DETERMINING THE GROWTH AND DEVELOPMENT OF GARLIC (*ALLIUM SATIVUM*) GROWN IN THE DROUGHT PRONE AREA OF VOSBURG, NORTHERN CAPE PROVINCE, SOUTH AFRICA.

By

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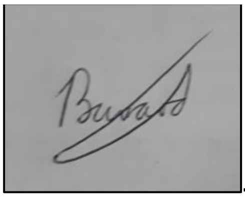
DECLARATION

I declare that the dissertation submitted under the title "Determining the growth and development of Garlic (*Allium Sativum*) grown in the drought prone area of Vosburg, Northern Cape Province, South Africa" is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. The dissertation was also subjected to turn it in report before submission as per the University policy.

Signed …………………………… Date: …19..July..2022...
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DEDICATION

I dedicate this dissertation to my mother, Sarie Viviers, my brother Rousseau Viviers, my father Pienaar Viviers and my wife Lize Viviers. I thank them for their prayers and support they offered during the duration of the study. Special gratitude to my brother Pienaar Viviers Jnr for all the advice he gave me whilst pursuing this qualification. Finally, I would like to dedicate this qualification to my family who believed in me when I wanted to better myself as they were very happy when I registered for Master of Science in Agriculture at University of South Africa.

ABSTRACT

Garlic (*Allium sativum*) belongs to the family Alliaceae, and is an important vegetable known all over the world for its medicinal properties and uses. It is known to help prevent high blood pressure, heart attack, hypertension, lung cancer, prostate cancer, breast cancer, stomach cancer, rectal and colon cancer. The crop garlic contains high content of Sulphur combining compounds which are responsible for the unique flavour, strong odour, and pungency that is used in food. However, most garlic growing farmers have been experiencing challenges regarding the yield as they (farmers) depend heavily on a balanced use of fertilizers. Fertilizer management is the major limiting factor that accounts for lower productivity of garlic. Field experiment which lasted for 5 months was carried out on a farm in the karoo region to record the response of liquid NPK fertilizers on growth and yield parameters. A complete randomized block design layout with the aim to find out the balance dose of NPK fertilizer with a half dose (150 ml NPK), a full dose (300 ml NPK) and a control which will produce a high number of cloves per bulb, high bulb diameter etc., was conducted. It is concluded that application of NPK at a rate of 300 ml NPK mixed with 100 L of water indicated a higher yield, followed by 150 ml NPK mixed with 100 L of water. On the contrary, control had the lowest performance on growth parameters and yield measured.

Key words: bulb diameter, bulb neck diameter, leaf area, number of cloves, plant height, NPK

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ABBREVIATIONS

B:	Boron
BC:	Before Christ
BD:	Bulb diameter
BND:	Bulb neck diameter
C:	Carbon
°C:	Degrees celsius
Ca:	Calcium
Caco3:	Calcium carbonate
Cl:	Chloride
Cm:	Centimeter
Cu:	Copper
E:	East
Fe:	Iron
FYM:	Farm yard manure
G:	Gram
Ha:	Hectare
Hiv:	Human immunodeficiency virus

K:	Potassium
Kg:	Kilogram
Kg/ha:	Kilogram per hectare
Km:	Kilometer
L:	Litre
LAI:	Leaf area index
Mg:	Magnesium
Mg:	Milligram
Mg/kg:	Milligram per kilogram
mg/l:	Milligram per liter
Mn:	Manganese
Na:	Sodium
NCpB:	Number of cloves per bulb
NL:	Number of leaf's
PH:	Plant height
pH:	Potential of Hydrogen
Pty:	Property Limited
So4:	Sulphate
T:	Ton
W:	West

Zn:	Zinc
%:	Percentage

CHAPTER ONE

1.1 INTRODUCTION

Garlic (*Allium sativum L.*) is the second most widely used cultivated bulb crops after onion and one of the main vegetable crops which have been cultivated since 3000 B.C. in Egypt by the Egyptians (Ipek and Simon, 2002). Garlic is a perennial plant of the amaryllis which belongs to the plant family *Amaryllidaceae* (Niederwieser, 2004). Garlic is an indigenous herb which originates from Western Asia and the Mediterranean where it has been cultivated for centuries (Apawu, 2009). The major garlic producing countries include China, India, Spain, Korean Republic, Argentina, Italy, Egypt, Thailand, United States, Turkey and Mexico (Rahim, 1992). China is the leading garlic producing country in the world with a 4986 thousand metric tons of production in an area of (372 thousand hectares) in 2017. The highest national yield ever recorded is from America (40 t/ha) in 2018. China is the leading garlic producing country in the world with a 4986 thousand metric tons of production (372 thousand hectares) in 2017. The highest national yield ever recorded is from America (40 t/ha) in 2018, when garlic bulbs were found in crates of ancient tombs of the pharaohs throughout the world.

The interest in growing garlic has been increasing, both among producers due to its high yield production; huge economic value and for household consumption (Totić and Ćanak, 2014). Thus, it is one of the main *Allium* vegetable crops in the world, which is a classic ingredient in many national cuisines, and it is used as a seasoning throughout the globe for many different types of food. The herb is a perennial and cold-weather crop which requires and demands a lot of nutrients, water and frequent irrigation for its successful production.

The crop can be grown in both irrigated and rain-fed environments which are suitable for growing the herb, however in the areas where garlic is cultivated in semi-arid areas, irrigation facilities are not easily available and rainfall is the only source of irrigation. Irrigation of garlic increases the cost of production. Garlic can adapt to most soil conditions; however, it prefers a sandy to sandy-loam soil with a very good drainage, with a pH of 6.5 –7.5 (Gosling, 2019). The previous devastating drought period was during 2004 and 2005 in South Africa (Krige, 2019). The current catastrophic drought began eight years ago in 2011 (Krige, 2019).

Although, the Karoo is a semi-arid area, it has reasonable water reserves to provide for small portions of irrigation and these water reserves can provide garlic plants with water. When growing garlic, it is recommended to avoid soils with heavy clay or soils that form a hard crust, as it leads to minimum bulb development (Sterling, 2000). Climate requirements for garlic is a very important factor for ultimate growth and production. According to Stork, (2004), garlic prefers a climate temperature of 25 °C to 32 °C. The constant and continuous drought in the Karoo region has left many farmers bankrupt or on the edge of bankruptcy. These drought conditions put enormous financial strain on the farmers, and they have received minimal support from the Government (Krige, 2019).

Garlic is grown for its edible bulbs, which can be eaten fresh, cooked, processed or preserved for seed (Hannan and Sorensen, 2001). The bulb contains smaller bulbs which consist of approximately 8 to 12 cloves (Totić and Ćanak, 2014). The bulbs have a powerful onion-like aroma and pungent taste. Garlic is known to contain a high content of sulphur combining compounds which are responsible for the unique flavour, strong odour, and pungency (Salomon, 2002). Garlic is mainly used for flavouring and serving dishes that include meat, soup, spaghetti, salads and sausages all over the world (Wiczkowski, 2011; Nagy *et al*., 2015). The strong flavour of garlic makes it stand out from other grown herbs. As a result, it has been widely used on pizza, pasta, meat, fish, vegetables, sauces, soup and salads as a garnish (Personal observation). In addition, it is reported that most used spice in India and Pakistan is garlic (Corzo-Martínez *et al*., 2007).

The oldest medicinal plant used in food over the world is garlic and it has also been used as a medicine in different ways (Shimon *et al*., 2007). Tattelman, (2005), reported that garlic has been used for medicinal purposes for thousands of years and its medicinal use records can be traced back to 5000 years ago. Additionally, the crop has been used for at least 3,000 years in Chinese medicine while the Egyptians, Babylonians, Greeks, and Romans have used it for healing purposes (Kamenetsky and Rabinowitch, 2001). When Egyptians realized the benefits of garlic as a remedy for a number of diseases, they recorded the use of garlic in the treatment of tumours, and it dates back to 1,550 BC (Bayoumy, 2006). It is known to help prevent high blood pressure, heart attack, hypertension, lung cancer, prostate cancer, breast cancer, stomach cancer, rectal cancer and colon cancer (Gosling, 2019).

The antibacterial properties of garlic were discovered by Pasteur in 1858, and it was utilized as an antiseptic to prevent gangrene during World War I and World War II. It was reported that the crop was also used to fend off evil spirits in various cultures (Tattelman, 2005). Garlic is one of the first crops 5000 years ago to be domesticated humans and it was tested on different species in the 1970s and showed inhibitory activities against Salmonella, S. Aureus, Mycobacterium and Proteus species. The cloves of garlic were tested against medicine including *S. epidermidis*, *S. aureus*, *Streptococcus pneumoniae*, *S. pyogenes*, *Haemophilus influenzae*, S. *typhi*, *Pseudomonas aeruginosa*, E. *coli*, *Shigella* spp and *Proteus* spp (Iwalokun *et al.*, 2004). Whilst it also possesses hypoglycaemia and anti-inflammatory properties, as well as hormone-like effects, it is reported to contain organosulfur (e.g., allicin and alliin) and flavonoid (e.g., quercetin) that are responsible for immunomodulatory effects (Khubber, 2020). Garlic can also help with the successful elimination of waste materials and dangerous free radicals from the human body (Durak *et al.,* 2004).

Historically, garlic has been known to treat aches, pains, deafness, leprosy, constipation, diarrhoea, parasitic infection, fever and to relieve stomach-ache and for sexually transmitted diseases and wounds (Banerjee and Maulik, 2002: Tattelman, 2005). In addition, it has also been used for preventing food poisoning (Ryzhenkov and Makarov, 2003). Research conducted revealed that garlic is considered to be a vital part of therapeutic armamentarium (Rivlin, 2009). There are many dietary supplements that reduce the risk of cancer and garlic is one among them. There are more than 3000 publications on garlic which have confirmed the efficacy of garlic for the prevention and treatment of a variety of diseases, acknowledging and validating its traditional uses. The main purpose in the 1940's for using this herb was for the herbal medicines which are more effective against several diseases and infections (Indigenous knowledge).

Garlic has also been used as an antibacterial, antifungal and antiviral agent worldwide due to its properties (Stork, 2004). Another research conducted reported that Human

Immunodeficiency Virus (HIV) infected people have been advised to eat at least one garlic clove a day (Niederwieser, 2004).

Garlic is known to kill streptococci and it contains sulphur compounds and has a pungent odour as a result freshly crushed garlic is normally used as an effective medicinal extract against common pathogenic (Corzo-Martínez *et al*., 2007; Flora, 2009). Currently, the most important global health concern is the viral pneumonia outbreak of coronavirus disease 2019 (COVID-19). Over the past three years, the COVID-19 related social distancing has seriously affected the psychological, economic and social well-being features globally. COVID-19 infection is quite variable, and the manifestations vary from respiratory infection, asymptomatic disease to severe acute (Donma *et al*., 2020). A strategy to combat the COVID-19 pandemic is by improving the nutritional pattern in humans. Garlic is one of the most efficient natural antibiotics against viruses and bacteria (Khubber *et al*., 2020) and it is also reported to be an antibacterial and anti-fungal agent (Block, 2010; Rivlin, 2001). The most prevalent general symptoms of covid-19 are fever, dry cough, dyspnea, myalgia, fatigue, loss of appetite, olfactory and gustatory dysfunctions (Donma, *et al* 2020). Compounds delivered from garlic have the potential to reverse the immunological abnormalities to a more acceptable level in the human body. Garlic is one of the most effective herbs that can be used against the influenza virus (Bilal *et al*., 2020; Chattopadhyay and Naik, 2007).

Bronchitis infection is another major symptom in the corona virus, garlic fights against bronchitis infection. Covid-19 is a new virus, and many researchers has done research on garlic but didn't have any satisfactory results, garlic can be used for immunity boosting purposes to fight against Covid-19 since reported to have properties to boost immunity to prevent infection (Khubber, 2020). *Allium sativum* can be used as a preventive measure before being infected with SARS-CoV-2 virus (Donma *et al.,* 2020). Garlic is known for several anti-bacterial properties to fight against bacteria and boost the immune system (Chattopadhyay and Naik, 2007). Coronavirus disease (COVID-19) is the current most major health issue of the world (Khubber, 2020). The recent rapid outgrow and rise in the production and use of garlic in South Africa has played a huge role in further understanding the use of liquid Codas NPK fertilizer and determining the correct rate and/or dosage which will influence faster growth and greater number of cloves per bulb of garlic grown in the Karoo, Northern Cape, since it is known to be one of the biggest provinces to produce garlic.

