         m.s.      v.r.    F pr.

Replication stratum                 2    0.0049600    0.0024800      3.36

Replication.*Units* stratum
Silicon_rates                       4   11.5478933    2.8869733   3910.12    <.001
Residual                            8    0.0059067    0.0007383

Total                              14   11.5587600
```

Variate: Plant height week_10

```
Source of variation              d.f.         s.s.         m.s.      v.r.    F pr.

Replication stratum                 2    1.853E-03    9.267E-04      6.86

Replication.*Units* stratum
Silicon_rates                       4    1.765E+03    4.412E+02 3.268E+06    <.001
Residual                            8    1.080E-03    1.350E-04

Total                              14    1.765E+03
```

Appendix 2 Analysis of variance

Variate: LAI at week_2

```
Source of variation              d.f.         s.s.         m.s.      v.r.    F pr.

Replication stratum                 2    0.0017733    0.0008867      1.29

Replication.*Units* stratum
Silicon_rates                       4   87.4660667   21.8665167  31844.44    <.001
Residual                            8    0.0054933    0.0006867

Total                              14   87.4733333
```

Variate: LAI at week_4

```
Source of variation              d.f.         s.s.         m.s.      v.r.    F pr.

Replication stratum                 2    0.0001733    0.0000867      0.84

Replication.*Units* stratum
Silicon_rates                       4   52.9065733   13.2266433 1.280E+05    <.001
Residual                            8    0.0008267    0.0001033

Total                              14   52.9075733
```

Variate: LAI at week 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	5.200E-04	2.600E-04	1.81	
Replication.*Units* stratum					
Silicon_rates	4	1.719E+02	4.298E+01	2.999E+05	<.001
Residual	8	1.147E-03	1.433E-04		
Total	14	1.719E+02			

Variate: LAI at week_8

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.005173	0.002587	1.28	
Replication.*Units* stratum					
Silicon_rates	4	215.307973	53.826993	26537.55	<.001
Residual	8	0.016227	0.002028		
Total	14	215.329373			

Variate: LAI at week_10

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.05700	0.02850	0.41	
Replication.*Units* stratum					
Silicon_rates	4	359.52689	89.88172	1299.18	<.001
Residual	8	0.55347	0.06918		
Total	14	360.13736			

Appendix 3 Analysis of variance

Variate: Stem diameter at week_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication stratum	2	0.0026533	0.0013267	9.26	
Replication.*Units* stratum					
Silicon_rates	4	1.7692933	0.4423233	3085.98	<.001
Residual	8	0.0011467	0.0001433		
Total	14	1.7730933			

Variate: Stem diameter at week_4

```
Source of variation          d.f.        s.s.         m.s.       v.r.    F pr.

Replication stratum             2   0.0021733    0.0010867       3.40

Replication.*Units* stratum
Silicon_rates                   4   2.3499600    0.5874900    1835.91    <.001
Residual                        8   0.0025600    0.0003200

Total                          14   2.3546933
```

Variate: Stem diameter at week_6

```
Source of variation          d.f.        s.s.         m.s.       v.r.    F pr.

Replication stratum             2    0.030760     0.015380       3.01

Replication.*Units* stratum
Silicon_rates                   4    4.163933     1.040983     203.58    <.001
Residual                        8    0.040907     0.005113

Total                          14    4.235600
```

Variate: Stem diameter at week_8

```
Source of variation          d.f.        s.s.         m.s.       v.r.    F pr.

Replication stratum             2  0.00457333   0.00228667      24.07

Replication.*Units* stratum
Silicon_rates                   4  5.39844000   1.34961000   14206.42    <.001
Residual                        8  0.00076000   0.00009500

Total                          14  5.40377333
```

Variate: Stem diameter at week_10

```
Source of variation          d.f.        s.s.         m.s.       v.r.    F pr.

Replication stratum             2   0.0017200    0.0008600       6.00

Replication.*Units* stratum
Silicon_rates                   4   4.1735333    1.0433833    7279.42    <.001
Residual                        8   0.0011467    0.0001433

Total                          14   4.1764000
```

Appendix 4 Analysis of variance

Variate: Number of leaves at week_2

```
Source of variation          d.f.        s.s.         m.s.       v.r.    F pr.

replication stratum             2     0.13333      0.06667       1.00
```

```
replication.*Units* stratum
Silicon_rates                    4     23.06667      5.76667     86.50    <.001
Residual                         8      0.53333      0.06667

Total                           14     23.73333
```

Variate: Number of leaves at week_4

```
Source of variation           d.f.         s.s.         m.s.      v.r.    F pr.

replication stratum              2      0.13333      0.06667      1.00

replication.*Units* stratum
Silicon_rates                    4     26.26667      6.56667     98.50    <.001
Residual                         8      0.53333      0.06667

Total                           14     26.93333
```

Variate: Number of leaves at week_6

```
Source of variation           d.f.         s.s.         m.s.      v.r.    F pr.

replication stratum              2      0.13333      0.06667      1.00

replication.*Units* stratum
Silicon_rates                    4     18.26667      4.56667     68.50    <.001
Residual                         8      0.53333      0.06667

Total                           14     18.93333
```

Variate: Number of leaves at week_8

```
Source of variation           d.f.         s.s.         m.s.      v.r.    F pr.

replication stratum              2       1.7333       0.8667      7.43

replication.*Units* stratum
Silicon_rates                    4      20.2667       5.0667     43.43    <.001
Residual                         8       0.9333       0.1167

Total                           14      22.9333
```

Variate: Number of leaves at week_10

```
Source of variation           d.f.         s.s.         m.s.      v.r.    F pr.

replication stratum              2       0.1333       0.0667      0.44

replication.*Units* stratum
Silicon_rates                    4      24.4000       6.1000     40.67    <.001
Residual                         8       1.2000       0.1500

Total                           14      25.7333
```

Appendix 5 Analysis of variance

Variate: Cob length at week_17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
replication stratum	2	0.01764	0.00882	0.85	
replication.*Units* stratum					
Silicon_rates	4	56.85184	14.21296	1377.22	<.001
Residual	8	0.08256	0.01032		
Total	14	56.95204			

Appendix 6 Analysis of variance

Variate: Cob weight at week_17

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
replication stratum	2	0.12017	0.06009	0.81	
replication.*Units* stratum					
Silicon_rates	4	242.16476	60.54119	815.97	<.001
Residual	8	0.59356	0.07419		
Total	14	242.87849			