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GROWTH AND YIELD RESPONSE OF ONION (*Allium cepa* L.) TO DIFFERENT RATES OF SOIL AMENDMENTS AND PLANT SPACING.

JOSHUA DEMAL

8181970002

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DECLARATION

STUDENT'S DECLARATION

I, **JOSHUA DEMAL**, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

JOSHUA DEMAL …………….... …………………...

(STUDENT) **SIGNATURE** **DATE**

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis/dissertation/project as laid down by the University of Education, Winneba.

Certified by:

MR. ISAAC TETE-MENSAH ….…….……….. …………..……..

(PRINCIPAL SUPERVISOR) **SIGNATURE** **DATE**

DR. STEPHEN LARBI-KORANTENG ……… …………. ………………….

(CO-SUPERVISOR) **SIGNATURE** **DATE**

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DEDICATION

To my beloved wife, Afia Comfort, my children (D. U. Josephine and D. U. Uriah) and all my brothers, I dedicate this work.

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ABBREVIATIONS

CSA = Central Statistical Agency

SRID = Statistics Research and Information Directorate

MoFA = Ministry of Food and Agriculture

FAO = Food and Agriculture Organization

NOA = National Onion Association

FDA = Food and Drug Authority

FYM = Farm Yard Manure

MBW = Mean Bulb Weight

NL = Number of Leaves

LL = Leaf Length

ABSTRACT

Two field experiments were conducted at the multipurpose research station of the College of Agriculture Education, University of Education Winneba-Mampong Campus, in the Ashanti Region of Ghana from October to December, 2019 and March to May, 2020, to determine the effects of different rates of soil amendments and plant spacing on growth and yield of onion. The experimental design used was a 5 x 3 factorial arranged in a randomized complete block design (RCBD) with three replications. The treatments consisted of five levels of soil amendments and three plant spacings. The five levels of soil amendments were; Control, 10 t/ha chicken manure, 15 t/ha chicken manure, 20 t/ha chicken manure and 300 kg/ha NPK (15-15-15). The three (3) plant spacings were; 10 cm × 10 cm, 15 cm × 10 cm and 15 cm × 15 cm. Data were collected on vegetative growth characteristics, yield and yield components. Significantly taller plant height was obtained at the plant spacing of 15 cm × 15 cm and 20 t/ha CM of soil amendment rate. The highest mean bulb weight and bulb diameter were produced at treatment combinations of the 15 cm × 15 cm and 20 t/ha CM of soil amendment. The highest marketable bulb yield and total bulb yield were produced at treatment combinations of 10 cm × 10 cm plant spacing with soil amendment rate of 15 t/ha CM. Significantly, the highest value of unmarketable bulb yield was produced at no soil amendment rate (control) and 10 cm × 10 cm of plant spacing. The partial budget analysis indicated the highest net benefit: cost ratio were obtained from the application of 15 t/ha CM and 10 cm × 10 cm plant spacing. The 15 t/ha CM and 10 cm × 10 cm plant spacing could be recommended for possible adoption.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Onions are one of the main vegetable crops in the world. They have high mineral and organic contents essential for human health (Yadav *et al*., 2003) and a commonly used ingredient in most recipes.

Sliced raw onions have antibiotic properties, which can reduce contamination by bacteria, protozoa or helminths in salads (Grubben and Denton, 2004). Onion is also used for medication (Cheema *et al*., 2003). The food habits of Ghanaians are such that a bulb of onion is used in almost every food preparation. Onion plays an economically important role in Ghana as many farmers cultivate it as a source of income. The country has enormous potential to produce the crop throughout the year for both domestic use and the export market. Onion production also contributes to commercialization of the rural economy and creates many off-farm jobs (Lemma and Shimeles, 2003; Nikus and Mulugeta, 2010).

Onion production in the country is increasing from time to time. During the 2013/2014 cropping season, the total area of onion cultivated was estimated to be 24, 375.7 ha with an average yield of about 9.02 tons per hectare and an estimated total production of greater than 2.19 metric tons (CSA, 2014). Soil nutrients play a significant role in improving productivity and quality of onion crops. Onions are the most susceptible crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence they require and often respond well to addition of fertilizers (Rizk *et al.,* 2012). Therefore, optimum fertilizer application and cultivation of suitable varieties with appropriate agronomic practices in specific environment are necessary for obtaining good yield of onion.

Nitrogen plays an important role for optimum yield of onion and is found to be essential to increase the bulb size and yield. Increasing nitrogen application rates significantly enhances plant height, number of green leaves per plant and weight of bulb, marketable yield and also total soluble solids (Nasreen *et al.*, 2007; Al-Fraihat, 2009). In addition to nitrogen, plant spacing is an important factor determining onion yield and quality.

Spacing is an important factor for the production of onion since it affects both bulb yield and bulb quality of onions. Planting density greatly influences quality, texture, taste and yield of onion even within a particular variety (Saud *et al*., 2013). Yield responses to plant population need to be known for practical purposes, as planting density is a major management variable used in matching crop requirements to the resources by the environment.

The enhancement of onion production and productivity can be related to different growth factors. Onion dry bulb production depends on nutrient requirements, location of production, variety, soil type, agronomic practices etc. Thus, it is against this background this study seeks to bring to the fore the growth and yield response of onion (*Allium cepa* L.) to different rates of soil amendments and spacing.

The study seeks to make suggestions that would yield fruitful results with respect to onion contribution to the socio-political and economic advancement of farmers, their communities and mother Ghana. The use of appropriate agronomic management has an undoubted contribution to increased crop yields. One of the major problems to onion production is improper agronomic practice used by farmers. The optimum level of any agronomic practice such as plant population, planting date, harvesting date, and fertilizer of the crop varies with environment, purpose of the crop and cultivar. Therefore, to optimize onion productivity in the study area, a specific package of recommendation of nitrogen fertilizer and plant spacing is required (Lemma and Shimeles, 2003).

1.2 Problem Statement and Justification

According to Bationo *et al*, (2012), 57.1 percent of the total land area of the country is suitable for agriculture. Thus 13,628,179 ha of arable lands in Ghana support the cultivation of various food and cash crops. Average crop yields have been found to be 20-60 percent below achievable yields. Most soils of the country are inherently low in fertility coupled with the failure to replace depleted nutrients after crop harvest. The issue of nutrient depletion is widespread across all agroecological zones of Ghana and nitrogen and phosphorus have been identified as the most deficient nutrients amongst all other crop nutrients (Bationo *et al*, 2012).

In Ghana, the average yields per unit area is 7.7 tons per ha (FAO, 2013) this is low compared to that of other onion producing countries in Africa (FAO, 2000). There are many production constraints responsible for low yield per unit area in Ghana.

The use of fertilizer in sub-Saharan Africa (SSA) in general has been found to be low compared to other regions of the world (Bationo *et al.,* 2012). Considering the fact that SSA has the fastest growing world population (Bationo *et al.,* 2012), improving soil fertility to increase yield and crop productivity would serve more good. Tetteh *et al*. (2017) reiterated that the use of fertilizer in Ghana is low. Soil fertility is a crucial factor that interplays in the growth and yield of both food and cash crops. Organic fertilizer such as chicken manure improves soil structure which increases water holding capacity and enhance nutrient exchange for plant growth. Inorganic fertilizer such as NPK (15:15:15) are known to supply nutrients that are readily available for plant use. They supply nutrients which enhances vegetative growth and fruit formation.

Onion growers in Ghana produce onions with the application of blanket recommendation of inorganic and organic fertilizers rates and spacing which they feel as best for obtaining higher yields. There is however very little information available in the literature to suggest the reasons for this state of affairs.

1.3 Objectives of the Study

The specific objectives were to:

- determine the appropriate soil amendment rate and plant spacing for the growth of onion
- determine the effects of soil amendment rates and plant spacing on the yield and yield components of onion
- determine the economic benefits of applying various soil amendment rates and plant spacing on onion production

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description of Onion Crop

Onion (*Allium cepa* L.) belongs to the family Alliaceae which is one of the most important monocotyledonous crops. Onion belongs to the genus Allium (Rabinowitch and Currah, 2002). Onion, (*Allium cepa* L), is a herbaceous biennial plant. Onion is indigenous to Central Asia but is actually grown across the world (Kuete, 2017).

Biennial plants produce roots, stems, and leaves during the first season of production. During the second season, plant produce flowers, fruits, and seeds, and then complete their life cycle. Onion is ranked the world's 4th most enjoyed vegetables apart from tomato, cabbage and watermelon, the production is 25 million tonnes per year (Boukary *et al.*, 2012). According to National Onion Association (NOA) records of 2011, onions are worldwide vegetables among others. Globally, dry onion bulbs around 54 million tonnes are grown per year.

The crop has been grown in over 134 different countries across the world. This represents a doubling in world production over the last ten years (GhanaVeg, 2018). Onion is a cross-pollinated cool season vegetable crop. Onion is an indispensable and important vegetable item which is used in every kitchen therefore its constant demand always remains throughout the year. Besides its high food value, it is also a good source of income for vegetable growers. It can be eaten as green leaves, bulbs that are mature and immature which can be eaten as fresh and also can be used in preparation of different dishes. Onion bulb is very pungent and this is due to the presence of a volatile oil that is allylpropyl disulfide (GhanaVeg, 2018). The onion has its own distinctive flavor and used in soups, dishes, salad and sandwiches and is cooked alone as a vegetable. It is consumed at its young green stage or after its full development and maturity when it is harvested in the form of a dry bulb. The mature bulbs contain some starch, appreciable quantities of sugar, some protein, and vitamins A, B and C (Jilani *et al.*, 2010).

Onion is a shallow rooted, biennial crop which is grown as annual. The leaves are long, hollow with widening, overlapping bases. The tubular leaf blades are flattened on the upper surface, and the stem of the plant also is flattened. Roots arise from the bottom of the growing bulb (Jilani *et al.*, 2010). Leaf initiation stops when the plant begins to bulb.

The base of each leaf becomes one of the “scales” of the onion bulb, so the final bulb size depends in part on the number of leaves present at bulb initiation. The leaf base begins to function as a storage organ at bulb initiation, so the size of the leafy part of the plant also influences bulb size. Thus, the more leaves present and the larger the size of the plant at the onset of bulb initiation, the larger will be the bulbs and the greater will be the crop yield (Jilani *et al.*, 2010). The onion develops distinct bulbs depending on the varieties. These bulbs are varying in size (small, medium and large). Bulb weight may be one kg in some Southern European cultivars, and the shape covers a wide range from globose and to flattened disk-form. The colour of the membranous skins may be white, silvery, buff, yellowish, bronze, rose red, purple or violet. The color of the fleshy scales can vary from white to bluish-red. There is also much variation in flavor and keeping or storage ability of the bulbs (Rabinowitch and Currah, 2002).

2.2. Importance of Onion

Onions serve as source of income, improved food security, sources of raw materials for industries and employment opportunity. Onions have been found to be useful in the relaxation of spasms, reduction of sugar and blood pressure levels, and are effective in the treatment of boils, acne, wounds and scars (Ageless, 2015). It was reported by Nuutila *et al.*, (2003), that onions are a source of antioxidant compounds such as polyphenols and compounds containing Sulphur.

Onion is important in the daily Ghanaian diet and almost all the plant parts are edible, although the bulbs are widely used as a seasoning or as a vegetable in various dishes. Onion is valued for its distinct pungency and form essential ingredients for flavouring varieties of dishes and snacks. It is popular over the shallot because of its high yield potential per unit area, availability of desirable cultivars for various uses and ease of propagation by seed (Lemma, 2004). Onion is grown not only because of the bulbs, but also because of its green leaves. Green leaves can be harvested and commercialized. They are usually used in salads. The bulbs are often eaten raw or cooked (Craig, 2010).

Onions are healthy vegetable. Onion bulbs are a source of fiber, folic acid and vitamin C and B helping the production of strong and new cells (Jarzabkowski, 2017). A medium size of onion bulb contains about 45 calories. In addition, onions provide flavour to various foods. Onions bulbs contain no sodium, fat, and cholesterol (Jarzabkowski, 2017; FDA, 2018). They are rich in sulphuric compounds, flavonoids and phytochemicals (Craig, 2010; Jessie, 2017). Onions are highly rich in antioxidants. This makes onion bulbs sweet and aromatic (Jessie, 2017).

Also eating onion can cause problems for some individual, but not seriously. National Digestive Diseases Information Clearing house reports that consuming onions can cause bloating of an individual, as well as accumulation of gases in the stomach of the individual because of the carbohydrate content it contains. The consumption of raw onions can also cause heartburn in people who chronically suffer from gastric reflux disease (Jessie, 2017). High consumption of green onions is likely to interfere with drugs that cause blood thinning. The high content of K in onions inhibits the function of a blood thinner. A study conducted in 2015 showed that yellow onions that were not refrigerated facilitated the growth of *E.coli* and salmonella and those that were refrigerated showed no such growth (Jessie, 2017).

2.3 Climatic and Soil Requirement of Onion.

2.3.1 Temperature and rainfall

Onion can be grown in a wide range of climatic environments, but it thrives best at mild climate without excessive rainfall or extremes of heat and cold. Onion is a cool season crop that has some frost tolerance but is best adapted to a temperature range between 18^0C and 27^0C (Raemaekers, 2001). Optimum temperatures for early seedling growth are between 23^0C and 27^0C; growth is slowed at temperatures above 30^0C. Acclimatized plants are able to tolerate some freezing temperature. Best production is obtained when cool temperature prevails over an extended period of time, permitting considerable foliage and root development before bulb formation starts. After bulb formation begins, high temperature and low relative humidity extending into the harvest and curing period are desirable (Jilani *et al.,* 2010).

2.3.2 Soil

Onions can be grown on a wide range of soils, varying in texture from coarse-grained sands to clays. Lighter soils are easy to manage. Soils should be 45-60 cm deep and well drained. Soils with high water holding capacity are better able to provide moisture to the shallow rooting system but must also drain well to be suitable. Growth is retarded when available soil moisture is low, but onions are also sensitive to a high water table or water logging. Uniform moisture availability about 400-800 mm per crop is conducive to large bulb size and high yields. The optimum soil pH is about 6.5–8.0 in mineral soils (Savva and Frenken, 2002).

2.3.3 Day length

The bulbs that acquire day length of 11.5 hours are categorized into short-day group and those take 14 hours or more for bulb formation fell into long-day group. Onion also requires varying day length and temperature for the purpose they produced. A relatively high temperature and long photoperiod are required for bulb formation, and for seed production, temperature is of immense importance than day length. Onion bulbs have specific temperature requirement for seed and bulb production (Okporie & Ekpe, 2008). According to GhanaVeg (2018), 12 to 15 hours' day length is needed for the formation of onion bulb, they also require high temperatures. Light intensity, light quality, and other factors interact with temperature and day length to influence the bulbing response of onion cultivars. With warm weather and bright days, onions bulb at shorter day lengths than when the days are cool and over cast (Dawling *et al*. 2006). Light and temperature influence the process of bulbing. Both factors must be at optimum for the initiation of the bulbs. Cool conditions with long days are normally important for production, although there are cultivars that tolerate warm conditions and short day-lengths. Cool conditions are usually required during the first part of the season, when the plants start to form bulbs. Warm and dry weather is needed for harvesting and curing. Each cultivar has its own sensitivity to day-length (Savva and Frenken, 2002). The onions are grouped into short-days and long-days depending on the day length requirements.

2.4 Management/Cultural Practices for Onion Production

Onion dry bulbs are established either by direct sowing of onion seeds onto the field, by transplanting seedling or from dry sets depending on the growing conditions of the specific regions. Sowing seeds directly into the soil where the crop is to be grown is potentially the most economical method of raising an onion crop, particularly where the availability of labour for transplanting is limited and its cost is high or where the availability of facilities for raising transplants is limited (Lemma and Shimeles, 2003). Sets and transplants are used in areas where the season is not long enough for proper bulb development. Transplants have the advantage on economic use of seeds, transplanting has the advantage of selecting healthy and vigorous seedlings. It also has the advantage of saving time (Lemma and Shimeles, 2003).

2.5. Production of Onions in Ghana

Onion production areas in Ghana include coastal savannah and transition zones as well as the savannah regions. For the coastal savannah, the onion growing areas include Sogakope and Akatsi in the Volta region, Ashaiman and Dawhenya in the Greater Accra, and Nsawam which is in the Eastern Region of Ghana (Awuah *et al.*, 2009). In the Upper East Region of Ghana, farming families active in onion production are at Bawku West and Garu

Tempane Districts (Trias, 2010). Onion yields in the Upper, Northern and Southern Regions of Ghana are 15-25 t/ha and 5-15 t/ha respectively (Alidu, 2013).

The short-day, local red cultivars (i.e. 'Red Creole', 'Bawku Red' and 'Malavi') are the commonly grown cultivars in Ghana. Other exotic cultivars such as Texas early Grano, Crystal White Wax, Lisbon White, Yellow Flat, Suttons, Australian Brown, Early Cape and Market Winner were in the past introduced into the country (Kyofa-Boamah *et al*., 2000; Awuah *et al.*, 2009). Cultivars that performed best (Texas Early Grano, Red Creole, Market Winner and Australian Brown) have been maintained to date (Awuah *et al.*, 2009).

2.6 Factors Mitigating Against Onion Production in Ghana

The dry season crop (under irrigation) constitutes much of the area under onion production. The productivity of onion is however, much lower in Ghana compared to other west Africa countries such as Burkina Faso. The low productivity could be attributed to the limited availability of quality seeds and associated production technologies used, among others (Nikus and Mulugeta, 2010). It has been indicated by Abbey *et al*. (2000), that the supply of onion in Ghana is significantly below consumer demand and this could be attributed to low yields, seasonal and small scale production. As a result, a lot of foreign exchange is spent annually on the importation of dry onion into the country. Records available from FAO show that between 2007 and 2011 alone, a total of 171,935 metric tonnes of dry onion valued at US$33,567.00 was imported into Ghana from Niger and Burkina Faso. On average, 34,387 metric tonnes of onion is imported annually into the country (FAO, 2013). In Ghana, the average yields per unit area is 7.7 tons per ha. This is on average five times lower than that of Niger (35 tons per ha), three times as low as those of Senegal, Mali and Burkina Faso (23 tons per ha) and 2.5 times as lower than the average of all countries in

West Africa (18 tons per ha). Several factors account for the low production of onion. These include, low yielding variety being grown in the country (Bawku Red), high incidences of pests and diseases, poor production and poor genetic quality of the onion seeds, limited use of (organic) soil and water conservation techniques, insufficient water for irrigation and limited suitable land for onion production.