1.2 Problem statement

Although garlic is mostly grown and consumed in the (Afrikaner's) community, especially in the Karoo region, few studies have been conducted about the correct fertilizers rates which can influence the growth stages and bulb clover formation of the crop. Most commercial farmers in the Karoo region growing garlic do not know the correct fertilizer rates and /or dosage to apply to get better yield, and this mostly affects their profit as the less the bulb neck diameter and number of cloves per bulb equals less money sold for.

1.3 Aim of study

The study aimed to determine the correct dosage of combined NPK which can be used to determine the fast growth and establishment of bulb formation of garlic (*Allium Sativum)* grown in the Karoo region, Northern Cape, South Africa.

1.4 Objectives of study

- To determine the optimum rate of liquid fertilizer which will contribute to the fast growth rate and development stages of garlic.
- To determine the optimum rate of combined NPK liquid fertilizer mixed with supplements to influence the formation and number of cloves per bulb of garlic.

1.5 Hypothesis of the study

- The growth of garlic bulbs and cloves does not depend on liquid NPK fertilizer.
- The number of cloves per bulb does not depend on the combination of liquid NPK fertilizer and supplements supplied.

1.6 Significance of study

The findings of the current research will influence farmers in the Karoo region and other famers at large to grow garlic with the correct fertilizer rate which will ultimately produce bigger bulbs with high numbers of cloves. In addition, the findings of this study will contribute to the body and knowledge of science and will also be used as a point of reference for future studies in the same field. Upon completion of the study, MSc qualification will be obtained, and one article will be published in an accredited scientific journal.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Botanical description

Garlic (*Allium sativum*), and other crops such as onions (*Allium cepa*), chives (*Allium schoenoprasum)* and leeks (*Allium porrum***)**, are a perennial herb in the Alliaceae family, which is native to Western Asia and the Mediterranean, where it has been cultivated for centuries (Lee *et al*., 2003). The English word garlic is derived from the Anglo-Saxon " gar-leac " or spear plant, which refers to the flowering stalk of garlic (Tyagi *et al*., 2013). “Gar” means spear (because the shape of a clove resembles the head of a spear) and leac means “leek” (Saif *et al*., 2020). Garlic is a herb that is well-known for its flavour and pungency, as well as its medical properties. It is reported to be the second most popular vegetable in the United States, and it has been used as a medicinal plant for over 5000 years for a variety of ailments all over the world (Bisen and Emerald, 2016). Lanzotti (2006), reported that Allium is one of the largest and most important representative genus of the Alliaceae family. Historically in South Africa, garlic has been widely consumed by Afrikaners and coloureds, however, black people in South Africa have recently warmed up to it due to the medicinal properties it possesses that’s been reported to cure COVID-19.

Garlic crop consists of fleshy edible cloves enclosed in a white or pink thin coat. It’s leaves, stem, and flowers are also edible located on the head, easy to grow and can be grown all year round. The leaves are long, narrow and flattened (Ourouadi *et al*., 2016). Garlic grows in many parts of the world and is known to be a popular ingredient in cooking due to its strong flavour and delicious taste (Saif *et al*., 2020) and is commonly consumed for nutrition and medicinal purposes (Akan *et al*., 2019). Throughout the ancient history, the main use of garlic was for its health and medicinal properties, however in South Africa, among black community, consumption of garlic was frowned upon due to its strong post-eating odour.

Garlic is one of the most popular herbs in the world which has a lot of medicinal health benefits to prevent conditions such as heart disease, cholesterol, blood pressure and can be used to help HIV patients (Niederwieser, 2004). Korea, China, India, the United

States, Spain, Argentina and Egypt are among the top garlic-producing countries, with China being by far the greatest producer (Ourouadi *et al*., 2016). According to data published by Mebratu and Mulie (2019), approximately 10 million tonnes of garlic is grown worldwide annually (Pạczka *et al*., 2021). China and India are the world's major garlic producers, with a combined 60% of production area and 69% of global yield (Martindale *et al*., 2011).

Garlic can be produced in the whole of South Africa but the areas in which it is mostly grown are Limpopo, Gauteng, Western Cape, Free State, Eastern Cape, North West, KwaZulu-Natal and Mpumalanga Provinces (Niederwieer, 2004). The Northern Cape Province drought that has lasted in some areas for more than 3 years may have had devastating effects on the province which led to farmers and communities losing their jobs (Milton *et al*., 2021).

2.2 Garlic cultivars

Allium sativum (Figure 2.1) is one of the most important vegetable crops grown throughout the world (Lanzotti, 2006). It is second in the rank after onion because of its important nutritional value in human diet and its cultivation (Tabor *et al*., 2004). It is believed that there are approximately 600 garlic cultivars worldwide. Garlic is generally classified into two types, namely softneck (*Allium sativum* sub var. *sativum*) and hardneck (*Allium sativum* sub var. *ophioscorodon*) (Volk *et al*., 2004), of which hardneck varieties are stored for shorter period than the softneck varieties (Akan, 2019). Hardneck cultivars are cold hardy, produce scapes (or flower stalks), and have only a single layer of cloves around the stalk within the bulb, whereas softneck cultivars do not typically produce a scape and have 12 to 25 cloves arranged in three to six layers within the bulb (Walters, 2007).

Kerr, (2019), classifies the garlic into three main types, namely softneck (*A. sativum*), stiff neck (*A. sativum* var. *ophioscorodon*) and elephant garlic (*A. ampeloprasum*). Softneck garlic does not have a flowering top and contains up to twenty-four cloves per bulb (Alam *et al*., 2016). It consists of two main cultivars namely Egyptian White and Egyptian Pink and is the most popular type in South Africa mainly because it grows easily in different environments which includes frost and semi-arid areas.

Elephant garlic is closely related to leeks, has a longer shelf life than the two other types, and has a milder flavour, which suits many consumers. The bulbs of softneck garlic consist of an outer layer of large cloves and two inner rows of smaller cloves, the outer cloves are normally used for planting (Kerr, 2019).

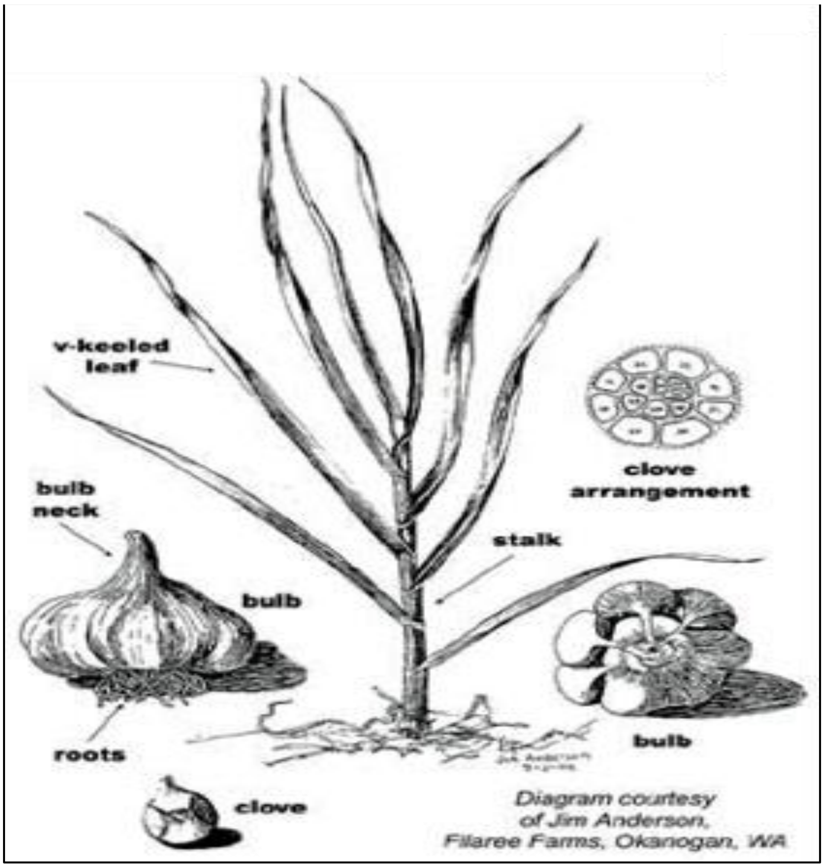

Figure 2.1: A schematic representation of garlic

2.3 The nutritional composition of garlic

Garlic has an exquisite defence system composed of as many different components boosting human immune system (Ourouadi *et al*., 2016). It is a significant source of micronutrients (minerals and vitamins) (Sharifi-Rad *et al*., 2016) as shown in Table 2.1 below.

Table 2.1: Nutritional composition of raw garlic (*Allium sativum L.)*

Constituents	Value per 100 g
Water	58.58 g
Energy	149 kcal
Fibre	2.10 g
Nutrients	
Protein	6.36 g
Total lipids	0.50 g
Sugars (total)	1.00 g
Minerals	
Calcium (Ca)	181 mg
Iron (Fe)	1.70 mg
Magnesium (Mg)	25 mg
Phosphorous (P)	153 mg
Potassium (K)	401 mg
Sodium (Na)	17 mg
Zinc (Zn)	1.16 mg
Vitamins	
Vitamin C (ascorbic acid)	31.2 mg
Vitamin B1 (thiamin)	0.20 mg
Vitamin B2 (riboflavin)	0.11 mg
Vitamin B3 (niacin)	0.70 mg
Vitamin B6 (piridoxine)	1.23 mg
Folate	3.00 µg
Vitamin E ((α-tocopherol)	0.089 g
Vitamin K (phylloquinone)	1.70 µg
Lipids	
Fatty acids (total saturated)	0.089 g
Fatty acids (total monounsaturated)	0.011 g
Fatty acids (total polyunsaturated)	0.249 g

Source: Sharifi-Rad *et al*., (2016)

2.4 Influence of fertilizers on garlic growth

In Ethiopia garlic production and the land area coverage is an increasing trend. The production of garlic in the year 2000 was estimated to be 52, 262 tons produced on 4,797 hectares of land (Central Statistic Agency [CSA], 2000). Currently the annual average production has reached 222,548 tons with the average productivity of 10, 5 tons per ha^{-1} (Central Statistic Agency, 2013). The low performance of garlic production can be attributed to the traditional production practices implemented by smallholder farmers. One of these practices that smallholder farmers follow involves poor application of fertilizer both in terms of rate and type, and also lack of evidence on how much to apply for agronomic and economic optimum. Only a small number of farmers are using chemical fertilizers, the rate of application is by far below the national blanket recommendation which is about 105 kg N ha−1 and 92 kg P ha−1 for garlic production (Ethiopian Institute of Agricultural Research [EIAR], 2007). A sustainable agricultural system is one that is economically viable, provides safe, nutritious food, and conserves resources and enhances the environment with a possessive impact (Campbell *et al.*, 2004). Fertilizers are known to be the basis to produce more crop output from existing land under cultivation (Ryan, 2008). Economic and environmental implications of excessive nutrient use by garlic crops demands for balanced fertilization and that nutrient needs of crops are according to their physiological requirements and expected yields (Ryan, 2008).

There are multiple efforts to obtain higher yields of garlic fields, which have led to the application of various types of fertilizers. Different fertilizers have dissimilar concentrations of plant nutrients and therefore affect the soil environment differently. Farmers strive to obtain higher yields of garlic through heavy application of certain fertilizers, and such procedures must equally preserve the quality of the crop (Cantwell *et al*., 2006). Bulb crops such as garlic are heavy feeders, requiring alot of N, P, and K in either the form of inorganic or organic fertilizers or a combination of them. A lack of these fertilizers affects the yield, quality and storability of the bulbs (Gubb and Tavis, 2002). Fertilizers are applied to vegetables in order to achieve a higher yield (Stewart et al., 2005). Researchers have found that extensive use of Nitrogen based fertilizers worldwide has resulted in significant environmental problems in agricultural production systems. Factors such as pollution of natural resources and rising costs of Nitrogen fertilizers has also attracted greater attention to improve their use in agriculture and created the development of improved Nitrogen use efficient crop plants (Good *et al*., 2004). Production of vigorous sprouts is one of the most important factors of successful garlic production (Potgieter, 2006). Crop yields is influenced by phosphoric fertilizers, because P deficiency limits the response of plants to other nutrients, and this can be seen especially on leached soils of both tropical and temperate regions of the world where soil acidity causes infertility and limitation to crop production (Alaam *et al*., 2002). Vegetable production, especially garlic, could be very profitable if the correct amount and the type of fertilizer is applied, and the crop that is grown utilizes the fertilizer nutrients very efficiently (Anonymous, 2002). Smallholder farmers are known to use low rates of inorganic nitrogen and phosphorus fertilizers (less than 100 kg ha-1 of urea and/or DAP) for garlic production due to very high prices (Morris *et al*., 2007).

