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EFFECT OF POULTRY MANURE AND NPK FERTILIZER ON THE GROWTH, YIELD AND MINERAL COMPOSITION OF ONION (*Allium cepa* L.) GROWN IN ACID SOIL

BY

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DECLARATION

In exception of references to the works of researchers which have been duly cited, this thesis is the result of my own work produced from research undertaken under supervision.

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DEDICATION

I dedicate this work to my dear wife Mrs. Elizabeth Akuamoah-Boateng, my two lovely daughters; Elizabeth Akosua Ampomaah Dromo Akuamoah-Boateng and Joycelyn Abena Biamah Suomo Akuamoah-Boateng and my late sister Elizabeth Abena Biamah Adom-Boafo.

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ABSTRACT

Two separate field experiments were conducted at the University of Ghana School farm, Legon, Accra, from 2015 to 2016 to determine the response of "Bawku Red" onion cultivar (*Allium cepa* L.) to different rates of poultry manure (Pm), NPK fertilizer and combinations of poultry manure and NPK fertilizer. The experimental design used was a randomized complete block design (RCBD) with 10 treatments and 4 replications. The treatments were; **T_1:** Control (no fertilizer), **T_2:** Pm at 5 t/ha, T_3: Pm at 10 t/ha, **T_4:** Pm at 15 t/ha, **T_5:** Pm at 20 t/ha, **T_6:** Pm at 5 t/ha + 2.5 t/ha + 2.5 t/ha as side dressing, **T_7:** Pm at 10 t/ha + 2.5 t/ha + 2.5 t/ha as side dressing, **T_8:** Pm at 5 t/ha and NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha as a side dressing, **T_9:** Pm at 10 t/ha and NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha as side-dressing and **T_{10}:** NPK 15-15-15 at 600 kg/ha and Urea at 60 kg/ha. The data collected was analysed using the analysis of variance (ANOVA) for randomized complete block design (RCBD) with the help of the GenStat 12th Edition software. Means which differed significantly were compared using the Fisher's Protected LSD at 5% level of significance. Associations among some parameters were determined by correlation. The results showed that "Bawku Red" responded positively to the application of soil amendments. Application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure on average produced higher vegetative attributes such as plant height (48.9 cm), leaf length (45.4 cm), leaf diameter (10.4 mm), number of leaves (9.5) and fresh shoot biomass (20.8 g/plant) compared to the other treatments at harvest. For bulb yield, application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure gave the highest yield of 14.2 t/ha followed by 15 t/ha poultry manure (13.9 t/ha) in experiment one. In the second experiment, poultry manure applied at 15 t/ha gave the highest yield of 15.5 t/ha followed by 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure (14.1 t/ha). Application of 20 t/ha Pm in experiment one and 10 t/ha + 2.5 t/ha + 2.5 t/ha Pm in experiment

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two increased the soil pH to the highest value of 7.3 and 7.0 respectively compared to the other treatments. The content of some macro nutrients (N, P, K, Ca and Mg) was found to be higher in onion bulbs from the poultry manure and combinations of poultry manure and NPK amendments. The application of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha gave the lowest results among the amended treatments in almost all the parameters evaluated and in some cases, the results were not significantly different form the control (no fertilizer). Total Bulb Yield had a strong significant positive association with Bulb Diameter (0.848**), Bulb Length (0.768**), Leaf Diameter (0.735**), Mean Bulb Weight (1.000**), Number of Leaves (0.652**) and Plant Height (0.728**) in experiment one. In experiment two, the TBY again had a strong significant positive association with BD (0.944**), BL (0.740**), LD (0.656**), MBW (1.000**), NL (0.705**) and PH (0.746**). On average, the application of 5 t/ha of poultry manure produced the highest net revenue (GH¢ 15,435.90) from the two experiments. Generally, the poultry manure and combination of poultry manure and NPK fertilizer amendments improved some of the chemical properties of the soil such as the Total N, available P, Total K, O.C, O.M and pH compared to the control and the NPK fertilizer amendment. It is recommended that farmers adopt 10 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha or 5 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha amendment, depending on the fertility status of their soil and as much as possible avoid acidic soils in onion production when only chemical fertilizers are used.

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LIST OF ABBREVIATIONS

BS	Base Saturation
Ca	Calcium
C	Compost
CEC	Cation Exchange Capacity
CM	Chicken Manure
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
Fe	Iron
FYM	Farm Yard Manure
K	Potassium
Mg	Magnesium
N	Nitrogen
O. M	Organic Matter
P	Phosphorus
Pm	Poultry manure
WAT	Weeks After Transplanting
mL	Milliliters

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CHAPTER ONE

1.0 INTRODUCTION

Onion (*Allium cepa* L.) is among the major vegetable crops grown in West Africa and it belongs to the family Alliaceae (Norman, 1992). According to Sinnadurai (1992), onion is the most popular crop in the Alliaceae family and is produced all around the globe. In West Africa, onion is intensively produced in Senegal, Niger, Nigeria, Ghana and Burkina Faso. Onion is grown on a large scale in the Northern and Upper Regions of Ghana especially in Bawku, Bolgatanga and Kusasi (Norman, 1992). The common onion cultivar currently being grown in Ghana is the 'Bawku Red' which is a local variety. Early Texas Grano and Red Creole are some exotic varieties being produced in the country (Abbey *et al*., 2000).

Onion is grown mainly for its bulb. The crop is highly valued for its flavour and nutritional value. Onions with high pungency are usually cooked whereas the mild types are eaten raw. The pungent onions are used in the preparation of soups, stews, gravies and are also preserved in the form of pickles. The leaves of spring onions are very useful in the preparation of salads and stews (Norman, 1992; Sinnadurai, 1992 and Opara, 2003). 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. According to Abbey and Oppong-Konadu (1997), onion is used extensively in Ghana and across the world as a food seasoning, a vegetable and for medication. This has led to a year round demand for the produce. It was 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

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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 order to reduce the level of imports, farmers have to increase the scale of onion production in the country. The sustainability of increased production is only feasible when adequate plant nutrient is supplied to the growing plants. This is imperative due to the practice of continuous cropping by farmers resulting in the depletion of the fertility of most agricultural lands in the country. Another challenge hindering the increased production of onions in the country is the fact that most farmers in the onion industry do not have sufficient knowledge and credible information on the application rates and benefits of organic manure such as poultry manure.

Onions respond positively to soils which are rich in nutrients; such soils should probably contain well-decomposed organic matter which could come from compost, poultry manure or cow dung (Norman, 1992). According to Sinnadurai (1992), soils ear-marked for the production of onions should be fertile and highly rich in humus. The incorporation of organic matter into the soil is able to improve the moisture retention of the soil and also make the soil loose enough for bulb expansion during its formation. Since onions do well in soils rich in nutrients, the application of inorganic and organic fertilizers to the soil is essential to the realization of sustainable high yields.

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The use of inorganic fertilizers comes with its own challenges, long term application of inorganic fertilizers leads to the reduction or increase in soil pH when the application is improperly done. That notwithstanding, the high cost of chemical fertilizers in recent times is pushing away farmers, especially the smallholder farmers, from using them (Vissoh *et al.*, 1998 and Svotwa, *et al.*, 2009). As a result of the high cost of chemical fertilizers and their negative long term effect on soil, attention is being directed towards the use of organic manure (Negassa *et al.*, 2001; Norman, 2004 and Tirol-Padre *et al.*, 2007).

According to Aisha *et al.* (2007), the use of chemical fertilizers alone could generate several deleterious effects to the environment and human health and more so since it must be added at every crop growing season, because the synthetic N, P and K fertilizer is rapidly lost by either evaporation or leaching. On the contrary, organic fertilizers have the advantage of enhancing the soil organic matter, structure, chemical properties and 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).

Organic fertilizers such as poultry manures can serve as a good substitute to the use of inorganic fertilizers. Organic fertilizers are a cheaper means of improving soil fertility and can be available in large quantities locally. They also play a significant role in enriching the soil microbial activity, improving the moisture holding capacity of the soil and finally the soil structure (Russel and Marsah, 1997). The national poultry numbers in the country stood at 47,752,000 birds as at 2010 and this could generate millions of tonnage of poultry manure per annum (FAO, 2014). It is suggested by Dapaah *et al.* (2014), that an integrated soil management approach in relation to the application of soil amendments is imperative to deriving the benefits of organic and inorganic fertilizers.

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Poultry manure is used by most onion farmers due to the benefits associated with the use of organic manure. The concern however, is that, these farmers do not have a specific rate of application. They only apply whatever is available to them without taking into consideration the effect it would have on the growth and yield of the onion plant. Previous research have shown that, the growth and yield of onions is significantly influenced by the different rates of poultry manure applied (Dapaah *et al.*, 2014; Gwari *et al.*, 2014 and Yoldas *et al.*, 2011).

Even though studies have been carried out on the effect of different soil amendments on onion production (Al-Fraihat, 2016; Gwari *et al.*, 2014; Dapaah *et al.*, 2014 and Yoldas *et al.*, 2011), much work has not been done on the effect of poultry manure, NPK and the combination of the two on the growth, yield and mineral composition of 'Bawku Red' onion variety grown in acid soil. This research was undertaken to determine the effect of the different rates of poultry manure application only and in combination with NPK fertilizer on the performance of the crop and acidity of the soil. The determination and eventual adoption of the best fertilization regime will result in increased yield which translates into increased income for farmers and subsequent reduction in the importation of onions into the country.

The general objective of the study was to evaluate the response of 'Bawku Red' onion cultivar to different rates of poultry manure and NPK fertilizer in the Coastal Savannah agro ecological zone of Ghana.

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The specific objectives of the study are to:

i. evaluate the effect of different rates of poultry manure and NPK fertilizer application on the growth and yield of 'Bawku Red' onion cultivar,

ii. determine the effect of different rates of poultry manure and NPK fertilizer application on the macro nutrient content of onions, and

iii. examine the effect of poultry manure and NPK fertilizer on soil pH.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climatic requirements of onion

Onions have the ability to perform well over a wide range of temperatures even though it is a cool season crop. Onions require cool temperatures at the early stages of growth and warm temperatures at bulbing, harvesting and curing. The time of bulbing is greatly influenced by the prevailing day length (photoperiod) which ranges between 12 to 16 hours. Each onion variety requires a specific photoperiod to encourage bulb formation. High day temperatures increase the rate of bulbing whiles low day temperatures may delay the formation of bulb. Cool night temperatures on the other hand bring about both bulbing and flowering in the West Africa cultivars (Obeng-Ofori *et al.*, 2007; Dawling *et al.* 2006; Sinnadurai, 1992 and Norman, 1992).

According to Tindall (1983), when the prevailing environmental temperatures are high, bulbing can occur in a shorter day length than under cooler conditions. Flower development is however impeded at high temperatures since a period of cool condition is needed after bulbing for flower initiation. Decapitation of flower stalks which may develop during bulb onion production can significantly enhance bulb formation.

In an experiment to determine the effect of photoperiod and temperature requirements on the bulb size and maturity in onions, Lancaster *et al.* (1996) reported that bulb diameter at bulbing is related to the thermal time accumulated prior to bulbing. The implication of this is that bulbing will only occur when the minimum thermal time and photoperiod are reached. It is evident that when these parameters are not satisfied at the requite time, bulbing is bound to delay. The

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authors concluded that the final bulb size could be predicted from bulb size at bulbing and number of leaves produced after bulbing. Bulb maturity date could also be predicted by number of leaves after bulbing.

2.2 Soil requirements of onion

The best soil type for onions is one which has the capacity to hold enough moisture around the root zone of the plant. The ideal soil is expected to be fertile, rich in humus and loose enough to allow for cultivation and bulb expansion (Obeng-Ofori *et al.*, 2007; Sinnadurai, 1992 and Norman, 1992). According to Sinnadurai (1992), sandy and clayey soils should be avoided since sandy soil needs organic manure to retain moisture and clayey soil becomes easily waterlogged. The ideal soil type should therefore be sandy loams and silt loams which can retain fair amount of water and are easy to cultivate.

According to Norman (1992) and Sinnadurai (1992), onions can perform well when planted in soils with pH ranging between 5.8 to 6.5 and 5.8 to 7.0 respectively. It was also reported by Raemaekers (2001), that onions are sensitive to soils low in pH and can grow best between a pH range of 6.2 and 6.8. The sensitivity of onion to acidic soil is evident from research work carried out by Raemaekers (2001), Norman (1992) and Sinnadurai (1992) and is therefore obvious that low soil pH can have a significant effect on the growth and yield of onions.

2.3 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

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quality of the crop. Soils in their natural state do not have adequate nutrients to support the growth and development of crops. It is therefore imperative 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).

Fertilizers are broadly classified into organic and inorganic with respect to their origin. The inorganic are synthesized from inorganic materials whilst the organic fertilizers are obtained from living organisms which are mainly plants and animals.

2.3.1 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 and Tisdale *et al.*, 1993).

2.3.2 Organic fertilizers

In recent times, attention has been drawn to the use of organic fertilizers which used to be an ancient practice of 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 and Tirol-Padre *et al.*, 2007).

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A report by Ruder and Bennion (2013), reiterates 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 organic matter, 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 readily available in large quantities in the country. According to FAO (2014), as at 2010, the national poultry numbers in the country 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.

2.4 Sources of organic manure

Norman (2004) and Parnes (2013) identified the sources of organic manure to include animal manure such as droppings from sheep, pigs, goats, cattle, horses and poultry and plant sources which comprise green manure, seaweed, cover crop, crop residue, biological nitrogen fixation, mulch and compost. Both the plant and animal sources of organic manure contain major and minor nutrients.

Waste materials emanating from plant and animals which are at different level of breakdown constitute soil organic manure. Some of these materials originate from dead plant roots, crop residues, green manure, dead soil microorganisms and farmyard manure (Abbey *et al.*, 2001).

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According to Carsky *et al.* (2002), leguminous crops like cowpea, groundnuts and the likes are viewed as a rich source of soil fertility improvement since they have the propensity to fix atmospheric nitrogen into the soil. Raemaekers (2001), reported that leguminous crops such as cowpea can fix atmospheric nitrogen into the soil which could be up to 240 kg/ha and residual nitrogen of 60-70 kg/ha for the succeeding crop.

In Florida, USA, the three most common sources of organic manures used by organic farmers was identified by Fluck (1992), as poultry manure, bagged organic fertilizers and fish emulsion products. The primary source of nutrient for these farmers is poultry manure with about 71 % of them utilizing fish emulsion as their secondary nutrient source.

Research by Smailing and Braun (1996) revealed that the use of fresh manure can be detrimental to the plant. This should be avoided since the heat released during the decomposition process in the soil can cause damage to the crops' root system. According to Jones *et al.* (1985), manure application rate is dependent to a large extent on the nutrient requirements of the crop in question. It is therefore prudent to apply organic manure at the optimum rate to ensure proper growth and development of crops.

2.5 Composition of poultry manure

The quantities of nutrients that can be derived from animal manure significantly differ from one animal species to another. Again, the feed composition, the quality and quantity of the bedding materials, the storage conditions and length of storage determines the quantum of nutrients that can be derived from animal manure (Dewes and Hunsche, 1998).

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According to Mathew and Karikari (1995), organic manure is a very rich source of organic matter but very low in plant nutrients. As a result, organic manure needs to be applied in large quantities in order to make up for the nutrient requirements by plants. It was reported by Sinnadurai (1992) that poultry manure which is one of the major sources of organic manure contains a significant percentage of nitrogen when analysed. In the case of cattle manure, those obtained during periods where there is abundant green grass for the cattle to graze on contains a higher percentage of plant nutrients than manure obtained during the lean season where fresh grasses are scarce. Other than the presence of nitrogen in poultry manure as reported by Sinnadurai (1992), poultry manure is an important source of nitrogen, phosphorus and potassium (Baffour, 1985).

Poultry manure is composed of all the essential plant nutrients (macro and micro elements) required for the growth and development of plants. The chemical composition of poultry manure is significantly affected by many factors such as age and diet of the bird, the moisture content of the manure, ratio of litter to manure, type of manure and age of the manure (Amanullah *et al*., 2010). It was indicated by Krogdahl and Dahlsgard (1981) that uric acid is the most abundant nitrogen compound in fresh excreta representing about 40 – 70% of the total nitrogen while urea and ammonium are available in minute quantities. Research by Amanullah *et al*. (2007) showed that different types of poultry manure have different chemical composition. The chemical composition of the different types of poultry manure is shown in Table 2.1.