2.7 Fertilizers

Fertilizer is any organic or inorganic material, natural or synthetic in origin which when added to the soil or plants tends to restore favourable plant nutrient level and increase the yield and/or the quality of the crop. It is important to supply the crop with the right quantity and kind of fertilizer in order to get the maximum yield from the crop and make enough returns (Norman, 2004).

2.8 Inorganic Fertilizers

Inorganic fertilizers are also referred to as commercial or chemical fertilizers. As a result of their ability to supply the essential nutrients much faster than the organic fertilizers; inorganic fertilizers are widely used by farmers. The two categories of inorganic fertilizers are the straight or simple fertilizers and the compound or mixed fertilizers. Simple fertilizers are composed of only one nutrient element; an example is sulphate of ammonia and potash. Compound fertilizers on the contrary contain two or three of the primary nutrients of nitrogen, phosphorus and potassium, for example, 15-15-15 NPK compound fertilizer (Norman, 2004).

2.9 Organic Fertilizers

In recent times, attention has been drawn to the use of organic fertilizers for maintaining soil fertility. The attention directed towards organic manure is as a result of the high cost of chemical fertilizers and their long term negative effect on the chemical properties of the soil (Negassa *et al.*, 2001; Norman, 2004; Tirol-Padre *et al*., 2007).

A report by Ruder and Bennion (2013), indicate the high cost of fertilizers world-wide by pointing to the rapid increase in the price of inorganic fertilizers in the U.S.A. Organic fertilizers on the other hand have the ability to improve soil structure, soil chemical properties and soil microbial activity. They again maintain the productivity of the soil (Norman, 2004; Chandra, 2005; Tirol-Padre *et al.*, 2007; Bhattacharyya *et al*., 2010 and Lasmini *et al*., 2015). In addition to the significant improvement of soil properties, poultry manure, which is one of the major sources of organic manure, is said to be available in large quantities in the country. According to FAO (2014), as at 2010, the national poultry numbers in the Ghana stood at 47,752,000 birds and this could very well translate into the production of millions of tonnage of poultry manure per annum. It should however be noted that the quality and quantity of poultry manure produced is dependent on the poultry feed, type and age of the bird.

2.10 Response of onion to nitrogen fertilization

Onion is among the high nitrogen demanding vegetables, its productivity depends on use of optimum fertilizer rates and if not adequately fertilized, considerable yield losses are apparent. Among all nutrients, nitrogen is the most important and also the most limiting to crop production. Efficient N use is important for the economic sustainability of cropping systems (Fageria and Baligar, 2005). Excessive use of nitrogen fertilizers is a concern, since large amounts of nitrogn can remain in the soil after crop harvesting (Norman, 2004).

In a temperate climate, usually ≤ 50% of nitrogen fertilizer applied is effectively used by plants, while a considerable part is lost by leaching and contaminates ground and surface waters (Fageria and Baligar, 2005).

Mineral fertilizers are one of the principal factors that materially set up onion growth and production. Onion plants take up large amounts of the three primary nutrients, i.e. nitrogen, phosphorus and potassium (Kandil *et al*., 2013). Norman, (2004) also stated that nitrogen and phosphorus are often referred to as the primary macronutrients because of the large quantities taken up from the soil relative to other essential nutrients.

Negash *et al.* (2009) reported that increasing the rate of N fertilization from 0 to 138 kg/ha increased total bulb yield of onions from 19.26 t/ha to 32.24 t/ha. Similarly, increasing the rate of nitrogen application from 0 to 138 kg/ha significantly increased marketable bulb yield from 18.82 t/ha to 31.90 t/ha which was 69.5% higher than the control. Jilani *et al*. (2004) reported that with increase in dose of nitrogen up to120 kg N/ha the marketable and total bulb yield was increased, but below this level the total yield t/ha began to decrease. A significant increase in total bulb yield in response to nitrogen fertilizer levels was also observed by Balemi *et al*. (2007). Bolting is triggered in response to exposure of the onion plant to limited N supply (Yamasaki and Tanaka, 2005). Al-Fraihat (2009) also, stated that highest percentage of bolting was obtained from plants fertilized with the lowest level of nitrogen (100 kg N/ha). Abdissa *et al.* (2011) indicated that nitrogen fertilization significantly reduced bolting in onion. The authors reported that ratio of bolting percentage per plot decreased by about 11 and 22% in response to the fertilization of 69 and 92 kg N/ha, respectively as compared to the control.

Onion fertilized with different N levels decreased the yield of small sized bulbs, but increased the yield of large sized bulbs. Small sized bulbs decreased by 61.8% when N application was increased from 0 to 138 kg/ha. On the hand, when N fertilization increased from 0 to 138 kg/ha the increased large size bulbs increased from 12.58 t/ha to 25.67 t/ha, respectively, resulting in 104% increment (Negash *et al*., 2009). Nitrogen fertilization increased the bulb yield of onion and yield components. Increasing nitrogen levels from 0 to 120 kg/ha resulted in progressive increase in bulb yield. Application of 120 kg N/ha increased the number of leaves per plant and plant height over the control as well as lower levels of nitrogen. There was an increase in diameter and weight of bulbs due to application of nitrogen up to 120 kg N/ha (Nasreen *et al.,* 2007). A report by Morsy *et al.* (2012) indicated that 120 kg N/ha resulted in higher values of plant height, number of leaves per plant, bulb diameter and days to maturity as compared to adding of 90 kg/ha.

Al-Fraihat (2009) stated that with increasing application of nitrogen fertilizer from 100 kg N/ha to 200 kg N/ha in the first and second growing seasons, the Treatment Sum of Squares (TSS) value increased from 13.75% to 14.70% and 13.90% to 15.07% respectively. Morsy *et al.,* (2012) also showed application of 120 kg/ha N led to the highest values of TSS whereas, application of 90 kg N/ha resulted in the lowest values of TSS in both seasons. Moursy *et al*., (2007) also indicated that increasing the level of N fertilizer to 80 kg N/ha resulted in about 8.5% increase in the TSS as compared to the level of 40 kg N/ha.

The different N levels affected the leaf diameter and length of onion. The application of 150 kg N/ha gave the highest value with regard to leaf diameter. Generally, with increasing nitrogen level from 0 kg/ha to 150 kg/ha, the leaf diameter of onion increased from 0.81

cm to 1.00 cm (Kokobe *et al.,* 2013). Al-Fraihat (2009) reported the highest level of nitrogen significantly increased plant height and number of green leaves per plant as compared to the control treatment.

Nitrogen fertilization significantly extended the number of days required for onion crop to attain its physiological maturity. Regardless of the rate, N fertilization extended physiological maturity by about 6 days over the unfertilized treatment (Abdissa *et al.*, 2011). A report by Meena *et al.* (2007) also described the delay in maturity of onion bulb due to application of enhanced level of nitrogen.

2.11 Response of Onion to Organic Soil Amendments

Onion, compared with most crops, is usually the weakest crop plant in terms of extracting nutrients, especially the immobile types, because of their shallow and unbranched root system (Sørensen and Grevsen, 2001). Onion crop is a heavy feeder, requiring ample supplies of nitrogen; hence it requires and often responds well to addition of fertilizers. However, excess application of nitrogen causes excessive vegetative growth, delayed maturity, increase susceptibility to diseases, reduces dry matter contents and storability and ultimately reduces yield and quality of bulbs (Sørensen and Grevsen, 2001).

Onion yield comprises of marketable and unmarketable dry bulbs (Lemma and Shimeles, 2003). According to the authors, marketable bulb weight can be grouped into five (5) bulb categories: Oversized (above 160 g), large (100-160 g), medium (50-100 g), small (20-50 g) and under-sized below (20 g). These sizes are preferred by consumers based on the purpose for which they are required. The sizes below 20 g are regarded as the unmarketable. The diseased, decayed and physiological disorder such as thick necked, splits and bolters are also regarded as unmarketable bulb.

Disorders are influenced by location, season, cultivar, and management practice. Some of the disorders like thick necked occurs mainly when some of the proportion of bulbs fail to complete bulbing in which the leaves continue growing. Under this condition, the neck does not get soften and the bulb does not become dormant. Other reasons for thick neck is heavy and continuous watering and late application of nitrogen (Lemma and Shimeles, 2003).

2.12 Effect of Plant Spacing on Onion Yield and Yield Components

Plant population refers to the number of plants per square meter (plants/m^2) or the number of plants per hectare (plants/ha) and is important in onion production since it has an influence on growth, yield and quality of onion bulbs (Decutt, 2012). Plant and row spacing are considered important to the optimum plant population which may be reflected in higher yield and quality. Onion bulb size can be controlled to a certain extent by plant population. In order to produce large bulbs (> 70 mm in diameter) a plant population of between 25 and 50 plants/m^2 is required, for medium bulbs (25-50 mm) between 50 and 100 plants/m^2 and for small bulbs (< 50 mm) more than 100 plants/m^2 are required (Decutt, 2012).

Dorcas *et al.* (2012) reported that with increasing plant density of onion from lower 100,000 plants/ha to higher plant density of 500,000 plants/ha, the average bulb weight and bulb diameter decreased from 58.22 g to 40.04 g and 4.56 cm to 2.83 cm respectively. Dorcas *et al.* (2012) also reported that highest and lowest yield was obtained in the higher plant density of 500,000 plants/ha and lower plant density of 100,000 plants/ha. Yemane *et al*. (2013) indicated that with increasing intra-row spacing from 5 to 10 cm, statistically bulb diameter and bulb neck diameter of onion increased from 4.66 to 5.63 cm and 1.48 to 1.74 cm respectively. Dawar *et al.*, (2005) indicated that as plant population increased from 40 to 80 plants/m^2 onion neck diameter declined significantly. Jilani *et al*. (2009) indicated that bulbs of thick neck of onion were found in plots of lowest plant density (20 plants/m^2). Bulb neck diameter decreased as population density increased. Mean bulb weight and plant height decreased as population density increased (Kantona *et al.*, 2003).

Khan *et al.* (2002) reported that plant spacing results in increase in plant height, onion bulb size, weight of the bulbs and number of bulbs/ha. Khan *et al*., (2003) reported that wider spacing (20 x 10 cm) produced higher size of leaf length and number of leaves, bulb length, diameter and weight of onion. Yemane *et al*. (2013) also indicated that as intra-row spacing increased from 5 to 10 cm, marketable bulb yield decreased from 34.49 to 28.10 t/ha. Seck and Baldeh (2009) reported that plant density has an impact on marketable bulb size and the higher the plant density the smaller the marketable size. Kantona *et al.*, (2003) also reported that as plant density increased number of marketable bulbs increased.

Sikder *et al.*, (2010) evaluated three intra-row spacing (20 x 20, 20 x 15 and 20 x 10 cm) for onion planting. Their findings indicated that maximum yields were obtained from 20 x 20 cm plant spacing. The narrow plant spacing produced comparatively lower values on fresh weight of leaves per plant. They also found out that the narrow plant spacing resulted in lower plant height and lower number of leaves per plant, lower bulb diameter and lower fresh weight of bulb. They also found that as number of rows per bed increased, marketable onion yields linearly increased and mean bulb size decreased. Latif *et al*. (2010) showed that yield of onion bulbs produced at the spacing of 20 x 10 cm was recorded as the highest compared to 20 x 20 cm spacing. Mahadeen, (2008) also reported that narrow intra-row spacing produced higher yield.

According to Mahadeen, (2008), with increase in plant spacing, the bulb weight and size increased, but the yield per ha decreased. Latif *et al*. (2010) indicated that the numbers of leaves per plant, bulb weight, foliage dry weight, plant height was highest when the plants were grown at wider spacing of 20 x 20 cm. However, yield per unit area was higher in the narrow spacing. Nasir *et al.* (2007) also stated that the highest leaf number per plant was recorded at lower planting density. Planting of onion at 20 cm and 25 cm spacing produced larger bulbs compared with planting at 10 cm and 15 cm spacing (Mahadeen, 2008). Jilani (2004) reported that onion plants from the lowest plant population (20 plants/m^2) recorded the highest number of leaves and leaf length.

According to Jan *et al*. (2003), the greatest yield (40.44 ton/ha) was found at spacing of 17 x 4.5 cm, and the lowest yield (19.95 ton/ha) at 27 x 14.5 cm spacing. Yemane *et al*., (2013) also indicated that the highest total bulb yields were achieved at 5 cm and 7.5 cm intra-row spacing, respectively as compared to the 10 cm intra-row spacing. Dereje *et al*., (2012) also indicated that total yield per hectare increased as plant density increased although yield of the individual plants and their components were significantly reduced suggesting a compensation of higher plant densities on yield in shallot. Kantona *et al*., (2003) observed that onion yield increased from 17.4 to 39.5 ton/ha as plant population per square meter increased from 50 to 150.

Dawar *et al*. (2007) also reported that maximum weight of medium and small sized bulb was achieved at higher planting density of 80 plants/4 m^2. However, maximum weight of large bulbs was found at the lowest planting density of 40 plants/4 m^2. Yemane *et al*. (2013) stated that the greatest percentage of small and medium size bulbs yield was recoded at narrow intra-row spacing of 5 cm as compared to 7.5 cm and 10 cm. However, as the intra-row spacing increased from 5 cm to 10 cm, the percentage of large size bulbs increased from 9.3 to 20.3%. Minimum plant population (20 plants/m^2) had larger bulb diameter against smaller bulb diameter of higher plants density (40 plants/m^2) (Jilani *et al*., 2009).

2.13 Response of Onion to Interaction Effect of Nitrogen and Plant Spacing

Rizk *et al.,(* 2012) reported the following as the interaction effect of spacing and nitrogen levels on vegetative growth of onion and bulb yield of onion: The greatest spacing (20 ×20 cm) in association with high nitrogen level up to 180 kg/ha increased number of leaves per plant and splitted bulbs. The highest bulb yield (31.6 ton/ha) was obtained from the narrowest spacing (20 x 10 cm) along with nitrogen level of 120 kg/ha but the large sized bulbs were obtained from the combination of wider spacing (20 x 20 cm) and at 120 kg nitrogen/ha

Naik and Hosamani (2003) stated that, the greatest bulb yield was recorded with treatment interaction of narrower spacing (15 x 10 cm) and higher levels of nitrogen (150 kg/ha). The bulb diameter was highest in the wider spaced (15 x 20 cm) followed by 15 x 15 cm than narrow spacing (15 x 10 cm). They also stated that, the highest bulb weight was found in the plots applied with 150 kg N/ha.

Maximum number of leaves per plant was produced by the treatment interaction of higher nitrogen (150 kg N/ha) with wider (15 cm spacing). Mean values of bulb diameter in response to different nitrogen levels were bigger in 200 kg N/ha over 100 kg N/ha and 0 kg N/ha. It was observed from the means of interactions that 200 kg/ha with 10 cm spacing produced maximum bulb yield per hectare. Nitrogen dose of 200 kg/ha when interacted with 15 cm spacing produced bigger bulbs per plant (Pervez *et al*., 2004).

Interaction effect of different intra-row spacing (10, 15, 20 and 25 cm) and levels of nitrogen fertilizer (0, 50, 100 and 150 kg N/ha) showed that an increase in nitrogen dose up to 100 kg/ha resulted in the increase of yield of onion bulbs 40.83 t/ha by interacting with 15 cm intra-row spacing. Further increase in nitrogen level up to 150 kg/ha did not significantly increase in bulb yield. The lowest bulb yield was recorded from the control plots when interacted with wider intra-row spacing of 25 cm (Aliyu *et al.,* 2008). They again stated that, the treatment combinations of 0 kg N/ha and 10 cm intra-row spacing produced lower values of average bulb weight, bulb diameter and number of leaves per plant.

2.14 Total and Marketable Bulb Yield

In a study to investigate the effects of poultry manure as a component of organic production on yield and quality of eggplant, Abbas *et al.* (2011), reported that organic fertilizers increased the yield of the eggplant. They realized that the treatment with 15 t/ha gave the highest yield which was significantly different from the 10 t/ha and 20 t/ha treatments. Yohannes *et al*. (2013), reported that, a combined application of 100 kg/ha N and 30 t/ha FYM increased the total bulb yield by about 53% over the control plot. The total bulb yield of garlic from the poultry manure plot was 42% better than the control and the mineral (NPK) treatment (Abou El- Magd *et al.,* 2012).

Kandil *et al.* (2013), found that the total and marketable yield of onion was higher for poultry manure manure plot (10.7 t/ha CM) than compost (11.9 t/ha C) and farmyard manure (35.7 t/ha FYM), but was, however, lower than the plot treated with mineral fertilizer (214.2 kg N + 71.4 kg P_2O_5 + 57.1 kg K_2O/ha). Bashir *et al.* (2015), indicated that, poultry manure was able to increase the total bulb yield of onion from 12.3 t/ha (control plot) to 38.2 t/ha. It was similarly reported by Dapaah *et al*. (2014), that the application of poultry manure led to a 23 – 63% increase in fresh bulb yields (1,194.5 kg/ha) over the control treatment (932 kg/ha).

An integrated application of N from organic and inorganic sources resulted in an increase in the total yield of onion (Sultana *et al.*, 2014). On the contrary, Seran *et al.* (2010) reported that higher bulb yields were obtained with the application of chemical fertilizers compared to organic manure only. Abdissa *et al.* (2011), reported a significant increase in the total bulb yield and marketable bulb yield by 18% and 17% respectively over the control treatment, with the application of 69 kg/ha N. Similar findings were made by Mohammadi-Fatideh and Hassanpour-Asil (2012), who observed a significant increase in the total bulb yield when nitrogen fertilization was increased from 50 to 150 kg/ha. There was, however, no significant difference between the total bulb yield from the 100 kg/ha and 150 kg/ha nitrogen fertilization treatments.

Poultry manure applied at 15 t/ha gave the highest total bulb yield (45.0 t/ha) among the three sources of organic manure applied (cow dung - 20 t/ha, goat dung - 20 t/ha and poultry litter - 15 t/ha). The control (no manure) produced the lowest bulb yield of 3.8 t/ha (Gwari *et al.*, 2014). Mousa and Mohamed (2009), reported that, the highest yield of onion bulbs was attained when poultry manure was applied at the rate of 4.0 t/ha; the yield obtained was higher than those coming from the animal manure (5.8 t/ha) and mineral fertilizer (Ammonium Nitrate – 495.2 kg/ha; Calcium super phosphate – 633.3 kg/ha and Potassium sulfate – 119.1 kg/ha) treatments.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site Description

Two separate experiments were conducted at the multipurpose Research Farm of the College of Agriculture Education, University of Education Winneba-Mampong Campus, in the Ashanti Region of Ghana from October-December, 2019(minor season) and March to May, 2020 (major season). The research farm is located between latitude 6°30’N to 9°45’N, and falls in the Forest-Savanna Transitional Zone of Ghana.