2.5 Medicinal properties and health benefits

Historical and popular uses of garlic is because of its antioxidant, haematological, antimicrobial, hepatoprotective and antineoplastic properties as well as its potential toxicity (from sulfoxide) (Rana *et al*., 2011). Garlic is known to have protective effects against stroke, coronary thrombosis, atherosclerosis, platelet aggregation, as well as infections and vascular disorders (Alam *et al*., 2016). Garlic is rich in minerals and vitamins, which are both essential nutrients for human health (Gambelli *et al*., 2021). Due to its biological active component allicin and its derivative, it has been used as a medicine to cure a wide range of diseases and conditions related to the heart and blood system, including high blood pressure, high cholesterol, coronary heart disease, heart attack, and "hardening of the arteries" (atherosclerosis) as pronounced (Mikaili *et al*., 2013).

Morihara *et al*., (2010), reported that garlic can be used to prevent various types of cancer including colon cancer, rectal cancer, stomach cancer, breast cancer, prostate cancer, prostate cancer, bladder cancer and lung cancer. It has also been used to treat cardiovascular disease, diabetes, osteoarthritis, hay fever (allergic rhinitis), traveller's diarrhoea, high blood pressure late in the pregnancy (pre-eclampsia), cold and flu, as well as building the immune system, preventing tick bites, and preventing and treating bacterial and fungal infections (Alam *et al*., 2016). In addition, It has also been found to have synergistic effects against *Helicobacter pylori* with a proton pump inhibitor (Rana *et al*., 2011). Garlic is a low maintenance plant with antimicrobial properties and is used for medicine by tribes all over South Africa.

Garlic is probably the most known as a complementary therapy for blood pressure control (Capraz *et al*., 2007). A recent in *vitro* study confirmed that the vasoactive ability of garlic sulphur compounds whereby the red blood cells converted garlic organic polysulphides into hydrogen sulphide, a known endogenous cardio-protective vascular cell signalling molecule (Benavides *et al*., 2007). Platelets and fibrin plays a very big role in blood clotting and higher amounts of fibrin in blood can cause heart attack or heart diseases (Gebreyohannes and Gebreyohannes, 2013). Fukao *et al.*, (2007), reported that garlic constituents can reduce fibrin formation and help reduce the fibrin existing in the blood better than aspirin. Ajoene is a sulfur compound that is found in garlic and is responsible for its anti-clotting effect, but ajoene is only viable at room temperature or above and is not present in raw or freeze- dried garlic. In addition, it is suggested that when garlic is added to a diet, it can help increase the breaking down of fibrin in people by 24 to 30% (Gebreab and Thirumurugan, 2014).

Inadequate nutrition, cigarette smoke, physical injury, mental tension and chemical pollution all have an impact on the human body. The enormous pressures, which our immune systems sustain, supplemental nutrients like garlic are clearly needed. This remarkable content of germanium can alone offer excellent immune stimulation to the body. In addition, to this germanium, garlic contains thiamine, sulfur, niacin, phosphorous, and selenium compounds which can afford the human body with protection by stimulating the production of certain beneficial enzymes (Gebreyohannes and Gebreyohannes, 2013) .

2.6 Climate and soil requirements of Garlic crop

Garlic can be grown in a wide range of soil types (Kerr, 2020). However, it grows best in well drained fertile soils that are high in organic matter, and the incorporation of compost or well-rotted manure into heavy soils will result in the soil being friable and suitable for production (Khade *et al*., 2017). Climatically, regions with a reasonably mild winter and an average rainfall (600 mm to 700 mm) followed by a sunny dry summer, which is good for maturity and harvesting the bulbs, are ideal for garlic production (Gebremeskel *et al*., 2017). Water should not be deficient during bulb formation until two weeks before harvesting time (Mudziwa, 2010), while excess supply of water at two weeks before harvesting affects the storage quality (Potgieter, 2006).

The best season to grow the *A. sativum* plant is during winter when it is cool (Stork et *al*., 2004). It is well adapted for the production in all parts of South Africa especially in cool and dry regions; areas such as Polokwane plateau and Northern Cape (Douglas area) (Mudziwa, 2010). It is important to stick to the correct planting time, from

February to May, depending on the production area. Bulb crops like garlic always require supplemental irrigation or watering where rainfall is insufficient (Tilahun *et al.,* 2011).

Figure 2.2: A schematic representation of garlic clove in soil

2.7 Growth and development of Garlic

Sprouting can be seen 20 to 30 days after sowing, and shoot growth from the end of sprouting until 140 days (Ledesma *et al.*, 1994). Garlic can only be grown to its best if it undergoes a period of cold temperatures followed by a period of light and heat (Siktberg *et al.*, 2006). Garlic plant is a species of vegetative propagation, showing high morphological diversity. Besides, its clones have specific adaptations to different agro-climatic regions (Paredes *et al.*, 2007). Garlic also shows wide morphological and agronomic variations in characteristics such as colour and size of the bulb, plant height, number and size of the cloves, days to harvesting, resistance to storage capacity, dormancy and adaptation to agro-climatic conditions (Figliuolo *et al*., 2001).

Figure 2.3: A schematic representation of garlic clove sprouting

2.8 Field management of garlic

Although garlic performs best under fertile soil and drainage, it is very sensitive to overwatering, and drip irrigation is the most effective way of watering, especially in heavy soils for improved infiltration (Butler, 2018). The use of sufficient and balanced sources of nutrients to obtain good growth and high yield with good quality garlic plants is an important practice in today's garlic production through addition to new technologically produced compound fertilizers that contains different nutrients in one fertilizer product, and should be fertilized with 75:40:40:40 kg NPK per hectare for higher yields (Teklu and Teklewold, 2009).

Studies conducted showed that the application of nitrogen (N) with additional sulphur (S) at an early vegetative (sprouting) stage is useful for the promotion of strong vegetative growth before cold winter months (Stork *et al*., 2004). Weed infestation in garlic is one of the major factors for loss in yield and bulb yield loss due to weed infestation to the tune of 30-60% was recorded (Kumar *et al*., 2013). Garlic is highly vulnerable to weed infestation due to its slow emergence and slow initial growth, non-branching habit, sparse foliage and shallow root system (Patil *et al*., 2021). According to Hickey, (2012), it is advised to use a knife to remove weeds.

2.9 Harvesting of garlic

At maturity, garlic plants start to die back, and the cloves fill rapidly. Harvesting of garlic should only be done when about 50% of the plant has died back (Kerr, 2020). The maturity of garlic that can be estimated by the time of harvest is governed by its subsequent use. Harvesting at the proper stage of physiological maturity is a prerequisite to obtaining successful planting material, whereby early harvesting produces small bulbs that exhibit rapid weight loss and cracking of the bulb wrapper skins, while delayed harvest results in loose (split), discoloured and sunburned bulbs, and occasionally cloves begin to sprout (Desta *et al*., 2021).

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was conducted at Keurfontein farm (Figure 3.1) on a 2-hectare land, 7 km outside of Vosburg, which is situated in the Northern Cape region of South Africa, with an elevation of 1167 metres. Vosburg is situated 61 km west of Britstown and 100 km north of Victoria West with coordinates of 30’34’S 22’53 ‘E in the Pixley ka Seme district. The total population is 1259 as recorded in the last South African census in 2011. In the Vosburg region, annual rainfall ranges from 130 mm to 380 mm (Mucina *et al*., 2003). The GPS location where the garlic was planted on the farm is: Latitude -30.6213° or 30° 37' 16.7" south Longitude 22.939° or 22° 56' 20.3" east.

The coldest night in the region average 2°C at night and daytime temperatures can reach 15°C in June, July and August months whilst January, February, March and November are the warmest months, with night temperatures ranging from 15 to 19°C and daytime temperatures in these months average around +/32°C.

Figure 3.1: Satellite photo taken of Keurfontein farm.

3.2 Field experiment and growth of garlic plants

Before the ploughing of the experimental site, soil samples were randomly collected from the farm and taken to Bemlab soil laboratory for sampling as shown in figure 3.2. In addition, water samples were also collected to determine and describe the physical, chemical, and biological attributes of water for irrigation. During the production of garlic in this experiment, insects, pests and diseases observed were controlled chemically when observed. For instance, in October Cyperphos leaf spray was done to prevent diseases. Foliar application to the leaves of garlic was applied at a dosage of 500 ml/500 L of water. There were Thrips (*Thysanoptera*) identified on some garlic leaves and Botrytis Rot (*Botrytis porri*) disease.

Figure 3.2: Taking soil samples with a hand shovel.

The 3000 square meter land was used for the production of garlic experiment, the land was ripped very deep with a depth of 40 cm and irrigated with a centre pivot with 25 mm of water for a total of three days to soften the hard texture of the soil and cultivated thereafter. About 300 kg of the Egyptian cultivar seed required for the 3000 square meter land was used to plant the area. After the garlic bulbs were broken into cloves, the 3000 square meter land was rotovated with a small tractor shown in figure 3.3 to not compact the soil. A total of 25 seasonal labourers were hired for breaking the bulbs to get the cloves used as planting material, as well as planting them by inserting the cloves in the soil using a small hand spade and covering with soil.

Figure 3.3: Ford 3000 small tractor used for ploughing the soil.

3.3 Weed control and identification in the experimental site

The cultivated land was well sprayed a week later with Galigan 240 EC (see Figure 3.4) to kill all the small grass and weeds that had emerged from the irrigation. The herbicide was sprayed on wet ground to control the weeds one week after planting. The 3 L Galigan 240 EC was thoroughly mixed with 350 L of water before application using boom spray. A 16 mm dripper pipes which had a dripper emitter every 30 cm delivering 1.11 litre of water per hour at 2 bar water pressure were pulled into the experimental site. Weed control was conducted every Monday morning for 7 hours, after irrigation with an interval of seven days until the next irrigation.

Figure 3.4: Galigan 240 EC herbicide applied one week after irrigation for weeds control.

3.4 Planting material

The garlic cloves (Egyptian White) cultivar (Figure 3.5) used in the current study were bought from Minta Karoo seeds company in the Britstown area from a registered garlic farmer. The seeds and bulbs were free from disease, any damage from insects, in good and healthy condition.

Figure 3.5: Egyptian white ready for planting the seeds out of the bulb

The seeds were stored in a cool, low humidity and dark room until use to prevent rays of sunlight, preserve their moisture state, and avoid resprouting. Garlic production for this experiment commenced in June of 2021 until November 2021 (termination) growing season and lasted for 21 weeks. The spacing between the plants (inter row) was 10 cm apart from each other while the spacing between the rows (intra row) was 25 cm (see Figure 3.6) apart from each other as prescribed by Kahsay *et al*., (2013). Small rows were ripped with a ripper mounted on a small tractor and the labourers placed the garlic seeds into the soil and closed it. The experiment was a randomized block design (CRBD). There were 3 replications and a total of 15 plants per treatment.

Figure 3.6: Bed of garlic grown under control and different NPK treatments

Figure 3.7: Measuring garlic bulbs at week 18.

3.5 Fertilizer application program for this experiment

The fertilizer treatment was developed and managed by the help of an independent field agent (Phillipus Breyl) from Minta Karoo from Britstown in the Northern Cape as indicated in table 3.1. Liquid fertilizer Codas NPK was used for its highly concentrated content and the ability to supply crops with the required nutrients at optimum levels. Additionally, this is highly soluble fertilizer which mixes easily with water. Furthermore, it also has a convenient packaging for ease of handling and is available on 1 L, 5 L and 20 L. The liquid fertilizer was applied through a 16 mm drip pipe that was laid on the soil parallel to the garlic plants.