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Table 2.1: Nutrient content of different types of poultry manure

Particulars	Deep litter	Broiler house	Cage manure
C/N ratio	9.5 - 11.5	9.4 - 11.2	5.8 - 7.6
Total N (%)	1.70 - 2.20	2.40 - 3.60	3.63 - 5.30
Total P_2O_5 (%)	1.41 - 1.81	1.56 - 2.80	1.54 - 2.90
Total K_2O (%)	0.93 - 1.30	1.4 - 2.31	2.5 - 2.90
Fe (ppm)	930 – 1380	970 - 1370	970 - 1450
Zn (ppm)	90 – 308	160 - 315	290 - 460
Cu (ppm)	24 – 42	27 - 47	80 - 172
Mn (ppm)	210 - 380	190 - 350	370 - 590
Ca (%)	0.90 - 1.10	0.86 - 1.11	0.80 - 1.02
Mg (%)	0.45 - 0.68	0.42 - 0.65	0.40 - 0.56

Source: Amanullah *et al*. (2007)

Poultry manure is known to contain between 2.0 and 3.0% nitrogen which is the highest form recorded by Agyenim-Boateng *et al.* (1997), for common farmyard sources (the dung of cattle, sheep, goat, rabbit and horse). Even though poultry manure is a rich source of nitrogen, its availability to the growing plants is dependent on factors such as; volatilization, denitrification, immobilization, mineralization, leaching and plant uptake. According to Wolf *et al*. (1988), about 37% of the total N in surface applied poultry manure was volatilized in 11 days, followed by immobilization between 1 - 2 weeks resulting in the reduction in inorganic nitrogen content. According to Bitzer and Sims (1988), close to 69% of organic nitrogen in poultry manure incorporated into a sandy loam soil was mineralized in 140 days.

2.6 Effect of poultry manure on chemical and physical properties of soil

The addition of organic manure such as poultry manure to soils helps enhance the chemical and physical properties of the soil. According to Young (1997), the addition of organic manure such

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as poultry manure increases the organic status of the soil which in the end improves the structural stability, lowers the bulk density and improves the porosity of the soil. The resultant effect is that there is ease of root penetration, improved soil water holding capacity, adequate aeration and reduced soil erosion. It was also reported by Adams *et al*. (1997), that an open soil structure is created and water holding capacity of the soil is increased, when there is the presence of partially decomposed organic matter in the soil. This shows that poultry manure plays a significant role in improving the physical properties of the soil.

In the area of soil chemical properties improvement, Young (1997), found that the addition of poultry manure to the soil enhanced the cation exchange capacity of the clay-humus complex. There was a higher retention of nutrients supplied to the soil in the form of fertilizers when the ion exchange capacity was improved. It was further reported by Young (1997), that poultry manure is able to improve phosphorous availability in acid soils. In a similar vein, Tisdale *et al*. (1993), reported that the organic matter present in poultry manure serves as the main source of boron in acid soil. It is therefore evident that poultry manure play a significant role in improving an acid soil.

According to work done by Snyman *et al*. (1998), organic manure, such as sheep and poultry manure, has the ability to improve both the physical and chemical properties of the soil. Poultry manure improves the structure, aggregation, cation exchange capacity, retention of mineral nutrients and decreases the acidity of the soil. It was indicated by Luna (1998), that organic manure supplies trace elements which are occasionally absent in conventional farming systems which depend solely on artificial sources of N, P and K. An experiment conducted by Baffour

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(1985), revealed that organic matter is able to supply about 90 – 99% of the soil nitrogen, phosphorous and potassium when applied to the soil. The author further observed that organic matter increases the water holding capacity of soils, increases the resistance of soil to erosion and decreases plasticity and cohesion of soils particles.

Research conducted by Decutt (2012), showed that the addition of poultry manure to slightly acidic soil increased the soil pH from 5.7 to 6.1. This could be attributed to the abundance of calcium in the poultry manure which emanated from the oyster shells included in the feed of poultry birds. Similarly, Chellemi and Lazarovits (2002) and Lombin *et al*. (1991), observed an increase in soil pH and a reduction of exchangeable acidity in the soil with the application of organic manure. The manure is able to lower the concentration of Al^{3+} and Fe^{2+} in the soil. According to Ano and Agwu (2006) and Agbede (2010), the increase in soil pH could be attributed to the application of poultry manure resulting in an increase in organic matter and calcium ions released into the soil solution during microbial decarboxylation of manure which is known to buffer change in soil pH. Even though onions are very sensitive to low soil pH, it is possible to successfully grow them in acid soil by amending the acid soil with poultry manure.

It was reported by Adeleye *et al*. (2010) and Frempong *et al.* (2006), that the available P and K, O. M, total N, CEC, pH, BS and soil water holding capacity were significantly improved when the soil was amended with organic manure. Experiments conducted by Zhang *et al.* (2009), also revealed that the application of organic manure had a positive impact on the organic carbon of the soil. In addition, Agbede *et al*. (2010), observed in an experiment that soils treated with poultry manure had an increase in soil organic carbon and other nutrients compared to those

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treated with only NPK fertilizer. An earlier research by Agbede *et al*. (2008), indicated that poultry manure when applied to the soil, significantly reduced soil bulk density and temperature and increased soil porosity, moisture content and soil organic matter. According to Onwu *et al.* (2014), the application of poultry manure enhanced the soil chemical properties by reducing soil acidity and increasing the total N, available P, organic matter content, cation exchange capacity and exchangeable cations.

Soil particle aggregation is improved with organic manure application due to an overall increase in soil organic matter content when manure is added. In addition to the reduction in soil bulk density, organic manure increases the porosity and water holding capacity of soil (Khalid *et al.*, 2014; Lombin *et al.*, 1991; Mbah *et al.*, 2004; Miller and Donahue, 1990 and Adeleye *et al.*, 2010). Furthermore, Adeleye *et al*. (2010) suggested that poultry manure improves soil moisture content owing to the hygroscopic nature of poultry manure. This is feasible since soils treated with poultry manure are able to retain water for a longer period of time compared to untreated soil.

Water infiltration rate 12 weeks after planting in okra production was higher in the poultry manure, cow dung and compost manure as compared to fields treated with inorganic fertilizer which recorded low bulk density as well as low water holding capacity. The poultry manure gave higher organic matter content compared to other manure treatments (Frempong *et al.*, 2006). These findings could be attributed to the fact that poultry manure loosens the soil particles thereby encouraging percolation and at the same retaining water unlike the chemical fertilizer field.

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The application of poultry manure to soil results in the reduction of soil bulk density and temperature and an increase in soil moisture content and porosity. Again, the soil chemical properties such as soil organic matter content, total N, available P, exchangeable K, Ca, Mg, Fe and pH are significantly increased with the application of poultry manure (Adekiya *et al.*, 2014; Ojeniyi *et al.*, 2013; Ayeni and Adetunji, 2010 and Ewulo *et al.*, 2008).

In an experiment to evaluate the effect of poultry manure and plant population on soil properties and agronomic performance of sweet maize, Uwah *et al.* (2014) reported that the application of poultry manure led to significant increase in soil pH, organic matter (OM) content, total N, available P, exchangeable K, Ca, Mg and the effective cation exchange capacity (ECEC) status of the soil. They again reported that the exchangeable acidity (EA) of the soil was lowered by more than two-fold in the two separate experiments. The results from an experiment conducted by Dikinya and Mufwanzala (2010), suggest an increase in EC, exchangeable bases, nitrogen and phosphorus with an increase in the application rate of poultry manure.

The various researches undertaken to determine the effect of poultry manure on the physical and chemical properties of soil reported of positive results. The chemical properties such as; soil pH, organic matter content, C.E.C., macro and micro elements were significantly improved with poultry manure amendment as compared to the sole use of mineral fertilizer. Similarly, the bulk density, temperature, infiltration, porosity and water holding capacity were all improved with the use of poultry manure.

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2.7 Effect of low pH on nutrient availability in the soil

According to Polomski and Kuhn (2002), several factors can cause soil acidification. Among some of the factors are heavy application of chemical fertilizers, acid deposition, high rainfall and greenhouse gas. They reported that the rise in the concentration of H^+ in the soil can impede root growth and development. The results from Chao *et al.* (2014) indicated that low soil pH can directly impede the function and development of root and limit the absorption of K, Ca and Mg.

The optimum uptake of most nutrients occurs at a soil pH near neutral. The availability of most macronutrients (nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium) decreases as soil pH decreases. The availability of these nutrients is therefore increased when the soil acidity is reduced. On the contrary, as the soil pH increases, the availability of most micronutrients decrease. The effect of the relationship between soil pH and nutrient uptake efficiency is that fertilizer use and crop response are expected to change as a function of soil pH (Silveira, 2013).

2.8 Effect of poultry manure and NPK on plant growth

2.8.1 Number of leaves per plant

The number of leaves of a plant is dependent on the rate of the vegetative growth of the plant as influencd by the availability of essential plant nutrients needed by the plant for photosynthesis and other metabolic activities (Sekhon and Meelu, 1994). Research conducted by Dapaah *et al.* (2014), showed that with the application of poultry manure to soil used in the production of 'Bawku Red' onion variety, there was 30 – 42% higher number of leaves per plant compared to the untreated plot. The 15 t/ha and 20 t/ha poultry manure treatments had about 8 – 21% more number of leaves per plant than the NPK (450 kg/ha) treatment. The increase in the number of

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leaves per plant was achieved because both organic and inorganic fertilizers supply the soil with high nutrients especially nitrogen which significantly supports vegetative growth (Blay *et al.*, 2002). Even though the treatments were all supplied with nitrogen through organic and inorganic medium, the plots treated with poultry manure performed better than plots treated with NPK 15-15-15. This could be attributed to the fact that the poultry manure is able to release the nitrogen slowly and at the needed period compared to the NPK 15-15-15 which may release the N when not needed by the plants. The control plot (no fertilizer) might not have produced considerable number of leaves due to the obvious reason that it was low in nitrogen which is very vital for vegetative growth.

According to Abdissa *et al.* (2011), nitrogen fertilization (92 kg/ha) was able to increase the number of leaves per plant of onion by 8% as compared with the control plot. Again, the application of 120 – 150 kg of nitrogen significantly increased the number of leaves per onion plant (Nasreen *et al.*, 2007 and Vachhani and Patel, 1993). It was indicated by Ibrahim (2010), that the application of fertilizers to soil can increase the number of onion leaves from 6 to 11 strands with an average of one leaf per week. All these findings support the fact that nitrogen, which is responsible for the vegetative growth of plants is relevant when it comes to leaf development. The number of leaves also depend on the amount of the nitrogen applied and possibly the source of the nitrogen.

It was reported by Blay *et al*. (2002), that the combination of poultry manure and inorganic fertilizer increased number of leaves in shallot grown on sandy soils. A combined application of compost and N fertilizer increased the number of onion leaves over the control (Al-Fraihat,

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2016; Mutetwa and Mtaita, 2014; Rabari *et al.*, 2014; Singh and Ram, 2014; Abdel-Mawgoud *et al.*, 2005 and Khalil *et al.*, 2002). The findings indicate that a combined application of poultry manure and mineral fertilizer can lead to an increase the number leaves of onions. This is because the manure will improve the water retention of the soil in addition to improving the other physical properties of the soil while the mineral fertilizer will be readily available to the plant in a conducive environment. This will inevitably enhance the growth and development of the plant.

In a study conducted by Kandil *et al.* (2013) using farmyard manure at 35.7 t/ha, chicken manure at 10.7 t/ha and compost at 11.9 t/ha, poultry manure produced the highest number of leaves per plant. The major reason which could be responsible for this finding is that the different sources of organic manure such as compost, cow dung, sheep and goat manure and the likes have different nutrient composition. Poultry manure seems to have a higher nitrogen level than the rest. Since nitrogen is responsible for the vegetative growth of plants, it is likely that the higher level of nitrogen in the poultry manure might have caused it to produce more leaves compared to the other sources of manure. Again, it is possible that the poultry manure is able to release the nutrients better than the other sources of the manure.

In agreement with previously reported findings, Meena *et al.* (2015), also found that the number of leaves per plant was 24.8% more for the poultry manure treated plot over the control plot. Out of the three sources of organic manure evaluated (10 t/ha of FYM, 5 t/ha of vermicompost and 5 t/ha of Pm), poultry manure registered the highest (12.4) number of leaves per plant. Similarly,

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Tukur *et al.* (2009), earlier reported that among the different sources of plant nutrients evaluated on onions, poultry manure produced the highest number of leaves per plant.

An increase in the N level results in an increase in the number of leaves per plant. A combined application of N and FYM significantly affected the mean number of leaves per plant. The control had the lowest mean number of leaves (7.9) while the combined application of 150 kg/ha N and 45 t/ha FYM had the highest mean value of 15.4 leaves per plant (Yohannes *et al.*, 2013). According to Bashir *et al.* (2015), application of organic manure significantly improved the number of onion leaves over the control treatment. Sultana *et al.* (2014), reported that the sole application of N had no significant effect on the number of leaves of onion. This may be attributed to the fact that N was quickly released and hence not available throughout the vegetative growth stage of the plant (Tirol-Padre *et al.*, 2007). In addition, it is likely the N was held to the soil due to the pH of the soil and as a result was not available to the plants for growth and development of leaves (Chao *et al.*, 2014 and Silveira, 2013).

2.8.2 Plant height and leaf length

In an experiement to evaluate the effect of poultry manure and NPK fertilzation on the growth of "Bawku Red" onion variety, Dapaah *et al.* (2014), found variations in the plant height of onions treated with different soil amendments. The amended treatments (poultry manure and NPK 15-15-15) recorded 9 – 21% higher plant height over the control. The 10 t/ha treatment produced the tallest plants. According to Rizk (1997), enhanced crop growth due to soil amendment can significantly improve the plant height of onions. Furthermore, Kandil *et al.* (2013), reported that among the three sources of organic manure (farmyard manure, chicken manure and compost) used in soil amendment, chicken manure gave the tallest plants. The plant height of plants from

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the plots treated with poultry manure was significantly higher (80.9 cm) than plants coming from FYM (78.2 cm) and compost treated fields (78.9 cm). This finding is in line with that reported by other researchers (Bashir *et al.*, 2015; Abou El- Magd *et al.*, 2012 and Blay *et al.*, 2002). There is therefore no doubt that poultry manure has the ability to release nutrients better than other sources of organic manure.

In a comparative study on the productivity of four Egyptian garlic cultivars grown in various organic media in comparison with conventional chemical fertilizer, poultry manure produced the tallest garlic plants which were significantly different from those from the other N- sources (Abou El- Magd *et al.*, 2012). In a similar study, Blay *et al.* (2002), reported a significant increase in the height of shallot plants grown on sandy soils with the addition of poultry manure and inorganic fertilizer. A recent study by Bashir *et al.* (2015), also showed an increase in plant height with the application of organic manure. All these experiments support the superiority of poultry manure compared to other sources of organic manure when it comes to release of nitrogen. This is clearly evident in the fact that poultry manure treated plots have always produced significantly taller plants compared to those from fields treated with other sources of organic manure.

It was reported by Abdissa *et al.* (2011), that the application of 69 kg/ha of nitrogen fertilizer increased the plant height of onion by 10% compared to the control. They however noted that further addition of nitrogen did not result in any change in the height of the onion plant. An earlier experiemnt by Rizk (1997), revealed that the height of the onion plant is generally increased when there is any increase in nitrogen application. In addition, the role of nitrogen in

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increasing plant height was also buttressed by findings from Bungard *et al.* (1999), who concluded that nitrogen forms the basis of cell components and as a result promotes vigorous plant growth.

The application of N from organic and chemical sources significantly influenced plant height. There was a significant increase in plant height for the plots treated with N over the control. The tallest plant (39.3 cm) was obtained with the application of 80 kg N/ha supplied from urea with 40 kg N/ha substituted by cow dung (Sultana *et al.*, 2014). It is clear from the study that the relevance of nitrogen to the vegetative growth of plants cannot be overemphasized. It can also be noted that the source of the nitrogen is not as important, however, the availability of the nitrogen to the plant at the time it is needed is the main issue. Poultry manure has been known to release plant nutrients at a slow rate throughout the growth stage of the plant. This may explain why fields amended with poultry manure exhibit superior performance in terms of plant height.

In an experiment conducted by Meena *et al.* (2015), to determine the effect of organic manures and bio-fertilizers on the growth and quality attributes of 'Kharif' onion (*Allium cepa* L.) in semi-arid regions, it was observed that the plant height of onion at harvest was significantly higher (58.2 cm) for the plot amended with 5 t/ha of poultry manure compared to the no fertilizer control plot (48.1 cm). The plots treated with 10 t/ha of FYM and 5 t/ha of vermicompost recorded a plant height of 51.9 cm and 55.1cm respectively, significantly lower than plants treated with 5 t/ha of poultry manure. The significant differences observed between the poultry manure amendment and that of other organic manure sources may be attributed to the chemical composition and the nutrient releasing characteristics being better in poultry manure than in farmyard manure and vermicompost.