The soil of the experimental site is the Savanna Ochrosol derived from the Voltarian Sandstone and belongs to the Bediase Soil Series (Asiamah, 1998). It is classified as Chromic Luvisol according to FAO/UNESCO classification (FAO/UNESCO, 1988). It is reddish in colour, sandy-loam in texture, deep and free from stones and pebbles, and contains some appreciable amount of organic matter (Adu, 1992).

The location has a bimodal rainfall pattern with an annual average of about 1,300 mm. The major season starts from April and ends in July with an average of about 1,250 mm, while the minor season begins from September and ends in November with an average of about 1,200 mm. August is usually characterized by a short dry spell between the two rainy seasons (MoFA, 2001). Percent relative humidity is generally high. It ranges from 75% to 97%, in the morning and falling to between 73% and 32% in the afternoons depending on the season. The diurnal temperature ranges from 24.4°C to 28.6°C (Obeng, 2007).

3.2 Experimental Design and Treatments

The experimental design used was a 5 x 3 factorial arranged in a randomized complete block design (RCBD) with three replications. The factor A consisted of five levels of soil amendments. Control (no soil amendment), 10 t/ha chicken manure (cm), 15 t/ha chicken manure, 20 t/ha chicken manure, and 300 kg/ha NPK (15-15-15). Factor B consisted of three (3) spacings: 10 cm × 10 cm, 15 cm × 10 cm, and 15 cm × 15 cm. In total there were 15 treatments.

Each plot size was 1.2 m x 1.7 m with a total land area of 2.04 m^2. About seven month-old chicken manure was obtained from a deep litter system and kept under shade for protection (from bad weather). Seeds of onion variety, 'Violet Damani' obtained from Kyeiwaa Agro-chemical stores at Mampong-Ashanti were used for the study.

3.3 Management and Cultural Practices

3.3.1 Land preparation

The experimental field was prepared by slashing on 8th September, 2019 for the 2019 minor season and 10th January 2020 for 2020 major season experiment. The fields were then ploughed and harrowed to a fine tilt. Two weeks later, the fields were sprayed with herbicide (Glyphosate) at a rate of 900 g active ingredient (isopropylamine salt) per hectare. Lining and pegging of the area into blocks and plots were done two weeks after spraying. The area was demarcated into three (3) blocks, each measuring 1.2 m x 43.5 m. Fifteen beds, each measuring 1.2 m wide, 1.7 m long and about 0.25 m high was prepared on each block (replication). A 1metre (m) buffer strip was left between the plots and the blocks (replication).

3.3.2 Nursery establishment and management

The nursery area was cleared and the nursery beds raised and a shade erected over them to regulate the intensity of the sunlight in the nursery. 'Violet Damani' onion seeds were nursed on 11th October, 2019 for 2019 minor season and 22nd January, 2020 for 2020 major season in drills, 10 cm apart, a depth of 0.5 cm and watered.

The nursery beds were watered in the mornings every day until transplanting. Pests such as grasshopper and crickets were prevented by spraying Cydim Super (Dimethoate 400 g and Cypermethrine 36 g) fortnightly at a rate of 2.3 ml per litre of water. Fungal disease in the nursery was prevented by spraying Agrithane (Mancozeb 80WP) at a rate of 2 g per litre of water every two weeks.

3.3.3 Decomposition of chicken manure

The chicken manure was allowed to decompose for three weeks before it was applied at the respective rates. The chicken manure was heaped at a particular place and covered with a polythene sheet. The chicken manure was stirred every day for three weeks to enable complete decomposition.

3.3.4. Transplanting

The six-week old onion seedlings were transplanted onto the main field on 8th October, 2019 for the 2019 minor season and on 7th March, 2020 for 2020 major season at the various planting distances. A week prior to transplanting, the seedlings were hardened off by reducing the watering regime and gradually reducing the shade cover.

3.3.5 Application of chicken manure and NPK 15-15-15 fertilizer

For treatments receiving chicken manure, the manure was incorporated into the soil a week prior to transplanting. The beds were then watered regularly to ensure proper decomposition of the poultry manure.

The NPK 15-15-15 fertilizer, was applied as side dressing about 1 cm away from the plant at 2 weeks after transplanting by burying into the soil.

3.3.6 Irrigation

To ensure that the soil has adequate moisture, the plants were watered uniformly on daily basis. However, on days that it rained, plants were not watered. This was to ensure that there was adequate moisture within the root zone of the plant. Watering was done using watering cans. Watering was done about 75 times in 2019 minor season with an estimated amount of about 600 mm water. In 2020 major season, watering was done about 50 times with an estimated amount of about 300 mm water.

3.3.7 Pests and Diseases Control

Weeds were manually controlled by hand picking and hoeing, respectively, as and when necessary. Grasshoppers and cutworms were controlled by spraying Attack 5% WDG (Emamectin Benzoate 5%) at a rate of 2 g per liter of water. Fungal diseases were controlled by spraying Agrithane (Mancozeb 80WP) at a rate of 2 g per litre of water at 7 days' interval. Weeding both was done four (4) times before harvesting whiles the spraying was done 4 times before harvesting

3.3.8 Earthen up and stirring

Earthing up was done when bulb formation and enlargement commenced. This was done by covering the exposed portions of the bulbs with soil to prevent the direct impact of the sun rays on the bulbs. Stirring of the bed was also done every 3 weeks to loosen the soil and enhance water infiltration and bulb enlargement.

3.3.9 Soil and chicken manure samples for laboratory analysis

The analysis of soil and chicken manure samples were carried out at Kwame Nkrumah University of Science and Technology laboratory at the faculty of Agriculture. Soil samples were taken from the two experimental sites before transplanting of onion seedlings for physical and chemical analysis. A total of seven samples were taken from the experimental site from the layer 0-15 cm due to the shallow roots of onions. All un-decomposed plant materials and stones were removed from the samples. The seven samples were thoroughly mixed, air-dried and a representative sample taken for analysis.

After harvesting, soil samples were taken from each of the 15 plots at the two experimental sites. Soil samples from the same treatment plots were thoroughly mixed and a representative sample taken. Samples for the 5 treatments were accordingly labelled and taken for chemical analysis. A representative sample of the poultry manure used for the two experiments were taken and analysed for its chemical properties.

3.4 Data Collection

Data was collected on vegetative growth and yield and yield components.

3.4.1 Number of leaves per plant

The total number of fully opened, grown and green leaves on ten tagged plants was counted at every two weeks’ interval. The mean number of leaves per plant for each treatment plot was then calculated.

3.4.2 Plant height

Plant height was taken at every two weeks' interval on ten tagged plants. Plant height was measured from the soil surface to the top of the longest leaf using a long meter rule. The mean plant height for each plot was determined.

3.4.3 Leaf length

The leaf length was taken on ten tagged plants at every two weeks' interval. The longest leaf of the onion plant was measured with meter rule from the base of the leaf to its apex. The mean leaf length for each treatment was calculated.

3.4.4 Leaf diameter

The leaf diameter was measured for the ten tagged plants at every two weeks' interval. The leaf diameter was determined by measuring the maximum diameter of the longest leaf using a pair of Vernier calipers. The mean leaf diameter for each treatment plot was subsequently calculated.

3.4.5 Number of days to maturity

The number of days from transplanting to the day at which more than 80% of the plants in a plot showed yellowing of leaves. Close monitoring was done to determine the number of days it took for more than 80% of the plants in a plot to show yellowing of leaves.

3.4.6 Mean bulb weight

Ten bulbs from the middle four rows were weighed together with an electronic weighing scale and the mean bulb weight for each treatment determined.

3.4.7 Bulb diameter

This was determined by taking the width at the widest point (in the middle of the bulb) of the ten mature bulbs using a pair of Vernier calipers. The mean bulb diameter was then calculated for each treatment plot.

3.4.8 Bulb length

Bulb length was determined by measuring the length of the ten mature bulbs at the widest point of the bulb using a pair of Vernier calipers. The mean bulb length was then calculated for each treatment plot. This was done immediately after harvest on the field.

3.4.9 Number of bulbs and grading

The criteria used for the grading was that; any bulb with a weight of less than 50 g (<50g) was graded as small, those with weights between 50-100 g were graded as medium, those with weights between 100-160 g were graded as large and those with weights above 160 g (>160 g) were graded as extra-large.

3.4.10 Total bulb yield

The bulb yield was computed based on the weight of bulbs harvested from the four middle rows per plot. The value obtained was then converted into yield per hectare.

3.4.11 Marketable bulb yield

Marketable bulb yield was determined after sorting out bulbs smaller than 20 g in weight, thick necked, rotten and discoloured. The mean marketable bulb yield was determined for each of the treatment.

3.4.12 Harvest index

Harvest index was determined as the ratio of dry bulb weight to total dry biomass yield per plant. Harvest index = $\frac{\text{dry bulb yield}}{\text{total dry biomass}}$ or $\frac{\text{yield of crop}}{total\ amount\ of\ biomas}$

3.5 Economic Analysis

Cost-benefit analysis was carried out to evaluate the profitability of "Violet Damani" onion production under the various soil amendments. The net revenue (NR) was determined from the total revenue (TR) and cost of production (TC). The net revenue (NR) from the investment was given by NR = TR – TC. Partial Budget Analysis was also calculated.

3.6 Data Analysis

The data collected was analyzed using the analysis of variance (ANOVA) using the GenStat 18th Edition software. Means which differed significantly were separated using the Fisher"s Protected Least Significance Difference (LSD) at 5% level of significance (P = 0.05).

CHAPTER FOUR

4.0 RESULTS

4.1 Field Results

4.1.1 Soil analysis

The chemical and physical properties of the soil at the experimental sites for 2019 minor and 2020 major seasons are presented in Table 4.1. The total N, available P, and total K were slightly lower in 2019 minor than in 2020 major. According to the CSIR-SRI Soil Test Interpretation Guide (SRI,1999), the N was adequate in experiment two but low in experiment one. P and K were, however, adequate in both experiments.

The organic matter content of the soil was found to be low whilst CEC was adequate in both experiments. The physical soil analysis shows that the soil used for both experiments was sandy loam with 60% sand, 25% silt and 15% clay.

Table .4.1: Soil Analysis at the Experimental Sites (0-15 cm depth) During 2019 Minor and 2020 Major Seasons.

Soil analysis	2019 minor	2020 major
Chemical properties		
Total Nitrogen (%)	0.12	0.13
Available Phosphorous (mg/kg)	30.80	31.47
Total Potassium (mg/kg)	173.22	176.92
Organic Carbon (%)	0.79	0.82
Organic Matter (%)	1.36	1.41
pH (water 1:1)	5.35	5.37
Ca (mg/kg)	5.11	5.25
Mg (mg/kg)	0.15	0.16
CEC (Cmol/kg)	6.05	6.15
Electrical Conductivity (dS/m)	0.98	1.01
Physical properties		
% Sand	60	60
% Silt	25	25
% Clay	15	15
Texture	Sandy loam	Sandy loam

4.1.2 Chicken manure analysis

Some of the chemical properties of chicken manure used in both experiments are shown in Table 4.2. The chicken manure used in 2020 major season had a slightly higher organic matter (24.96%) compared with 2019 minor season (23.23%). The percent N, P, K and Ca and Mg were all higher in 2020 major season than in 2019 minor season. The pH of the manure was, however, higher in 2019 minor season (8.13) compared to 2020 major season (7.79).

Table 4.2: Chemical Properties of Chicken Manure Used in 2019 Minor and 2020 Major Seasons.

Chemical properties	2019 minor	2020 major
Total Nitrogen (%)	1.13	1.15
Total Phosphorus (%)	0.70	0.74
Total Potassium (%)	0.78	0.81
Organic Carbon (%)	13.44	14.44
Organic Matter (%)	23.23	24.96
Ca (mg/kg)	2.12	2.13
Mg (mg/kg)	0.22	0.25
pH (water 1:5)	8.13	7.79

4.1.3 Chemical properties of soil after harvesting

Tables 4.3 and 4.4 for 2019 minor season and 2020 major, respectively report some chemical properties of soil after harvesting. The results from 2019 minor season (Table 4.3) shows that the pH of the control (5.35) was moderately acidic but with the application of the different chicken manure and inorganic fertilizer, the pH had increased to 7.32.

Application of only NPK, further reduced the soil pH to 5.21. The total N, available P and O. M. were higher in the amended plots than the control treatments. The electrical conductivity of the amended plots was higher than the control (0.23 dS/m). In 2020 major season, the pH of the NPK 15-15-15 at 300 kg/ha amendment again reduced to 5.16 (Table 4.4). The amendments containing chicken manure however raised the pH of the soil to 7.01. Again, the electrical conductivity of the control (0.24 dS/m) was lower compared to the amended plots. The total N, available P and Organic matter of the control was less than that of the amended plots.

Table 4.3: Chemical Properties of Soil After Harvesting at 0 – 15 cm Depth for 2019 Minor Season

Chemical properties	Treatments				
	Control	10 t/ha cm	15 t/ha cm	20 t/ha cm	300 . kg/ha (NPK)
Total Nitrogen (%)	0.12	0.18	0.18	0.19	0.14
Available Phosphorous (mg/Kg)	30. 4	32.67	37.07	35. 47	32.933
Total Potassium (mg/Kg)	171.00	166.53	170.53	170.60	17.87
Organic Carbon (%)	0.78	0.82	1.12	1.38	1.21
Organic Matter (%)	1.34	1. 41	1.94	2.39	1.55
P^H (water 1:1)	5.35	7.10	7.32	7.31	6.55
Ca (mg/Kg)	5.04	4.71	5.19	5.19	5.33
Mg (mg/Kg)	0.15	0.16	0.19	0.18	0.20
CEC (C mol/Kg)	5.97	7.91	6.15	6.93	4.03
Electrical Conductivity (ds/m)	0.23	0.72	0.63	0.97	0. 44

Table 4.4: Chemical Properties of Soil After Harvesting at 0 – 15 cm Depth for 2020 Major Season.

Chemical properties	Treatments				
	Control	10 t/ha cm	15 t/ha cm	20 t/ha cm	300 . kg/ha (NPK)
Total Nitrogen (%)	0.12	0.19	0.19	0.20	0.15
Available Phosphorous (mg/Kg)	30. 92	33.23	37.70	36. 07	33. 49
Total Potassium (mg/Kg)	173.78	168.27	173.30	173.39	177.52
Organic Carbon (%)	0.81	0.86	1.16	1. 43	0.92
Organic Matter (%)	1.39	1. 45	2.02	2. 49	1.62
P^H (water 1:1)	5.38	6.86	6.63	6.63	6.28
Ca (mg/Kg)	5.17	4.81	5.32	5.32	5.43
Mg (mg/Kg)	0.16	0.16	0.19	0.19	0.20
CEC (C mol/Kg)	6.03	7.99	6.22	7.02	4.07
Electrical Conductivity (ds/m)	0.24	0.73	0.66	1.01	0. 45

4.2 Vegetative growth

The parameters used as indices of vegetative growth were, crop establishment, number of leaves per plant, plant height, leaf length, leaf diameter, and number of days to maturity

4.2.1 Crop establishment

As shown in Figure 4.1, the crop establishment for both experiments ranged between 95.90 – 98.80% and 95.10 – 98.80% for 2019 minor and 2020 Major Seasons, respectively. There were no significant differences in percentage establishment of seedlings observed at 28 DAT among the various soil amendments and control in both experiments. Chicken manure at 15 t/ha had the highest crop establishment (98.80%) with chicken manure at 20 t/ha had the lowest (95.90 %) in 2019 Minor Season. In 2020 Major Season, the highest crop establishment of 98.80% with the application of 15 t/ha of chicken manure whilst the control treatment (no fertilizer) had the lowest crop establishment of 95.10%. The mean crop establishment was greater in 2019 minor season (97.35%) than 2020 major season (96.95%).

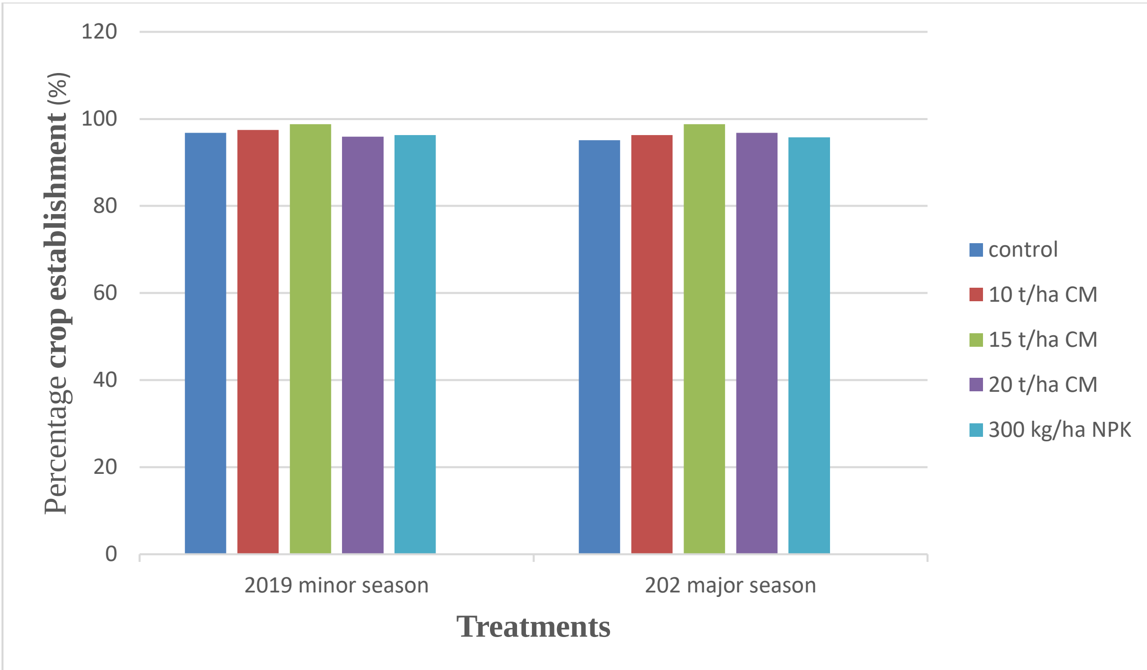

Figure 4.1 Effect of Soil Amendment on Crop Establishment of Onion for 2019 Minor and 2020 Major Seasons at 28 DAT.