Table 3.1: Garlic fertiliser program used during the growth of garlic

Period	Fertilizer applied and different concentration used per treatment		
	Treatment 1	Treatment 2	Treatment 3 (control
June (one week after planting)	• Codas (NPK) 5:10:3 • Dosage 150ml Codas (NPK) 5:10:3 per 100 litre water • 1 leaf stage	• Codas liquid fertilizer (NPK) 5:10:3 • Dosage 300ml (NPK) 5:10:3 per 100 litre water • 1 leaf stage	
July	• Codas liquid fertilizer (NPK) 5:10:3. • Dosage 150ml Codas liquid fertilizer (NPK) 5:10:3 per	• Codas liquid fertilizer (NPK) 5:10:3 • Dosage 300ml (NPK) 5:10:3 per 100 litre water	

	100 litre water • 4 leaf stage	• 4 leaf stage	
August	• Codas (NPK) 5:10:3 • Dosage 150ml Codas (NPK) 5:10:3 per 100 litre water • 6 leaf stage	• Codas liquid fertilizer (NPK) 5:10:3 • Dosage 300ml (NPK) 5:10:3 per 100 litre water • 6 leaf stage	
September	• Codas (NPK) 5:10:3 • Dosage 150ml Codas (NPK) 5:10:3 • 8 leaf stage	• Codas (NPK) 5:10:3 and 300ml Codas (NPK) 5:10:3 per 100 litres of water • 10 leaf stage	
October	• Codas (NPK) 5:10:3 • Dosage 150ml	• Codas (NPK) 5:10:3 and • Dosage 300ml	

	Codas (N.P.K) 5:10:3 per 100 litre water ● 12 leaf stage	Codas (NPK) 5:10:3 per 100 litre water ● 13 leaf stage	
November	● Codas (NPK) 5:10:3 ● Dosage 150ml per 100 litre water ● 14 leaf stage	● Codas (NPK) 5:10:3 ● Dosage 300 ml Codas (NPK) 5:10:3 per 100 litre water ● 15 leaf stage	

3.6 Fertilizer supplements applied with NPK150/100L during garlic production

Codas Dalgin Active seaweed extracts, which is a micro and macro element booster, was sprayed at a later stage in the growth period in August (4 leaf stage). The dosage of Dalgin active applied was 150 ml /100 L of water. Additionally, a pH buffer formulation with high Nitrogen and Sulphur content, enriched with micro elements which is also an acidifier and soil nutrients unlocker was dripped into the drip lines of the irrigation at a ratio of 1 L of pH buffer into 500 L of water. In September, the application of Dalgin active at a ratio of 150 ml into 100 L of water was repeated In addition, a nutrient supplement called Codaphos K was also applied for strengthening the natural defense system of plants against cryptogamic diseases such as, root rotting, and neck diseases such as Phytophthora sp. and Pythium sp, with a dosage of 5 L per 500 L of water. Codafol K35 Acid, which is a pH neutral liquid solution with a high potassium content, specially formulated for foliar application, and that acts as a potassium deficiency corrector in all types of crops to improve the quality and colouring of treated crops was the last supplement that was applied in September (8 leaf stage) with a dosage of 100 ml into 100 L of water**.**

Codas Dalgin active seaweed extract micro and macro elements was again applied in November (13 leaf stage) with the same dosage 150 ml/ 100 L of water with the pH buffer at the application rate of 1 L of pH buffer per 500 L of water through the dripline during irrigation. A Fruitmax supplement was used to strengthen the bulb of garlic and was applied in November (13 leaf stage), where 2 L of Fruitmax was thoroughly mixed with 500 L of water before application. In the last six weeks and three weeks of the growth period of garlic, Potassium 50 kg per 1 hectare were washed in through drip irrigation in November (13 leaf stage) before the harvest date. In addition, Potassium application prior to harvesting of garlic was done to generally strengthen the crops, increase radicular mass and improve crop growth and production as well as increasing resistance to stressful conditions. Lastly, the foliar feed mix of Codasting and Codamin B was sprayed as a foliar application, 250 ml/ 100 L of water was applied to the garlic plants at three, two and one week consecutively before harvesting/termination of the experiment.

3.6.1 Fertilizer supplements and herbicide application applied with NPK 300/100L during garlic production

A herbicide was sprayed in June one week after planting. Galigan 240EC were sprayed on wet ground for weeds as a precaution. The dosage was 4 litre Galigan 240EC on 250 litre of water per hectare. In July (2 leaf stage) there were no supplements sprayed because of the cold month. In August (5 leaf stage) Codas Dalgin active seaweed extract micro and macro elements was applied with a dosage of 300 ml Dalgin active seaweed on 100 litre water. In the middle of August (5 leaf stage) a pH buffer was applied at a rate of 2 Litre per 500 litre water through a drip pipe during irrigation. The last supplement applied in August (5 leaf stage) was Radimax through drip lines with a dosage of 4 litres Radimax per hectare on 500 litre water mix. September (10 leaf stage) had two supplements. The first one was Codaphos K with a dosage of 10 litre per hectare on 500 litre of water. The last supplement for September (10 leaf stage) was Codafol K35 Acid with a dosage 200ml of 100 litres of water. October (13 leaf stage) had no supplements record. There was only a leaf spray with Cyperphos 1 litre on 500 litres of water. November (15 leaf stage) had the most supplements applied, with Fruitmax with a dosage of 4 litre Fruitmax per hectare applied on 500 litres of water mix. Codas Dalgin Active seaweed extract micro and macro elements was also applied with a dosage of 300 ml Codas Dalgin Active seaweed on 100 litre water. pH buffer was applied in drip irrigation at 2 Litre per 500 litre water through drip pipe irrigation balance the pH of the soil. The first application of Potassium was done at a rate of 100 kg per 1 hectare where it was washed in through drip irrigation 6 weeks before the commencement of harvest. The second Potassium application of 100 kg per 1 hectare was washed in through drip irrigation 3 weeks before harvest. At the end of the growth period in November (15 leaf stage), 500ml of Codasting and Codamin B with a dosage of 1 litre mix on 200 litres of water were sprayed at 3 weeks, repeated at 2 weeks and one week before harvest.

3.7 Harvesting and storage of garlic

Seven days before harvest at week 19, irrigation was stopped to allow drying of garlic bulbs and accumulation of dry mass on the bulb as shown in figure 3.8.

Figure 3.8: A representative of garlic crops after irrigation was stopped and irrigation pipes pulled out of the field.

Garlic plants from different treatments were harvested when the tips of the leaves had dried to about 30% to 50%. Harvesting was carried out using an Erdvark harvester (figure 3.9), where it was used to lift the crops up. The harvested garlic bulbs were dried for 3 weeks in the field to preserve the storage life as shown in figure 3.10. From the harvested garlic plants, 10 to 15 plants were tied to each other in a bundle, hanged and stored in a dark room at low temperatures to extend shelf life as prescribed by (Chope *et al*., 2006).

Figure 3.9: Erdvark harvester used in harvesting/ lifting garlic bulbs from the soil.

Figure 3.10: Harvested garlic left in the field to allow drying of the bulbs

3.8 Data collection

3.8.1 The following growth parameters were measured:

- Plant height (cm) was measured using a measuring tape.
- Leaf area (cm) measured using leaf area index
- Numbers of leaves per plant were counted and recorded.

3.8.2 Yield per treatment was measured through the following:

- Bulb neck diameter (cm)
- Bulb diameter (cm) was measured by digging out a bulb and placing a rope around the bulb and the rope was also stretched over a measuring tape.
- The number of cloves per bulb.
- Total yield

3.9 Statistical Analysis

To determine the effect of NPK (5:10:3) fertilizer applied at two dosage levels (150 ml and 300 ml) and time progression across a 21 week period on plant growth and development traits of garlic (i.e., PH, LAI, NL, BND, BD and NCpB), simple linear regression analysis was performed. Regression statistics were generated using the ‘lm’ function in the agricolae v1.3-1 R package and the linear relationships were visualized using the ‘ggplot’ function in the ggplot2 v3.3.5 R.

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CHAPTER FOUR

RESULTS

4.1 Physical and chemical properties of soil experimental site pre garlic growth

Pre-planting of garlic, soil samples at a depth of 30cm at the Keurfontein farm were collected and sent to (Bemlab (Pty) Limited (registration number: 1996/006836/07) for analysis and the results are indicated in detail in table 4.1 and 4.2. In summary, the soil texture of the experimental site was found to be clay and had a pH of 7.2, with two types of phosphorus (Olsen and Brayll) ranging from 6.5-58.4 mg/kg respectively. In addition, the soil had a potassium of 314 mg/kg and sodium was low at 1.2%. The percentage of potassium was found to be 0.80% while calcium was 13%. Magnesium had a 3.2% while sulphur had a 9.3% index respectively and the data is presented in table 2 below:

Table 4.1: Soil characteristics and properties of the experimental site (Keurfontein farm) at 30 cm depth

Soil characteristics	Value
Textural class	Clay
Resist (ohms)	270
Stone (%)	7.94
pH	7.2

Table 4.2: Macro nutrients content of the soil mg/kg found in Keurfontein farm pre-garlic production

Micronutrients content	**Value**
Phosphorus Brayll (mg/kg)	58.4
Phosphorus Olsen (mg/kg)	6.5
Potassium (mg/kg)	314
Sulphur (mg/kg)	9.3
Sodium (%)	1.2
Potassium (%)	0.80
Calcium (%)	13.0
Magnesium (%)	3.2

4.1.1 Micronutrients

In addition, pre-garlic planting, soil analysis also revealed the micronutrients available in Keurfontein farm soils as shown in table 4.3. The soil micronutrients content of pre-garlic production was 2.4 mg/kg copper, 0.86 mg/kg of zinc, 176 mg/kg manganese, 0.81 mg/kg boron, 29.7 mg/kg iron and 0.79% of carbon.

Table 4.3: Micronutrients content found in Keurfontein farm pre-garlic production

Cu mg/kg	**Zn mg/kg**	**Mn mg/kg**	**B mg/kg**	**Fe mg/kg**	**C %**
2.4	0.86	176	0.81	29.7	0.79

Where Cu represents Copper

Zn represents Zinc

Mn represents Manganese

B represents Boron

Fe represents Iron

C represents Carbon

4.2 Analysis of the irrigation water

Water sample was taken from the irrigation dam at the Keurfontein farm and sent to Bemlab for analysis to determine the physical and chemical determinants that are available in the irrigation water before garlic growth and development. The detailed results of water analysis are shown in table 4.4. In brief, the findings revealed that there was 59.3 mg/l of chloride, with over 100 irrigation limits and about 129 mg/l of sodium, which made it the highest with over 70 irrigation limits. Sulphate (So4) was the second highest with a result of 85.6 mg/l and had no irrigation limits.

Magnesium and Sulphur also had no irrigation limits with 41.9 mg/l and 28.6 mg/l content respectively. In addition, calcium had 38.4, with no limitation on irrigation, Potassium was the lowest with 2.9 mg/l measurement.

Table 4.4: Macro nutrients contents of the irrigation water from the dam.

Macronutrients	Methode ID	Unit	Results	Irrigation limits
Chloride (Cl)	3778	mg/l	59.3	<100
Sodium (Na)	3132	mg/l	129	<70
Calcium (Ca)	3132	mg/l	38.4	Not Applicable
Magnesium (Mg)	3132	mg/l	41.9	Not Applicable
Potassium (K)	3132	mg/l	2.9	Not Applicable
Sulphur (S)	3255	mg/l	28.6	Not Applicable
Sulphate (So4)	calc	mg/l	85.6	Not Applicable

In addition, the results of the micro chemical elements are shown in the table 4.5 below. In brief, boron had no irrigation limits and had a result of 0.33 mg/l. Iron was measured in two parts for results. The one part was total iron, and the other part was dissolved iron. They both had a <0.06 mg/l with a <0.30 irrigation limit. In addition, manganese indicated an irrigation limit of <0.10 and a <0.04.

Table 4.5: Analysis of micro chemical content of the irrigation water

Micronutrients content	Methode ID	Unit	Results	Irrigation limits
Boron (B)	3132	mg/l	0.33	Not Applicable
Iron (Fe) dissolved	3132	mg/l	<0.06	<0.30
Iron (Fe) Total	3132	mg/l	<0.06	<0.30
Manganese (Mn) dissolved	3132	mg/l	<0.04	<0.10
Manganese (Mn) Total	3132	mg/l	<0.04	<0.10

The pH of the water characteristics was measured and indicated 8.4 pH while the irrigation limit was ≥5.5 to ≤9.0. Alkalinity of the water calcium carbonate (caco3) (mg/L) had a result of 386 mg/l with a ≤150 irrigation limit. The Electrical conductivity (mS/m (25 °C) was measured at 25 °C and yielded a result of 108, indicating an irrigation limit of ≤270. Langelier index was recorded at 1.0. with the irrigation limit of ≥-0.5 to ≤0.5. Sodium adsorption ratio was the lowest, resulting in ≥-0.5 with no irrigation limit.