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The application of 100 kg/ha N and 15 t/ha FYM increased the plant height of onion by about 21% over that of the control treatment. The plant height however remained unaffected with an increase in the fertilizer rates (Yohannes *et al*., 2013). Despite the fact that nitrogen is needed for vegetative growth, this finding points out that over utilization of fertilizer does not result in any further increase in vegetative growth but rather fertilizer wastage and environmental pollution. A recent study by Al-Fraihat (2016), revealed that N-fertilizer source had a significant effect on the plant height of onions. The application of 30 m^3 compost and 45 kg/ha N resulted in 5.0% increase in plant height over the control.

The application of N and FYM significantly increased the leaf length of onion. The mean leaf length per plant was increased by 28% over the control when the level of farmyard manure was increased from 0 to 45 t/ha. In addition, the application of N at varying rates indicated a significant effect on the mean leaf length per plant. The plots treated with 150 kg/ha N registered about 16% increase in the mean leaf length per plant over the control; but was not significantly different from plots treated with 100 kg/ha N. An increase in the N application above 100 kg/ha did not result in a significant change in the mean leaf length per plant (Yohannes *et al.*, 2013). An earlier experiment conducted by Gupta *et al.* (1999), also indicated that the application of FYM improves the growth of onion. It has been reported by Jilani (2004), that application of 200 kg N/ha increased the leaf length of onions. On the contrary, current research works have proven that using nitrogen rates above 100 kg/ha would not result in a significant increase in leaf length. The findings made by Singh and Chaure (1999) and Kumar *et al.* (1998) indicate that the application of 150 kg/ha N resulted in the highest leaf length as far as onion is concerned. In agreement with earlier findings, Sultana *et al.* (2014), reported that the longest leaf (34.4 cm)

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was observed when 80 kg/ha N from urea and 40 kg/ha N from cow dung was applied to the field.

2.8.3 Total dry and fresh biomass

In a study to determine the influence of organic fertilizers on yield, essential oils and mineral content of onion, Yassen and Khalid (2009) reported that chicken manure treatment performed better than the recommended NPK treatment. The application of chicken manure increased the total dry and fresh biomass of the onion by 6.1% and 14.9% respectively over the control (recommended NPK). The fresh shoot biomass per onion plant was increased with the application of poultry manure.

An application of 5 t/ha of poultry manure saw a significant increase in the weight of the fresh shoot biomass of onions by 13.8% over the check (Meena *et al.*, 2015). It was similarly reported that, the application of chicken manure significantly increased onion dry biomass (16.9 g) over animal manure (14.9 g) and the control (13.2 g) (Mousa and Mohamed, 2009). In line with other research findings, Eliakira and Yohana (2013), reported that, of the three sources of organic manure (poultry manure, goat manure and cattle manure) applied, poultry manure registered the highest shoot biomass weight (8.9 g) at 56 days after transplanting. It is possible that these results were achieved because of the potential of essential nutrients present in poultry manure compared to the other sources of organic manure.

The application of poultry manure and NPK fertilizer significantly increased the total dry biomass of onion over the control. Poultry manure application increased the total dry biomass by

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17.1% over the NPK treatment (Dapaah *et al.*, 2014). It was further reported by Kandil *et al.* (2013), that the average fresh foliage weight per plant for plots treated with chicken manure was significantly higher (169 g) than those treated with farmyard manure (142 g) and compost (152 g) in all the three onion varieties studied. These findings are in conforminty with other research works where poultry manure performed remarkably better than mineral fertilzers and other sources of organic manure.

The fresh and dry biomass together with the total biomass were significantly increased with the combined application of compost and mineral N (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). This could be attributed to the presence of nitrogen in those fertilizers which play a significant role in the vegetative growth of plants. Again, the dry biomass yield of onion was significantly increased when the nitrogen fertilization, from inorganic sources, was increased from 100 kg/ha to 150 kg/ha N (Mohammadi-Fatideh and Hassanpour-Asil, 2012). A similar result was achieved by (Abdissa *et al.*, 2011), who reported that the total dry biomass of onion increased by 20% when 69 Kg/ha N was applied.

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2.8.4 Leaf diameter

According to Kumar *et al.* (1998), the application of 150 kg/ha of N produced the widest leaf in onion plants. Similar finding was made by Suresh *et al.* (2004), who indicated that use of farmyard manure gave the leaf with the widest width compared with the control which was the recommended dose of NPK fertilizer. Farmyard manure, like poultry manure, also ensures proper uptake of nutrients compared to mineral fertilizers. This brings to the fore that organic

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manure, irrespective of the type, performs better than the sole application of mineral NPK fertilizer. On the contrary, Yohannes *et al*. (2013), found that the application of N and FYM did not significantly influence the diameter of onion leaves. Abdissa *et al.* (2011), also noted that N fertilization from urea did not affect the leaf diameter of onion.

2.8.5 Days to physiological maturity

In an experiment to determine the growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on the vertisol of Shewa Robit, North East Ethiopia, Abdissa *et al.* (2011), reported that nitrogen fertilzation was able to increase the number of days to physiological maturity by six more days compared to the control irrespective of the N rate applied. This finding is plausible and could be attributed to the fact that the presence of nitrogen in the soil promoted the vegetative growth of the onion plant and hence delayed the number of days to maturity. The control plot, on the contrary, had less quantity of nitrogen and as a result its vegetative growth period was shortened. Yohannes *et al*., (2013), also reiterated that an increase in the N application is associated with the prolonged physiological maturity period.

2.9 Effect of poultry manure and NPK on bulb yield

2.9.1 Mean bulb weight

It was reported by Yohannes *et al*. (2013), that the application of farmyard manure significantly affected the mean bulb weight of onion. An application of 45 t/ha of the FYM gave the maximum mean bulb weight of 61.4 g which was 20% higher than the control treatment. Similar findings were made by Abbey and Kanton (2004), who reported that the application of farmyard

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manure, inorganic fertilizer or a combination of the two culminated in an increase in the mean bulb weight of onion. An improved mean bulb weight for chicken manure treated plot over FYM and compost plots was reported by Kandil *et al.* (2013). According to Mousa and Mohamed (2009), the mean bulb weight of onion (104.8 g) was improved by the application of chicken manure compared to goat manure (94.0 g) and mineral fertilizer (91.7 g).

According to Yohannes *et al*. (2013), the increase in the mean bulb weight of onion in response to N could be due to the increase in the number of leaves, leaf length and the extended physiological maturity associated with an increase in N application. The mean bulb weight exhibited a significant and strong correlation with the listed variables. The increase in the mean bulb weight of onion in relation to the listed parameters could be due to the large leaf surface area of the plant created by the leaf length and number which would increase the quantum of photosynthates translocated to the bulb. Again, the prolonged physiological maturity of the crop will give room for more photosynthates to be translocated to the bulb thereby resulting in an increased mean bulb weight. In the same vein, Abdissa *et al.* (2011), reported a significant increase in the mean bulb weight with N fertilization. There was 21.5% increase in the mean bulb weight with N fertilzation over the control.

The mean bulb weight of onion was significantly improved with the application of nitrogen from 50 to 100 kg/ha. It was however not statistically improved when the nitrogen was increased from 100 to 150 kg/ha (Mohammadi-Fatideh and Hassanpour-Asil, 2012 and Agumas *et al.*, 2014). This finding could be attributed to excessive vegetative growth resulting from the application of high levels of nitrogen fertilizer. In an experiment conducted by Sultana *et al.* (2014), a

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significant increase in the mean bulb weight of onion was recorded when N was applied in an integrated pattern.

2.9.2 Neck thickness, bulb diameter and bulb length

According to Yohannes *et al*. (2013), N when applied at different rates showed a significant effect on the mean bulb length. The authors indicated that among the different levels of N evaluated, the maximum N rate (150 kg/ha) gave the highest mean bulb length which was 12% more than the control. It was also indicated by Yadav *et al*. (2003) and Reddy (2005) that N fertilization increased the bulb length of onion. In an experiment conducted by Sultana *et al*. (2014), a combined application of N from organic and inorganic sources resulted in increased bulb length. The highest bulb length (2.8 cm) was obtained when 80 kg N/ha supplied from urea and 40 kg N/ha substituted by cow dung was applied to the soil. On the contrary, Abdissa *et al*. (2011), observed no effect of N fertilzation on the bulb length of onion.

Poultry manure is able to increase bulb diameter depending on the rate applied. The bulb diameter of onion was increased by 4.3% over that of the control/recommended NPK treatment (recommended NPK = 146.4 N/ha; 73.19 P_2O_5/ha; 48.8 K_2O/ha) with the incorporation of chicken manure (71.4 m^3 CM/ha) into the soil (Yassen and Khalid, 2009). It was also reported by Mousa and Mohamed (2009) that the application of chicken manure significantly increased bulb diameter of onions. According to Yohannes *et al*. (2013), the application of 45 t/ha of farmyard manure gave the highest mean bulb diameter (6.0 cm) compared to the control plot which registered a mean bulb diameter of 5.6 cm. The farmyard manure significantly influenced the mean bulb diameter of onion.

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The diameter of shallot bulbs can significantly be increased when both organic and inorganic fertilizers are incorporated into the soil (Yoldas *et al.*, 2011 and Akoun, 2005). Al-Fraihat (2016) reported that the application of organic manure and mineral N resulted in an increase in the bulb diameter of onion over the control. According to Mondal *et al.* (2004), the application of organic manure in addition to 75% of the recommended inorganic fertilizer (100 kg/ha N; 60 kg/ha P and 80 kg/ha K) produced onion bulbs with higher mean bulb diameter compared to using only inorganic fertilizers. It was indicated by Abdissa *et al.* (2011), that irrespective of the rate of application, nitrogen fertilization increased the bulb diameter of onion by about 12% compared to the unfertilized plot. It was further reported by Mohammadi-Fatideh and Hassanpour-Asil (2012) that bigger bulb sizes were produced when nitrogen was applied at the rate of 150 kg/ha. There was however no significant difference between the bulb diameter from 100 kg/ha and 150 kg/ha treatments. The various experiments conducted have clearly depicted that nitrogen fertilization is very important in the formation of bulbs in onions irrespective of the rate and the N source. Poultry manure can hence be used to increase the bulb size of onions since it is a rich source of nitrogen.

In an experiment to evaluate the effect of chemical fertilizers, organic fertilizers and bio-fertilizer on the yield and quality of onion, Singh and Ram (2014), reported that the neck thickness of onion bulbs coming from poultry manure amended soil was significantly higher (2.3 cm) than those from the control plot (2.2 cm). This is possible because the entire growth of the shoot and bulb of the onion is facilitated by nitrogen and hence the results from the experiment could be attributed to the higher amount of N present in the fields treated with poultry manure compared to the control field. According to Yohannes *et al.* (2013), the harvest index of onion was

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increased by 36% over the control treatment with combined application of 150 kg/ha N and 45 t/ha FYM. Earlier, Abdissa *et al.* (2011), had reported a 4% increase in the harvest index of onion with the application of 69 kg/ha N over the control treament.

2.9.3 Total and marketable bulb yield

In a study to investigate the effects of chicken 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 m^3/ha gave the highest yield which was significantly different from the 10 m^3/ha and 20 m^3/ha treatments. According to Yohannes *et al*. (2013), an increase in N and FYM levels led to a progressive increase in the total bulb yield of onion. A combined application of 100 kg/ha N and 30 t/ha FYM increased the total bulb yield by about 53% over the check plot. Similarly, Yoldas *et al.* (2011), reported that application of organic manure significantly improved the bulb yield and suggested that 20 t/ha of cattle manure could be adopted in onion production.

The total yield of garlic was significantly higher with the application of poultry manure as compared with the other forms of organic manure. The total bulb yield of garlic from the poultry manure plot was 42% better than the control (mineral NPK) treatment (Abou El- Magd *et al.*, 2012). Kandil *et al.* (2013), also found that the total and marketable yield of onion was higher for chicken 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). According to Bashir *et al.* (2015), 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

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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).

According to Jayathilake *et al.* (2002), the combination of organic fertilizers with chemical fertilizers gave better yield than the sole application of inorganic fertilizer. The highest yield of onion bulbs was obtained from the combination of organic and inorganic fertilizers compared with the application of chemical fertilizers alone (Mondal *et al.*, 2004; Sharma *et al.*, 2003, and Rizk *et al.*, 2014). 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), indicated 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. The results from the study by Al-Fraihat (2016) revealed that the nitrogen fertilizer source significantly improved the total and marketable yield of onions. In agreement with other research, Halvorson *et al.* (2008), reported that the total marketable onion yield increased significantly with increasing N fertilization rate.

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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) registered the lowest bulb yield of 3.8 t/ha (Gwari *et al.*, 2014). It was also reported by Eliakira and Yohana (2013), that poultry manure application resulted in the improved yield of onions. Giardini *et al.* (1992) also found that poultry manure application had a significant increase on the bulb yield of onions. According to Mousa and Mohamed (2009), the highest yield of onion bulbs was attained when chicken 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.

2.10 Effect of poultry manure and NPK on mineral composition of onions

The findings of Yassen and Khalid (2009), showed that the mineral content (N, P and K) of onion is slightly increased with the application of different rates of organic manure as compared to the control (recommended NPK fertilizer). The percentage of nitrogen, phosphorus and sulphur in onion bulbs was significantly higher in a poultry manure amended plot than in the control plot (Meena *et al.*, 2015). According to Abdelrazzag (2002), the application of poultry manure at different rates (20 t/ha, 40 t/ha and 80 t/ha) increased the concentration of N, P, K in onion bulb over the control (NPK at 400 kg/ha N, 200 kg/ha P_2O_5 and 100 kg/ha K_2O). There was however no significant difference among the various poultry manure rates used.

The concentrations of N, P, K and S in the bulbs of the onion at harvest increased with the combined application of organic and inorganic sources of fertilizers. The highest concentrations

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of N (2.30%), P (0.19%), K (1.71%) and S (0.96%) were achieved when 80 kg N/ha supplied from urea with 40 kg N/ha substituted by cow dung was incorporated into the soil (Sultana *et al.*, 2014).

It was reported by Yoldas *et al.* (2011), that addition of organic manure significantly increased the K content of onion bulb. An application of 60 t/ha of cattle manure registered the highest K (4.1%) content in the bulb. Addition of NPK fertilizer also resulted in a rise in the K content of the onion bulb over the control. In a similar experiment, Coolong *et al.* (2005), also found that N application increased the N and P content of onion bulbs.

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

Two separate experiments were conducted at the University of Ghana Research farm, Legon, Accra, in the Greater Accra Region of Ghana from December, 2015 to May, 2016. The objective of the research was to investigate the effect of poultry manure and NPK fertilizer on the growth and yield attributes of "Bawku Red" onion variety grown in acid soil. This chapter outlines the details of the materials and methods used for the study.

3.2 Experimental site

The research farm is located on latitude 5° 39'N and longitude 0° 11' W and falls in the Coastal Savannah agro-ecological zone of Ghana. The soil of the experimental site is the Adenta series, which is described as an Alfisol (Soil Survey Staff, 1998) and forms part of the soil series along a catena down the Legon hill. Adenta series has been classified as Typic Kandiustalf (Eze, 2008) according to USDA classification system. The topsoil (20-30 cm) is sandy loam and is inherently poor in fertility. The rainfall pattern of the site is bi-modal and records a total annual rainfall of about 800 mm. The major season stretches from April to July whilst the minor season occurs within August and October (Dowuona *et al.*, 2012).

The climatic conditions that prevailed during the experimental period are indicated in Table 3.1. The rainfall during the experimental period of December, 2015 to May, 2016 ranged from 0.0 mm to 159.2 mm. No rainfall was recorded in the months of December, 2015; January and

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February, 2016. The temperature of the period ranged from 22.3 ºC to 34.5 ºC. The photoperiod was between 6.4 and 8.3 hours for the experimental period (Table 3.1).

Table 3.1: Climatic data during the experimental period

Year	Month	Total Rainfall (mm)	Temperature (ºC)		Photoperiod (hours)
			Mean Maximum	Mean Minimum	
2015	December	0.0	33.8	22.3	6.4
2016	January	0.0	33.9	22.4	6.7
	February	0.0	34.5	24.0	6.9
	March	169.8	33.0	25.4	7.6
	April	46.6	33.2	25.5	8.3
	May	159.2	33.6	24.9	8.1

Source: Ghana Meteorological Agency, Mempeasem, Legon, Ghana

3.3 Experimental design and treatments

The experimental design used was randomized complete block design (RCBD) with 10 treatments and 4 replications. The treatments were as follows:

T_1: Control – No fertilizer

T_2: Poultry manure at 5 t/ha

T_3: Poultry manure at 10 t/ha

T_4: Poultry manure at 15 t/ha

T_5: Poultry manure at 20 t/ha

T_6: Poultry manure at 5 t/ha + 2.5 t/ha + 2.5 t/ha as side-dressing

T_7: Poultry manure at 10 t/ha + 2.5 t/ha + 2.5 t/ha as side-dressing

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T_{8}: Poultry manure at 5 t/ha and NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha as side-dressing

T_{9}: Poultry manure at 10 t/ha and NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha as side-dressing

T_{10}: NPK 15-15-15 at 600 kg/ha and Urea at 60 kg/ha as side-dressing

3.4 Experimental layout

The plot size was 1.2 m x 1.7 m with a total area of 2.04 m^2. Each block (replication) consisted of 10 plots with 1 m buffer strip between the plots and blocks. Each plot had 70 plants (7 rows and 10 plants within rows) at a plant spacing of 15 cm x 15 cm (Figure 3.1).