4.2.2 Number of leaves per plant

Table 4.5 indicates significant difference in the number of leaves among the different soil amendments and the control and plant spacing in both experiments. The application of 20 t/ha of chicken manure at plant spacing of 15 cm × 15 cm resulted in higher number of leaves compared to the other treatments in 2019 minor season at 28 DAT, 42 DAT and 56 DAT. Again, all the amended plots had significantly higher number of leaves at the various plant spacing than the control plot.

In 2020 major season, the mean number of leaves recorded for all the amended plots at the various plant spacing were significantly higher than the control plot except 300 kg/ha NPK at the plant space of 10 cm × 10 cm which had similar number of leaves as the control at 28 DAT, 42 DAT and 56 DAT. The mean number of leaves recorded for 2019 minor season was statistically similar to that of 2020 major season (Table 4.5). On average, soil amendment and plant spacing was able to increase the mean number of leaves of onion between 12.5 – 44.6% and 5 – 33.3% over the control in both experiments, respectively (Table 4.5).

Table 4.5: Effect of soil Amendment and Plant Spacing on Number of Leaves of Onion for 2020 Major Season.

Soil amendment	2019 minor season Number of leaves per plant				2020 major season Number of leaves per plant			
	28 DAT	42 DAT	56 DAT	mean	28 DAT	42 DAT	56 DAT	mean
10 t/ha cm	4	6	7	6	5	7	7	6
15 t/ha cm	4	7	8	6	5	7	8	7
20 t/ha cm	5	8	8	7	6	8	8	7
300 kg/ha NPK	4	6	7	6	4	6	6	5
Control	3	5	5	4	4	5	6	5
Mean	4	6	7		5	7	7	
LSD	NS	NS	NS		NS	NS	NS	
Spacing (cm)								
10 × 10	4	6	7	6	4	6	7	6
15 × 10	4	6	8	6	5	6	7	6
15 × 15	5	7	8	7	5	7	8	7
Mean	4	6	8		5	6	7	
LSD	NS	NS	NS		NS	NS	NS	

4.2.3 Plant height

The influence of different rates of soil amendments and plant spacing on plant height is shown in Table 4.6. In 2019 minor season, application of 20 t/ha and 15 t/ha chicken manure at plant spacing of 15 cm × 15 cm had taller plants at 56 days after transplanting (DAT). The various chicken manure rates and plant spacing at 10 cm × 10 cm and 15 cm × 10 cm produced plants which were statistically similar in height at 28 and 42 DAT, respectively, but significantly taller compared to the NPK and control treatments (Table 4.6). The height of plants from the chicken manure amended plots at plant spacing of 15 cm × 15 cm did not differ significantly, but these were significantly taller than those from the NPK and control plots at 56 DAT (Table 4.6). The application of 15 t/ha of chicken manure at plant spacing of 15 cm × 15 cm produced the tallest plant (44.3 cm) compared to the other soil amendments and the control. This was however not statistically different from the 20 t/ha chicken manure treatments at plant spacing of 15 cm × 15 cm (43.9 cm). In addition, the plant height of onion from the amended plots was significantly different from the control plot.

Table 4.6: Effect of Soil Amendment and Plant Spacing on Plant Height of Onion for 2019 Minor and 2020 Major Seasons.

Soil amendment	2019 minor season Plant height (cm)			mean	2020 major season Plant height (cm)			mean
	28 DAT	42 DAT	56 DAT		28 DAT	42 DAT	56 DAT	
10 t/ha cm	17.0	35.9	44.2	32.4	17.0	35.4	42.0	32.2
15 t/ha cm	17.8	37.5	44.3	33.1	17.5	37.2	44.1	32.9
20 t/ha cm	17.0	36.9	43.9	32.3	17.1	36.7	44.6	32.1
300 kg/ha NPK	14.0	32.9	40.3	29.1	14.1	32.8	40.2	29.0
Control	14.9	32.4	38.7	28.7	14.7	32.3	38.5	28.5
Mean	16.1	35.1	42.0		16.1	34.9	41.9	
LSD	NS	3.2	4.2		2.3	3.2	4.2	
Spacing (cm)								
10 x 10	16.2	35.0	42.2	31.1	16.3	35.2	42.2	31.2
15 x 10	16.0	35.0	42.0	31.0	16.2	35.3	43.5	31.7
15 x 15	16.2	35.5	50.1	33.9	16.5	35.1	50.2	33.9
Mean	16.1	35.2	44.8		16.3	35.2	45.3	
LSD	NS	NS	4.2		NS	NS	4.2	

Similarly, significantly taller plants (44.6 cm) and (44.1 cm) were produced with the application of 20 t/ha and 15 t/ha of chicken manure at plant spacing of 15 cm × 15 cm respectively in 2020 major season at 56 days after transplanting (DAT). All the chicken manure amendments rates at plant spacing of 15 cm × 15 cm produced significantly taller plants than the control and NPK 15-15-15 at 300 kg/ha amendment at 56 DAT. Also, the height of plants from the chicken manure amended plots at the various plant spacing did not differ significantly, but these plants were significantly taller than those from the NPK and control plots at 56 DAT (Table 4.6). In 2020 major season, the application of 15 t/ha chicken manure and 20 t/ha of chicken manure at plant spacing of 15 cm × 15 cm resulted in significantly taller plant compared to the other amendments and the control.

On average, plants from 2019 minor season were relatively taller (42.8 cm) compared to those from 2020 major season (40.9 cm). Soil amendments at plant spacing of 15 cm × 15 cm on average produced plants which were about 47% and 26% taller than plants from the control plots at plant spacing of 15 cm × 15 cm in 2019 minor and 2020 major season, respectively. The control at plant spacing of 10 cm × 10 cm had the shortest plant height in both experiments (38.7 cm) and (38.5 cm), respectively.

4.2.4 Leaf length

As indicated in Table 4.7, there were significant differences in the leaf length of, 'Violet damani' onion cultivar at 42 DAT among the different treatments in both experiments at the various plant spacing. Chicken manure applied at 20 t/ha at plant spacing of 15 cm × 15 cm produced the longest leaf in both 2019 minor (47.2 cm) and 2020 major seasons (42.3 cm) respectively, at 56 DAT which was significantly different from the other treatments with the exception of the 15 t/ha of chicken manure treatment at plant spacing of 15 cm × 15 cm. The control plants at plant spacing of 10 cm × 10 cm had the shortest leaf in both 2019 minor (22.6 cm) and 2020 major seasons (23.3 cm) at 28 DAT respectively.

The leaf length of plants from the amended plots, on average, was 65.3% and 28.4% higher than plants from the control plots in experiment one and two respectively. The leaf length of onions in 2019 minor season (47.2 cm) at soil amendment of 20 t/ha CM and at plant spacing of 15 cm × 15 cm was slightly longer compared to 2020 major season (42.2 cm) at soil amendment of 20 t/ha CM and at plant spacing of 15 cm × 15 cm at 56 DAT.

There were significant differences in the leaf length of onion plants at 56 DAT among the different soil amendments at the various plant spacing and the control plots at the various plant spacing in both experiments (Table 4.7). In addition, there was no significant difference between the leaf length of plants from NPK 15-15-15 at 300kg/ha (32.2 cm) at plant spacing of 15 cm × 15 cm and the control plot (31.6 cm) at plant spacing of 15 cm × 15 cm at 56 DAT. On average, plants from 2019 minor season had longer leaf (47.4 cm) compared to 2020 major season (42.5 cm) at 56 DAT.

Table 4.7: Effect of Soil Amendment and Plant Spacing on Leaf Length of Onion for 2019 Minor and 2020 Major Seasons

Soil amendment	2019 minor season Leaf length (cm)			mean	2020 major season Leaf length (cm)			mean
	28 DAT	42 DAT	56 DAT		28 DAT	42 DAT	56 DAT	
10 t/ha cm	29.5	36.4	40.6	35.5	28.4	34.1	39.6	34.0
15 t/ha cm	25.6	38.2	46.2	36.7	28.2	35.2	40.2	35.5
20 t/ha cm	29.8	39.1	47.2	38.7	28.3	37.3	42.3	36.0
300 kg/ha NPK	25.3	28.5	32.2	28.7	23.2	30.5	30.2	28.1
Control	22.6	27.8	31.6	27.3	23.3	25.5	29.6	26.1
Mean	26.6	34.0	39.6		16.1	34.9	41.9	
LSD	NS	3.3	4.1		2.3	3.2	4.2	
Spacing (cm)								
10 x 10	17.3	36.2	40.2	31.2	17.2	36.1	40.1	31.2
15 x 10	17.6	37.1	42.0	32.2	17.4	37.2	43.1	32.6
15 x 15	17.6	37.5	43.2	32.8	17.6	37.3	43.6	32.8
Mean	17.5	36.9	41.8		17.4	36.9	42.3	
LSD	NS	NS	NS		NS	NS	NS	

4.2.5 Leaf diameter

Table 4.8 shows that there were significant differences in leaf diameter at 28 DAT, 42 DAT and 56 DAT among the different treatments and plant spacing in 2019 minor season. The leaf diameter of plants from all the amended plots at the various plant spacing with the exception of NPK 15-15-15 at 300 kg/ha amendment were significantly higher compared to the control plots at the various plant spacing. The application of 15 t/ha CM (0.70 cm), 20 t/ha CM (0.78 cm) and 10 t/ha CM (0.59 cm) at the plant spacing of 10 cm × 10 cm produced plants with significantly wider leaf diameter compared to the other treatment at 28 DAT. The leaf diameter of plants from 20 t/ha (1.00 cm) and 15 t/ha (0.92 cm) chicken manure treatments at the plant spacing of 15 cm × 15 cm was significantly wider compared to the other amendments and the control in 2019 minor season at 56 DAT.

The results from 2020 major season shows that the leaf diameter of plants from all the amended plots at the various plant spacing were not statistically different from each other (Table 4.8). No significant difference was observed among all the chicken manure treatments at the various plant spacing. Again, there was no significant difference between NPK 15-15-15 at 300 kg/ha and the control.

On average, 2019 minor season had plants with wider leaf diameter (0.80 cm) than 2020 major season (0.72 cm) at 56 DAT. The control plots at plant spacing of 10 cm × 10 cm had the least leaf diameter in both 2019 minor (0.47 cm) and 2020 major seasons (0.48 cm) at 28 DAT.

Table 4.8: Effect of Soil Amendment and Plant Spacing on Leaf Diameter of Onion for 2019 Minor and 2020 Major Seasons

Soil amendment	2019 minor season Leaf diameter (cm)			mean	2020 major season Leaf diameter (cm)			mean
	28 DAT	42 DAT	56 DAT		28 DAT	42 DAT	56 DAT	
10 t/ha cm	0.59	0.65	0.84	0.69	0.55	0.60	0.70	0.62
15 t/ha cm	0.70	0.75	0.92	0.79	0.69	0.72	0.81	0.74
20 t/ha cm	0.78	0.82	1.00	0.87	0.76	0.77	0.90	0.81
300 kg/ha NPK	0.49	0.52	0.65	0.55	0.50	0.55	0.61	0.55
Control	0.47	0.50	0.61	0.53	0.48	0.53	0.58	0.53
Mean	0.61	0.65	0.80		0.60	0.63	0.72	
LSD	NS	3.3	2.3		NS	3.2	2.2	
Spacing (cm)								
10 x 10	0.54	0.56	0.57	0.56	0.55	0.56	0.63	0.58
15 x 10	0.55	0.58	0.65	0.59	0.57	0.58	0.68	0.61
15 x 15	0.57	0.58	0.68	0.61	0.57	0.59	0.69	0.62
Mean	0.55	0.57	0.67		0.56	0.57	0.67	
LSD	NS	NS	1.3		NS	NS	1.2	

4.2.6 Days to maturity

Increasing the rate of chicken manure from 10 t/ha to 20 t/ha, prolonged the days to maturity of the onion crop across the increasing plant spacing. Thus, plants grown at the higher rates of chicken manure (20 t/ha) application and the wider plant spacing (15 cm × 15 cm) required a greater number of days to mature than plants that were supplied with the lower rates of chicken manure (10 t/ha) and narrower plant spacing (10 cm ×10 cm). Onion plants grown at 15 and 20 t/ha of chicken manure at the spacing of 15 cm × 15 cm as well as those grown at the rate of 20 t/ha chicken manure at the spacing of 10 cm × 10 cm required the highest number of days to reach maturity.

In contrast, the least number of days to reach maturity was required by onion plants grown in the control and 300 kg/ha spaced with 10 cm × 10 cm between plants as well as those grown in the control, spaced with 15 cm × 15 cm between plants. This was the same for both experiments.

Table 4.9: Effect of Soil Amendment and Plant Spacing on Number of Days to Maturity of Onion for 2019 Minor and 2020 Major seasons

	2019 minor season Days to maturity				2020 major season Days to maturity			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	104	107	111	107	104	108	111	108
15 t/ha cm	107	110	112	110	106	109	111	108
20 t/ha cm	108	112	114	111	107	111	113	110
300 kg/ha NPK	103	106	110	106	104	106	110	107
Control	103	105	108	105	104	105	107	105
Mean	105	108	111		105	108	110	
Spacing p =	5.5	8.5	5.0		2.0	5.7	4.8	
LSD (0.05)	1.24	1.64	1.3		1.2	1.3	1.6	
Soil amendments	5.2	8.3	5.0		2.3	5.6		
LSD (0.05)	1.3	1.6	1.3		1.3	1.2	1.5	

4.2.7 Fresh shoot and bulb biomass

The analysis of variance revealed that the main effects of soil amendments and plant spacing significantly influenced fresh shoot and bulb biomass of the onion plants for both experiments (Table 4.10 A and B). With decreasing population density, fresh shoot and bulb biomass per plant of onion significantly increased across the different rates of soil amendments. Thus, plant spacing of 15 cm × 15 cm and soil amendment rate of 20 t/ha chicken manure was the treatment combination at which the highest fresh shoot and bulb biomass was attained.

The least fresh shoot and bulb biomass was recorded for onion plants spaced at 10 cm × 10 cm than that grown on the control plots. Comparing the onion fresh shoot and bulb biomass, the treatment combination of 20 t/ha chicken manure and 15 cm × 15 cm increased the fresh shoot and bulb biomass by 34% as compared to the narrow plant spacing of 10 cm × 10 cm and the control in both experiments. There were significant differences in the shoot fresh weight and bulb biomass of ‟ Violet damani’ onion cultivar at harvest in both 2019 minor and 2020 major seasons (Table 4.10 A and A).

The weight of bulb biomass produced from NPK 15-15-15 at 300 kg/ha plot at plant spacing of 10 cm × 10 cm (55 g/plant) was significantly lower than the other amended plots but statistically not different from the 10 t/ha chicken manure at plant spacing of 10 cm × 10 cm plot (67 g/plant) in 2020 major season. On average, the fresh bulb biomass of the amended plots was higher than the control in both experiments.

Table 4.10 A: Effect of Soil Amendment and Plant Spacing on Fresh Shoot Biomass of Onion for 2019 Minor and 2020 Major Seasons

Soil amendments	2019 minor season Fresh biomass of shoot (g/plant)			mean	2020 major season Fresh biomass of shoot (g/plant)			mean
	10 × 10	15 × 10	15 × 15		10 × 10	15 × 10	15 × 15	
10 t/ha cm	8	10	12	10	8	11	11	10
15 t/ha cm	9	13	14	12	8	14	14	12
20 t/ha cm	9	14	15	13	9	13	14	12
300 kg/ha NPK	7	9	10	9	6	10	11	9
Control	5	7	8	7	5	7	9	7
Mean	8	11	12		7	11	12	
Spacing p =	2.8	8.3	8.2		2.7	7.5	4.7	
LSD (0.05)	1.2	1.4	1.3		1.2	1.3	1.3	
Soil amendments	2.7	8.3	8.1		2.7	7.4	4.5	
LSD (0.05)	1.2	1.3	1.4		1.2	1.4	1.3	

Table 4.10 B: Effect of Soil Amendment and Plant Spacing on Fresh Bulb Biomass of Onion for 2019 Minor and 2020 Major Seasons

	2019 minor season Fresh biomass of bulb (g/plant)				2020 major season Fresh biomass of bulb (g/plant)			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	68	80	100	83	67	80	98	82
15 t/ha cm	75	85	155	105	72	82	150	101
20 t/ha cm	78	90	162	110	76	88	160	108
300 kg/ha NPK	64	78	88	77	63	77	87	76
Control	55	67	78	67	55	68	77	67
Mean	68	80	117		7	11	12	
Spacing p =	8.5	7.5	1.8		6.3	5.0	1.3	
LSD (0.05)	1.6	1.3	1.4		1.5	1.3	1.4	
Soil amendments	8.5	7.6	1.8		6.2	5.0	1.3	
LSD (0.05)	1.5	1.3	1.3		1.5		1.4	

4.2.8 Dry shoot and bulb biomass

The interaction effect of the two factors significantly influenced dry shoot and bulb biomass yield in both 2019 minor season and 2020 major season (Table 4.11 A and B). With the increase in plant spacing, dry shoot and bulb biomass yield of the onion plants increased significantly across the increasing rate of the chicken manure. Thus, plants treated with chicken manure at 20 t/ha and spaced at 15 cm × 15 cm plant spacing produced the highest dry shoot and bulb biomass yield. However, plants grown on the control plots and spaced 10 cm × 10 cm apart produced the lowest dry bulb biomass yield. Thus, the total dry biomass yield obtained from plants treated with the combination of 20 t/ha chicken manure and plant spacing of 15 cm × 15 cm was about 6.5 tones higher than the total dry shoot and bulb biomass yield produced by onion plants treated with no soil amendment and spaced 10 cm × 10 cm apart in both 2019 minor and 2020 major seasons (Table 4.11 A and B). The shoot dry weight and bulb biomass resulting from the application of NPK

15-15-15 at 300 kg/ha was not significantly different from the control. On average, the weight of the bulb and total biomass from the amended plots was higher than the control in both experiments.