Table 4.6: Physical and aesthetic water quality characterization elements of the irrigation water

Water characteristics	Results	Irrigation limits
pH	8.4	≥5.5 to ≤9.0
Alkalinity as caco3 (mg/L)	386	≤150
Electrical conductivity (mS/m (25 °C)	108	≤270
Langelier index	1.0	≥-0.5 to ≤0.5
Sodium adsorption ratio	≥-0.5	Not Applicable

4.3 Weeds identified in the experimental site

During garlic growth, three kinds of weeds were observed to be dominant and identified as Blou dissel, Field bindweed and Pechuel-Loeschea leubnitziae shown in the figures (4.1, 4.2, 4.3).

Figure 4.1: Blou dissel (*Mexican poppy)*

Figure 4.2: Field bindweed (*Convolvulus arvensis)*

Figure 4.3: Pechuel-Loeschea leubnitziae (Kuntze) O.Hoffm (Asteraceae)

4.4 Growth parameters measured at week 5 to week 20

Table 4.7: Summary regression statistics showing relationship between time progression (i.e., in weeks) and garlic plant growth and development traits

	Control			T1 Half dose (Only 50% fertilizer rate applied)			T2 Full dose (100% fertilizer rate applied)		
	Regression equation	Adj. R^2	p-value	Regression equation	Adj. R^2	p-value	Regression equation	Adj. R^2	p-value
Plant height (PH; cm)	y=-0.93+0.82x	0.945	***	y=-5.27+0.79x	0.854	***	y=-3.303+0.597x	0.888	***
Leaf area index (LAI; cm)	y=-3.7+0.7x	0.854	***	y=-3.71+0.62x	0.837	***	y=-3.55+0.56x	0.857	***
No. of leaves (NL)	y=-1.97+1.57x	0.869	***	y=-2.07+1.38x	0.892	***	y=-2.23+1.34x	0.952	***
Bulk neck diameter (BND; cm)	y=-9.96+9.42x	0.977	***	y=-8.01+9.14x	0.955	***	y=-8.01+9.14x	0.955	***
Bulk diameter (BD; cm)	y=-5.96+3.05x	0.833	***	y=-6.47+2.95x	0.876	***	y=-6.47+2.95x	0.876	***
No. of cloves/bulb	y=4.79+2.72x	0.698	***	y=2.84+1.696x	0.935	***	y=2.23+1.75x	0.957	***

4.4.1 Plant height

The results shown in figure 4.4 indicated that at week 5 of the experiment, control showed a 7 cm in plant height. Garlic crops treated with half dose (150ml Codas NPK 5:10:3) indicated a plant height of 12 cm while those treated with full dose (300ml Codas NPK 5:10:3) had a plant height of 14 cm. The measurements taken on week 10 indicated that there was a very slight improvement in the height of garlic where no treatment (control) was applied, with a 13 cm plant height whilst half dose (150ml Codas NPK 5:10:3) had a 22 cm recorded. On the contrary, full dose (300ml Codas NPK 5:10:3) showed a significant improvement on growth and height with a 27 cm plant height. Garlic grown under control treatment measured a plant height of 22 cm at week 15, which was not significant from plant height measured at week 5. Half dose (150ml Codas NPK 5:10:3) showed a 26 cm in plant height and full dose (300ml Codas NPK 5:10:3) with 30 cm plant height. The last measurement was taken on week 20, which indicated that control had a measurement of 25 cm while half dose (150ml Codas NPK 5:10:3) had a 32 cm in plant height and full dose (300ml Codas NPK 5:10:3) had 39 cm respectively. The results showed that there was a significant difference in the plant height of grown garlic applied with full dose (300ml Codas NPK 5:10:3) between week 5 and week 20 with 39 cm being the peak height among all treatments at termination period as shown in figure below.

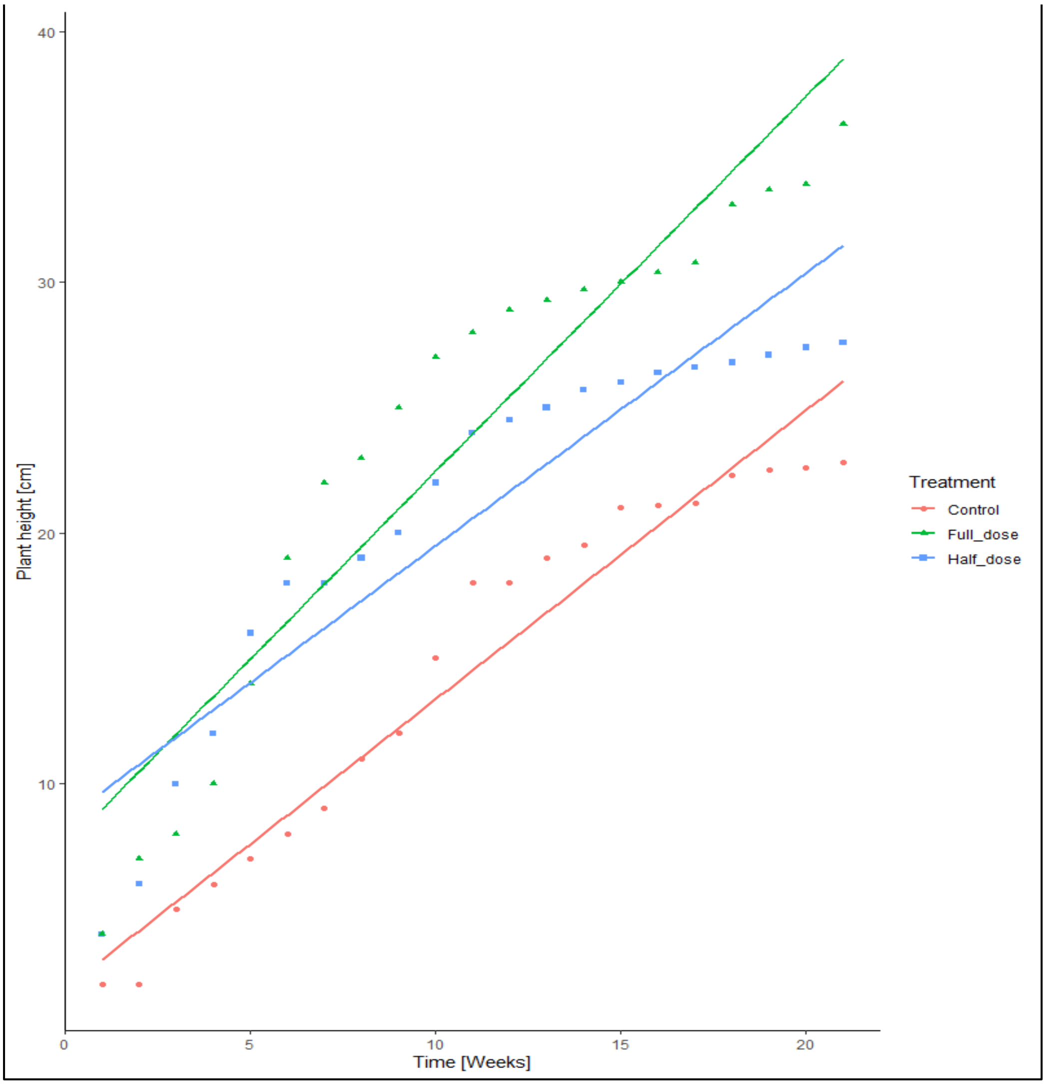

Figure 4.4: Performance of garlic on plant height measured at different week intervals

4.4.2 Leaf area (cm)

The results of the study showed that there was a significant difference between full dose (300ml Codas NPK 5:10:3) and control treatments. Leaf area in all treatments had a relatively small size in the beginning of the experiment, however, a steady increase was observed as the growth progressed until termination stage. In week 5 of the experiment, the results indicated that control treatment had a leaf area of 13 cm. Garlic grown and treated with half dose (150ml Codas NPK 5:10:3) showed a leaf area of 15.8 cm while the full dose (300ml Codas NPK 5:10:3) measurement showed 15.7 cm leaf area size. In figure 4.5, it is very prominent that at week 10, control treatment had the lowest leaf area of 22 cm, followed by those grown with half dose (150ml Codas NPK 5:10:3) measured at 26 cm and full dose (300ml Codas NPK 5:10:3) at 29 cm. In week 15, control had a larger leaf area index than in week 10. The leaf area index was 27 cm while half dose (150ml Codas NPK 5:10:3) had 30 cm and full dose (300ml Codas NPK 5:10:3) was measured at 33 cm, respectively. The most significant difference was projected when comparing week 5 versus week 20. Garlic treated with full dose (300ml Codas NPK 5:10:3) had a higher leaf area estimated at 42 cm, with half dose (150ml Codas NPK 5:10:3) being the second highest performing treatment with 38 cm leaf area index. On the contrary, control had the least/ lowest leaf area estimated at 32 cm.

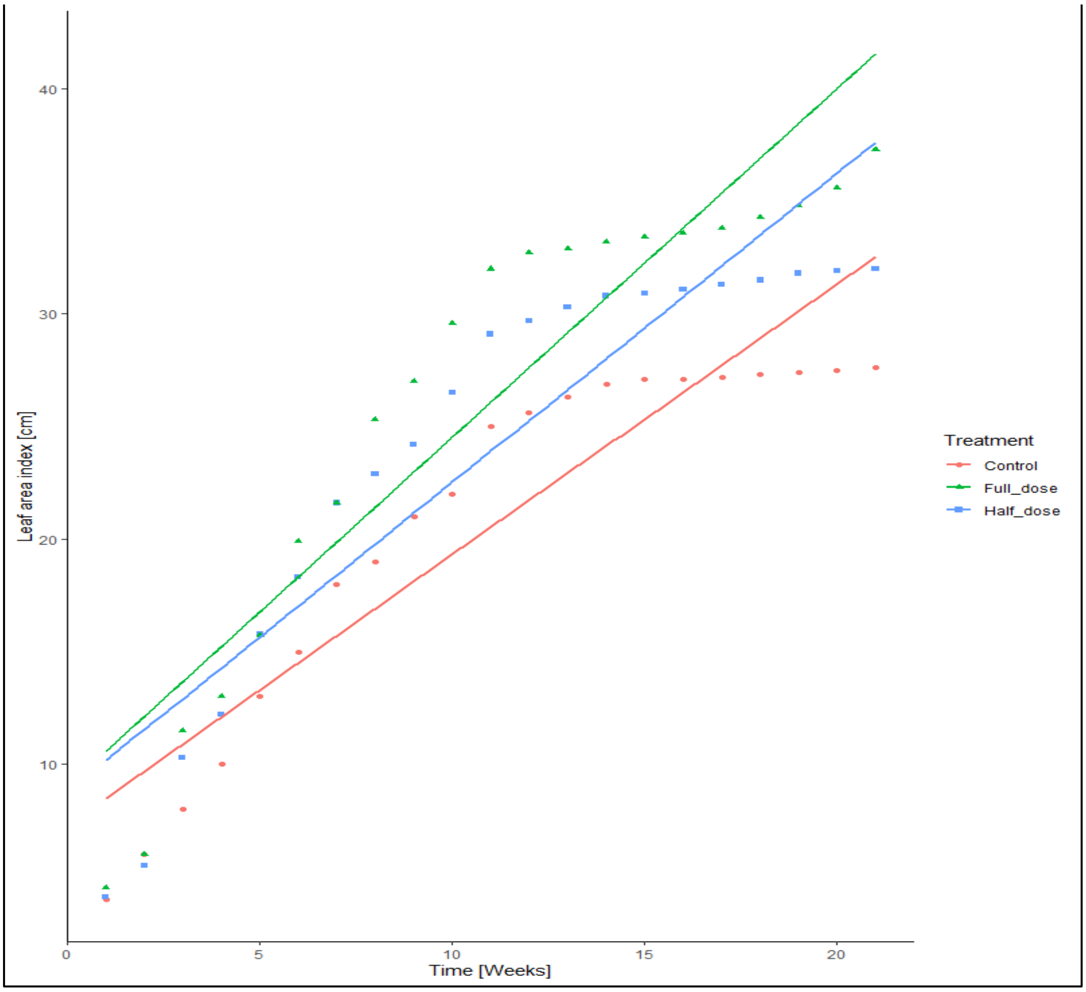

Figure 4.5: The leaf area results, showing the leaf area, as measured on weekly basis

4.4.3 Number of leaves

There were significant differences in the number of leaves on the different concentration levels of fertilizers applied during garlic production at different weeks, as indicated in figure 4.6. A significantly higher number of leaves per plant was recorded under plants where a full dose (300ml Codas NPK 5:10:3), whilst control treatment showed the least number of garlic leaves. In week 5, the results of the experiment revealed 6 numbers of leaves per garlic plant when full dose (300ml Codas NPK 5:10:3) of fertilizer was applied, however, half dose (150ml Codas NPK 5:10:3) had 2 number of leaves less than full dose (300ml Codas NPK 5:10:3) and in control, 1 leaf per plant was recorded. At week 10, it was worth noting that there was no significant difference in number of leaves per plant recorded in control and fertilizer treatment applied at half dose (150ml Codas NPK 5:10:3) and full dose (300ml Codas NPK 5:10:3) with approximately (10-11) number of leaves observed. It is evident from the study that, amongst the fertilizer treatments applied during the growth and establishment of garlic in week 15, full dose (300ml Codas NPK 5:10:3) showed the greatest number of leaves (14 leaves per plant) and same results as full dose were observed for the garlic that received no fertilizes (control). On the other hand, when half dose (150ml Codas NPK 5:10:3) fertilizers were applied to the garlic plants at week 15, at least 12 numbers of leaves were exhibited. The growth of garlic in week 20 had the greatest number of leaves when compared to the other weeks in control grown garlic plants however, least number of leaves (12) for control at week 20 were recorded with full dose (300ml Codas NPK 5:10:3) and half dose (150ml Codas NPK 5:10:3) whereby 15 and 14 number of leaves were observed, respectively.