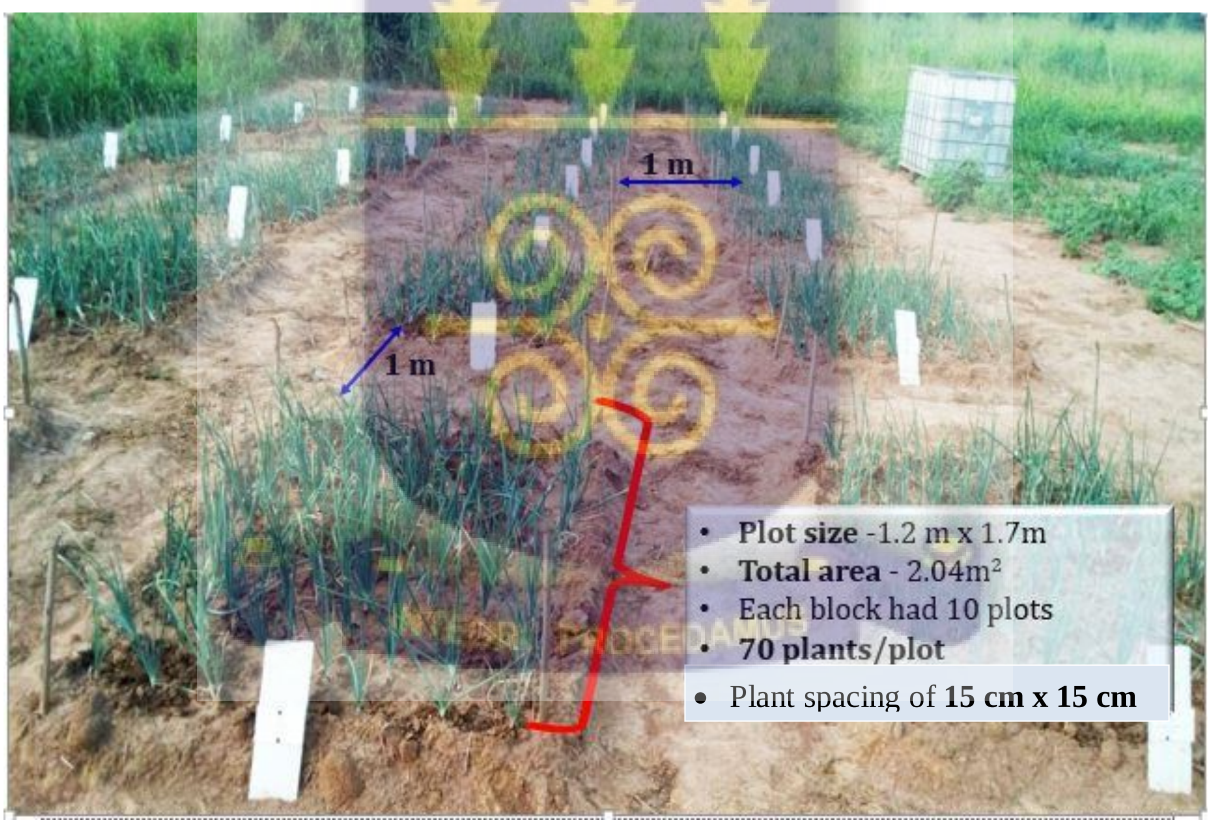

Figure 3.1: Picture of experimental layout

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About seven month-old poultry manure was obtained from a deep litter system and kept under shade for protection (from bad weather). The onion cultivar planted was the local “Bawku red” onion which was obtained from sellers at the Agbogbloshie market in the Greater Accra Region of Ghana.

3.5 Cultural practices

3.5.1 Land preparation

The experimental field was prepared by slashing on 8th December, 2015 and was immediately followed by ploughing and harrowing. Two weeks later, the field was 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 was done two weeks after spraying. Each plot was converted into a sunken bed for experiment one and a raised bed for experiment two. A 1 m buffer strip was left between the plots and the blocks.

3.5.2 Nursery establishment and management

The nursery area was cleared and seed trays filled with dry and sieved soil. The seed trays were then placed on a raised platform and a shade erected over them to regulate the intensity of the sunlight in the nursery. “Bawku Red”onion seeds were sown on 3rd December, 2015 for experiment one and 1st February, 2016 for experiment two in drills 10 cm apart in seed trays and watered.

The seed trays were watered usually in the mornings until transplanting. The seedlings were fertigated with 5 g of NPK 15-15-15 dissolved in 1 litre of water weekly. 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

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nursery was prevented by spraying Agrithane (Mancozeb 80WP) at a rate of 2 g per litre of water every two weeks.

3.5.3 Application of fertilizers

For treatments receiving poultry 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. For treatments that received poultry manure as side dressing, the manure was applied in two splits at 3 and 6 weeks after transplanting.

NPK 15-15-15 fertilizer was incorporated into the soil on the day of planting. The urea used as side dressing for treatments receiving mineral fertilizer was applied 5 weeks after transplanting by burying into the soil about 3 cm from the plants.

3.5.4 Transplanting

The six week old onion seedlings were transplanted onto the main field on 18th January, 2016 for the first experiment and on 15th March, 2016 for the second experiment at a planting distance of 15 cm x 15 cm. A week prior to transplanting, the seedlings were hardened off by reducing the watering regime and gradually increasing the intensity of sunlight in the nursery by removing the cover used.

3.5.5 Irrigation

The plants were watered uniformly (mostly on daily basis) depending on the soil and climatic conditions of the experimental site. This was to ensure that there was adequate moisture within the root zone of the plant. Watering was done using watering cans.

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3.5.6 Crop protection measures

Weeds growing on the beds and the inter plots were manually controlled by hand picking and hoeing respectively every fortnight. 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 prevented by spraying Agrithane (Mancozeb 80WP) at a rate of 2 g per litre of water at 7 days interval.

3.5.7 Earthing 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.

3.6 Laboratory analysis

The analysis of soil, poultry manure and onion bulb samples were carried out at the Council for Scientific and Industrial Research-Soil Research Institute (CSIR-SRI), Accra and Ecological Laboratory of the University of Ghana, Legon.

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Soil samples were randomly taken from the two experimental sites before transplanting of onion seedlings for physical and chemical analysis. The sampling was done along a Z plan using a soil augur. 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.

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After harvesting, soil samples were taken from each of the 40 plots at the two experimental sites. Soil samples from the same treatment plots were thoroughly mixed and a representative sample taken. Samples for the 10 treatments were accordingly labelled and taken for chemical analysis. For soil pH determination, all the 40 samples from the 40 treatments were used in each experiment.

A representative sample of the poultry manure used for the two experiments were taken and analysed for its chemical properties. Samples of onion bulbs from each of the 40 plots at the two experimental sites were taken at harvest. The 40 samples representing the 40 treatments under study were put in brown envelopes and labelled. The samples were oven dried at 70 ºC for 48 hours and analysed for macro nutrient content (N, P, K, Ca and Mg).

3.6.1 Determination of soil and poultry manure pH

The pH of soil and poultry manure samples were measured using the electrometric method by Peech (1965). Poultry manure and soil samples were added to distilled water at a ratio of 1:5 poultry manure: water and 1:1 soil: water, using a Hanna H19017 microprocessor pH meter standardized with standard aqueous solutions of pH 4 and pH 7. Ten (10 g) of sieved soil/poultry manure was weighed into a 100 mL beaker. Ten (10 mL) and 50 mL of distilled water was added to the soil and poultry manure respectively to form a suspension. The suspension was then vigorously stirred with a glass rod for 30 minutes and allowed to sand for 1 hour. The pH of the suspension was read after carefully and gently immersing the glass electrodes of the pH meter into the supernatant.

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3.6.2 Total digestion of poultry manure and onion samples

0.1 g of poultry manure and 0.2 g of onion samples were weighed into different 100 mL conical flasks and 5 mL of concentrated sulphuric acid (H_2SO_4) was added. The flasks were allowed to stand overnight for the sulphuric to dissolve the sample entirely. The solutions were heated for some few minutes and at the release of white fumes, hydrogen peroxide (H_2O_2) was added drop wise until a clear digest was observed. Distilled water was added and the solutions were allowed to cool. They were then filtered into 100 mL volumetric flask and topped up to the mark. Aliquots of the digest were taken for nitrogen, phosphorus, potassium, calcium, and magnesium analysis.

3.6.2.1 Determination of total nitrogen (N) in poultry manure and onion samples

Five milliliters (5 mL) aliquot each of the digest (as describe in section 3.6.2 above) were taken into Markham distillation apparatus. Five milliliters (5 mL) of 40% NaOH solution was added to the aliquot and the mixture distilled. The distillate was collected in 5 mL of 2% boric acid with mixed indicator. The distillate was then titrated against 0.01M Hydrochloric acid (HCl). The percentage nitrogen was calculated as follows:

$$\text{Total N (\%)} = \frac{\text{Titre x Molarity of HCl x Volume of distillate x 0.01}}{\text{Volume of aliquot x weight of sample}} \text{ X } 100$$

Where 0.014 = milliequivalent weight of nitrogen

3.6.2.2 Determination of total phosphorus (P) in poultry manure and onion samples

One milliliter (1 mL) aliquot of the digest (as described in section 3.6.2 above) was pipetted into a 50 mL volumetric flask. The pH was adjusted using p – nitrophenol indictor and neutralized

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using few drops of 4 M NH_4OH until the solution turned yellow. Eight milliliters (8 mL)of reagent B; prepared by dissolving 1.056 g of ascorbic acid in 200 mL of reagent A (12 g of ammonium molybdate + 0.2998 g of antimony potassium tartrate dissolved in 250 mL of distilled water). The dissolved reagent was added to 1000 mL of concentrated sulphuric acid whiles cooling the flask in an ice bath, mixed thoroughly and made to volume in a 2000 mL volumetric flask (Watanabe and Olsen, 1965). The solutions were made to the mark with distilled water, mixed thoroughly by shaking and left to stand for about 15 min to allow the colour to develop. The standards and sample absorbance (blue colour) at 880 nm wavelength were measured in colorimeter. The total P was determined as follows:

$$\text{Total P (\%)} = \frac{\text{(sample reading – blank reading) x digest volume x 100}}{\text{Weight of sample x aliquot taken x 1000000}}$$

3.6.2.3 Determination of total potassium (K) in poultry manure and onion samples

Two milliliters (2 mL) of the digest (as described in section 3.6.2 above) was pipetted into a 50 ml volumetric flask and was topped to make the mark with distilled water. The solutions were sprayed directly into the flame photometer starting with standards, the sample and blank solutions. The amount of potassium present in the solution was then read. The concentration of potassium in the poultry manure and onion samples expressed in percentage was calculated as follows;

$$\text{K (\%)} = \frac{\text{(a-b) x v x f x 100}}{\text{1000 x w x 1000}}$$

Where:

a = concentration of K in the digest

b = concentration of K in the blank digest

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w = weight of sample

v = volume of digest solution

f = dilution factor

3.6.2.4 Determination of calcium (Ca) in poultry manure and onion samples

Ten milliliters (10 mL) of the wet digested sample solution (as described in section 3.6.2 above) was pipetted into a 50 ml volumetric flask and topped to the mark with distilled water; the contents were well shaken. The standard, blank and sample solutions were sprayed into the flame of the atomic absorption spectrophotometer (AAS) at wavelength 422.7 nm. The concentration of calcium in the sample and blank solutions were then read. The concentration of calcium in the poultry manure and onion samples expressed in percentage were calculated as follows;

$$Ca\ (\%) = \frac{(a-b) \times v \times f \times 100}{1000 \times w \times 1000}$$

Where:

a = concentration of Ca in the digest

b = concentration of Ca in the blank digest

w = weight of sample

v = volume of digest solution

f = dilution factor

3.6.2.5 Determination of magnesium (Mg) in poultry manure and onion samples

Five milliliters (5 mL) of the digested sample (as described in section 3.6.2 above) was pipetted into a 50 ml volumetric flask and was filled to the 50 ml mark with distilled water and contents well mixed. The Mg standard series, the blank and sample solutions were sprayed into the flame of atomic absorption spectrophotometer (AAS). The concentration of the magnesium in the

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standard series, sample and the blank solutions were measured. The concentration of magnesium in the poultry manure and onion samples expressed in percentage was calculated as follows;

$$Mg\ (\%) = \frac{(a-b) \times v \times f \times 100}{1000 \times w \times 1000}$$

Where:

a = concentration of Mg in the digest

b = concentration of Mg in the blank digest

w = weight of sample

v = volume of digest solution

f = dilution factor

3.6.3 Determination of organic carbon in poultry manure and onion samples

0.1 g each of poultry manure and onion samples were weighed and screened through 0.5mm sieve into a 250 Erlenmeyer flask. Exactly 10 ml. of potassium dichromate solution was added followed by 20 ml. of conc. H_2S0_4. The flask was swirled to ensure that the solution is in contact with all the particles of the poultry manure/onion samples. Two blanks (Erlenmeyer flasks without soil) were included to determine the molarity of the ferrous ammonium sulphate solution. The flask and content were allowed to stand on an asbestos sheet for 30 minutes (in a fume cup-board) for the reaction to complete. Two hundred milliliters (200mL) of distilled water and 10ml of ortho phosphoric acid was added using a measuring cylinder and allowed to cool. Two milliliters (2mL) of barium diphenylamine sulphonate indicator solution was finally added and titrated with the ferrous ammonium sulphate solution until the colour changed to blue then to a green end-point. The volume of the ferrous ammonium sulphate was noted.

The percent organic carbon was calculated as follows:

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$$\% \text{ Organic carbon} = \frac{(1 - T/S) \times 10 \text{ mL} \times N \times 0.003 \text{ g} \times 1.33 \times 100}{W \text{ (g)}}$$

Where;

T = volume of ferrous ammonium sulphate solution used in sample titration (mL)

S = volume of ferrous ammonium sulphate solution used in blank titration (mL)

10 mL= volume of potassium dichromate ($K_2Cr_2O_7$) solution used for carbon oxidation

N = Normality of $K_2Cr_2O_7$ solution

0.003= equivalent weight of carbon in gram

1.33 = correction or compensation factor for the incomplete combustion of organic matter (if heat is not supplied)

w = weight of sample in gram.

Organic matter was obtained by multiplying the percent carbon by 1.729.

3.6.4 Determination of total nitrogen (N) in soil samples

The Kjedahl method (Black, 1965) was used to determine total nitrogen. A 2.0 g soil sample was put into a micro Kjedahl flask and 1.0 g of digester accelerator (10 g of K_2SO_4 + 1.0 g $CuSO_4.5H_2O$ 0.1g Selenium) was added. About 1 ml distilled water was added to moisten the soil and 5 ml concentrated sulphuric acid was also added. The flask was put on the digester and the mixture was allowed to digest for at least two hours until the digest became clear. It was then allowed to cool and then transferred with distilled water into a 50 ml volumetric flask and topped up to the volume.