Table 4.11 A: **Effect of Soil Amendment and Plant Spacing on Dry Shoot Biomass of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

Soil amendments	2019 minor season Dry shoot biomass(g/plant)			mean	2020 major season Dry shoot biomass (g/plant)			mean
	10 × 10	15 × 10	15 × 15		10 × 10	15 × 10	15 × 15	
10 t/ha cm	5	7	10	7	5	9	8	7
15 t/ha cm	5	9	10	8	6	11	11	9
20 t/ha cm	6	9	11	9	6	10	12	9
300 kg/ha NPK	5	6	8	6	4	8	9	7
Control	4	5	6	5	3	5	7	5
Mean	5	7	9		5	9	9	
Spacing p =	0.5	3.2	4		1.7	5.3	4.3	
LSD (0.05)	2.2	3.3	1.6		2.1	3.3	1.5	
Soil amendments	0.5	3.2	4.0		1.7	5.3	4.3	
LSD (0.05)	2.2	3.3	1.6		2.1	3.3	1.5	

Table 4.11 B: **Effect of Soil Amendment and Plant Spacing on Dry Bulb Biomass of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

Soil amendments	2019 minor season Dry bulb biomass (g/plant)			mean	2020 major season Dry bulb biomass (g/plant)			mean
	10 × 10	15 × 10	15 × 15		10 × 10	15 × 10	15 × 15	
10 t/ha cm	60	76	95	77	61	75	91	76
15 t/ha cm	70	81	150	100	68	78	145	97
20 t/ha cm	71	85	158	105	70	82	151	101
300 kg/ha NPK	60	73	83	72	56	73	82	70
Control	53	62	74	63	51	62	73	62
Mean	63	75	112		61	74	108	
Spacing p =	5.7	7.3	5.5		6.7	5.5	3.8	
LSD (0.05)	3.3	4.4	3.2		3.2	4.2	3.3	
Soil amendments	5.6	7.4	5.5		6.8	5.5	3.8	
LSD (0.05)	3.3	4.4	3.2		3.1	4.2	3.3	

4.3 Yield and yield components

4.3.1 Bulb diameter

The interaction of the two factors influenced this parameter significantly (Table 4. 12). Increasing the rate of soil amendment from 10 t/ha CM to 20 t/ha CM consistently increased the bulb diameter of onion across the increasing plant spacing. The widest bulb diameter was recorded in response to the application of 20 t/ha CM and plant spacing of 15 cm × 15 cm. The narrowest average bulb diameter was obtained at the lower soil amendment rates of 10 t/ha CM and closer plant spacing of 10 cm × 10 cm respectively (Table 4. 12)

Table 4.12: **Effect of Soil Amendment and Plant Spacing on Bulb Diameter of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

Soil amendments	2019 minor season Bulb diameter (cm)			mean	2020 major season Bulb diameter (cm)			mean
	10 × 10	15 × 10	15 × 15		10 × 10	15 × 10	15 × 15	
10 t/ha cm	2.10	2.60	3.00	2.57	2.20	2.50	2.90	2.53
15 t/ha cm	2.60	3.60	4.10	3.43	2.50	3.30	3.10	2.97
20 t/ha cm	2.50	3.50	3.90	3.30	2.60	3.40	3.20	3.07
300 kg/ha NPK	2.10	2.50	2.70	2.43	2.10	2.30	2.20	2.20
Control	1.50	2.10	2.20	1.93	1.60	2.00	2.00	1.87
Mean	2.16	2.86	3.18		2.20	2.70	2.68	
Spacing p =	0.18	0.43	0.64		0.15	0.35	0.29	
LSD (0.05)	3.2	3.5	3.4		3.2	3.3	3.0	
Soil amendments	0.18	0.43	0.64		0.15	0.35	0.29	
LSD (0.05)	3.2	3.5	3.4		3.2	3.3	3.0	

There was a significant difference in the bulb diameter among the different treatments in both 2019 minor and 2020 major seasons (Table 4.12). In 2019 minor season, the application of 15 t/ha of chicken manure (4.10 cm) together with plant spacing 15 cm × 15 cm produced bulb with the widest diameter but was not significantly different from 20 t/ha (3.90 cm) and 10 t/ha (3.00 cm) chicken manure treatments. All the fertilizer amendments were significantly higher than the control except NPK 15-15-15 at 300 kg/ha (2.50 cm) treatment which was not significantly different from the control (2.10 cm). In 2020 major season, application of 20 t/ha CM together with 15 cm × 10 cm resulted in the widest bulb diameter (3.40 cm) but this was not significantly different from the application of 15 t/ha CM with plant spacing 15 cm × 15 cm (3.10 cm). Furthermore, the bulb diameter of onion from the NPK 15-15-15 at 300 kg/ha amendment with plant spacing 10 cm × 10 cm (2.10

cm) was significantly lower than the other amended plots but statistically similar to the control (1.60 cm).

4.3.2 Bulb length

The main effect of soil amendment and that of plant spacing as well as their interactions significantly influenced the average bulb length of the onion plants in both experiments (Table 4. 13). Increasing the rate of soil amendment application progressively increased the average bulb length of the onion plants across the increasing plant spacing. The highest average bulb length was found in response to the application of 20 t/ha CM and plant spacing of 15 cm × 15 cm.

The bulb length of onion from all the amended plots were significantly higher than the control (33.70 mm) in 2019 minor season. In addition, the longest bulb length (43.70 mm) was achieved with the application of 15 t/ha of chicken manure with plant spacing of 15 cm × 15 cm which was significantly higher compared to 10 t/ha chicken manure (42.60 mm) and NPK 15-15-15 at 300 kg/ha amendments (39.90 mm) but similar to the other amendments (Table 4.13). In 2020 major season, the NPK 15-15-15 at 300 kg/ha treatment with plant spacing of 10 cm × 10 cm had the shortest bulb (34.20 mm) but was significantly different to the control (28.10 mm) with plant spacing of 10 cm × 10 cm. Again, the longest bulb was recorded for the 15 t/ha chicken manure treatment (43.60 mm) which was higher than the 20 t/ha chicken manure treatment (42.90 mm) but statistically the same.

Table 4.13: **Effect of Soil Amendment and Plant Spacing on Bulb length of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Bulb length (mm)				2020 major season Bulb length (mm)			
Soil amendments	10 × 10	15 × 15	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	36.50	38.40	42.60	39.17	36.30	39.80	42.50	39.53
15 t/ha cm	37.20	39.20	43.70	40.03	37.30	39.10	43.60	40.00
20 t/ha cm	37.80	39.40	43.80	40.33	37.40	39.30	42.90	39.87
300 kg/ha NPK	34.60	36.40	39.90	36.97	34.20	35.90	39.10	36.40
Control	28.70	29.80	33.70	30.73	28.10	30.00	33.60	30.57
Mean	34.96	36.64	40.74		34.66	36.82	40.34	
Spacing p =	13.69	16.02	17.96		15.10	16.89	17.20	
LSD (0.05)	3.2	2.3	2.4		3.1	2.1	2,3	
Soil amendments	13.78	16.12	17.97		15.21	16.89	17.31	
LSD (0.05)	3.3	2.3	2.4		3.2	2.1	2.3	

4.3.3 Mean bulb weight

The two factors interacted to influence this parameter significantly (Table 4. 14). Increasing the rate of soil amendment application increased the mean bulb weight of the onion plants across the increasing plant spacing. The highest mean bulb weight was found in response to the application of 20 t/ha CM and plant spacing of 15 cm × 15 cm.

Table 4.14: **Effect of Soil Amendment and Plant Spacing on Mean bulb weight of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

Soil amendments	2019 minor season Mean bulb weight(g)			mean	2020 major season Mean bulb weight(g)			mean
	10 × 10	15 × 10	15 × 15		10 × 10	15 × 10	15 × 15	
10 t/ha cm	69	82	100	83.67	68	81	98	82
15 t/ha cm	76	86	156	106	73	83	152	103
20 t/ha cm	78	91	163	111	77	89	161	109
300 kg/ha NPK	65	79	89	78	64	78	87	76
Control	56	68	78	67	57	69	78	68
Mean	69	81	117		68	80	115	
Spacing p =	7.7	7.7	5.7		6.7	5.0	4.7	
LSD (0.05)	2.4	2.3	3.2		2.4	2.2	3.1	
Soil amendments	7.7	7.7	5.7		6.7	5.0	4.7	
LSD (0.05)	2.4	2.3	3.2		2.3	2.2	3.1	

In both experiments, the mean bulb weight of onions from the amended plots were significantly higher than the control, except in 2020 major season where the control (57 g) with plant spacing of 10 cm × 10 cm was not significantly different from NPK 15-15-15 at 300 kg/ha amendment (64 g) with plant spacing of 10 cm × 10 cm. The application of 20 t/ha CM (163 g) with spacing of 15 cm × 15 cm and 15 t/ha chicken manure (156 g) with spacing of 15 cm × 15 cm produced significantly higher mean bulb weight compared to the other amendments in 2019 minor season.

In 2020 major season, the highest mean bulb weight was produced by the 20 t/ha chicken manure treatment (161 g) with spacing of 15 cm × 15 cm which was significantly different from the 10 t/ha chicken manure (68 g) with plant spacing of 10 cm × 10 cm and NPK 15-15-15 at 300 kg/ha treatments (64 g) with plant spacing of 10 cm × 10 cm.

4.3.9 Marketable bulb yield

The interaction effect of soil amendment application and plant spacing significantly influenced the marketable bulb yield of the crop (Table 4. 15) in both experiments. Similar to the total bulb yield, increasing the rate of soil amendment significantly increased the production of marketable bulb yield across the increasing rate of the plant spacing. However, the increase occurred only up to the application of 15 t/ha CM and 10 cm × 10 cm plant spacing, beyond which the marketable bulb yield decreased.

The highest marketable bulb yield was recorded from onion plants grown at the rate of 15 t/ha CM and the plant spacing of 10 cm × 10 cm. The lowest marketable bulb yield was obtained in response to no application of soil amendment combined with the plant spacing of 10 cm × 10 cm. The marketable bulb yield obtained in response to the application of 15 t/ha CM at the plant spacing of 10 cm × 10 cm exceeded the marketable bulb yield of plants grown with no application of the soil amendment at the plant spacing of 10 cm × 10 cm by 120% (Table 4.15). The marketable bulb yield from the amended plots were statistically higher compared to the control in 2019 minor season.

In 2020 major season however, even though the marketable bulb yield from the amended plots were significantly higher than the control, there was no significant difference between the control (7.10 t/ha) and the NPK 15-15-15 at 300 kg/ha amendment (9.10 t/ha) with plant spacing 10 cm × 10 cm. The highest marketable bulb yield was registered by the 15 t/ha chicken manure treatment (12.85 t/ha) with plant spacing 10 cm × 10 cm in 2020 major season.

Table 4.15: **Effect of Soil Amendment and Plant Spacing on Marketable bulb yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Marketable bulb yield(t/ha)				2020 major season Marketable bulb yield (t/ha)			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	9.30	10.50	10.60	10.13	9.20	10.40	10.30	9.97
15 t/ha cm	12.40	12.90	12.90	12.73	12.20	12.85	12.85	12.63
20 t/ha cm	12.70	12.80	12.90	12.80	12.70	12.80	12.80	12.77
300 kg/ha NPK	9.20	10.00	10.80	10.00	9.10	9.95	10.50	9.85
Control	7.20	8.30	9.10	8.20	7.10	8.20	9.00	8.10
Mean	10.16	10.90	11.26		10.06	10.84	11.09	
Spacing p =	5.4	3.8	2.6		5.4	3.9	2.8	
LSD (0.05)	3.2	2.4	2.3		3.2	2.1	2.2	
Soil amendments	5.4	3.8	2.7		5.4	3.9	2.8	
LSD (0.05)	3.3	2.5	2.4		3.2	2.1	2.2	

4.3.8. Unmarketable bulb yield

Unmarketable bulb yield was significantly influenced by the combined effect of plant spacing and soil amendment levels. Significant effects were observed in unmarketable bulb yield in response to the main effects of both plant spacing and soil amendment rate (Table 4.16) in both experiments. With the increase in the plant spacing and soil amendment rate, unmarketable bulb yield of onion decreased significantly. The highest value of unmarketable bulb yield was recorded in control soil amendment rate application at the plant spacing of 10 cm × 10 cm. This was followed by the narrow plant spacing at the rate of 300 kg/ha soil amendment. The minimum unmarketable bulb yield was obtained when onion plants were fertilized with 20 t/ha CM and planted at spacing of 10 cm × 10 cm and 15 cm × 10 cm and when the 15 t/ha CM was combined with the plant spacing of 10 cm × 10 cm, 15 cm × 10 cm and 15 cm × 15 cm. Similarly, when 10 cm × 10 cm, 15 cm × 10 cm and 15 cm × 15 cm, of plant spacing was combined with 10 t/ha CM, minimum unmarketable bulb yield was produced. On average experiment two produced the highest unmarketable bulb yield (Table 4.16)

Table 4.16: **Effect of Soil Amendment and Plant Spacing on Unmarketable bulb yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Unmarketable bulb yield (t/ha)				2020 major season Unmarketable bulb yield (t/ha)			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	3.20	3.10	3.00	3.10	3.40	3.30	3.10	3.27
15 t/ha cm	2.80	2.50	2.10	2.47	2.90	2.60	2.20	2.57
20 t/ha cm	2.60	2.30	2.00	2.30	2.70	2.50	2.20	2.47
300 kg/ha NPK	3.50	3.20	3.00	3.23	3.70	3.60	3.20	3.17
Control	5.30	5.20	4.90	5.13	5.40	5.30	4.90	5.20
Mean	3.48	3.26	3.00		3.62	3.46	3.12	
Spacing p =	1.15	1.32	1.35		1.14	1.27	1.21	
LSD (0.05)	3.2	4.3	4.2		3.2	4.1	4.3	
Soil amendments	1.26	1.36	1.45		1.14	1.27	1.21	
LSD (0.05)	3.3	4.2	4.4		3.2	4.1	4.3	

4.3.7 Total bulb yield

The interaction effect of soil amendment application and plant spacing significantly influenced the total bulb yield of the onion (Table 4. 17). Total bulb yield increased significantly in response to increasing the rate of soil amendment application across the increasing rate of the plant spacing, except in treatment combination of no soil amendment application of which it decreased with increasing plant spacing. The increase occurred only up to the application of 15 t/ha CM and 15 cm × 10 cm plant spacing, beyond which the total bulb yield decreased. The highest total bulb yield was obtained from onion plants grown at the rate of 15 t/ha CM and the plant spacing of 15 cm × 10 cm. The lowest total bulb yield was obtained in response to no application of soil amendment at plant spacing of 10 cm × 10 cm. The total bulb yield obtained in response to the application of 15 t/ha CM at the plant spacing of 15 cm × 15 cm exceeded the total bulb yield obtained from plants grown with no application of the fertilizer at the plant spacing of 10 cm × 10 cm by 90% (Table 4.17) in both experiments. In the 2020 major season, the control with plant spacing of 10 cm × 10 cm had a significantly lower total bulb yield (12.50 t/ha) compared to the other amendments but was not significantly different from the NPK 15-15-15 at 300 kg/ha amendment with plant spacing of 10 cm × 10 cm (12.80 t/ha).

Table 4.17: **Effect of Soil Amendment and Plant Spacing on Total bulb yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Total bulb yield (t/ha)				2020 major season Total bulb yield (t/ha)			
Soil amendments	10 × 10	15 × 15	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	12.50	13.50	13.60	13.20	12.60	13.70	13.40	13.23
15 t/ha cm	15.20	15.40	15.00	15.20	15.10	15.45	15.05	15.20
20 t/ha cm	15.30	15.10	14.90	15.10	15.40	15.30	15.00	15.23
300 kg/ha NPK	12.70	13.20	13.80	13.23	12.80	13.55	13.70	13.35
Control	12.50	13.50	14.00	13.33	12.50	13.50	13.90	13.30
Mean	13.64	14.14	14.26		13.68	14.10	14.21	
Spacing p =	2.16	1.05	0.41		2.07	0.97	0.58	
LSD (0.05)	4.4	3.3	3.2		4.2	3.2	3.1	
Soil amendments	2.21	1.14	0.43		2.07	0.97	0.58	
LSD (0.05)	4.4	3.3	3.2		4.2	3.1	3.1	

4.3.4 Harvest index

Table 4.18 shows the effect of soil amendments and plant spacing on the harvest index of ‟ Violet damani’ onion cultivar in two separate experiments. Significant difference was observed in harvest index among the different treatments and plant spacing in 2019 minor season. There was no statistical difference in the harvest index among the different treatments and plant spacing imposed on the onion plant in 2020 major season.

Chicken manure at 15 t/ha with plant spacing of 15 cm × 15 cm registered the highest harvest index (0.76) in 2020 major season but this was not significantly different from the other treatments.

Table 4.18: **Effect of Soil Amendment and Plant Spacing on Harvest index of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Harvest index				2020 major season Harvest index			
Soil amendments	10 × 10	15 × 15	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	0.69	0.70	0.75	0.71	0.66	0.69	0.74	0.70
15 t/ha cm	0.71	0.73	0.78	0.74	0.70	0.71	0.76	0.72
20 t/ha cm	0.69	0.73	0.79	0.74	0.70	0.72	0.75	0.72
300 kg/ha NPK	0.64	0.66	0.69	0.66	0.63	0.65	0.68	0.65
Control	0.59	0.62	0.66	0.62	0.57	0.61	0.64	0.61
Mean	0.66	0.69	0.73		0.65	0.68	0.71	
Spacing p =	0.23	0.22	0.32		0.29	0.20	0.26	
LSD (0.05)	1.2	1.3	1.5		1.2	1.4	1.3	
Soil amendments	0.23	0.22	0.32		0.29	0.20	0.26	
LSD (0.05)	1.2	1.3	1.5		1.2	1.4	1.3	

4.4 Grading Systems of Marketable Bulb Yield

4.4.1 Small-sized bulb yield (<50g)

The main effect of plant spacing and soil amendments rates and their interaction effect significantly influenced the small bulb size distribution of onion (Table 4.19) in both experiments. Increasing the plant spacing significantly decreased the production of small sized bulb yield across the increasing rate of soil amendments.

The highest small sized bulb yield was obtained from onion plants grown at the control soil amendment and 300 kg/ha NPK and spaced at the plant spacing of 10 cm × 10 cm. The lowest small sized bulb yield of onion was recorded in response to the application of higher soil amendment rate at 20 t/ha CM and 15 t/ha CM and planted at the plant spacing of

15 cm × 15 cm and 15 cm ×10 cm. The small sized bulb yield obtained in response to the application of control soil amendment planted at the plant spacing of 10 cm × 10 cm exceeded small sized bulb yield of plants grown with 20 t/ha CM application of the soil amendment planted at the plant spacing of 15 cm × 15 cm by 2131% (Table 4.19). On average, 2020 major season had the highest small sized bulb yield.