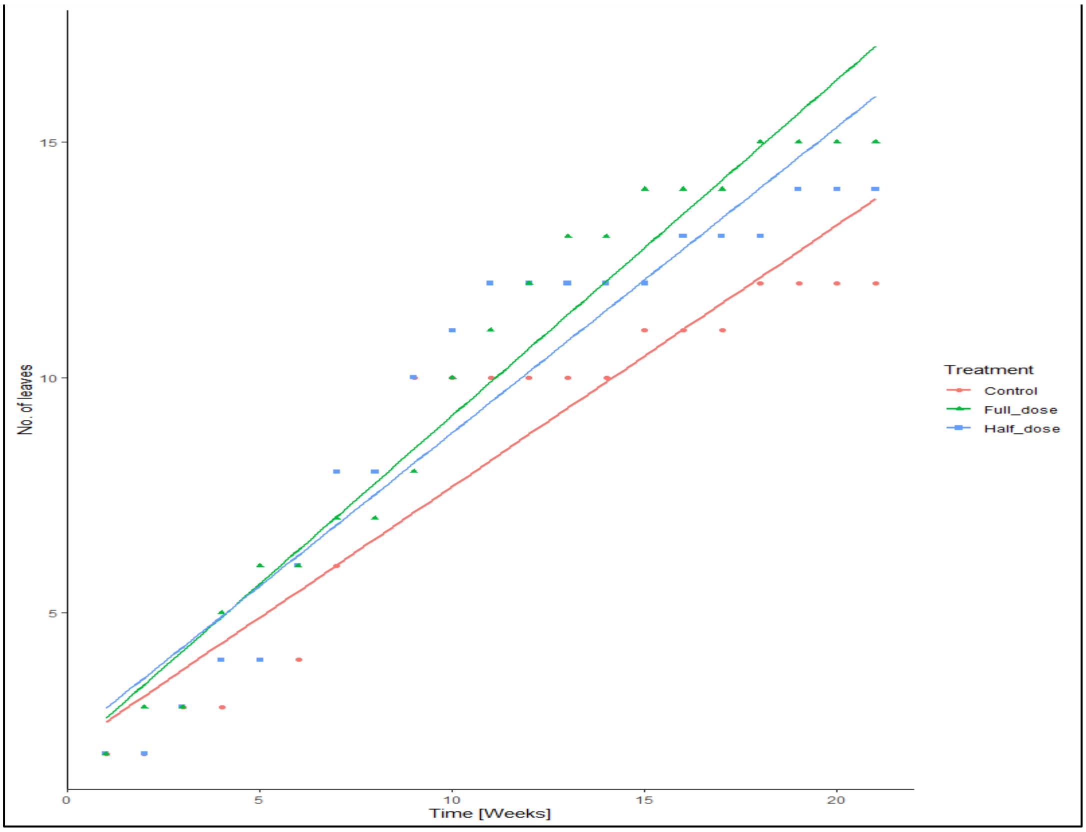

Figure 4.6: Number of leaves per week recorded

4.4.4 Bulb diameter

The findings in figure 4.7 shows the bulb diameter of garlic measured during the growth of garlic in the period of (5-20 weeks) with control and two fertilizers treatments Full (300ml Codas NPK 5:10:3) and half dose (150ml Codas NPK 5:10:3). The application of full (300ml Codas NPK 5:10:3) and half dose (150ml Codas NPK 5:10:3) fertilizers and the control (no treatments) no significant difference in the bulb diameter of the garlic. The bulb diameter of garlic was more or less the same (consistent) across all the treatments. However, with progression in time, it was noted that there was an increase in the size of bulb diameter of garlic from week 15. Moreover, whilst Full (300ml Codas NPK 5:10:3) and half dose (150ml Codas NPK 5:10:3) exhibited an increase of bulb diameter (8.4 and 7.9 cm respectively) in week 20, control showed a decrease in bulb diameter when compared to the other two treatments mentioned above.

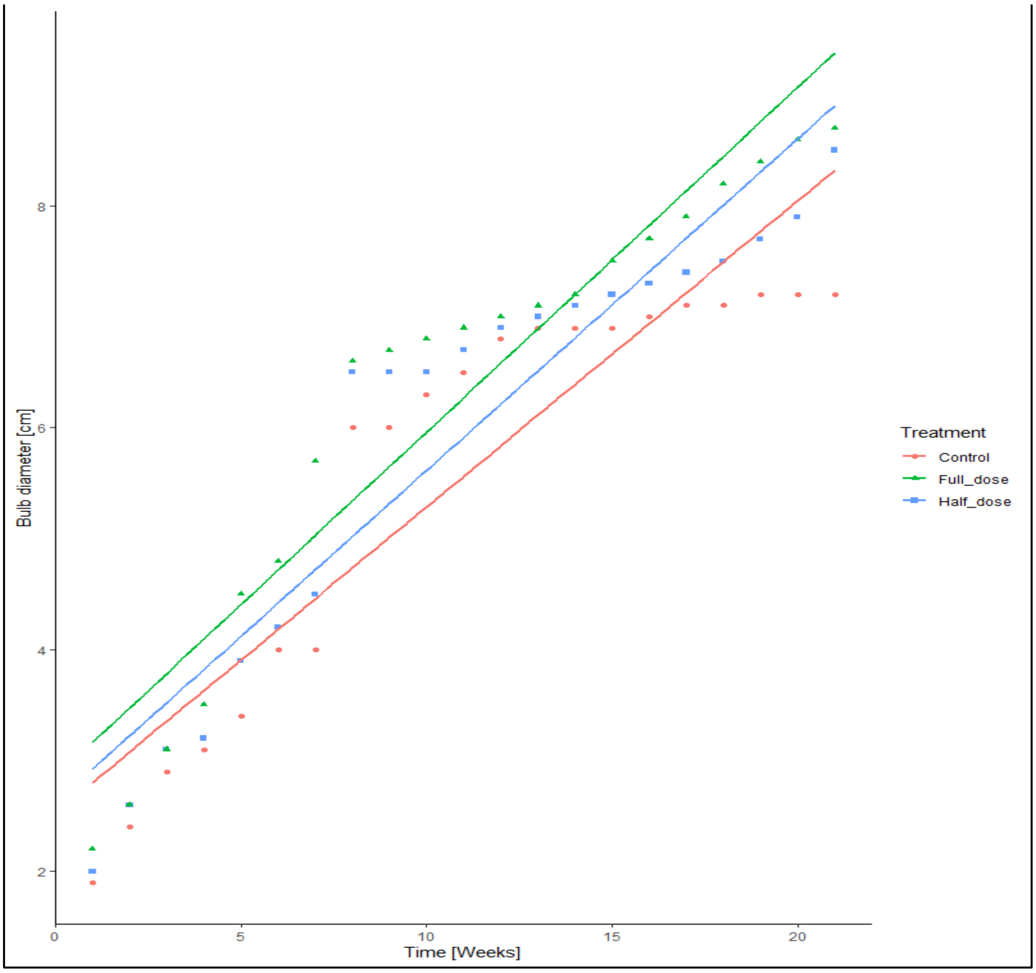

Figure 4.7: The bulb diameter measured graph, showing weeks 5, 10,15 and 20

4.4.5 Bulb neck diameter

The bulb neck diameter was measured at week 5, 10, 15 and 20. The bulb neck diameter measured revealed that control had an average of 1.6 cm diameter at week 5 while half dose (150ml Codas NPK 5:10:3) was slightly lower than control with a 1.5 cm diameter and full dose (300ml Codas NPK 5:10:3) had 1.7 cm bulb neck diameter. At week 10, half dose (150ml Codas NPK 5:10:3) treatment showed a bulb neck diameter of 1.8 cm and control indicated 1.9 cm while the measured bulb neck diameter at full dose (300ml Codas NPK 5:10:3) attained the results of 2.1 cm. The results in week 15 showed that the bulb diameter at control was 2.2 cm, with half dose (150ml Codas NPK 5:10:3) and full dose (300ml Codas NPK 5:10:3) at 2.4 cm and 2.5 cm diameter, respectively. At the end of the experiment (week 20), control showed growth and indicated a 2.9 cm measurement. Half dose (150ml Codas NPK 5:10:3) and full dose (300ml Codas NPK 5:10:3) had the same results with a 3.2 cm bulb neck diameter.