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Five milliliters (5 mL) aliquot was put into a Markham distilled apparatus and 5 ml of 40 % NaOH was added and distilled. The distillate was collected into 5 mL 2 % boric acid to which about three drops of a mixture of methyl red and methylene blue indicator solution were added. The distillate was titrated with 0.01N HCl from a green to an indicator reddish end point. Total Nitrogen was calculated using:

$$\%\text{Nitrogen} = \frac{M \times X \times 50 \times 0.014}{W \times V} \times 100$$

Where;

M = Molarity of HCl used (N)

X = Volume of HCl used for titration (ml)

V = volume of filtrate (aliquot used for the distillation, ml)

W = Weight of soil for the digestion (g)

3.6.5 Determination of available phosphorus (P) in soil samples

Available phosphorus was determined using Bray 1 method (Bray and Kurtz, 1945). Five grams (5 g) of air-dried and sieved soil was weighed into extraction bottle and 50 mL of Bray 1 (mixture of 0.03M NH_4F and 0.025M HCl) solution was added and shaken on a mechanical shaker for 3 minutes at 200 rpm. The suspension was centrifuged and filtered through No. 42 Whatman filter paper into a clean solution bottle. Five milliliters (5 mL) aliquot of the filtrate was taken into a 50 mL volumetric flask in duplicate. The pH was adjusted using P-nitrophenol indicator and neutralized with a few drops of 4M NH_4OH until the solution turned yellow. Eight milliliters (8 mL) of reagent B was prepared by dissolving 1.056 g of ascorbic acid in 200 mL of reagent A. Reagent A was made by dissolving 12 g of ammonium molybdate and 0.2998 g of antimony potassium tartrate in 250 mL of distilled water. The dissolved reagents were added to

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1000 mL 0f 2.5M H_2SO_4, mixed thoroughly and made to the 2000 mL mark (Watanabe and Olsen, 1965). The solutions (i.e. the aliquot of the filtrate and 8 mL of reagent B) were mixed thoroughly by shaking and allowed to stand for 15 minutes for the colour to stabilize (the colour changed to blue of different intensities depending on the concentration of phosphorus available in the soil). A blank was prepared with distilled water and 8mL of reagent B. The spectrophotometer was calibrated using 25mg L^{-1} standard P solution prepared in the same manner as above. The intensity of the blue colour was measured using the Pharo 300 spectrophotometer at a wavelength of 712 nm. The available P concentration in the soil sample was read and calculated using the spectrophotometer reading as follows:

$$\text{P } mg/kg = \frac{\text{R} \times \text{Vol. of extract}}{\text{Vol. of aliquot} \times \text{Weight of soil}}$$

Where R = Spectrophotometer reading in mg L^{-1}

3.6.6 Determination of total potassium (K) in soil samples

Two milliliters (2 mL) of the digest (as described in section 3.6.4 above) was pipetted into a 50 ml volumetric flask and was topped to make the mark with distilled water. The solutions were sprayed directly into the flame photometer starting with standards, the sample and blank solutions. The amount of potassium present in the solution was then read. The concentration of potassium in the soil samples expressed in percentage was calculated as follows;

$$\text{K (\%) in the sample} = \frac{(a-b) \times v \times f \times 100}{1000 \times w \times 1000}$$

Where;

a = concentration of potassium in the digest;

b = concentration of the blank digest;

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w = the weight of sample;

v = volume of the digest solution and

f = dilution factor.

3.6.7 Determination of organic carbon in soil samples

Organic Carbon was determined by the wet combustion method of Walkley and Black (1934). Soil samples were sieved through 0.5 mm sieve and 0.5 g was weighed into 500 mL Erlenmeyer flask. Ten milliliters (10 mL) of potassium dichromate was added followed by 20 mL of concentrated H_2SO_4, to provide heat. The flask was swirled making sure that the solution was in contact with all the soil particles and then allowed to stand for one hour. After that, 200 mL of distilled water, 10 mL of H_3PO_4 and 2 ml of Barium Diphenyl Sulphate indicator were added and titrated against 0.25 M Ferrous Sulphate solution until the colour changed. A blank in which the same procedure was followed but without any soil sample soil was used as a check.

The titre value was used to calculate the organic carbon in g/kg soil as:

$$\text{OC } g/kg = \frac{[10 - (\text{XM}) \times 0.003 \times 1.33]}{\text{W}} \times 1000$$

Where OC g/kg= organic carbon in g per kg soil

X =Titre value (mL)

M=Molarity of ferrous ammonium Sulphate [Fe $(NH_4)_2(SO_4)_2$]

W= Weight of soil sample

Organic matter was obtained by multiplying the percent carbon by 1.729.

3.6.8 Cation exchange capacity (CEC) of soil samples

Ten grams (10 g) of soil was weighed into 200 mL extraction bottle and 100 mL of 1 M ammonium acetate (NH_4OAc) solution buffered at pH 7.0 was added. The bottle and its content

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were shaken on a mechanical shaker for 1 hr. at 200 rpm. The solution was filtered through a number 42 Whatman filter paper. The filtered samples were washed with 100 mL methanol to wash off the non-adsorbed ammonium ions. The ammonium saturated soil was leached with acidified 1M KCl solution. Five milliliters (5mL) of the leachate were transferred into a Kjedahl flask and then distilled after addition of 5 mL of 1M NaOH. The distillate was collected into 5mL of boric acid. Three drops of mixed indicator containing methyl red and methylene blue were added to the distillate in a 50 mL Erlenmeyer flask and then titrated against 0.01M HCl from green to violet endpoint to obtain the total CEC. The CEC was calculated as follows:

$$\text{CEC } (cmol_c kg^{-1} \text{ soil}) = \frac{V_{HCl} \times M_{HCl} \times 10^{-3} \times \text{Vol. of Extract.} \times 10^{3} \times 10^{2}\text{cmol}}{\text{Vol. of Aliquot} \times \text{Weight of soil(g)}}$$

Where:

V_{HCl}=Titre value of the HCl

M_{HCl}=Molarity of the HCl

3.6.9 Determination of electrical conductivity (EC) of soil samples

A 10 g of each air – dry soil sample was weighed and placed in a 100 ml disposable plastic cup; 20 ml of deionized water was added. The slurry was shaken on a reciprocating shaker for 45 minutes and then filtered. The suspension was allowed to settle for 20-30 minutes. The conductivity cell and meter were calibrated by using KCL reference solution at the temperature of the suspension. The conductivity electrodes were placed into the supernatant gently without disturbing the settled soil. The reading was then taken and recorded. The same procedure was repeated for all the samples.

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3.6.9 Determination of extractable soil cations (Ca^{+} and Mg^{+})

Ten grams (10 g) of the soil samples (2 mm sieved) were weighed into a 200 mL extraction bottles. Hundred (100) mL of 1N ammonium acetate (NH_4OAc) solution buffered at pH 7.0 was added. The bottles were covered and then placed on a reciprocating shaker and shaken for 1 hr at 180 strokes per min. The soil suspension was then filtered through a No. 42 Whatman filter paper. The filtrates were used for the determination of Ca and Mg.

A 5 mL aliquot of the filtrates was pipetted into 50 mL volumetric flask and made up to the mark with deionized water. The Perkin Elmer atomic absorption spectrometer (A Analyst 800) was calibrated with the appropriate standards for Ca and Mg respectively and the absorbance for each element determined. Exchangeable bases was calculated as:

$$\text{Ca}\ (\text{cmol}_c\text{kg}^{-1}) = \frac{\text{R} \times \text{Vol.of extract} \times 10^3\ (\text{g}) \times 10^2 (\text{cmol}) \times \text{E}}{\text{Weight of soil} \times 10^6\ (\mu\text{g}) \times 40}$$

Where 40 = Atomic mass of Ca

R = AAS (Atomic absorption spectroscopy) reading in mg L^{-1}

E = Charge of Ca

$$\text{Mg}\ (\text{cmol}_c\text{kg}^{-1}) = \frac{\text{R} \times \text{Vol.of extract} \times 10^3 (\text{g}) \times 10^2 (\text{cmol}) \times \text{E}}{\text{Weight of soil} \times 10^6 (\mu\text{g}) \times 24}$$

Where 24 = Atomic mass of Mg

R = AAS (Atomic absorption spectroscopy) reading in mg L^{-1}

E = Charge of Mg

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3.6.10 Particle size analysis

The particle size analysis was determined using the Bouyoucos Hydrometer method modified by Day (1965). Forty grams (40 g) of 2 mm sieved soil sample which had been air-dried was weighed into a dispersing bottle and 100 mL of 5 % Calgon (Sodium Hex metaphosphate) solution was added and shaken on a mechanical shaker for two hours at 200 rpm. The suspension was transferred into a 1 L graduated sedimentation cylinder and was brought to the mark by adding distilled water. A plunger was used to stir the suspension vigorously by moving it in and out of the suspension several times. The first and second hydrometer readings were taken at 5 minutes (i.e. silt plus clay) and 5 hours (i.e. clay) after the plunger was removed, a hydrometer was gently lowered into the content and the scale at the top of the meniscus was noted and recorded. These readings represented the silt plus clay fraction and the clay fraction, respectively. The suspension was poured from the sedimentation cylinder into a 47-micron sieve and the effluent discarded. Tap water was run through the sediment on the sieve to wash off most of the fine material. The sand particles left in the sieve were transferred into a moisture can, oven dried for 24 hours, cooled in a desiccator and the dry weight determined. The particle distributions for the various soil series were then computed as follows:

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Clay content = hydrometer reading at 5 hrs. = Ag

Silt content = hydrometer reading at 5 min- hydrometer reading at 5hrs = Bg

Sand content (weight of oven dried sample) = Cg

% clay $= Ag/40g \times 100$

% silt $= Bg/40g \times 100$

% sand $= Cg/40g \times 100$

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Where: 40 = weight of soil sample in grams

The distribution values were used to determine the textural class of the soils using the USDA textural triangle presented in appendix 1.

3.7 Data collection

Data was collected on vegetative growth characteristics and yield and yield components at bulb appearance stage and at harvest.

3.7.1 Vegetative growth characteristics

Ten randomly selected plants from the three middle rows in each treatment plot were tagged for data collection on vegetative growth parameters.

3.7.1.1 Percentage crop establishment

Crop establishment at 4 Weeks After Transplanting (WAT) was estimated. This was done by counting all the plants on each plot with the exception of the guard row plants. The percentage crop establishment was then estimated by dividing the number of established plants by the total number of seedlings transplanting and expressing it as a percentage.

Mathematically, Percentage crop establishment $= \frac{\text{No.of established plants}}{\text{Total number of seedlings transplanting}} \times 100\%$

3.7.1.2 Number of leaves per plant

The total number of leaves on 10 tagged plants was counted at bulb appearance and at harvest. The mean number of leaves per plant for each treatment plot was then calculated.

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3.7.1.3 Plant height

Plant height was taken at bulb appearance and at harvest on 10 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.

3.7.1.4 Leaf length

The leaf length was taken on 10 tagged plants at bulb appearance and at harvest. 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.

3.7.1.5 Leaf diameter

The leaf diameter was measured for the 10 selected plants at bulb appearance and at harvest. The leaf diameter was determined by measuring the maximum diameter of the longest leaf using a pair of digital Vernier calipers. The mean leaf diameter for each treatment plot was subsequently calculated.

3.7.1.6 Fresh and dry shoot biomass

At both bulb appearance and harvest, five plants were randomly uprooted from each of the treatment plot with the exception of plants in the three middle rows. The shoot was cut, chopped and the fresh weight taken using an electronic balance. The shoot was then oven-dried at 70 ^{o}C for 48 hours to constant weight. The dried samples were then weighed using an electronic balance to determine the dry shoot yield of the plants.

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3.7.1.7 Fresh and dry bulb biomass

Five plant samples were randomly uprooted from each of the treatment plots with the exception of plants in the three middle rows at bulb appearance and at harvest. The bulbs were severed and their fresh weight taken using an electronic balance. The bulbs were then oven-dried at 70 ^{o}C for 48 hours to constant weight. The bulb dry matter yield of the plants per treatment was then determined.

3.7.1.8 Total fresh and dry biomass

This quantity was estimated from the summation of the fresh and dry matter yield of the plants per treatment for fresh and dry shoot biomass and fresh and dry bulb biomass of the five sampled plants at bulb appearance and at harvest.

3.7.1.9 Days to 50% bulb appearance

Close monitoring was done to determine the number of days it took for bulb appearance of 50% of the plants from the middle harvestable rows. Bulb appearance commenced when there was enlargement at the base of the stem regions of the plant and it assumed the colour of the bulb (purple).

3.7.1.10 Days to physiological maturity

This was determined as the number of days from transplanting to the day at which more than 80% of the plants in a plot showed yellowing of leaves.

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3.7.2 Yield and yield components

Ten randomly selected plants from the three middle rows in each treatment plot which were tagged for data collection on vegetative growth parameters were also used for data collection on yield and yield components.

3.7.2.1 Mean bulb weight

Twenty-four bulbs from the middle three rows were weighed together with a digital weighing scale and the mean bulb weight for each treatment determined.

3.7.2.2 Bulb diameter

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

3.7.2.3 Bulb length

Bulb length was determined by measuring the length of the twenty-four 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.

3.7.2.4 Bulb neck diameter

The stem diameter was measured at the narrowest point of the neck using a pair of digital Vernier calipers. This was done for all the 10 tagged plants at bulb appearance and at harvest. The mean stem diameter was determined for the treatment plots.

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3.7.2.5 Number of bulbs and grading

Based on the diameter of the bulbs, the number of bulbs in each grade category for the various treatments was counted and their percentages determined. The criteria used for the grading was that; any bulb with a diameter of less than 30 mm (<30 mm) was graded as small, those with diameters between 30 – 50 mm were graded as medium and those above 50 mm (>50 mm) were graded as large.

3.7.2.6 Total bulb yield

The bulb yield was computed based on the weight of bulbs harvested from the 3 middle rows per plot. The value obtained was then converted into yield per hectare.

3.7.2.7 Marketable bulb yield

Marketable bulb yield was determined after discarding the following; bulbs smaller than 10 mm in diameter, thick necked, rotten and discoloured. The mean marketable bulb yield was determined for each of the treatment.

3.7.2.8 Bulbing ratio

Bulbing ratio was determined as the ratio of bulb neck diameter to bulb diameter.

Mathematically, bulbing ratio = neck diameter/bulb diameter.

3.7.2.9 Harvest index

Harvest index was determined as the ratio of dry bulb weight to total dry biomass yield per plant.

Mathematically, harvest index = dry bulb yield/total dry biomass or yield of crop/ total amount of biomass.

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3.8 Economic analysis

Cost-benefit analysis was carried out to evaluate the profitability of 'Bawku red' 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.

3.9 Data analysis

The data collected was analysed using the analysis of variance (ANOVA) for randomized complete block design (RCBD) with the help of the GenStat 12th Edition software. Means which differed significantly were compared using the Fisher's Protected Least Significance Difference (LSD) at 5% level of significance (P = 0.05).

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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 experiments one and two are presented in Table 4.1. The results from the analysis showed that the soil was moderately acidic in both experiments (Appendix 5). The total N, available P, and total K were slightly lower in experiment one than in experiment two. According to the CSIR-SRI Soil Test Interpretation Guide (Appendix 4), the N was adequate in experiment two but low in experiment one. P and K were however adequate in both experiments. Furthermore, Ca was adequate whilst Mg was low in both experiments. The organic matter content of the soil was found to be low whilst CEC on the contrary, 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.

4.1.2 Poultry manure analysis

Table 4.2 shows some of the chemical properties of poultry manure used in experiments one and two. The poultry manure used in experiment two had a slightly higher organic matter (24.96%) compared to experiment one (23.23%). The percent N, P, K and Ca and Mg were all higher in experiment two than in experiment one. The pH of the manure was however higher in experiment one (8.13) compared to experiment two (7.79).

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Table 4.1: Soil analysis at the experimental site at 0 -15 cm depth

Soil analysis	**Experiment 1**	**Experiment 2**
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^{2+} (mg/kg)	5.11	5.25
Mg^{2+} (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

Table 4.2: Chemical properties of poultry manure used in experiment 1 and 2

Chemical properties	**Experiment 1**	**Experiment 2**
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^{2+} (mg/kg)	2.12	2.13
Mg^{2+} (mg/kg)	0.22	0.25
pH (water 1:5)	8.13	7.79

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4.1.3 Chemical properties of soil after harvesting

Some chemical properties of soil after harvesting are reported in Tables 4.3 and 4.4 for experiment one and two respectively. The results from experiment one (Table 4.3) indicate that the pH of the control (5.35) was moderately acidic but with the application of the different poultry manure and a combination of poultry manure and inorganic fertilizer, the pH was increased to a maximum of 7.32. Application of only chemical fertilizer on the contrary, further reduced the soil pH to 5.21. The total N, available P and O.M. were higher in the amended plots than the controls. The electrical conductivity of the amended plots was higher than the control (0.23 dS/m). In experiment two (Table 4.4), the pH of the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment again reduced from 5.37 to 5.16. The amendments containing poultry manure however raised the pH of the soil from 5.37 to a maximum level of 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.