Table 4.19: **Effect of Soil Amendment and Plant Spacing on Small-sized Bulb Yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

Soil amendments	2019 minor season Small-sized Bulb Yield (t/ha)			mean	2020 major season Small-sized Bulb Yield(t/ha)			mean
	10 × 10	15 × 10	15 × 15		10 × 10	15 × 10	15 × 15	
10 t/ha cm	9.7	8.8	6.8	8.4	9.9	8.9	6.7	8.5
15 t/ha cm	3.0	2.8	1.2	2.3	3.5	2.8	1.3	2.5
20 t/ha cm	2.7	2.4	1.0	2.0	2.9	2.6	1.1	2.2
300 kg/ha NPK	14.0	13.6	13.0	13.5	14.3	13.8	13.3	13.8
Control	16.7	15.4	14.7	15.6	16.8	15.5	14.7	15.7
Mean	9.2	7.3	7.3		9.5	8.7	7.4	
Spacing p =	4.05	3.8	4.09		3.01	3.07	4.37	
LSD (0.05)	3.2	3.3	3.4		3.1	3.2	3.3	
Soil amendments	4.05	3.8	4.09		3.01	3.07	4.37	
LSD (0.05)	3.2	3.3	3.4		3.2	3.2	3.3	

4.4.2 Medium bulb size yield (50-100g)

Plant spacing and soil amendment levels had highly significant variation on medium bulb size yield of onion in both experiments. The interaction effect also exerted a significant influence on this parameter (Table 4.20). The production of medium sized bulb yield of onion was significantly increased by increasing the soil amendment rate across the increasing of plant spacing. However, the increase was not consistent and occurred only up to the soil amendment rate of 15 t/ha CM at the plant spacing of 10 cm × 10 cm beyond which the medium sized bulb yield decreased. However, medium sized bulb yield increased with application of no soil amendment rate spaced at all plant spacing. The highest medium sized bulb yield was achieved from onion plants grown with the application of 10 t/ha CM at the plant spacing of 10 cm × 10 cm. The medium sized bulb yield obtained in response to the application of 10 t/ha CM at the intra-row spacing of 15 cm × 10 cm exceeded the medium sized bulb yield of plants grown with the application of no soil amendment rate at the plant spacing of 10 cm × 10 cm by 632% (Table 4.20).

Table 4.20: **Effect of Soil Amendment and Plant Spacing on Medium Bulb Size Yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Medium Bulb Size Yield (t/ha)				2020 major season Medium Bulb Size Yield (t/ha)			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	9.0	7.5	6.2	7.6	9.1	7.6	6.3	7.7
15 t/ha cm	4.4	4.2	2.3	3.6	4.5	4.3	2.4	3.7
20 t/ha cm	4.3	3.2	1.4	3.0	4.6	3.3	1.6	3.2
300 kg/ha NPK	9.7	7.2	5.8	7.6	9.8	7.3	5.8	7.6
Control	4.3	4.1	3.8	4.1	4.7	4.2	3.9	4.3
Mean	6.3	5.2	3.9		6.5	5.3	4.0	
Spacing p =	7.61	3.87	4.43		7.12	3.87	4.21	
LSD (0.05)	5.5	2.2	2.4		3.5	2.2	2.3	
Soil amendments	7.63	3.88	4.56		7.22	3.87	4.32	
LSD (0.05)	5.5	2.3	2.5		4.5	2.1	2.4	

4.4.3 Large-sized bulb yield (100-160g)

Soil amendment rate and plant spacing interacted to influence large-sized bulb yield (Table 4.21). Large sized bulb yield increased significantly in response to the increased application of soil amendment rate across the increasing of plant spacing, except for the control and 300 kg/ha NPK combined with all the plant spacings. The increase occurred only up to the soil amendment application and plant spacing combination of 15 t/ha CM and 15 cm × 10 cm of plant spacing above which decrease in the yield of large sized bulb occurred. When the onion plants were spaced at 15 cm × 10 cm large sized bulb yield increased across the different soil amendment rates. The maximum large sized bulb yield was obtained in response to the application of 15 t/ha CM and plant spacing of 15 cm × 10 cm. The minimum value was achieved from the treatment combination of narrowest plant spacing of 10 cm × 10 cm and control soil amendment rate (Table 4.21).

Table 4.21: **Effect of Soil Amendment and Plant Spacing on Large-sized Bulb Yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Large-sized Bulb Yield (t/ha)				2020 major season Large-sized Bulb Yield (t/ha)			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	9.3	10.2	11.1	10.2	9.2	10.0	11.0	10.1
15 t/ha cm	11.3	12.3	13.5	12.4	11.2	12.1	13.2	12.2
20 t/ha cm	11.4	12.5	13.7	12.5	11.3	12.4	13.3	12.3
300 kg/ha NPK	1.5	2.5	2.6	2.2	1.3	2.3	2.3	2.0
Control	0.0	0.1	0.2	0.1	0.0	0.1	0.2	0.1
Mean	6.7	7.5	8.2		6.6	7.4	8.0	
Spacing p =	3.48	3.77	4.52		3.41	3.28	3.36	
LSD (0.05)	6.2	2.3	8.2		4.3	2.5	6.2	
Soil amendments	3.58	3.77	4.54		3.46	3.36	3.47	
LSD (0.05)	3.6	2.3	4.8		3.4	2.6	6.3	

4.4.4. Extra-Large bulb yield (>160 g)

Interaction effect of plant spacing and soil amendment rate was also significant on extra-large bulb yield of onion (Table 4.22). Increasing the rate of soil amendment, increased extra-large sized bulb yield of onion across the increasing plant spacing. The lowest extra-large bulb yield was recorded when the onion plants were grown with no soil amendment application and planted at the plant spacing of 10 cm × 10 cm and 15 cm × 10 cm as well as when the onion plants were treated with 300 kg/ha NPK and 10 cm × 10 cm plant spacing. Plant spacing and soil amendment rate combinations of 20 t/ha CM and 15 cm ×

15 cm plant spacing resulted in the highest extra-large bulb yield of onion in both 2019 minor and 2020 major seasons. On average 2019 minor season registered the highest extra-large bulb yield of onion than 2020 major season.

Table 4.22: **Effect of Soil Amendment and Plant Spacing on Extra-Large Bulb Yield of Onion at Harvest for 2019 Minor and 2020 Major Seasons.**

	2019 minor season Extra-Large Bulb Yield (t/ha)				2020 major season Extra-Large Bulb Yield (t/ha)			
Soil amendments	10 × 10	15 × 10	15 × 15	mean	10 × 10	15 × 10	15 × 15	mean
10 t/ha cm	2.0	2.1	2.4	2.2	1.9	2.0	2.3	2.1
15 t/ha cm	5.3	5.6	5.8	5.6	5.2	5.4	5.6	5.4
20 t/ha cm	5.4	5.7	5.8	5.6	5.3	5.5	5.7	5.5
300 kg/ha NPK	0.0	0.0	1.0	0.3	0.0	0.0	0.9	0.3
Control	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	2.5	2.7	3.0		2.5	2.6	2.9	
Spacing p =	7.24	8.08	7.26		6.99	7.53	6.97	
LSD (0.05)	3.4	3.5	7.2		3.5	3.6	7.3	
Soil amendments	7.34	8.18	7.48		6.98	7.56	6.96	
LSD (0.05)	3.5	3.6	7.3		3.5	3.7	7.2	

4.5 Partial Budget Analysis of Soil Amendments and Plant Spacing on Onions.

The average yields of treatments were obtained and adjusted down wards by 10% according to CIMMYT (1988) for both experiments. This is for the reason that, researchers have assumed that using the same treatments the yields from the experimental plots and farmers' fields are different, thus average yields should be adjusted downward. Based on this, the recommended level of 10% was adjusted from all the treatments in 2019 minor and 2020 major seasons to get the net yield.

The adjusted yields were multiplied by field price to obtain gross field benefit of onion. The total costs and net benefits were calculated for both experiments. The different costs of both experiments include cost for NPK, seed, chicken manure and labour cost. The purchasing price of NPK and seeds were GH¢2.8 per kg and GH¢ 10.00 per Kg respectively. The cost for daily labour during the seasons was GH¢ 25 per day. The field price of onion during the harvesting seasons were GH¢ 5 per Kg and 7 per Kg for 2019 minor and 2020 major seasons respectively. All the variable costs were subtracted from gross benefit to obtain net benefit.

In 2019 minor season, in applying 300 kg/ha NPK over control, if you invest an additional GH¢ 10.0 as a result, you will recover your GH¢ 10.0 and obtain an additional GH¢ 33.08. In applying 10 t/ha CM over 300npk, if you invest additional GH¢ 10.0 as a result, you will recover your GH¢ 10 and obtain an additional GH¢ 1388.8. *D, the treatment 20 t/ha CM is dominated by 15 t/ha CM because it has a higher total cost but a lower net benefit than 15 t/ha CM, calculated MRR (4.23 A)

In 2020 major season, in applying 300 kg/ha NPK over control, if you invest an additional GH¢ 10.0 as a result, you will recover your GH¢ 10.0 and obtain an additional GH¢ 440.1. In applying 10 t/ha CM over 300npk, if you invest additional GH¢ 10.0 as a result, you will recover your GH¢ 10.0 and obtain an additional GH¢ 612.0. *D, the treatment 20 t/ha CM is dominated by 15 t/ha CM because it has a higher total cost but a lower net benefit than 15 t/ha CM, calculated MRR (4.23 B)

The minimum acceptable marginal rate of return (MARR %) should be between 50% and 100% CIMMYT (1988). Thus, the current study indicated that marginal rate of return is higher than 100% with the exception of the application of soil amendment rate of 20 t/ha CM at plant spacing of 15 cm × 15 cm for both experiments. This showed that all the treatment combinations with the exception of the application of soil amendment rate of 20 t/ha CM at plant spacing of 15 cm × 15 cm are economically important as per the MRR is greater than 100%. Hence, the most economically attractive combinations for small scale farmers with low cost of production and higher benefits were in response to the application of 15 t/ha CM at 10 cm × 10 cm plant spacing. However, for resource full producers (investors), application of 20 t/ha CM and 10 cm × 10 cm plant spacing was also profitable with higher cost and highest net benefit is recommended as a second option.

Table 4.23 A: Partial Budget Analysis of Soil Amendment and Plant Spacing for 2019 Minor Season.

Treatments	Total revenue (GH¢)	Total cost (GH¢)	Net benefit (GH¢)
Soil amendments			
Control	5,810.00	6075.00	(265.00)
10 t/ha Pm	20,912.50	8,360.70	12,551.80
15 t/ha Pm	24,115.00	9,503.60	14,611.50
20 t/ha Pm	16,712.50	10,646.40	6,066.10
300 kg/ha N P K	7527.00	8,417.50	890.50
LSD (p=0.05)	11188.4	160.8	1313.2
CV (%)	22.1	17.2	18.2

MRR	Control	300 Kg NPK	10 t/ha CM	15 t/ha CM	20/ha CM
TVC	6,075	7,527	8,360.7	9,503.6	10,646.4
NB	265	890.5	12,551.8	14, 611.5	6,0 66.1
MRR (%) = $\frac{\Delta NB}{\Delta TVC}$ x 100	-	43.08	1,398.8	180.2	*D

Treatments	Total revenue (GH¢)	Total cost (GH¢)	Net benefit (GH¢)
Spacing			
10 × 10 cm	5,810.00	6,075.00	265.00
15 × 10 cm	26,115.10	8,360.70	13,551.80
15 × 15 cm	28,868.00	12,086.40	16,781.60
LSD (p=0.05)	1454.8	7474.0	830.4
CV (%)	22.1	17.2	18.1

MRR	10 x 10	15 x 10	15 x 15
TVC	6,075	8,360.7	12,086.4
NB	265	13,551.8	16,781.6
MRR (%) = $\frac{\Delta NB}{\Delta TVC}$ x 100	-	581.3	86.7

Table 4.23 B: Partial Budget Analysis of Soil Amendment and Plant Spacing for 2020 Major Season.

Treatments	Total revenue (GH¢)	Total cost (GH¢)	Net benefit (GH¢)
Soil amendments			
Control	9,659.00	6,675.00	2,984.00
10 t/ha Pm	22,544.10	8,762.50	13,781.60
15 t/ha Pm	26,456.40	9,643.60	16,812.80
20 t/ha Pm	29,085.10	12,096.60	15,988.50
300 kg/ha N P K	15,876	7,826.00	8,050
LSD (p=0.05)	12387.3	165.6	1322.1
CV (%)	21.2	19.3	22.2

MRR	Control	300 Kg NPK	10 t/ha CM	15 t/ha CM	20/ha CM
TVC	6,675	7,826	8,762.50	9,643.60	12,096.60
NB	2,984	8,050	13,781.60	16, 812.80	15, 988.50
MRR (%) = $\frac{\Delta NB}{\Delta TVC} x\ 100$	-	440.1	612.0	344.06	*D

Treatments	Total revenue (GH¢)	Total cost (GH¢)	Net benefit (GH¢)
Spacing			
10 × 10 cm	11,259.00	6,675.00	4,584.00
15 × 10 cm	22,214.10	8,762.50	13,451.80
15 × 15 cm	26,456.40	9,643.60	16,812.80
LSD (p=0.05)	1534.6	748.2	930.8
CV (%)	21.2	19.3	22.2

MRR	10 x 10	15 x 10	15 x 15
TVC	6,675	8,762.50	12,086.4
NB	4,584	13,451.8	16,781.6
MRR (%) = $\frac{\Delta NB}{\Delta TVC} x\ 100$	-	424.1	86.7

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of Fertilizer on Soil Chemical Properties

Results from soil analysis indicated that some of the chemical properties of the soil at the experimental site prior to the application of the soil amendments were very low showing the poor fertility status of the soil. Magnesium, organic carbon, nitrogen and organic matter content were inadequate in the soil. The application of fertilizers, especially the chicken manure, remarkably improved the soil fertility status when the soil was analysed after harvesting.

With the application of soil amendments, there was an increase in the organic carbon and organic matter content of the soil. Zhang *et al.* (2009), also found that the application of organic manure had a positive impact on the organic carbon of the soil. In addition, Agbede *et al*. (2010), observed that soils treated with chicken manure had an increase in soil organic carbon and other nutrients compared to those treated with only NPK fertilizer.

The application of soil amendments also resulted in an increase in the nitrogen, phosphorus, potassium, cation exchange capacity, electrical conductivity and calcium and magnesium ions of the soil. This finding agrees with reports by Adekiya *et al.,* (2014) and Uwah *et al*.., (2014) that the application of poultry manure led to a significant increase in organic matter content, total N, available P, exchangeable K and Ca, of the soil. The findings by Adeleye *et al*. (2010) and Frempong *et al.* (2006), also confirm that soils amended with organic manure have improved cation ion exchange capacity, organic matter content, total nitrogen, potassium and phosphorus.

5.2 Effect of Fertilizer and Spacing on Vegetative Growth

5.2.1 Crop establishment

The results from the experiment indicated that the percentage crop establishment was high for treatments and the control in both experiments. This phenomenon could be attributed to the young onion seedlings were supplied with the right soil condition for proper growth and development. According to Sinnadurai (1992), the ideal soil type for onion production should be sandy loam which can retain a fair amount of water and easy to cultivate. Since the onion was planted on sandy loam soil, it is possible that may have favoured its growth hence the higher percentage of crop establishment. Good land preparation, regular watering and the rainfall received during the first two weeks after transplanting and the use of high quality seedlings might have contributed to the higher percentage of crop establishment attained.

5.2.2 Number of leaves

The number of leaves of the onion plant was influenced by the different treatments imposed on the plant. The amended plots produced greater number of leaves compared to the control (no fertilizer) at the various plant spacings. The increase in the number of leaves with respect to fertilizer application is consistent with the finding of Dapaah *et al.* (2014) who reported that the application of chicken manure led to greater number of leaves per plant compared to the untreated plot. Similar findings were also made by Bashir *et al*. (2015), who indicated that application of organic manure significantly increased the number of onion leaves over the control. The increase in the number of leaves per plant was because fertilizers supply the soil with high nutrients especially nitrogen which significantly supports vegetative growth (Blay *et al.*, 2002).

Results of the present study is in agreement with the work by Al-Fraihat (2016), who reported an increase in the number of onion leaves over the control with a combined application of compost/FYM and N fertilizer. In support of the current research finding, Meena *et al*. (2015), reported that the application of chicken manure produced the highest number of leaves per plant compared to the other sources of organic manure and the control (no fertilizer). The increase in the number of leaves per onion plant with the application of N fertilizer has also been documented by Abdissa *et al*., (2011).

The study further showed that there were no significant differences in the number of leaves per plant between the control and plants amended with NPK 15-15-15 at 300 kg/ha in 2020 major season. This may be attributed to the acidic nature of the soil which reduced the absorption and utilization of nutrients by the plants (Chao *et al*., 2014; Silveira, 2013). Results from the current study are consistent with findings by Sultana *et al.*, (2014) who reported that the sole application of N (without organic manure) had no significant effect on the number of leaves of onion.

The maximum number of leaves per plant of onion obtained in wider spacing of (15 cm × 15 cm) might be due to the availability of nitrogen and its mainly related to production of new shoots and vigor in vegetative growth of plants which is directly responsible for increasing leaf number as described by Rizk (2012) and Kokobe *et al*., (2013). Thus, there is less competition for nutrients, moisture and light among the plants to achieve the required food for their growth due to the wider spacing. This result is in agreement with the findings of Rao *et al.,* (2013) who reported that highest leaf number per plant of onion was recorded with the highest plant spacing of 20 cm x 12.50 cm.

Consistent with the results of this study, Khan *et al*. (2002) also indicated that lower leaf number per plant of onion was recorded from the treatment of narrow plant spacing. Dawar *et al.*, (2007), Latif *et al.*, (2010), Sikder *et al*., (2010) and Jilani *et al*., (2009) also reported that higher leaf numbers per plant of onion were recorded in response to wider plant spacing.