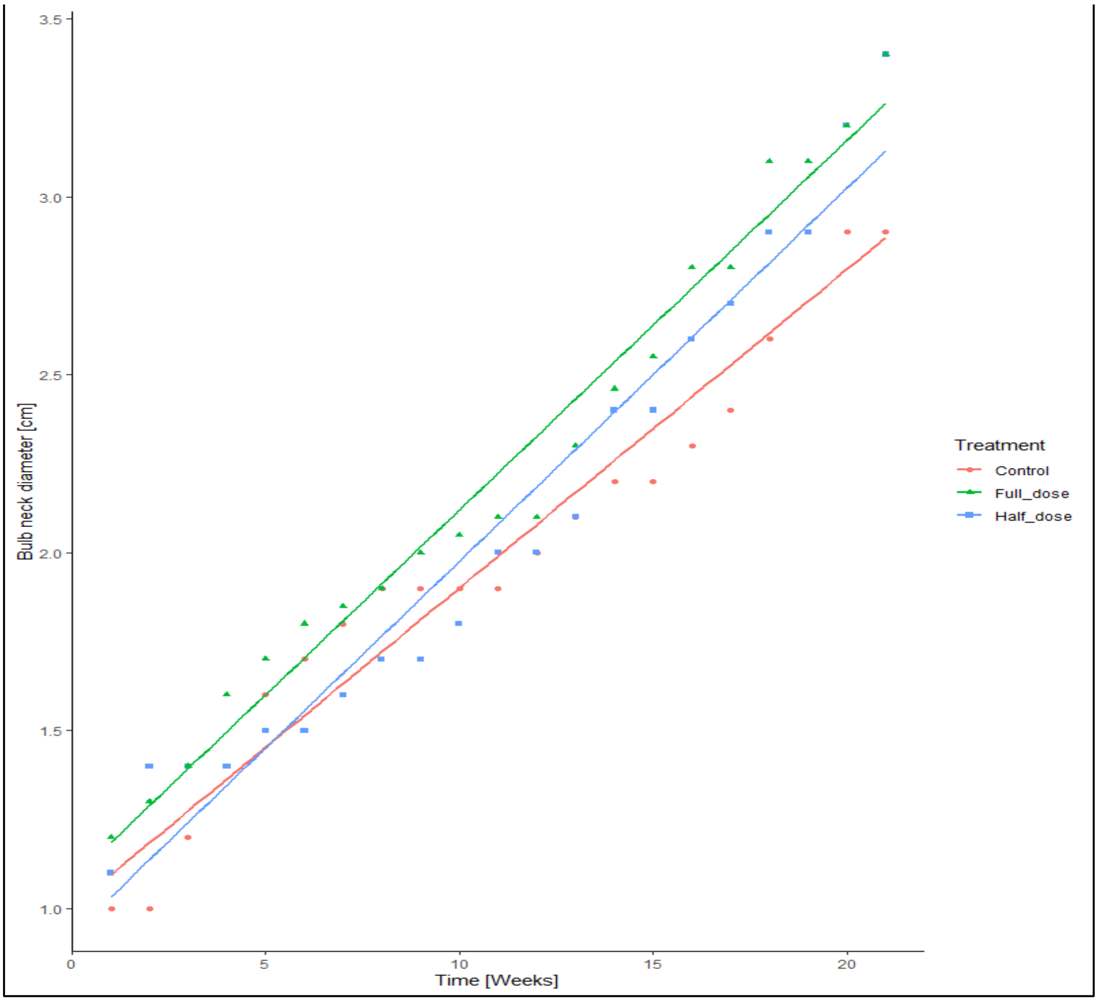

Figure 4.8: Bulb neck diameter measured for 20 weeks

4.4.6 Number of cloves per bulb per treatment

Figure 9 showed that the number of cloves per bulb increased with time in the garlic grown were Full (300ml Codas NPK 5:10:3) and half dose (150ml Codas NPK 5:10:3) fertilizer treatments was applied, whilst control revealed the least number of cloves per bulb as compared to other treatments. Although there was no significant difference noted amongst the treatments at week 5 to week 15, half dose (150ml Codas NPK 5:10:3) exhibited a higher number of approximately 11 clovers per bulb at week 20. On the contrary, control showed the least number of cloves per bulb at week 20 with 6 cloves recorded. Even though a least number of cloves were recorded in control at week 20, the number of cloves slightly increased from 3 cloves to 6 cloves per bulb. full dose (300ml Codas NPK 5:10:3) had more cloves per bulb than control. Full dose had a clove count of 10 cloves per bulb in week 20. Half dose (150ml Codas NPK

5:10:3) had an average of 1 clove per bulb more than full dose (300ml Codas NPK 5:10:3) recorded at week 20 of the experiment.

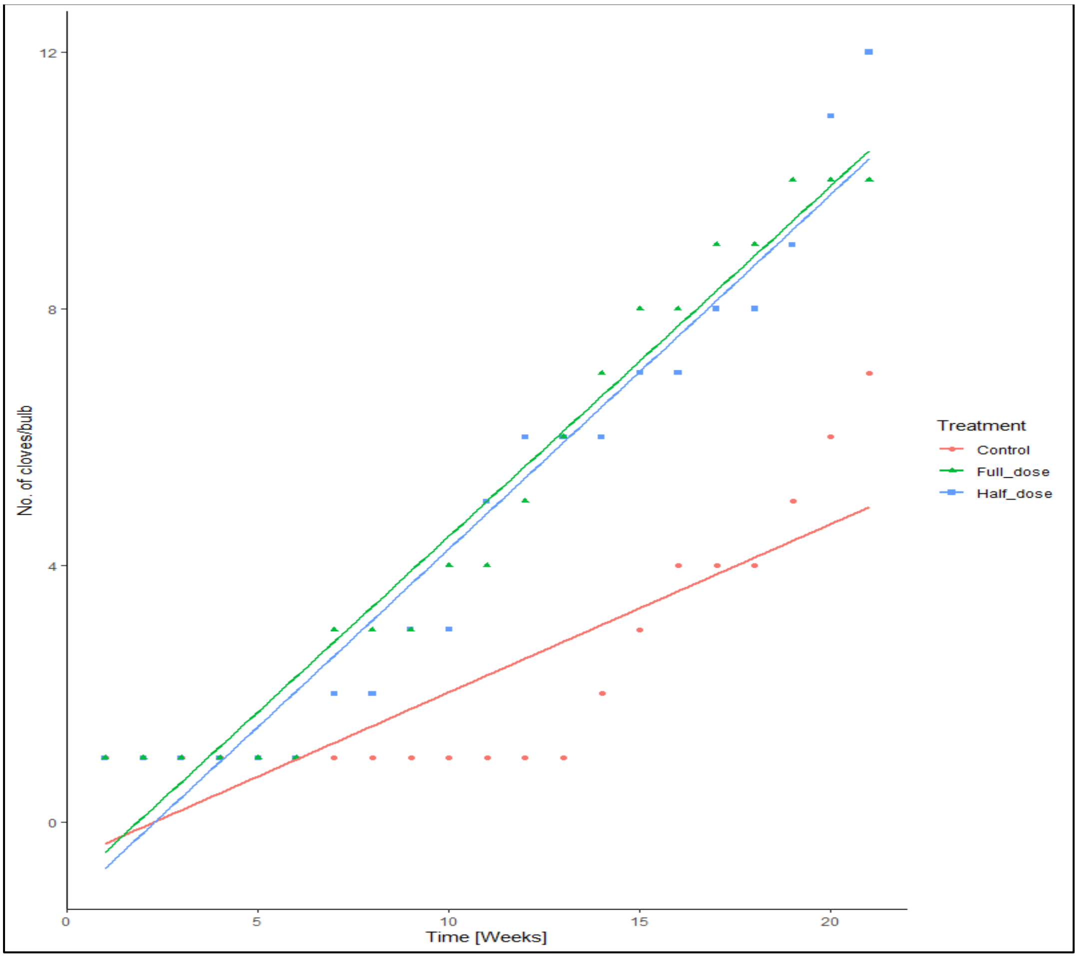

Figure 4.9: Number of cloves per bulb measured for the period of 20 weeks

CHAPTER 5

DISCUSSION

Garlic farmers in the Karoo region, Northern cape are facing a huge challenge regarding optimum yield, particularly the number of cloves produced by each bulb production. This challenge has caused most famers into growing alternative crops such as onions instead of garlic as less yield equals less profit for them. The current study focused on different dosages of NPK fertilizers in the growth and establishment of garlic for optimum growth and yield. An observation made in the current study revealed that weed infestation in garlic production is one of the major contributing factors for loss in yield and bulb diameter. Three dominant weeds were identified as Blou dissel (*Mexican poppy),* Field bindweed (*Convolvulus arvensis) and* Pechuel-Loeschea leubnitziae (Kuntze) O. Hoffm (Asteraceae) which are commonly known to attack garlic. This was in agreement with the study by Rahman *et al* (2012) who indicated that garlic is highly vulnerable to weed infestation due to its slow emergence, slow initial growth, non-branching habit, sparse foliage and shallow root system.

In the current study, frequent irrigation and high fertilizer application were observed to be two other factors that contributed to the rapid growth of weeds mentioned above, which were found to be problematic in the growth and establishment of garlic. This is because weeds are known to highly compete for nutrients, soil, moisture, space and light considerably reducing the yield, quality and value through increased production and harvesting costs Koray *et al* 2018. In addition, garlic is a closely planted crop with a very small canopy, with a smaller leaf size and cannot compete with the weeds hence the need to control weeds in the early stages after planting garlic is of paramount importance and was implemented in the current study. The herbicide, Galigan 240 EC used in the current study is a good stand-alone herbicide that controls emerging weeds within one week and it gives the crop an excellent start. After application of the above mentioned herbicide, it was observed that it is strongly absorbed in the soil, shows negligible leaching, contribute to the effective control of weeds and causes no danger and/harm to garlic plants. According to Yirefu, (2009) Galigan 240 EC controls a wide variety of grasses and broadleaf weeds.

5.1 Plant height

In the first week, control only had a growth of 2 cm growth while both half dose (150 ml NPK) and full dose (300 ml NPK) had a growth of 4 cm. The results of this study showed that garlic that was treated with different dosages of liquid NPK fertilizer had no significant effect on the plant height in the first 2 weeks after treatment. Similarly, control showed the same results as the other two NPK treatments. Applying NPK 5:10:3 at 150 ml herein referred to as Half dosage and NPK 5:10:3 at 300 ml (Full dosage) had a positive effect in plant height growth after five weeks. Notably, a significant increase in plant height showed in week 5 and continued to be steady and constant in growth until week 20 at termination. This might be attributed to steady release of nutrients throughout the growing period, from additional application of NPK in week 15 as shown in chapter 3 table1. The stimulating effect of NPK combination on plant height was also confirmed by (Jilani *et al.*, 2003), who found that NPK doses (150:100:50 kg/ha) resulted in the tallest garlic plant.

In addition, the findings in this study is in conformity with the report of Farooqui *et al*., (2009), where an experiment conducted to enhance the productivity of garlic by applying different rates of Nitrogen and Sulphur, found that application of 200 kg nitrogen per ha-1 significantly increased the plant height (cm), number of leaves per plant, neck thickness (cm), bulb diameter(cm), number of cloves per bulb, fresh weight of 20 cloves (g), dry weight of 20 cloves (g), fresh and dry weight of bulb (g) and bulb yield per hectare.

Among the growth parameters, plant height (38 cm) was significantly higher under full dose (300 ml NPK), applied with 100 L of water in week 20. Control showed a plant height of 22 cm while half dose (150 ml NPK) showed a 27 cm in plant height in week 20. The findings of the current study are also in agreement with Jawadagi *et al*., (2012), where it was revealed that the growth parameters in onions, plant height (60.70 cm) and leaf length (22.43 cm) were significantly higher under T6, where 100% NPK + FYM at 20 t ha-1 + PSB + Trichoderma were used. According to Jawadagi *et al*., (2012), higher number of leaves (9.2) and average root length (7.84 cm) were reported by the treatment T6, which in turn is in agreement with the report of Gaiki *et al.* (2006), that Azotobacter + PSB + 75% NPK significantly increased the plant height and leaf number in garlic. From the above findings, it is concluded that combined application of Trichoderma and PSB is much more effective in comparison to independent application of either of the above. These findings are also supported by Gowda *et al*., (2007), who reported that 100% NPK + biofertilizer + vermicompost recorded significantly higher plant height. It is therefore concluded that application of NPK in higher dosage positively increases the plant height.

Furthermore, the findings of the current study indicated that the control treatment was significantly poor with respect to growth and yield characters as shown in chapter 4, in figure 4.4. In several studies conducted (El-Morsy e*t al*., 2004), it was discovered that the effect of NPK fertilization on enhancing plant growth may be due to the positive effects of these elements on activation of photosynthesis and metabolic processes of organic compounds in plants, which leads to the encouragement of vegetative growth by the plant. Furthermore, a positive reaction was reached when NPK fertilizers and two biofertilizers in combination with (P, K, Ca, Mg, Cu, Fe, Mn and Zn) minerals were applied to established plant roots (Bardisi *et al*., 2004).

5.2 Leaf area

The application of NPK at the rate of half dose (150 ml NPK) and full dose (300 ml NPK) both significantly increased the leaf area at week 15 as shown in chapter 4 figure 4.5. A 31 cm on half dose (150 ml NPK) and a 35 cm on full dose (300 ml NPK) was measured on leaf area index at the end of the growth period, contrary to control, which had only a leaf area of 25 cm at termination. The results concur with those of Kakara *et al*., (2002) who reported that maximum leaf area produced by the maximum dose of NPK fertilizer might be attributed to the plants receiving more nutrients which resulted in higher photosynthesis and in turn produced wider leaves and vice versa. In addition, other findings reported that, high rate of NPK application led to increase in photosynthesis, which was further utilized in building up new cells within the plant and these physiological processes might have led to a plant of better vigor, a greater number of leaves per plant ultimately leaf area index (Kale, 2010). Stork *et al*., (2004), also reported that nitrogen fertilizer is necessary for ensuring successful vegetative growth of garlic. High yield and good quality garlic plants can be improved through Nitrogen application strategies as influenced by the source of Nitrogen and Sulphur, as well as rates and times (Luo *et al*., 2000). As a result, increased leaf area index might be due to increased uptake of Nitrogen and Sulphur elements, which are constituents of protein; component of protoplasm and cell wall of the cell might have imparted a favourable effect on the chlorophyll content of the leaves of the garlic plant.

Availability and balancing of nutrients such as nitrogen and micronutrients impose a direct effect on the structure of chlorophyll and protein synthesis within the garlic plant that could have led to the development of vegetative growth and leaf area in the garlic plant which is related to plant metabolism. It is therefore important to supply the needs of a plant with correct dosages of elements such as Nitrogen and photosynthetic production that cause vegetative growth increment, such as leaf number and leaf area (Zariri *et al.*, 2014).