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Table 4.3: Chemical properties of soil after harvesting at 0 - 15cm depth for experiment 1

Chemical properties	**Treatments**									
	T_1: Control (No fertilizer)	**T_2:** Pm at 5 t/ha	**T_3:** Pm at 10 t/ha	**T_4:** Pm at 15 t/ha	**T_5:** Pm at 20 t/ha	**T_6:** Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	**T_7:** Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	**T_8:** Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	**T_9:** Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	**T_{10}:** NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha
Total Nitrogen (%)	0.12	0.22	0.18	0.18	0.19	0.30	0.18	0.14	0.14	0.23
Available Phosphorous (mg/kg)	30.4	33.73	32.67	37.07	35.47	36.00	36.40	32.93	33.20	32.93
Total Potassium (mg/kg)	171.00	166.73	166.53	170.53	170.60	174.40	174.87	174.67	173.27	157.20
Organic Carbon (%)	0.78	0.78	0.82	1.12	1.38	1.21	1.19	0.90	0.87	0.87
Organic Matter (%)	1.34	1.34	1.41	1.94	2.39	2.10	2.05	1.55	1.50	1.50
pH (water 1:1)	5.35	7.09	7.10	7.32	7.31	7.06	7.03	6.55	6.89	5.21
Ca^{2+} (mg/kg)	5.04	4.71	4.71	5.19	5.19	5.61	5.61	5.33	5.14	4.37
Mg^{2+} (mg/kg)	0.15	0.19	0.16	0.19	0.18	0.13	0.17	0.20	0.15	0.16
CEC (C mol/kg)	5.97	2.69	7.91	6.15	6.93	7.08	9.73	4.03	7.29	6.92
Electrical Conductivity (dS/m)	0.23	0.54	0.72	0.63	0.97	0.85	0.53	0.44	0.67	0.61

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Table 4.4: Chemical properties of soil after harvesting at 0 - 15cm depth for experiment 2

Chemical properties	Treatments									
	T_1: Control (No fertilizer)	**T_2:** Pm at 5 t/ha	**T_3:** Pm at 10 t/ha	**T_4:** Pm at 15 t/ha	**T_5:** Pm at 20 t/ha	**T_6:** Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	**T_7:** Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	**T_8:** Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	**T_9:** Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	**T_{10}:** NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha
Total Nitrogen (%)	0.12	0.23	0.19	0.19	0.20	0.31	0.19	0.15	0.15	0.24
Available Phosphorous (mg/kg)	30.92	34.30	33.23	37.70	36.07	36.61	37.02	33.49	33.76	33.49
Total Potassium (mg/kg)	173.79	169.45	169.25	173.31	173.38	177.24	177.72	177.51	176.09	159.76
Organic Carbon (%)	0.81	0.81	0.85	1.16	1.43	1.25	1.23	0.93	0.90	0.90
Organic Matter (%)	1.39	1.39	1.46	2.01	2.48	2.18	2.13	1.61	1.56	1.56
pH (water 1:1)	5.37	6.33	6.85	6.63	6.64	6.80	7.01	6.29	6.79	5.16
Ca^{2+} (mg/kg)	5.16	4.82	4.82	5.31	5.31	5.74	5.74	5.45	5.26	4.47
Mg^{2+} (mg/kg)	0.16	0.20	0.16	0.19	0.19	0.14	0.18	0.21	0.16	0.17
CEC (C mol/kg)	6.04	2.72	7.99	6.21	7.01	7.16	9.84	4.08	7.37	7.00
Electrical Conductivity (dS/m)	0.24	0.55	0.74	0.65	1.00	0.87	0.54	0.45	0.69	0.63

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4.2 Vegetative growth

The parameters used as indices of vegetative growth were crop establishment, plant height, leaf length, leaf diameter, number of leaves, number of days to 50% bulb appearance, days to physiological maturity and fresh and dry biomass.

4.2.1 Crop establishment

As indicated in Table 4.5, the crop establishment for the two experiments ranged between 76.1 – 86.8% and 64.9 – 87.8% for experiment one and two respectively. There were no significant differences observed among the various soil amendments and control in both experiments. Poultry manure at 15 t/ha registered the highest crop establishment (86.8%) with poultry at 20 t/ha scoring the lowest (76.1 %) in experiment one. In experiment two, the highest crop establishment of 87.8% was attained with the application of 5 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure whilst the control treatment (no fertilizer) registered the lowest crop establishment of 64.9%. The mean crop establishment was greater in experiment one (81.6%) than experiment two (76.7%).

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Table 4.5: Effect of soil amendment on crop establishment of onion for experiment 1 and 2

Treatments	Crop establishment (%)	
	Experiment 1	Experiment 2
T_1: Control (No fertilizer)	80.6	64.9
T_2: Pm at 5 t/ha	84.5	82.3
T_3: Pm at 10 t/ha	82.3	79.9
T_4: Pm at 15 t/ha	86.8	73.6
T_5: Pm at 20 t/ha	76.1	72.8
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	85.5	87.8
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	81.3	79.3
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	77.0	74.4
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	83.6	79.5
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	78.0	72.3
LSD (P = 0.05)	**NS**	**NS**

4.2.2 Plant height

Significant differences were observed among the different treatments in both experiments (Table 4.6). In experiment one, the application of 10 t/ha + 2.5 t/ha + 2.5 t/ha and 5 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure resulted in significantly taller plants (48.1 cm) and (45.9 cm) respectively compared to the other amendments and the control. Similarly, significantly taller plants (49.7 cm) and (46.3 cm) were produced with the application of 10 t/ha + 2.5 t/ha + 2.5 t/ha and 5 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure respectively in experiment two. All the fertilizer amendments produced significantly taller plants than the control in both experiments except NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (37.2 cm) which was not significantly different from the control (34.1 cm) in experiment two. On average, plants from experiment two were relatively taller (42.8 cm) compared to those from experiment one (40.9

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cm). Soil amendments on average produced plants which were 46.6% and 25.5% taller than plants from the control plots in experiment one and two respectively.

In both experiments one and two, there were significant differences in the plant height of 'Bawku Red' onion cultivar at harvest among the different treatments (Table 4.7). In experiment one, the application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure produced the tallest plant (50.1 cm) compared to the other soil amendments and the control. This was however not statistically different from the 20 t/ha (48.5 cm) and 5 t/ha + 2.5 t/ha + 2.5 t/ha (47.7 cm) poultry manure treatments. In addition, the plant height of onion from the amended plots was significantly different from the control plot. In experiment two, the application of 10 t/ha + 2.5 t/ha + 2.5 t/ha poultry manure (52.2 cm), 10 t/ha poultry manure + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha (49.1 cm) and 15 t/ha of poultry manure (48.4 cm) resulted in significantly taller plant compared to the other amendments and the control. Furthermore, with the exception of NPK 15-15-15 at 600kg/ha + Urea at 60kg/ha treatment and the control which were statistically the same, all the other soil amendments were significantly different from the control. The control registered the shortest plant height in both experiment one (33.7 cm) and two (39.8 cm). The average plant height of onions from the treated plots in experiment one and two was higher than the control treatment by 35.3% and 19.3% respectively. The onion plants from experiment one, on average, were relatively shorter (45.6 cm) compared to the experiment two (47.5 cm).

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Table 4.6: Effect of soil amendment on plant height (cm) of onion at bulb appearance for experiments 1 and 2

Treatments	Plant height (cm)	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	27.9	34.1
T_2: Pm at 5 t/ha	43.1	44.0
T_3: Pm at 10 t/ha	39.4	43.2
T_4: Pm at 15 t/ha	44.5	44.7
T_5: Pm at 20 t/ha	40.9	42.2
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	45.9	46.3
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	48.1	49.7
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	35.8	41.1
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	43.1	45.2
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	40.1	37.2
LSD (P = 0.05)	**3.4**	**3.7**

Table 4.7: Effect of soil amendment on the plant height (cm) of onion at harvest for experiments 1 and 2

Treatments	Plant height (cm)	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	33.7	39.8
T_2: Pm at 5 t/ha	44.3	46.7
T_3: Pm at 10 t/ha	43.3	47.8
T_4: Pm at 15 t/ha	45.9	48.4
T_5: Pm at 20 t/ha	48.5	47.3
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	47.7	47.1
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	50.1	52.2
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	41.8	47.0
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	47.1	49.1
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	42.1	42.2
LSD (P = 0.05)	**2.8**	**4.1**

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4.2.3 Leaf length

As shown in Table 4.8 there were significant differences in the leaf length of 'Bawku Red' onion cultivar at the bulb appearance stage among the different treatments in both experiments. Poultry manure applied at 10 t/ha + 2.5 t/ha + 2.5 t/ha produced the longest leaf in both experiment one (44.2 cm) and two (46.2 cm) which was significantly different from the other treatments with the exception of the 5 t/ha + 2.5 t/ha+2.5 t/ha of poultry manure treatment. As expected, the control plants had the shortest leaf in both experiment one (23.3 cm) and two (31.6 cm). The leaf length of plants from the amended plots was significantly different from the control in both experiments with the exception of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment which was not significantly different from the control in experiment two. 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 experiment two (39.7 cm) was slightly longer compared to that of experiment one (37.0 cm).

There were significant differences in the leaf length of onion plants at harvest among the different soil amendments and the control plots in both experiments (Table 4.9). The leaf length of plants from the 20 t/ha (44.3 cm), 10 t/ha + 2.5 t/ha + 2.5 t/ha (43.1 cm) and 5 t/ha + 2.5 t/ha + 2.5 t/ha (41.8 cm) poultry manure treatments was significantly longer compared to the other treatments and the control in experiment one. Again, there was no significant difference between the leaf length of plants from NPK 15-15-15 at 600kg/ha + Urea at 60kg/ha (31.4 cm) and the control plot (31.0 cm). No significant difference was observed in the leaf length of plants from the different rates of poultry manure and a combination of the poultry manure and NPK 15-15-15 fertilizer amendments in experiment two. There was however significant difference in the leaf

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length of plants from the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (41.0 cm) amendment and the control. The leaf length of plants from the control plot was significantly different from the amended plots and had the shortest leaf (31.0 cm). On average, plants from experiment two had longer leaf (44.4 cm) compared to experiment one (38.5 cm).

Table 4.8: Effect of soil amendment on the leaf length (cm) of onion at bulb appearance for experiment 1 and 2

Treatments	**Leaf length (cm)**	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	23.3	31.6
T_2: Pm at 5 t/ha	40.4	40.6
T_3: Pm at 10 t/ha	35.5	40.8
T_4: Pm at 15 t/ha	40.6	42.3
T_5: Pm at 20 t/ha	37.0	39.2
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	42.0	43.0
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	44.2	46.2
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	31.9	38.6
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	39.2	41.0
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	36.2	34.0
LSD (P = 0.05)	**3.6**	**4.1**

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Table 4.9: Effect of soil amendment on the leaf length (cm) of onion at harvest for experiment 1 and 2

Treatments	**Leaf length (cm)**	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	31.0	36.6
T_2: Pm at 5 t/ha	39.6	45.5
T_3: Pm at 10 t/ha	37.0	45.0
T_4: Pm at 15 t/ha	37.6	46.9
T_5: Pm at 20 t/ha	44.3	44.9
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	41.8	44.9
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	43.0	47.7
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	37.7	44.7
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	41.4	47.0
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	31.4	41.0
LSD (P = 0.05)	**2.8**	**3.9**

4.2.4 Leaf diameter

There was significant difference in leaf diameter at bulb appearance stage among the different treatments in both experiment one and two (Table 4.10). In both experiments, the leaf diameter of plants from all the amended plots with the exception of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment were significantly higher compared to the control plots. In experiment one, application of 10 t/ha + 2.5 t/ha + 2.5 t/ha Pm (9.0 mm), 15 t/ha Pm (8.6 mm) and 10 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha (8.4 mm) produced plants with significantly wider leaf diameter compared to the other treatments. The results from experiment two depicts that the leaf diameter of plants from all the amended plots were not statistically different from each other with the exception of 20 t/ha Pm, 5 t/ha + 2.5 t/ha + 2.5 t/ha Pm and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha. The control plots had the least leaf diameter in both experiment

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one (5.6 mm) and two (6.0 mm). The average leaf diameter of plants in experiment one (7.5 mm) was slightly higher compared to that of experiment two (7.3 mm).

Table 4.11 shows the influence of poultry manure and NPK fertilizer application on the leaf diameter at harvest. The leaf diameter of plants from the soil amended plots was significantly wider compared to the control in both experiment one and two. There was no significant difference between the leaf diameter of plants from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment and the control in both experiments. The leaf diameter of plants from 15 t/ha (10.7 mm) and 10 t/ha + 2.5 t/ha + 2.5 t/ha (11.0 mm) poultry manure treatments was significantly wider compared to the other amendments and the control in experiment one. In experiment two, no significant difference was observed among all the poultry manure treatments and their combination with NPK fertilizer. Again, there was no significant difference between NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha and the control. On average, experiment one had plants with wider leaf diameter (9.5 mm) than experiment two (9.0 mm).

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Table 4.10: Effect of soil amendment on the leaf diameter (mm) of onion at bulb appearance for experiment 1 and 2

Treatments	Leaf diameter (mm)	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	5.6	6.0
T_2: Pm at 5 t/ha	7.2	7.5
T_3: Pm at 10 t/ha	7.0	7.6
T_4: Pm at 15 t/ha	8.6	7.9
T_5: Pm at 20 t/ha	8.1	7.2
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	7.9	7.2
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	9.0	7.9
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	7.0	7.3
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	8.4	7.8
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	6.1	6.5
LSD (P = 0.05)	**0.8**	**0.7**

Table 4.11: Effect of soil amendment on the leaf diameter (mm) of onion at harvest for experiment 1 and 2

Treatments	Leaf diameter (mm)	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	7.6	7.7
T_2: Pm at 5 t/ha	9.3	9.2
T_3: Pm at 10 t/ha	9.0	9.2
T_4: Pm at 15 t/ha	10.7	9.7
T_5: Pm at 20 t/ha	10.1	9.0
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	10.1	9.2
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	11.0	9.7
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	9.1	9.0
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	10.0	9.3
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	8.2	8.3
LSD (P = 0.05)	**0.8**	**0.8**

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4.2.5 Number of leaves

Table 4.12 indicates significant difference in the number leaves among the different soil amendments and the control in both experiment one and two at bulb appearance stage. The application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure resulted in higher number of leaves (8.1) compared to the other treatments in experiment one. Again, all the amended plots registered significantly higher number of leaves than the control plot. In experiment two, the mean number of leaves recorded for all the amended plots were significantly higher than the control plot except NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment (6.3) which was not statistically different from the control (6.0). The mean number of leaves recorded for experiment one (6.9) was slightly lower compared to that of experiment two (7.2). On average, soil amendment was able to increase the mean number of leaves of onion between 12.5 – 44.6% and 5 – 33.3% over the control in experiment one and two respectively.

As expected, significant differences were observed in the number of leaves of onion plant from the treated and control plots in both experiments at harvest (Table 4.13). The mean number of leaves from all the amended plots were significantly higher than the control plot (7.1) in experiment one. Similarly, the mean number of leaves from the amended plots were significantly higher than the control in experiment two with the exception of those from 20 t/ha poultry manure (8.3) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (8.2) treatments which were statistically not different from the control (7.8). On average, the mean number of leaves registered in experiment two was 8.4% more compared to that of experiment one. In general, soil amendment increased the number of leaves of onion by 31% and 18% over the control in experiment one and two respectively.

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Table 4.12: Effect of soil amendment on the number of leaves at bulb appearance for experiment 1 and 2

Treatments	No. of leaves	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	5.6	6.0
T_2: Pm at 5 t/ha	7.5	7.7
T_3: Pm at 10 t/ha	6.6	7.4
T_4: Pm at 15 t/ha	7.3	7.2
T_5: Pm at 20 t/ha	6.8	6.7
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	6.9	7.8
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	8.1	8.0
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	6.9	7.5
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	7.5	7.6
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	6.3	6.3
LSD (P = 0.05)	**0.5**	**0.6**

Table 4.13: Effect of soil amendment on the number of leaves at harvest for experiment 1 and 2

Treatments	No. of leaves	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	7.1	7.8
T_2: Pm at 5 t/ha	8.4	9.3
T_3: Pm at 10 t/ha	8.0	9.1
T_4: Pm at 15 t/ha	8.9	9.6
T_5: Pm at 20 t/ha	8.7	8.3
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	8.6	9.2
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	9.2	9.8
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	7.7	9.3
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	8.9	9.7
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	8.1	8.2
LSD (P = 0.05)	**0.7**	**0.7**

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4.2.6 Number of days to 50% bulb appearance

Table 4.14 indicates that there was no significant difference in the number of days to 50 % bulb appearance in 'Bawku Red' onion cultivar in both experiment one and two with the application of poultry manure, NPK 15-15-15 fertilizer, a combination of poultry manure and NPK 15-15-15 and no fertilizer (control). The application of 15 t/ha of poultry manure gave the least number of days to bulb formation in both experiment one (21 days) and two (19 days). Similarly, the highest number of days to bulb formation was observed in both experiment one (25 days) and two (23 days) with the application of 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha respectively. On average, it took fewer days for bulb appearance in experiment two (21 days) compared to experiment one (23 days).

Table 4.14: Effect of soil amendment on the number of days to 50% bulb appearance for experiment 1 and 2

Treatments	No. of days	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	25	23
T_2: Pm at 5 t/ha	22	20
T_3: Pm at 10 t/ha	21	20
T_4: Pm at 15 t/ha	21	19
T_5: Pm at 20 t/ha	22	21
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	21	20
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	22	21
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	25	23
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	24	23
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	25	23
LSD (P = 0.05)	**NS**	**NS**

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4.2.7 Number of days to physiological maturity

Significant differences were observed in the number of days to physiological maturity of 'Bawku Red' onion cultivar in both experiments one and two among the different treatments (Table 4.15). There was no significant difference in the number of days to physiological maturity between onion plants from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment and the control in both experiments. Poultry manure and a combination of poultry manure and NPK fertilizer amendments scored significantly higher number of days to physiological maturity than the control plot in both experiments. On average, soil amendments increased the number of days to physiological maturity by 7 more days over the control in both experiment one (37 days) and two (35 days). In general, the number of days to physiological maturity was slightly higher in experiment one (43 days) compared to experiment two (41 days).