There were no significant differences in the number of leaves among plants treated with chicken manure at the various plant spacing

5.2.3 Plant height and leaf length

The results from the two experiments showed increased plant height with soil amendments compared to the control at the various days after transplanting. The different soil amendments supplied the soil with considerable levels of- N and which resulted in increase in plant height over the control. This is in conformity with the work of Morsy *et al*., (2012) who reported that onion plant height significantly increased as nitrogen fertilizer rates increased. There was a variation in plant height with respect to the treatment received. This observation agrees with Dapaah *et al*., (2014), who found a variation in plant height of "Bawku Red" onion cultivar when treated with different soil amendments. In agreement with the current findings, Bashir *et al.*, (2015) reported of an increased plant height with the application of organic manure. Similarly, Blay *et al.* (2002), reported that the plant height of shallots grown on sandy soils was significantly increased with the addition of chicken manure and inorganic fertilizer to the soil. The observation of Sultana *et al*. (2014) that application of N from organic and chemical sources significantly influenced plant height, further supports the findings of this current study. The findings by Kandil *et al.*,

(2013) that among the three sources of organic manure used in soil amendment, chicken manure gave the tallest plants further supports this current study.

The results from this study also showed that the chicken manure amendments resulted in higher plant height compared to the NPK treatment. This result is also in agreement with the work of Abou El- Magd *et al*., (2012) who found that chicken manure produced the tallest garlic plants compared to the conventional chemical fertilizer. Also, the findings of Al-Fraihat, (2016), Meena *et al.*, (2015), Yohannes *et al.*, (2013) and Abdissa *et al.*, (2011) are all consistent with this present study.

The different treatments investigated had a significant effect on the leaf length, at the various days after planting in both experiments. Leaf length was observed to be higher among the fertilizer amended treatments compared to the control. The results obtained are in agreement with that by Yohannes *et al.,* (2013), who found that the application of N and FYM significantly increased the leaf length of onion. In agreement with the current findings, Sultana *et al.,* (2014) and Jilani (2004), have all reported increased leaf lengths of onion with the application of N from organic and inorganic sources.

The increase in plant height at the maximum plant spacing of (15 cm × 15cm) may be due to less interplant competition for the growth factors like water, nutrient and light, which may lead to better growth and significantly taller plant height as compared to closed spacing (10 cm × 10 cm) as explained by Khan *et al.*, (2002). This finding agrees with results of Khan *et al.,* (2003), Kantona *et al*., (2003) and Aliyu *et al.,* (2008), who reported that wider rather than narrower plant spacing produced taller onion plants, showing that narrower plant spacing leads to stiffer competition among plants for growth factors, causing reduced growth, Hamma I. L. (2013).

5.2.4 Leaf diameter

Chicken manure and NPK amendments resulted in an increase in the leaf diameter of the 'Violet damani' onion cultivar, at the various days after planting over the control in both experiments but there was no significant differences in leaf diameter among plants treated with different soil amendment rates. The increase in the leaf diameter could be due to the availability of N in the fertilizer which is responsible for proper vegetative growth. The results from the experiment further showed that the chicken manure treatments produced plants with wider leaf width compared to the NPK treatment. Similar observations were made by Suresh *et al.,* (2004). Yohannes *et al*., (2013) and Abdissa *et al.,* (2011) reported that application of N did not affect the leaf diameter of onion which contradict the results of the current study.

The increase in leaf diameter with the increase in the plant spacing could be associated with less stiff competition for other growth factors among the onion plants. Thus, more widely spaced plants are able to intercept more light and capture other resources for photosynthesis and better growth and development. In agreement with the results of this study, Seid *et al.,* (2014) and Yemane *et al.,* (2013) also showed that the lowest leaf diameter was recorded for narrow plant spacing of garlic and onion respectively.

5.3 Number of days to maturity

Results from the current study revealed that there were higher number of days to maturity in the chicken manure amended plots compared to the other treatments for both experiments. This may be attributed to the fact that chicken manure contains good amounts of nitrogen, phosphorus, potassium and other macro and micro elements needed by the plant for proper growth and development (Amanullah *et al.*, 2007). The delay in maturity in response to the increased rate of soil amendments and wider plant spacing may be attributed to nitrogen enhancing plant biochemical processes, which in turn extends vegetative growth as a result of which it leads to delayed maturity (Abdissa *et al*., 2011). The current study is in agreement with the findings of Meena *et al*. (2007) and Morsy *et al*. (2012) who reported that maturity of onion plants was delayed in response to increasing nitrogen application.

5.4 Fresh shoot and bulb and biomass

The higher onion fresh shoot bulb and total biomass were recorded at wider intra-row spacing and higher soil amendments rates might be linked to nitrogen increases or enhances assimilate production in onion plants (Sharma, 1992). The plant grown at the widest spacing produced the highest shoot dry matter yield might also be attributed to the less stiff competition among onion plants for growth factors, as a result more accumulation of dry matter may have occurred. The present finding is in agreement with the results of Nasreen *et al*. (2007) who indicated that higher fresh shoot bulb and total biomass was obtained when the rate of nitrogen fertilizer was increased from 0 N kg/ha to 150 kg/ha. Rao *et al*. (2013) also stated that the maximum weight of leaves per plant was recorded with the application of nitrogen at the higher rate of 75 kg/ha and wider spacing of 20 x 12.5 cm. Consistent with this results Yemane *et al*. (2014) showed that leaf dry matter yield of onion decreased from 2.63 to 1.48 g per plant in response to increasing planting densities. Meena *et al.* (2015) reported that application of 5 t/ha of chicken manure saw a significant increase in the weight of the fresh shoot biomass of onions over the control and this is in support of the current study. Mousa and Mohamed (2009) reported that the application of chicken manure increased the total dry biomass of onion over the control, it also confirms this current study. In agreement with this study, Eliakira and Yohana (2013) and Kandil *et al.*, (2013) also observed an increase in the fresh weight of shoot biomass of onion with the application of chicken manure.

The results from this study further showed that the NPK amendment had lower biomass weight compared to chicken manure. Similar findings were reported by Yassen and Khalid (2009), who indicated that the application of chicken manure increased the weight of fresh shoot, total dry and total fresh biomass of onion compared to the control treatment (recommended NPK). Dapaah *et al.*, (2014) documented that chicken manure application increased the weight of the total dry biomass of onion over the NPK treatment and that confirm the current study.

The results from experiment one of this current study revealed that the weight of the total dry biomass from the NPK plots was significantly higher compared to the control (no fertilizer). Similar findings were documented by Mohammadi-Fatideh and Hassanpour-Asil (2012) and Abdissa *et al.*, (2011) that the total dry biomass of onion was increased when N from inorganic sources were applied.

The findings of Dapaah *et al*., (2014), that the application of chicken manure and NPK fertilizer significantly increased the total dry biomass of onion over the control is consistent with the result from this study. In addition, the outcome of this study is in agreement with the findings of Al-Fraihat (2016), Mutetwa and Mtaita (2014), Rabari *et al.,* (2014), Singh and Ram (2014), Abdel-Mawgoud *et al.*, (2005) and Khalil *et al.,* (2002), that an application of compost and mineral N significantly increased the total fresh shoot bulb and total biomass of onion.

5.5 Dry shoot and bulb biomass

The increase in total dry shoot, bulb and total biomass in response to the increasing rate of soil amendments and wider plant spacing may be probably associated with the nitrogen supply, which enhances the vegetative growth of plants like leaf number, leaf diameter, leaf length and plant height which contribute for improved rate of photosynthesis and assimilate production in the vegetative part and partitioning to the bulbs (Sharma, 1992). In addition, plants grown at the widest spacing produced the highest dry shoot, bulb and total biomass possibly due to less competition among them for growth resources. Supporting the current study, Sikder *et al*. (2010) reported that higher values of shoot and bulb dry weight leads to higher in dry total biomass of onion in wider spacing.

Similarly, Nasreen *et al*. (2007) and El-Tantawy and El-Beik (2009) indicated that application of higher N/ha doses increased dry total biomass yields of onion. In harmony with the results of this study, Pervez *et al*. (2004) indicated that maximum total biomass per plant of radish was obtained in response to the application of higher nitrogen doses interacting with wider intra-row spacing of radish.

5.6 Effect of Fertilizer and Spacing on Yield and Yield Components

5.6.1 Bulb diameter

The development of wider bulb diameter with increasing plant spacing and rate of soil amendments could be associated with the availability of more growth resources due to less competition and with application of N, which could be associated with promoting nature of nitrogen in cell elongation, above ground vegetative growth and synthesis of chlorophyll to impart dark green color of leaves. This may be linked to metabolic processes which increase dry matter production and translocation to the bulbs (Brady, 1985). The current results are supported by the findings of Jilani *et al*. (2009), Akoun (2005) and Muhammad *et al*. (2011) who stated that higher bulb diameter was achieved for the wider plant spacing as compared to the closer spacing of onion. Similarly, Soleymani and Shahrajabian (2012) showed that nitrogen fertilization increased bulb diameter of onion compared to the control plots. Ghaffoor *et al*. (2003) also reported that the nitrogen dose of 120 kg/ha N proved the best for the maximum bulb diameter of onion.

5.6.2 Bulb length

The study revealed that the bulb length of onion from all the amended plots in experiment one were significantly higher than the control. In experiment two, plots amended with chicken manure had a significantly higher bulb length than the control and NPK fertilizer application. This outcome could be due to the more availability of nitrogen in the chicken manure. In agreement with this result, Sultana *et al*. (2014) reported increased bulb length with a combined application of N from organic and inorganic sources.

Similar results were also reported by Yohannes *et al.* (2013), Yadav *et al*. (2003) and Reddy (2005) that N fertilization increased the bulb length of onion. Also, the results of this study contradicts the findings by, Abdissa *et al.* (2011) who observed no effect of N fertilization on the bulb length of onion.

5.6.3 Bulb weight

The findings showed that the mean bulb weight from the amended plot was higher than the control in both experiments. This result is in agreement with the findings by Sultana *et al*. (2014) that the integrated application of N resulted in a significant increase in the mean bulb weight of onion over the control and NPK amendment. Similar findings were made by Abbey and Kanton (2004), who reported that the application of farmyard manure and inorganic fertilizer resulted in an increase in the mean bulb weight of onion. The study further showed that the mean bulb weight of onion from the NPK treatment performed better than the control. Agumas *et al*. (2014), Mohammadi-Fatideh and Hassanpour Asil (2012) and Abdissa *et al*. (2011) also reported that the mean bulb weight of onion was significantly increased with the application of mineral N which is in consistent with results of this study. The chicken manure amendment was found to perform better than the other amendments. Similar results were reported by Kandil *et al*. (2013) and Mousa and Mohamed (2009), that an improved mean bulb weight for chicken manure amended plot over mineral fertilizer and other sources of organic manure. In agreement with the results of the current study, Yohannes *et al.* (2013) indicated that the application of farmyard manure significantly affected the mean bulb weight of onion.

The results from the study indicated that the mean bulb weight (MBW) showed a strong significant positive association with the number of leaves (NL) and the leaf length (LL) in both experiments. The increase in the mean bulb weight of onion in response to N application could be due to the increase in the number of leaves and leaf length associated with an increase in N application. In agreement with this finding, Yohannes *et al.* (2013)

reported that the mean bulb weight of onion showed a significant and strong correlation with the number of leaves and leaf length in response to increase in N application.

In harmony with this result, Muhammad *et al.* (2011), Mahadeen, (2008), Dorcas *et al.* (2012) and Jilani *et al.* (2010) found that the lowest average bulb weight was obtained for narrowly spaced onion plants. In agreement with the results of this study, Soleymani and Shahrajabian (2012), Aliyu *et al.* (2008) and Morsy *et al.* (2012) mentioned that average bulb weight of onion increased with nitrogen rate.

5.6.4. Marketable bulb yield

The maximum marketable bulb yield of onion obtained at treatment combination of 10 × 10 cm plant spacing and 15 t/ha pm might be attributed to optimum number of plant population per unit area which leads to maximum number of bulbs due to closer spacing and optimal supply of nitrogen in the soil. Although plant height, number of leaves per plant and leaf length increased with increasing spacing, it could not be compensated for the yield of closely spaced plants due to higher plant population. The marketable bulb yield of onion per unit area does not completely depend up on the performance of individual plants but also related with the total number of plants per unit area and yield contributing parameters (Latif *et al*., 2010; Aliyu *et al*., 2008).

Similar observations were reported by Latif *et al*. (2010), Jan *et al*. (2003), Sikder *et al.* (2010), Dorcas *et al*. (2012) and Mahadeen (2008) who reported that maximum marketable bulb yields of onion were obtained at lower intra-row spacing. Naik and Hosamani (2003) also stated that maximum bulb yield of onion was recorded in treatment combination of narrow plant spacing and optimum nitrogen fertilizer level. Similarly, Soleymani and

Shahrajabian (2012) and Balemi *et al*. (2007) also showed that the higher value of marketable yield was achieved under higher rate of nitrogen fertilization (120 kg/ha).

5.6.5. Unmarketable bulb yield

The higher unmarketable bulb yield of closely spaced onion plants and combined with control (10 cm × 10 cm and control) might be due to more interplant competition for nutrient, water, light and air (Sikder *et al*, 2010). These results are in agreement with those of Seck and Baldeh (2009), Yemane *et al*. (2013) and Dereje *et al*. (2012) who mentioned that narrow intra-row spacing increased unmarketable bulb yield of onion, onion, and shallot respectively. Similarly, Negash *et al*. (2009) and Jilani *et al*. (2004) indicated that nil nitrogen fertilizer rates resulted in more unmarketable bulb yields.

5.6.6 Total bulb yield

The enhancement of total bulb yield in response to the treatment combination of 10 cm × 10 cm plant spacing and 15 t/ha pm might be due to the higher number of harvestable bulbs per unit area as described by Latif *et al*. (2010). Hence, onion plants planted at the optimum plant spacing helps for attaining their optimum bulb size (Rumpel *et al*., 2000). However, bulb yield per plant was observed to have increased with increase in plant spacing at all soil amendment rates via increasing their bulb weight. This result agrees with the finding of Khan *et al*. (2003), Muhammad *et al*. (2011), Latif *et al*. (2010), Yemane *et al*. (2013) and Jan *et al*. (2003) who reported that the highest onion bulb yields were observed at the closest spacing.

Dereje *et al*. (2012) also indicated that total bulb yield decreased with increase in the plant spacing of shallot. Similarly, Jilani *et al*. (2004) showed that with increase in dose of nitrogen up to120 kg/ha the total bulb yield was increased, but below this rate, the total bulb yield began to decrease. Soleymani and Shahrajabian, (2012) and Al-Frahat (2009) also indicated that the control plots achieved lower total yields as compared to the higher nitrogen doses. Balemi *et al*. (2007) also observed a significant increase in total bulb yield in response to increased application of nitrogen.

5.6.7. Harvest index

The results from the study indicate a higher harvest index in the chicken manure and NPK amendments with the narrow plant spacing of 10 cm × 10 cm compared to the control in both experiment one and two. Similarly, Yohannes *et al*. (2013), reported that the harvest index of onion was increased over the control with application of N and FYM. The results of Abdissa *et al*. (2011) that harvest index of onion increased with the application N compared to the control treatment is consistent with the current study. This result is also in conformity with the findings of Yohannes *et al*., (2013) and Abdissa *et al.*, (2011) that N application can significantly influence the harvest index of onion.

5.6.8. Grading System (Bulb size distribution)

5.6.8.1. Small-sized bulb yield (<50 g)

The increment in small size bulb yield of onion in response to the application of zero soil amendment rate and close spacing may have resulted in reduction in above growth biomasses like leaf number, leaf area, leaf length and diameter due to less availability and more competition for growth resources. With close plant spacing, bulb expansion suffers (Rumpel *et al.,* 2000; Negash *et al.,* 2009). Negash *et al*., (2009) reported that increasing the rate of nitrogen application from 0 kg/ha to 138 kg/ha significantly decreased the yield of small sized bulbs of onion by 61.8%. Similarly, Nasreen *et al*., (2007) indicated that small size bulb yield reduction in response to increased N fertilization. Moreover, supporting the current result, Dorca *et al*., (2012) and Yemane *et al.,* (2013) indicated that higher population density increased the yield of small sized bulbs.

5.6.8.2. Medium bulb size yield (50-100 g)

The increase in medium sized bulb yield of onion in response to the application of 300 kg ha-1 nitrogen at the spacing of 10 × 10 cm may be due to the fact that this rate of nitrogen and spacing were optimum for growth and enhanced productivity of the crop. The results of the present study are in agreement with the finding of Negash *et al.,* (2009) and Nasreen *et al.,* (2007) who reported that highest weights of medium sized bulb yield were recorded at application of higher nitrogen. Similarly, Nasir *et al.,* (2007), Rumpel *et al.,* (2000) reported that maximum weights of medium sized bulbs were obtained at higher planting densities.

5.6.8.3. Large-sized bulb yield (100-160g)

The achievements of higher yields of large sized bulbs by increasing plant spacing up to the optimum spacing and chicken manure level might be due to resource availability and assimilation and less stiff competition among the onion plants (Khan *et al*., 2002). This may lead to increased weights of individual bulbs shifting from small to medium and then to large bulb categories. In agreement with the current result, Negash *et al.,* (2009) and Kokobe *et al*., (2013) reported that onion bulb size increased with increasing nitrogen dose. Similarly, Dawar *et al*. (2007), Jilani *et al*., (2009), Yemane *et al*., (2013) and Mallor *et al*., (2011) indicated that maximum value of large bulbs were obtained in lower population densities.

5.6.8.4. Extra-Large bulb yield (>160 g)

The lower oversized bulb yield recorded at narrow plant spacing and control might be due to stiffer competition among onion plants for growth resource, which may have resulted in smaller bulb expansion in size (Rumpel *et al*., 2000). On the other hand, ample availability of growth resources including wider space may lead to high bulb expansion and growth, leading to the production of markedly higher yields of over-sized bulbs. Comparable results were reported by Khan *et al.* (2002) and Nasir *et al.* (2007) that the highest proportions of large bulbs were found at lower planting densities.

5.7. Partial budget analysis

The results from the study showed that fertilizer application together with the use of optimum spacing in onion production is profitable. The chicken manure amended plots together with optimum spacing had significant net revenue compared to the control and application of NPK fertilizer. The substantial profit made from the application of fertilizer could be attributed to the high marketable yield attained with the application of chicken manure and NPK fertilizer treatments.

The net revenue of onion production in the study using the different soil amendments were higher in 2020 major season compared to 2019 minor season. This may be as a result of the high marketable yields obtained in 2020 major season compared to 2019 minor season which could also be attributed to onion being out of season in 2020 major season and therefore, there was high demand for onion bulbs. The net revenue from the NPK treatment was low compared to the other amendments. This occurrence could be linked to the acidic nature of the experimental soil which reduced the marketable bulb yield of the crop. The control treatment had the least net revenue in both experiments. This could be due to the low total and marketable bulb yield of the crop resulting from poor fertility.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Findings

The analysis of variance showed that number of leaves per plant, plant height, leaf length, leaf diameter, fresh shoot and bulb biomass per plant, dry shoot and bulb biomass, days to maturity, mean bulb weight, bulb diameter, marketable bulb yield, unmarketable bulb yield, total bulb yield, small-sized bulb, medium-sized bulb, large sized bulb, Extra-large bulb and harvest index were significantly influenced by the interaction effect of plant spacing and soil amendment rates.