5.3 Number of leaves

There were more leaves on the garlic plants that were supplied with NPK half dose (150 ml) and/or the full dose (300 ml). The results of the current study showed that garlic plants grown under control had only 10 leaves while those that received more NPK had 14 leaves per plant. By adding (300 ml NPK) the number of leaves were very close to each other in growth and at the end of the growing season it was found that the NPK with macro and micro elements (Dalgin Active, Codaphos K, Codafol K35 Acid, Fruitmax, Codasting and Codamin B) had a greater number of leaves that better developed with more fertilizer than with less fertilizer applied. Moreover, a higher number of leaves was recorded when half dose (150 ml NPK) or full dose (300 ml NPK) fertilizer was applied in comparison to the control treatment which had the least number of leaves (12). As a result, this is in agreement with the findings by (Gaiki *et al*., 2006) were Azotobacter + PSB + 75% NPK applied during garlic production significantly increased the number of leaves. These results clearly demonstrate that 100% and or more NPK application rate can improve vegetative growth of garlic. The stimulating effect of NPK fertilizer in garlic plants has a positive effect on the leaf numbers and will increase leaf area. This was also confirmed by (Jilani *et al*., 2003), who reported that NPK concentrations of (150:100:50 kg/ha) resulted in a maximum number of leaves per plant and higher plant height in onions when compared to the control treatment. In the findings of this study as shown in chapter 4, the highest leaf number was recorded in garlic applied with full dose (300 ml NPK) fertilizer treatment. As a result, the number of leaves per plant significantly increased as the growth time proceeds in response to the cumulative effect of the applied fertilizers, which could be attributed to the cumulative role of the nutrients compound available in the fertilizers, which influences the plant development and growth. Similarly, Nori *et al*., (2012), reported that as the experiment progressed, there was an increase in the number of leaves and their growths. Nirmalatha, (2009) also reported that the availability of nutrients from most of the bulky organic manures, and the release of nutrients from vermicompost could be the reason for higher leaf number.

5.4 Bulk neck diameter

The results in chapter 4 of this study revealed that adding NPK to the garlic in half dose (150 ml NPK) and in full dose (300 ml NPK) concentration increased the bulb neck diameter within the first 5 weeks of production. On the contrary, when compared to the control treatment, the bulb neck diameter did not grow as fast as the other two treatments that had received fertilizer. In addition, when NPK fertilizer application was doubled in full dose (300 ml NPK), the bulb neck diameter measured was significantly the widest in comparison to the half dose (150 ml NPK) concentration as shown in chapter 4, (figure 8). Moreover, during the last couple of weeks before termination (week 15 to week 20), there was a rapid increase in the bulb neck diameter of garlic on half dose (150 ml NPK) and full dose (300 ml NPK) NPK. Findings by Diriba-Shiferaw *et al*., (2013) revealed that the growth of the bulb neck diameter significantly increased at 90 and 120 days after planting. This indicates that lower fertilizer application has no influence on the horizontal growth of garlic bulb necks at the initial development stages, however, as growth proceeds with time and higher fertilizer concentration applied and or added, significantly increased the growth parameters of garlic. The widest bulb neck diameter (3.4 cm) observed when full dose (300 ml NPK) fertilizer was applied at week 15 to week 20 might be due to the allocation of assimilates from plants to the dry matter storage organs of bulbs as a results of water stress which in turn increased the growth of bulb neck. This can be traced in chapter 4 figure 8 when the bulb neck diameter was developing very slowly in control (2.1 cm) when compared to half dose (150 ml NPK) with (2.4 cm) and full dose (300 ml NPK) at (2.5 cm) fertilizer concentration. Moreover, optimum nutrient supplied from the full dose (300 ml NPK) treatment possibly favoured plant growth and development, thus producing wider bulb neck diameter (3.4 cm). In agreement with the above-mentioned results of the current study, Arian *et al*., (2004) reported that combined application of NPK resulted in a higher bulb yield than control treatment and this is mainly related to the increase in bulb size and weight which as a result of the nutrients applied. This concur with the findings of Islam *et al*., (2007) that concluded that increasing the application rate of NPK fertilizers caused an increase in the growth parameters of onion plants. Mudziwa, (2010), findings also stated that garlic plants height and neck diameter significantly increased with time of growth up to 175 days with different levels of Ammonium sulphate and Calcium nitrate and maximum at 200 kg ha-1. According to Kale, (2010), the tallest onion plant height, large neck diameter and highest number of leaves per plant was due to the application of ammonium sulphate and sulphate of potash (K). This concurs with the statement above were variations in the neck thickness of onion bulbs was observed with different treatments. The study showed a higher neck width for bulbs from the amended plots compared to the control plot in both experiments. These findings are in agreement with the results of Singh and Ram, (2014), that the neck thickness of onion bulbs coming from poultry manure amended soil was significantly higher than those from the control plot. The results from their study indicated a higher harvest index in the poultry manure and a combination of poultry manure and NPK amendments, when compared to the control. Similarly, Yohannes *et al*., (2013), reported that the harvest index of onion was increased over the control with combined application of N and farm yard manure (FYM).

5.5 Bulb diameter

Different NPK application levels showed that at the beginning of development stages, 50% of the bulb diameter and growth of garlic was statistically similar and growing at the same rate in both, half dose (150 ml NPK), full dose (300 ml NPK) and control treatment. These results were consistent with the findings of (Soundy *et al*., 2001) where it was reported that Nitrogen deficiency during development of garlic and other crops reduces the growth. This agrees with the slow growth findings observed in the current study in the control treatment as there was no fertilizers applied. However, Wang *et al*., (2000) demonstrated that increasing nitrogen concentrations resulted in increased shoot growth of garlic. According to the results shown in chapter 4, figure

4.7, there was no significant difference in bulb diameter growth when NPK was applied at half (150 ml NPK) dose or full dose (300 ml NPK). However, in week 15, a change was observed where full dose (300 ml NPK) and half dose (150 ml NPK) showed better results than control treatment. Control had a bulb diameter of 7 cm, half dose (150 ml NPK) had 8.5 cm and full dose (300 ml NPK) had a 9 cm bulb diameter. This might be attributed to the availability of K+ to plants which is usually limited in soil, which may lead to severely restricted plant growth and yield, although K+ is considered to be one of the most abundant soil elements in the fertilizer (Hafsi *et al,*. 2014).

(Abdissa *et al*., 2011), observed that regardless of the rate, N fertilization increased bulb diameter by about 12% as compared to control treatment which may be linked to the increase in dry matter production and allocation to the bulbs. However, the findings of (Nori *et al*., 2012), revealed that there was an increase in the size of bulb diameter with increased fertilizer doses up to 200 kg N/ha and this in turn decreased with further increase in the amount of fertilizer applied. The same trend was also noted in the current study as the bulb diameter of the garlic increases and slows down with increase in amount of fertilizer applied and time. Similarly, El-Hadidi *et al*., (2016), stated that increasing phosphorus and nitrogen fertilizer levels increased onion bulb yield and its quality. This is probably due to phosphorus having a function in building energy for metabolism of plant growth through cellular productions such as adenosine triphosphate from the early stages to the end of plant life. Moreover, nitrogen is known to play a very essential role in formation of proteins, chlorophyll and protoplasm, this consequently could increase cell size, leaf area, photosynthetic processes which improved the assimilation and accumulation of food in bulbs for the growth period (Khan *et al*., 2002).

Moreover, Khan *et al.*, (2002), further reported that application of nitrogen fertilization significantly increased bulb diameter without affecting bulb length whilst application of Phosphorus fertilization and its interaction with N did not significantly influence either bulb diameter or length. Regardless of the rate, Nitrogen fertilization increased bulb diameter by about 12% in reference to the control (6.44 cm), which may be linked to the increase in dry matter production and allocation to the bulb. This was in agreement with (Nasreen *et al*., 2007), who reported a significant increase in the diameter of bulbs due to the application of N up to 120 kg ha^{-1}. Similar results were also reported by (Yadav *et al*., 2003) who found that N at 150 kg ha^{-1}, enhanced the formation of bulbs with larger diameters. Radimax, which is a highly effective root development product, was dripped through drip lines with a dosage of 2 L into 500 L of water. As a result of its composition, Radimax contains amino acids, vitamins, natural auxins, betaines, high percentage of organic matter and macro and micro elements which are needed to make the roots have more longevity and resistance to some of pathogens attacks.

5.6 Number of cloves per bulb

According to (Fanaei *et al*., 2014), the number of cloves per bulb may be an important trait in increasing bulb yield and should be considered in breeding of local garlic varieties. Half dose (150 ml NPK) resulted in one more clove per bulb than full dose (300 ml NPK) measured at week 10. Full dose (300 ml NPK) had received two times more fertilizer than half dose (150 ml NPK). A minimum number of five cloves per bulb at week 20 was recorded in control treatments as the growth was noted in the last five weeks before harvest. Application of phosphorus with nitrogen in crops like garlic enhances root initiation and development that improves better utilization of moisture and food material. However, since there was no fertilizer application in the control treatments, the lowest number of cloves were recorded per bulb. Research conducted by Desta *et al.*, (2021), also indicated that planting of large-sized cloves increases the number of cloves per bulb as higher amount of reserve nutrients in large sized cloves could promote vigorous vegetative growth and increased production of assimilates and translocation of these food materials during the bulb formation and development resulted in more cloves per bulb. In the current study, an increased number of cloves due to sufficient nutrients was achieved, possibly due to better growth conditions received by the plants during development stages.

The related findings were also reported by (Kore *et al*., 2006) and (Bhandari *et al*., 2012) their findings are in agreement of this study. They reported that a significant effect on the number of cloves per bulb in their study was achieved through applying NPK. Maximum number of cloves per bulb (26.09) were reported in treatment 100 % RDF + 6 Azotobacter + PSB followed by treatment 80 % RDF + 7 Azotobacter + PSB, treatment 100% RDF, treatment 80% RDF 2 3 and treatment 60 % RDF +

Azotobacter + PSB whereas under control untreated, minimum number of cloves per bulb (18.45) were observed.

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CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Garlic can grow in any soil in South Africa, although there are a lots of different cultivars of garlic, the current study focused on the Egyptian white cultivar. The current study was to determine the growth and development of Garlic (Allium Sativum) grown in the drought prone area of Vosburg, Northern Cape Province, South Africa, with the use of a correct fertilizer plan. The climate is warm and a lot of sunshine in the summer with little or less rain in the winter and very low temperatures during the months of May, June, July and August. Very low temperatures help with the bulb forming and keep weeds from not taking over as garlic is sensitive to weeds. From the results of the current study, it was concluded that garlic (Egyptian white) depends on Nitrogen, Phosphorus and Potassium for optimal growth. The results also suggests that adequate application of NPK fertilizer at a rate of 300 ml NPK (full dose) per 100 litre of water every month improves plant growth parameters significantly, leading to a positive effect on plant height, bulb diameter, bulb neck diameter, leaf area index, number of leaves per plant and number of cloves per bulb that affects yields positively.

In addition, NPK liquid fertilizers applied at a rate of 150 ml NPK (half dose) per 100 litre of water was found to be the second best and had a significant effect on the yield as well as the growth. On the contrary, control had a slower growth rate and all parameters performed at the lowest.

Based on the findings of this study, the recommended fertilizers for optimum, plant height, bulb diameter, bulb neck diameter, number of leaves per plant, number of cloves per bulb and leaf area index is applied at a rate of 300 ml NPK liquid fertilizer on 100 litre water every 30 days. It can be concluded that the growth and development of Egyptian garlic were significantly affected positively by the fertilizers applied as well as fertilizer rates thereof.

A further recommendation is that more commercial garlic farmers should start using liquid NPK fertilizer to obtain and/or secure a better yield and harvest with bigger bulb diameters, which leads to highest number of cloves per bulb and increase profits.

Currently, most garlic farmers are not aware of the existence of liquid NPK fertilizer and have always used granule fertilizers. Although, the biggest negative challenge with liquid fertilizers is that it is very expensive and, in some cases, not available in certain areas, it has proven to be very effective in the contribution of bulb neck diameter as well as the number of cloves per bulb of garlic grown.

FUTURE RESEARCH

Future work will involve advanced research in using different application rates of liquid NPK fertilizers combined with supplements as ways and means of ensuring bigger bulbs on other related crops such as onions, leeks, chives and elephant garlic in order to achieve and influence yield and profit.