Table 4.15: Effect of soil amendment on the number of days to physiological maturity for experiment 1 and 2

Treatments	**No. of days**	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	37	35
T_2: Pm at 5 t/ha	44	42
T_3: Pm at 10 t/ha	44	42
T_4: Pm at 15 t/ha	45	43
T_5: Pm at 20 t/ha	46	45
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	47	43
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	47	45
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	41	39
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	44	42
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	39	37
LSD (P = 0.05)	**4**	**4**

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4.2.8 Fresh shoot, bulb and total biomass

The influence of soil amendments on the fresh shoot, bulb and total biomass of 'Bawku Red' onion cultivar at the bulb appearance stage is presented in Table 4.16. The application of organic and inorganic fertilizers and no fertilizer did not significantly affect the fresh shoot and total biomass of onion at the bulb appearance stage in both experiment one and two. The application of 10 t/ha + 2.5 t/ha + 2.5 t/ha poultry manure however scored the highest fresh shoot and total biomass values in both experiments. The results from the analysis of variance further showed that, there were significant differences in the fresh bulb biomass in both experiments. On average, the fresh bulb biomass of the amended plots was higher (1.0 g/plant and 1.1 g/plant) than the control (0.8 g/plant) in both experiments.

There were significant differences in the fresh weight of shoot, bulb and total biomass of Bawku Red' onion cultivar at harvest in both experiment one and two (Table 4.17). In experiment one, the application of 5 t/ha and 10 t/ha + 2.5 t/ha+2.5 t/ha poultry manure gave a significantly higher weight (20.6 g/plant) of shoot biomass compared to the other treatments. Again, the highest mean weight of bulb and total biomass was achieved with the application of 20 t/ha, 15 t/ha, 5 t/ha, 10 t/ha + 2.5 t/ha+2.5 t/ha and 5 t/ha + 2.5 t/ha +2.5 t/ha of poultry manure. In experiment two, the weight of shoot, bulb and total biomass from all the amended plots were significantly higher compared to the control. In addition, the weight of the total biomass from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment (50.4 g/plant) was found to be significantly lower compared to the other amended plots. Similarly, the weight of bulb biomass produced from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha plot (32.7 g/plant) was

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significantly lower than the other amended plots but statistically not different from the 20 t/ha poultry manure plot (40.0 g/plant).

Table 4.16: Fresh biomass of 'Bawku Red' onion cultivar at bulb appearance for experiments 1 and 2

Treatments	Experiment 1			Experiment 2		
	Shoot (g/plant)	Bulb (g/plant)	Total (g/plant)	Shoot (g/plant)	Bulb (g/plant)	Total (g/plant)
T_1: Control (No fertilizer)	3.0	0.8	3.7	3.3	0.8	4.1
T_2: Pm at 5 t/ha	4.4	1.0	5.4	4.8	1.0	5.9
T_3: Pm at 10 t/ha	3.9	0.7	4.6	4.3	0.7	5.0
T_4: Pm at 15 t/ha	6.0	0.8	6.8	6.5	0.9	7.4
T_5: Pm at 20 t/ha	5.3	1.3	6.5	5.8	1.4	7.2
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	4.2	0.9	5.1	4.6	1.0	5.6
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	6.4	1.2	7.5	7.0	1.3	8.2
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	4.4	0.9	5.3	4.8	1.0	5.8
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	4.7	1.2	5.8	5.1	1.3	6.4
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	3.4	0.9	4.3	3.7	1.0	4.7
LSD (P = 0.05)	**NS**	**0.3**	**NS**	**NS**	**0.4**	**NS**

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Table 4.17: Fresh biomass of 'Bawku Red' onion cultivar at harvest for experiments 1 and 2

Treatments	Experiment 1			Experiment 2		
	Shoot (g/plant)	**Bulb (g/plant)**	**Total (g/plant)**	**Shoot (g/plant)**	**Bulb (g/plant)**	**Total (g/plant)**
T_1: Control (No fertilizer)	8.1	7.7	15.7	11.2	23.1	34.3
T_2: Pm at 5 t/ha	17.0	22.0	39.0	23.1	45.7	68.8
T_3: Pm at 10 t/ha	14.6	16.5	31.1	20.8	46.1	66.8
T_4: Pm at 15 t/ha	15.1	20.2	35.2	21.1	51.7	72.8
T_5: Pm at 20 t/ha	16.1	20.9	37.0	23.8	40.0	63.8
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	14.9	22.5	37.4	22.8	46.3	69.1
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	20.6	23.4	44.0	21.2	48.7	69.8
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	7.9	16.6	24.4	18.9	44.3	63.2
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	15.9	18.1	34.0	19.3	44.8	64.0
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	11.7	8.4	20.0	17.8	32.7	50.4
LSD (P = 0.05)	**4.5**	**4.8**	**7.5**	**6**	**8.6**	**11.3**

4.2.9 Dry shoot, bulb and total biomass

Table 4.18 depicts the influence of soil amendments and control on the dry biomass of 'Bawku Red' onion cultivar at the bulb appearance stage. There was significant difference in the dry weight of the shoot and total biomass among the different treatments imposed on the onion plant in experiment one. No statistical difference was however, observed in the dry bulb biomass among the different treatments. The dry weight of shoot and total biomass resulting from the

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application of 5 t/ha Pm, 5 t/ha PM + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha was not significantly different from the control. In experiment two, the results from the analysis of variance indicated that the application of soil amendments did not influence dry shoot, bulb and total biomass of the onion plant.

The effect of soil amendment treatments on the dry biomass of 'Bawku Red' onion cultivar at harvest is presented in Table 4.19. There was significant difference in the dry weight of the bulb and total biomass in experiment one. No significant difference was registered in the weight of the dry shoot among the different treatments. On average, the weight of the bulb and total biomass from the amended plots was higher than the control. There was however no significant difference in the weight of the bulb and total biomass between the control and the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment. Significant difference was observed in the weight of shoot, bulb and total biomass among the different treatments in experiment two. The analysis of variance showed that the dry weight of the shoot and total biomass from the control was significantly lower than the amended plots. Furthermore, with the exception of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment, the dry weight of bulb biomass from all the amended plots were significantly higher than the control.

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Table 4.18: Dry biomass of 'Bawku Red' onion cultivar at bulb appearance for experiments 1 and 2

Treatments	Experiment 1			Experiment 2		
	Shoot (g/plant)	Bulb (g/plant)	Total (g/plant)	Shoot (g/plant)	Bulb (g/plant)	Total (g/plant)
T_1: Control (No fertilizer)	0.3	0.2	0.5	0.4	0.2	0.5
T_2: Pm at 5 t/ha	0.6	0.3	0.7	0.7	0.4	0.9
T_3: Pm at 10 t/ha	0.4	0.1	0.5	0.6	0.2	0.7
T_4: Pm at 15 t/ha	0.6	0.2	0.8	0.5	0.2	0.6
T_5: Pm at 20 t/ha	0.7	0.2	0.8	0.7	0.2	0.9
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	0.6	0.3	0.8	0.7	0.2	0.8
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	0.7	0.3	0.9	0.7	0.3	0.9
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.4	0.2	0.5	0.6	0.3	0.7
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.7	0.3	0.8	0.6	0.2	0.8
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	0.4	0.2	0.5	0.5	0.2	0.6
LSD (P = 0.05)	**0.3**	**NS**	**0.3**	**NS**	**NS**	**NS**

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Table 4.19: Dry biomass of 'Bawku Red' onion cultivar at harvest for experiments 1 and 2

Treatments	Experiment 1			Experiment 2		
	Shoot (g/plant)	Bulb (g/plant)	Total (g/plant)	Shoot (g/plant)	Bulb (g/plant)	Total (g/plant)
T_1: Control (No fertilizer)	0.9	1.6	2.4	1.2	4.4	5.0
T_2: Pm at 5 t/ha	1.6	4.2	5.8	2.4	8.3	10.1
T_3: Pm at 10 t/ha	1.4	2.7	4.1	2.2	8.3	9.8
T_4: Pm at 15 t/ha	1.5	3.8	5.3	2.2	9.3	10.7
T_5: Pm at 20 t/ha	1.8	3.8	5.6	2.5	7.2	9.4
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	2.0	4.3	6.3	2.4	8.4	10.1
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	1.8	4.0	5.7	2.2	8.8	10.2
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.9	3.0	3.9	2.0	8.0	9.3
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	1.8	2.9	4.7	2.0	8.1	9.4
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	1.2	1.7	2.8	1.9	5.9	7.4
LSD (P = 0.05)	**NS**	1.3	1.9	**0.6**	**1.6**	**1.7**

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4.3 Yield and yield components

The following parameters were used as indices of yield; bulb diameter, bulb length, neck thickness, harvest index, bulbing ratio, mean bulb weight, total bulb yield, marketable bulb yield and bulb grades.

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4.3.1 Bulb diameter

There was a significant difference in the bulb diameter among the different treatments in both experiment one and two (Table 4.20). In experiment one, the application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure (49.0 mm) produced bulb with the widest diameter but was not significantly different from 20 t/ha (45.6 mm), 15 t/ha (46.1 mm) and 5 t/ha (43.4 mm) poultry manure treatments. All the fertilizer amendments were significantly higher than the control except NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (25.9 mm) treatment which was not significantly different from the control (21.5 mm). In experiment two, application of 15 t/ha and 10 t/ha of poultry manure resulted in the widest bulb diameter (47.2 mm) but this was not significantly different from the other poultry manure amendments. Furthermore, the bulb diameter of onion from the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (37.1 mm) was significantly lower than the other amended plots but statistically the same as the control (35.9 mm).

4.3.2 Bulb length

Significant differences were registered among the various treatments in both experiment one and two (Table 4.20). The bulb length of onion from all the amended plots were significantly higher than the control (33.7 mm) in experiment one. In addition, the longest bulb length (43.3 mm) was achieved with the application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure which was significantly higher compared to 10 t/ha poultry manure (39.9 mm) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendments (37.1 mm) but statistically the same as the other amendments. In experiment two, the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment had the shortest bulb (36.7 mm) but was significantly the same as the control (37.3 mm). Again,

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the longest bulb was recorded for the 5 t/ha poultry manure treatment (44.6 mm) which was significantly higher than the 20 t/ha poultry manure treatment (40.8 mm) but statistically the same as the other poultry manure amendments.

4.3.3 Neck thickness

Table 4.20 indicates significant differences in the neck thickness of 'Bawku Red' onion cultivar in both experiment one and two. The application of 20 t/ha of poultry manure scored the highest value (11.6 mm) for neck thickness but was significantly not different from 10 t/ha + 2.5 t/ha + 2.5 t/ha Pm (11.5 mm), 5 t/ha + 2.5 t/ha + 2.5 t/ha Pm (10.8 mm), 15 t/ha Pm (11.0 mm) and 10 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha (11.3 mm) treatments in experiment one. In addition, the neck thickness of bulbs from control (9.0 mm) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (9.8 mm) were not significantly different from each other. Similarly, in experiment two, no statistical difference was observed between the control (8.3 mm) and the following treatments; 20 t/ha Pm (9.1 mm), 5 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha (8.9 mm) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (8.4 mm).

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Table 4.20: Effect of soil amendments on the bulb diameter, bulb length and neck thickness of onion at harvest for experiment 1 and 2

Treatments	Experiment 1			Experiment 2		
	Bulb diameter (mm)	Bulb length (mm)	Neck thickness (mm)	Bulb diameter (mm)	Bulb length (mm)	Neck thickness (mm)
T_1: Control (No fertilizer)	21.5	33.7	9.0	35.9	37.3	8.3
T_2: Pm at 5 t/ha	43.4	43.0	10.2	45.2	44.6	10.1
T_3: Pm at 10 t/ha	40.0	39.9	10.3	47.2	43.6	9.3
T_4: Pm at 15 t/ha	46.1	43.0	11.0	47.2	42.3	9.5
T_5: Pm at 20 t/ha	45.6	43.8	11.6	43.0	40.8	9.1
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	42.3	42.4	10.8	44.8	42.8	9.5
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	49.0	43.9	11.5	46.1	43.3	9.4
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	37.4	41.1	10.6	45.4	41.7	8.9
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	40.7	42.6	11.3	47.0	42.2	9.6
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	25.9	37.1	9.8	37.1	36.7	8.4
LSD (P = 0.05)	**5.9**	**2.8**	**0.8**	**5.2**	**3.5**	**0.9**

4.3.4 Harvest index

Presented in Table 4.21 is the effect of soil amendments on the harvest index of 'Bawku Red' onion cultivar in two separate experiments. Significant difference was observed in harvest index among the different treatments in experiment one. On the contrary, there was no statistical difference in the harvest index among the different treatments imposed on the onion plant in experiment two. Poultry manure at 10 t/ha registered the highest harvest index (0.88) in experiment two but this was not significantly different from the other treatments.

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4.3.5 Bulbing ratio

The bulbing ratio of 'Bawku Red' onion cultivar as influenced by different soil amendments and control is shown in Tables 4.21. There was statistical difference in the bulbing ratio among the different treatments in experiment one. The case was however different in experiment two where no significant difference was observed among the different treatments. In experiment one, the bulbing ratio of the control (0.42) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (0.38) amendment were significantly higher compared to the other treatments. Similarly in experiment two, the control (0.23) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (0.23) scored the highest bulbing ratio but this was not significantly different from the other treatments.

Table 4.21: Effect of soil amendment on harvest index and bulbing ratio of onion for experiment 1 and 2

Treatments	Experiment 1		Experiment 2	
	Harvest index	**Bulbing ratio**	**Harvest index**	**Bulbing ratio**
T_1: Control (No fertilizer)	0.59	0.42	0.81	0.23
T_2: Pm at 5 t/ha	0.73	0.24	0.85	0.22
T_3: Pm at 10 t/ha	0.64	0.26	0.88	0.2
T_4: Pm at 15 t/ha	0.71	0.24	0.83	0.2
T_5: Pm at 20 t/ha	0.69	0.25	0.77	0.22
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	0.7	0.25	0.86	0.21
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	0.69	0.24	0.82	0.21
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.77	0.29	0.87	0.2
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.61	0.28	0.83	0.2
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	0.57	0.38	0.86	0.23
LSD (P = 0.05)	**0.1**	**0.04**	**NS**	**NS**

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4.3.6 Mean bulb weight

There was a significant difference in the mean bulb weight among the different treatments applied in both experiment one and two (Table 4.22). In both experiments, the mean bulb weight of onions from the amended plots were significantly higher than the control except in experiment two where the control (24.3 g) was not significantly different from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (29.8 g). The application of 10 t/ha + 2.5 t/ha + 2.5 t/ha (40.4 g) and 15 t/ha poultry manure (41.4 g) produced significantly higher mean bulb weight compared to the other amendments in experiment one. Furthermore, the application of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha gave a significantly lower mean bulb weight (14.9 g) compared to the other fertilizer treatments. In experiment two, the highest mean bulb weight was produced by the 15 t/ha poultry manure treatment (45.1 g) which was significantly different from the 20 t/ha poultry manure (32.5 g) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatments (29.8 g) but statistically not different from the other amendments.

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Table 4.22: Effect of soil amendments on mean bulb weight of onion for experiment 1 and 2

Treatments	Mean bulb weight (g)	
	Experiment 1	Experiment 2
T_1: Control (No fertilizer)	10.3	24.3
T_2: Pm at 5 t/ha	36.4	41.1
T_3: Pm at 10 t/ha	34.9	42.4
T_4: Pm at 15 t/ha	40.4	45.1
T_5: Pm at 20 t/ha	28.7	32.5
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	35.9	39.9
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	41.4	42.2
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	28.1	40.1
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	36.2	42.6
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	14.9	29.8
LSD (P = 0.05)	**3.8**	**6.3**

4.3.7 Total bulb yield

There were significant differences in the total bulb yield of 'Bawku Red' onion cultivar among the different treatments in both experiments one and two (Table 4.23). In experiment one, the total bulb yield from the amended plots were significantly higher than the control (3.5 t/ha). In addition, the highest total bulb yield was recorded for the 10 t/ha + 2.5 t/ha+2.5 t/ha (14.2 t/ha) and 15 t/ha (13.9 t/ha) poultry manure treatments which were statistically different from the other amendments applied. In the second experiment, the control had a significantly lower total bulb yield (8.3 t/ha) compared to the other amendments but was not significantly different from the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (10.2 t/ha). Again, the 15 t/ha poultry manure treatment gave the highest total bulb yield (15.5 t/ha).