6.2 Conclusion

Farmers could substitute NPK fertilizers with chicken manure to reduce the cost of inorganic fertilizers required and their damaging effects on the soil. The study showed that the application of 15 t/ha decomposed chicken manure at the plant spacing of 10 cm × 10 cm resulted in the greatest improvement on vegetative growth, increased yield and yield components of onion. It also resulted in higher income and more profit. The application of 300kg/ha NPK (15:15:15) did not bring about any significant improvement in the vegetative growth, bulb length, total yield and marketable yield of onion relative to the control. Onion growers in Mampong-Ashanti can increase their yield and income with the application of 15 t/ha decomposed chicken manure and plant spacing at 10 cm x 10 cm spacing. However, for growers who have full resources (investors), application of 20 t/ha chicken manure spaced at 10 cm x 10 cm plant spacing was also profitable with higher cost of production and highest net benefit is recommended as a second option.

6.3 Recommendations for Further Research

1. More cultivars of onion should be evaluated under a similar study to assess their response to different soil amendments and plant spacing.

2. The experiment should be carried out in other agro-ecological zones to evaluate the response of the onion cultivars to different soil amendments and plant spacings and assess their economic benefits.

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APPENDICES

Appendix 1: Analysis of variance for 2019 minor season.

Variate: Crop establishment (%) at 28 DAT.

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.018	1.005		
SOIL		0.437	0.218	0.19	0.842
AMENDMENT	2				
SPACING	2	0.129	0.170	0.07	0.934
INTERACTION	4	8.437	2.112	1.174	0.180
ERROR	16	118.823	1.175		
TOTAL	26	29.865			

Variate: Number of leaves at 28 DAT

Source of variation	df	SS	MS	F	Pr > F
REP	2	10.856	5.432		
SOIL		4.903	2.452	0.85	0.443
AMENDMENT	2				
SPACING	2	1.408	0.706	0.26	0.746
INTERACTION	4	19.303	4.824	1.71	0.202
ERROR	16	45.513	2.836		
TOTAL	26	81.982			

Variate: Number of leaves at 42 DAT

Source of variation	df	SS	MS	F	Pr > F
REP	2	8.561	4.262		
SOIL		1.426	0.715	0.56	0.589
AMENDMENT	2				
SPACING	2	1.596	0.789	0.62	0.546
INTERACTION	4	12.153	3.114	2.31	0.102
ERROR	16	20.944	1.315		
TOTAL	26	44.564			

Variate: Number of leaves at 56 DAT

Source of variation	df	SS	MS	F	Pr > F
REP	2	42.463	21.742		
SOIL		4.873	2.438	0.45	0.568
AMENDMENT	2				
SPACING	2	10.905	5.461	0.94	0.417
INTERACTION	4	13.164	3.293	0.57	0.686
ERROR	16	91.576	5.724		
TOTAL	26	162.976			

Variate: Plant height at 28 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.463	2.742		
SOIL		4.873	2.448	0.42	0.527
AMENDMENT	2				
SPACING	2	1.905	5.462	0.92	0.418
INTERACTION	4	3.164	3.292	0.53	0.687
ERROR	16	9.576	5.723		
TOTAL	26	16.976			

Variate: Plant height at 42 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	3.465	2.842		
SOIL		6.874	2.546	0.52	0.524
AMENDMENT	2				
SPACING	2	9.935	5.468	0.96	0.413
INTERACTION	4	7.166	4.282	0.58	0.68
ERROR	16	9.975	5.753		
TOTAL	26	19.978			

Variate: Plant height at 56 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.465	5.842		
SOIL		16.874	8.546	0.59	0.624
AMENDMENT	2				
SPACING	2	19.935	4.468	0.99	0.512
INTERACTION	4	17.166	7.282	0.67	0.683
ERROR	16	19.975	8.753		
TOTAL	26	22.978			

Variate: Leaf length at 28 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.118	1.013		
SOIL		0.432	0.215	0.18	0.844
AMENDMENT	2				
SPACING	2	0.124	0.171	0.06	0.932
INTERACTION	4	8.438	2.113	1.173	0.181
ERROR	16	118.524	1.176		
TOTAL	26	29.863			

Variate: Leaf length at 42 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	9.562	4.264		
SOIL		1.427	0.712	0.66	0.578
AMENDMENT	2				
SPACING	2	2.596	0.787	0.63	0.535
INTERACTION	4	11.153	3.113	2.33	0.104
ERROR	16	21.944	1.416		
TOTAL	26	42.564			

Variate: Leaf length at 56 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	43.465	21.742		
SOIL		5.875	2.439	0.47	0.569
AMENDMENT	2				
SPACING	2	12.915	5.464	0.93	0.419
INTERACTION	4	13.149	3.294	0.59	0.688
ERROR	16	92.586	5.728		
TOTAL	26	162.986			

Variate: Leaf diameter at 28 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.019	1.205		
SOIL		0.423	0.229	0.23	0.843
AMENDMENT	2				
SPACING	2	0.132	0.173	0.07	0.937
INTERACTION	4	8.428	2.115	1.176	0.183
ERROR	16	18.823	1.177		
TOTAL	26	29.866			

Variate: Leaf diameter at 42 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	4.465	2.842		
SOIL		7.274	2.546	0.52	0.551
AMENDMENT	2				
SPACING	2	8.915	5.468	0.96	0.472
INTERACTION	4	7.166	4.282	0.58	0.659
ERROR	16	9.975	5.753		
TOTAL	26	19.978			

Variate: Leaf diameter at 56 DAT (cm)

Source of variation	ss	df	MS	F	Pr > F
REP	37.290	2	18.645		
SOIL		2	41.86125	2.36	0.126
AMENDMENT	41.86125				
SPACING	94.53125	2	94.53125	0.79	0.469
INTERACTION	0.00125	4	0.00125	0.44	0.776
ERROR	1.665	16	0.41625		
TOTAL	138.0588	26			

Variate: Number of days to maturity

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.465	5.843		
SOIL		16.874	8.544	0.53	0.621
AMENDMENT	2				
SPACING	2	19.935	4.463	0.92	0.513
INTERACTION	4	17.166	7.283	0.65	0.681
ERROR	16	19.975	8.755		
TOTAL	26	22.978			

Variate: Fresh shoot and bulb biomass

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.466	5.842		
SOIL		15.878	8.543	0.54	0.622
AMENDMENT	2				
SPACING	2	18.936	4.463	0.96	0.514
INTERACTION	4	18.168	7.281	0.67	0.683
ERROR	16	19.965	8.757		
TOTAL	26	22.958			

Variate: Dry shoot and bulb biomass

Source of variation	df	SS	MS	F	Pr > F
REP	2	12.466	5.842		
SOIL		13.878	8.543	0.64	0.628
AMENDMENT	2				
SPACING	2	16.936	4.463	0.74	0.514
INTERACTION	4	17.168	7.281	0.58	0.681
ERROR	16	18.965	8.757		
TOTAL	26	21.958			

Variate: Bulb diameter (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	11.421	5.843		
SOIL		14.872	8.544	0.55	0.648
AMENDMENT	2				
SPACING	2	15.939	4.465	0.75	0.532
INTERACTION	4	16.164	7.283	0.68	0.664
ERROR	16	18.935	8.756		
TOTAL	26	22.968			

Variate: Bulb length (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	12.423	5.863		
SOIL		11.873	8.564	0.65	0.642
AMENDMENT	2				
SPACING	2	16.939	4.455	0.85	0.535
INTERACTION	4	17.164	7.273	0.78	0.661
ERROR	16	19.935	8.766		
TOTAL	26	23.968			

Variate: Mean bulb weight

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.466	5.842		
SOIL AMENDMENT	2	15.878	8.543	0.54	0.622
SPACING	2	18.936	4.463	0.96	0.514
INTERACTION	4	18.168	7.281	0.67	0.683
ERROR	16	19.965	8.757		
TOTAL	26	22.958			

Variate: Marketable bulb yield

Source of variation	df	SS	MS	F	Pr > F
REP	2	11.421	5.843		
SOIL AMENDMENT	2	14.872	8.544	0.55	0.648
SPACING	2	15.939	4.465	0.75	0.532
INTERACTION	4	16.164	7.283	0.68	0.664
ERROR	16	18.935	8.756		
TOTAL	26	22.968			

Variate: Unmarketable bulb yield

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.466	5.842		
SOIL AMENDMENT	2	15.878	8.543	0.54	0.622
SPACING	2	18.936	4.463	0.96	0.514
INTERACTION	4	18.168	7.281	0.67	0.683
ERROR	16	19.965	8.757		
TOTAL	26	22.958			

Variate: Total bulb yield

Source of variation	df	SS	MS	F	Pr > F
REP	2	15.423	5.863		
SOIL		13.873	8.564	0.65	0.642
AMENDMENT	2				
SPACING	2	18.939	4.455	0.85	0.535
INTERACTION	4	19.164	7.273	0.78	0.661
ERROR	16	20.935	8.766		
TOTAL	26	24.968			

Variate: Harvest index

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.118	1.013		
SOIL		0.432	0.215	0.18	0.844
AMENDMENT	2				
SPACING	2	0.124	0.171	0.06	0.932
INTERACTION	4	8.438	2.113	1.173	0.181
ERROR	16	118.524	1.176		
TOTAL	26	29.863			

Variate: Grading system (Bulb sized distribution)

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.466	5.842		
SOIL		15.878	8.543	0.54	0.622
AMENDMENT	2				
SPACING	2	18.936	4.463	0.96	0.514
INTERACTION	4	18.168	7.281	0.67	0.683
ERROR	16	19.965	8.757		
TOTAL	26	22.958			

Appendix 2: Analysis of variance for 2020 major season

Variate: Crop establishment (%) at 28 DAT.

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.115	1.102		
SOIL		0.532	0.236	0.18	0.861
AMENDMENT	2				
SPACING	2	0.137	0.182	0.09	0.943
INTERACTION	4	8.437	2.213	1.175	0.182
ERROR	16	117.624	1.184		
TOTAL	26	28.874			

Variate: Number of leaves at 28 DAT

Source of variation	df	SS	MS	F	Pr > F
REP	2	10.743	5.343		
SOIL		4.912	2.353	0.75	0.453
AMENDMENT	2				
SPACING	2	1.407	0.724	0.27	0.764
INTERACTION	4	19.303	4.835	1.73	0.213
ERROR	16	45.514	2.842		
TOTAL	26	81.984			

Variate: Number of leaves at 42 DAT

Source of variation	df	SS	MS	F	Pr > F
REP	2	8.522	4.263		
SOIL		1.517	0.716	0.64	0.557
AMENDMENT	2				
SPACING	2	1.587	0.787	0.63	0.535
INTERACTION	4	12.162	3.112	2.33	0.112
ERROR	16	20.951	1.325		
TOTAL	26	44.553			

Variate: Number of leaves at 56 DAT

Source of variation	df	SS	MS	F	Pr > F
REP	2	42.454	21.843		
SOIL		4.863	2.429	0.49	0.565
AMENDMENT	2				
SPACING	2	10.925	5.472	0.93	0.418
INTERACTION	4	13.254	3.284	0.58	0.676
ERROR	16	91.586	5.733		
TOTAL	26	162.966			

Variate: Plant height at 28 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.364	2.841		
SOIL		4.774	2.349	0.52	0.537
AMENDMENT	2				
SPACING	2	1.914	5.364	0.82	0.428
INTERACTION	4	3.263	3.391	0.63	0.677
ERROR	16	9.677	5.822		
TOTAL	26	16.875			

Variate: Plant height at 42 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	3.467	2.843		
SOIL		6.875	2.545	0.53	0.514
AMENDMENT	2				
SPACING	2	9.936	5.467	0.97	0.423
INTERACTION	4	7.167	4.283	0.59	0.69
ERROR	16	9.976	5.754		
TOTAL	26	19.977			

Variate: Plant height at 56 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.468	5.843		
SOIL		16.873	8.545	0.58	0.621
AMENDMENT	2				
SPACING	2	19.937	4.467	0.98	0.513
INTERACTION	4	17.167	7.284	0.68	0.684
ERROR	16	19.976	8.751		
TOTAL	26	22.975			

Variate: Leaf length at 28 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.128	1.026		
SOIL		0.422	0.224	0.19	0.824
AMENDMENT	2				
SPACING	2	0.134	0.174	0.16	0.931
INTERACTION	4	8.448	2.215	1.273	0.281
ERROR	16	118.514	1.276		
TOTAL	26	29.853			

Variate: Leaf length at 42 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	9.563	4.263		
SOIL		1.427	0.714	0.67	0.678
AMENDMENT	2				
SPACING	2	2.597	0.788	0.64	0.525
INTERACTION	4	11.154	3.112	2.34	0.124
ERROR	16	21.941	1.417		
TOTAL	26	42.563			

Variate: Leaf length at 56 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	44.465	21.751		
SOIL		5.876	2.339	0.53	0.559
AMENDMENT	2				
SPACING	2	12.921	5.364	0.83	0.426
INTERACTION	4	13.243	3.394	0.69	0.676
ERROR	16	92.578	5.628		
TOTAL	26	162.987			

Variate: Leaf diameter at 28 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.023	1.215		
SOIL		0.434	0.219	0.24	0.842
AMENDMENT	2				
SPACING	2	0.141	0.163	0.08	0.926
INTERACTION	4	8.429	2.135	1.175	0.174
ERROR	16	18.824	1.167		
TOTAL	26	29.868			

Variate: Leaf diameter at 42 DAT (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	4.367	2.834		
SOIL		7.372	2.552	0.54	0.552
AMENDMENT	2				
SPACING	2	8.926	5.467	0.97	0.473
INTERACTION	4	7.165	4.283	0.59	0.669
ERROR	16	9.976	5.754		
TOTAL	26	19.969			

Variate: Leaf diameter at 56 DAT (cm)

Source of variation	df	ss	MS	F	Pr > F
REP	2	37.292	18.646		
SOIL			41.863	2.37	0.226
AMENDMENT	2	41.863			
SPACING	2	94.52	94.534	0.78	0.369
INTERACTION	4	0.126	0.225	0.43	0.676
ERROR	16	1.667	0.416		
TOTAL	26	138.578			

Variate: Number of days to maturity

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.466	5.842		
SOIL		16.872	8.543	0.51	0.623
AMENDMENT	2				
SPACING	2	19.936	4.464	0.93	0.523
INTERACTION	4	17.167	7.284	0.66	0.683
ERROR	16	19.976	8.756		
TOTAL	26	22.977			

Variate: Fresh shoot and bulb biomass

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.467	5.844		
SOIL		15.876	8.542	0.55	0.633
AMENDMENT	2				
SPACING	2	18.937	4.464	0.97	0.524
INTERACTION	4	18.167	7.283	0.68	0.653
ERROR	16	19.966	8.758		
TOTAL	26	22.959			

Variate: Dry shoot and bulb biomass

Source of variation	df	SS	MS	F	Pr > F
REP	2	12.467	5.845		
SOIL		13.877	8.544	0.53	0.638
AMENDMENT	2				
SPACING	2	16.946	4.462	0.65	0.544
INTERACTION	4	17.265	7.282	0.68	0.661
ERROR	16	18.866	8.756		
TOTAL	26	21.957			

Variate: Bulb diameter (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	11.425	6.843		
SOIL		14.878	7.544	0.65	0.548
AMENDMENT	2				
SPACING	2	15.948	3.478	0.66	0.632
INTERACTION	4	16.173	8.283	0.67	0.764
ERROR	16	18.945	8.757		
TOTAL	26	22.976			

Variate: Bulb length (cm)

Source of variation	df	SS	MS	F	Pr > F
REP	2	12.434	5.864		
SOIL		11.865	8.565	0.66	0.543
AMENDMENT	2				
SPACING	2	16.946	4.464	0.86	0.633
INTERACTION	4	17.173	7.274	0.79	0.762
ERROR	16	19.946	8.767		
TOTAL	26	23.975			

Variate: Mean bulb weight

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.366	5.743		
SOIL		15.778	8.644	0.74	0.532
AMENDMENT	2				
SPACING	2	18.836	4.364	0.86	0.614
INTERACTION	4	18.268	7.383	0.77	0.583
ERROR	16	19.865	8.856		
TOTAL	26	22.958			

Variate: Marketable bulb yield

Source of variation	df	SS	MS	F	Pr > F
REP	2	11.432	5.854		
SOIL		14.881	8.561	0.65	0.653
AMENDMENT	2				
SPACING	2	15.948	4.464	0.78	0.551
INTERACTION	4	16.173	7.281	0.76	0.653
ERROR	16	18.946	8.748		
TOTAL	26	22.975			

Variate: Unmarketable bulb yield

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.423	5.834		
SOIL		15.881	8.535	0.63	0.613
AMENDMENT	2				
SPACING	2	18.947	4.471	0.87	0.525
INTERACTION	4	18.154	7.283	0.75	0.691
ERROR	16	19.967	8.762		
TOTAL	26	22.966			

Variate: Total bulb yield

Source of variation	df	SS	MS	F	Pr > F
REP	2	15.432	5.871		
SOIL		13.882	8.573	0.67	0.651
AMENDMENT	2				
SPACING	2	18.945	4.456	0.86	0.553
INTERACTION	4	19.161	7.274	0.77	0.664
ERROR	16	20.946	8.765		
TOTAL	26	24.974			

Variate: Harvest index

Source of variation	df	SS	MS	F	Pr > F
REP	2	2.128	1.122		
SOIL		0.414	0.226	0.19	0.853
AMENDMENT	2				
SPACING	2	0.134	0.175	0.17	0.941
INTERACTION	4	8.446	2.114	1.182	0.183
ERROR	16	118.535	1.275		
TOTAL	26	29.881			

Variate: Grading system (Bulb sized distribution)

Source of variation	df	SS	MS	F	Pr > F
REP	2	13.564	5.836		
SOIL		15.8765	8.527	0.63	0.625
AMENDMENT	2				
SPACING	2	18.957	4.472	0.97	0.523
INTERACTION	4	18.256	7.273	0.73	0.691
ERROR	16	19.974	8.766		
TOTAL	26	22.963			