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4.3.8 Marketable bulb yield

As presented in Table 4.23, there were significant differences in the marketable bulb yield of 'Bawku Red' onion cultivar in both experiment one and two. The marketable bulb yield from the amended plots were statistically higher compared to the control (3.3 t/ha) in experiment one. Furthermore, application of 10 t/ha + 2.5 t/ha + 2.5 t/ha poultry manure gave the highest marketable bulb yield (14.2 t/ha) which was significantly higher than the other amendments but statistically not different from the 15 t/ha (13.8 t/ha) poultry manure treatment. In experiment two 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 (7.3 t/ha) and the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (8.6 t/ha). The highest marketable bulb yield was registered by the 15 t/ha poultry manure treatment (14.6 t/ha) in experiment two.

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Table 4.23: Effect of soil amendments on total and marketable bulb yield of onion for experiment 1 and 2

Treatments	Experiment 1		Experiment 2	
	Total bulb yield (t/ha)	Marketable bulb yield (t/ha)	Total bulb yield (t/ha)	Marketable bulb yield (t/ha)
T_1: Control (No fertilizer)	3.5	3.3	8.3	7.3
T_2: Pm at 5 t/ha	12.5	12.5	14.1	13.4
T_3: Pm at 10 t/ha	12.0	12.0	14.5	14.0
T_4: Pm at 15 t/ha	13.9	13.8	15.5	14.6
T_5: Pm at 20 t/ha	9.8	9.6	11.2	11.1
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	12.3	12.3	13.7	13.0
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	14.2	14.2	14.5	14.1
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	9.6	9.6	13.8	12.9
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	12.4	12.4	14.6	14.3
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	5.1	4.8	10.2	8.6
LSD (P = 0.05)	**1.3**	**1.4**	**2.2**	**2.8**

4.3.9 Bulb grades

There were significant differences in the large, medium and small bulb grades among the different treatments in both experiment one and two with the exception of large bulb grades in experiment two which did not register any significant difference (Table 4.24). In experiment one, application of 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure produced significantly higher percentage of large bulbs (32.1%) compared to other treatments. The highest percentage of medium bulbs (85.9%) was achieved with 5 t/ha + 2.5 t/ha +2.5 t/ha poultry manure amendment. As expected, the control had significantly higher percentage of the small bulbs (73.3%) than the

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other treatments. The highest percentage of large bulbs (18.8%) was recorded for 15 t/ha poultry manure treatment in experiment two even though there was no significant difference in the percentage of the large bulbs among the different treatments. Again, the 5 t/ha amendment scored the highest percentage of medium bulbs (82.9%) but this was not significantly different from all the poultry manure and NPK/poultry manure amendments. The percentage of the small bulbs from the control treatment (37.9%) was significantly higher than poultry manure and NPK/poultry manure amendments but statistically not different from the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment (26.8%).

Table 4.24: Effect of soil amendments on bulb grades (%) for experiment 1 and 2

Treatments	**Experiment 1**			**Experiment 2**		
	Large (>50 mm)	**Medium (30 - 50 mm)**	**Small (<30 mm)**	**Large (>50 mm)**	**Medium (30 - 50 mm)**	**Small (<30 mm)**
T_1: Control (No fertilizer)	0	16.8	73.3	2.9	51.5	37.9
T_2: Pm at 5 t/ha	16.5	67.5	6.0	7.1	82.9	0
T_3: Pm at 10 t/ha	9.7	76.1	4.2	9.7	80.3	0
T_4: Pm at 15 t/ha	16.3	73.8	0	18.8	71.3	0
T_5: Pm at 20 t/ha	13.3	76.7	0	9.4	77.7	2.9
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	0	85.9	4.2	14.3	75.8	0
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	32.1	57.9	0	17.6	72.5	0
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0	58.0	32.1	10.4	79.7	0
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	7.1	75.9	9.0	13.9	76.1	0
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	0	29.9	60.2	4.2	59.1	26.8
LSD (P=0.05)	**15**	**15.6**	**11.2**	**NS**	**17.2**	**16.2**

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4.4. Soil pH

Significant differences in soil pH were observed among the different treatments applied in both experiment one and two (Table 4.25). In experiment one, poultry manure applied at 15 t/ha registered the highest pH (7.32) which was not significantly different from 20 t/ha (7.31) and 10 t/ha (7.10) poultry manure amendments. The pH of the amended plots were significantly higher than the control except for the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment whose pH (5.21) was not significantly different from the control (5.35). The poultry manure and a combination of NKP 15-15-15 and poultry manure amendments were able to raise the soil pH from 5.35 to a range of 6.55 – 7.32. On the contrary, application of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha reduced the soil pH from 5.35 to 5.21. In experiment two, 10 t/ha + 2.5 t/ha+2.5 t/ha poultry manure treatment scored the highest pH value (7.01) but was not significantly different from 10 t/ha Pm (6.85), 5 t/ha + 2.5 t/ha +2.5 t/ha Pm (6.80) and 10 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha (6.79) treatments. The pH values recorded for the poultry manure and NPK + poultry manure amendments were significantly higher compared to the control (5.37). The NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment however reduced the soil pH from 5.37 to 5.16. The application of poultry manure and NPK + poultry manure amendments were able to increase the soil pH from 5.37 to a range of 6.29 – 7.01.

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Table 4.25: Effect of soil amendments on the soil pH in experiment 1 and 2

Treatments	Soil pH	
	Experiment 1	**Experiment 2**
T_1: Control (No fertilizer)	5.35	5.37
T_2: Pm at 5 t/ha	7.09	6.33
T_3: Pm at 10 t/ha	7.10	6.85
T_4: Pm at 15 t/ha	7.32	6.63
T_5: Pm at 20 t/ha	7.31	6.64
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	7.06	6.80
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	7.03	7.01
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	6.55	6.29
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	6.89	6.79
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	5.21	5.16
LSD (P = 0.05)	**0.23**	**0.35**

4.5 Mineral composition of onion bulb

4.5.1 Nitrogen content

There was significant difference in the N content of bulb among the different treatments applied in both experiments (Table 4.26). In experiment one, the highest N content was achieved with the application of 15 t/ha of poultry manure (1.33%) which was significantly different from the other treatments. The content of N in bulbs from the amended plots were significantly higher compared to the control (0.62%) except NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (0.63%) treatment which was not significantly different from the control. The results from experiment two indicated no significant difference in the percentage content of N between NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (0.65%) amendment and the control (0.64%). Poultry manure and a combination of poultry manure and NPK amendments on the other hand were significantly

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higher than the control. Application of 15 t/ha of poultry manure recorded a significantly higher percentage of N content in bulb (1.37%) than the other amendments.

4.5.2 Phosphorus content

There were significant differences in the P content among the various treatments (Table 4.26). All the poultry manure amendments and a combination of poultry manure and NPK amendments had higher P content than the control and the NPK treatment in both experiments. In experiment one, application of 20 t/ha (1.69%) and 10 t/ha + 2.5 t/ha + 2.5 t/ha (1.57%) of poultry manure gave higher level of P content which was significantly different from the other treatments. NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (0.82%) gave the lowest level of P content compared to the other treatments. In the second experiment, similar results were obtained. NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha treatment produced the lowest (0.87%) percentage P content in onion bulb. The highest P content was obtained by 10 t/ha + 2.5 t/ha + 2.5 t/ha of poultry manure (1.76%) but this was not significantly different from 20 t/ha Pm treatment (1.60%).

4.5.3 Potassium content

Significant differences were observed in the percentage content of K in the onion bulbs among the various treatments (Table 4.26). In experiment one, poultry manure applied at 5 t/ha + 2.5 t/ha +2.5 t/ha produced bulbs with the highest K content compared to the other treatments. NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha registered the lowest level of K content (0.93%) but this was statistical the same as the control (1.04%). In experiment two, 15 t/ha poultry manure amendment had the highest level of K content (2.99%) compared to the other treatments. The

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control registered the lowest level of K content (1.03%) but was not significantly different from the NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha amendment (1.07%). In both experiments, the application of poultry manure and a combined application of poultry manure and NPK fertilizer resulted in higher K accumulation compared to the control and NPK treatment.

Table 4.26: Effect of soil amendment on N, P and K content in onion bulb for experiment 1 and 2

Treatments	Experiment 1			Experiment 2		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
T_1: Control (No fertilizer)	0.62	1.05	1.04	0.64	1.06	1.03
T_2: Pm at 5 t/ha	0.75	1.52	2.45	0.78	1.56	2.43
T_3: Pm at 10 t/ha	0.91	1.24	2.34	0.94	1.25	2.54
T_4: Pm at 15 t/ha	1.33	1.45	2.56	1.37	1.48	2.99
T_5: Pm at 20 t/ha	0.74	1.69	2.12	0.76	1.76	1.72
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	0.71	1.34	2.93	0.73	1.38	1.96
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	0.94	1.57	2.50	0.97	1.60	2.56
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.77	1.25	1.63	0.79	1.26	2.18
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	1.07	1.23	1.84	1.10	1.24	2.64
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	0.63	0.82	0.93	0.65	0.87	1.07
LSD (P = 0.05)	**0.04**	**0.17**	**0.19**	**0.04**	**0.18**	**0.12**

4.5.4 Calcium content

Table 4.27 indicates significant differences in the accumulation of Ca in the bulbs of onion among the different treatments. The poultry manure amendments and the combination of poultry manure and NPK amendment had higher level of Ca accumulation compared to the control and

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NPK treatment in both experiments. In both experiment one and two, the application of NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha gave the lowest Ca content in onion bulb (0.12%) but was statistical the same as the control (0.13%). In addition, the Ca content in the bulbs from the control was not significantly different from the 20 t/ha poultry manure amendment in both experiments. With the exception of the control, NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha and 20 t/ha Pm amendments, Ca content in all the amendments were not significantly different from each other in both experiments.

4.5.5 Magnesium content

There were significant differences in the Mg content of the bulbs of onion among the various treatments in both experiments (Table 4.27). Application of poultry manure and a combined application of poultry manure and NPK had higher percentage of Mg content than the control and NPK treatment. In experiment one, application of 15 t/ha of poultry manure gave the highest percent of Mg content (2.99%) but this was statistically the same as 5 t/ha + 2.5 t/ha + 2.5 t/ha poultry manure amendment (2.95%). The control (0.88%) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (0.74%) registered the lowest Mg content and were not significantly different from each other. In the second experiment, the highest Mg accumulation in onion bulb was recorded by 15 t/ha of poultry manure amendment (3.01%) which was not significantly different from Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha amendment (2.99%). As expected, the control (0.83%) and NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (0.94%) had the lowest Mg content.

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Table 4.27: Effect of soil amendment on Ca and Mg content in onion bulb for experiment 1 and 2

Treatments	**Experiment 1**		**Experiment 2**	
	Ca (%)	**Mg (%)**	**Ca (%)**	**Mg (%)**
T_1: Control (No fertilizer)	0.13	0.88	0.13	0.83
T_2: Pm at 5 t/ha	0.19	2.33	0.18	2.46
T_3: Pm at 10 t/ha	0.19	2.28	0.19	2.67
T_4: Pm at 15 t/ha	0.19	2.99	0.2	3.01
T_5: Pm at 20 t/ha	0.15	1.46	0.16	1.47
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	0.19	2.95	0.19	1.52
T_7: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	0.19	2.54	0.19	2.38
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.18	1.45	0.18	1.58
T_9: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	0.19	1.55	0.19	2.99
T_{10}: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	0.12	0.74	0.12	0.94
LSD (P = 0.05)	**0.03**	**0.15**	**0.03**	**0.14**

4.6 Relation among some parameters in onion

The correlation for experiment one and two are presented in Tables 4.28 and 4.29 respectively. The associations among the following parameters were determined in both experiments; BD, BL, DBB, DSB, LD, LL, MBW, ND, NL, PH, TDB and TBY. The correlation coefficient (r) of most of the parameters measured were significant at P = 0.05 and P = 0.01 for both experiments.

In experiment one, there was significant positive association (P = 0.05 and P = 0.01) among all the parameters compared. There was a strong significant positive association between TBY and MBW (1.000**). The TDB registered a very strong significant positive correlation with DBB (0.969**) followed by DSB (0.857**) and LL (0.721**). Again, BL had a strong significant

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positive association with BD (0.886**) and PH (0.859**). Furthermore, a weaker significant positive correlation was observed between ND and DSB (0.355*).

There was positive correlation (P = 0.05 and P = 0.01) between all the parameters compared in experiment two. All the parameters compared showed a significant positive association except DSD with BL (0.230) and NL (0.238) which had no significant correlation. The TBY however had a stronger significant positive association with MBW (1.000**). Again, a very strong significant positive correlation was shown between DBB and TDB (0.939**) followed by TBY (0.879**), MBW (0.879**) and LL (0.758**). A very strong association was also observed between MBW and BD (0.944**) and PH and LL (0.935**). The LD had a weak significant positive correlation with DSB (0.348*).

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Table 4.28: Matrix of correlation (r) among some parameters of 'Bawku Red' onion cultivar in experiment 1

BD	-											
BL	0.886**	-										
DBB	0.673**	0.693**	-									
DSB	0.468**	0.542**	0.713**	-								
LD	0.774**	0.770**	0.696**	0.506**	-							
LL	0.838**	0.850**	0.727**	0.542**	0.748**	-						
MBW	0.848**	0.768**	0.593**	0.421**	0.735**	0.698**	-					
ND	0.686**	0.756**	0.576**	0.355*	0.844**	0.774**	0.582**	-				
NL	0.669**	0.620**	0.457**	0.459**	0.591**	0.620**	0.652**	0.627**	-			
PH	0.827**	0.859**	0.667**	0.598**	0.786**	0.856**	0.728**	0.768**	0.713**	-		
TDB	0.662**	0.702**	0.969**	0.857**	0.687**	0.721**	0.590**	0.5506**	0.498**	0.706**	-	
TBY	0.848**	0.768**	0.593**	0.421**	0.735**	0.698**	1.000**	0.5824**	0.652**	0.728**	0.590**	-
	BD	**BL**	**DBB**	**DSB**	**LD**	**LL**	**MBW**	**ND**	**NL**	**PH**	**TDB**	**TBY**

* Significant at 5%   ** Significant at 1%

Legend

BD: Bulb diameter
BL: Bulb length
DBB: Dry bulb biomass
DSB: Dry shoot biomass
LD: Leaf diameter
LL: Leaf length
MBW: Mean bulb weight
ND: Neck diameter
NL: Number of leaves
PH: Plant height
TDB: Total dry biomass
TBY: Total bulb yield

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Table 4.29: Matrix of correlation (r) among some parameters of 'Bawku Red' onion cultivar in experiment 2

	BD	BL	DBB	DSB	LD	LL	MBW	ND	NL	PH	TDB	TBY
BD	-											
BL	0.763**	-										
DBB	0.850**	0.568**	-									
DSB	0.413**	0.230	0.523**	-								
LD	0.589**	0.468**	0.655**	0.348*	-							
LL	0.719**	0.496**	0.758**	0.543**	0.785**	-						
MBW	0.944**	0.740**	0.879**	0.447**	0.656**	0.749**	-					
ND	0.614**	0.589**	0.598**	0.504**	0.475**	0.655**	0.630**	-				
NL	0.633**	0.515**	0.648**	0.238	0.661**	0.596**	0.705**	0.368*	-			
PH	0.765**	0.616**	0.723**	0.451**	0.760**	0.935**	0.746**	0.614**	0.590**	-		
TDB	0.789**	0.512**	0.939**	0.781**	0.629**	0.767**	0.823**	0.631**	0.584**	0.707**	-	
TBY	0.944**	0.740**	0.879**	0.447**	0.656**	0.749**	1.000**	0.630**	0.705**	0.746**	0.823**	-

* Significant at 5% ** Significant at 1%

Legend

BD: Bulb diameter
BL: Bulb length
DBB: Dry bulb biomass
DSB: Dry shoot biomass
LD: Leaf diameter
LL: Leaf length
MBW: Mean bulb weight
ND: Neck diameter
NL: Number of leaves
PH: Plant height
TDB: Total dry biomass
TBY: Total bulb yield

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4.7 Cost-Benefit Analysis

From Tables 4.30 and 4.31, the cost-benefit analysis for the two experiments indicated large net revenue resulting from the application of fertilizer. In experiment one, application of 10 t/ha + 2.5 t/ha+2.5 t/ha of poultry manure gave the highest net revenue of GH¢ 15,363.95 which was closely followed by 15 t/ha (GH¢ 14,611.45) and 5 t/ha (GH¢ 14,604.65) poultry manure amendments. The control registered the lowest and a negative net revenue of GH¢ 265.00. The net revenue resulting from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha application was very low (GH¢ 890.50) compared to the other soil amendments. In the second experiment, 5 t/ha poultry manure amendment had the highest net revenue (GH¢ 16,267.15) followed by 10 t/ha (GH¢ 16,191.80) and 15 t/ha (GH¢ 16,116.45) poultry manure amendment. As expected, the control gave the lowest net revenue of GH¢ 6,752.50 which was not quite different from NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha (GH¢ 7,523.00) and 20 t/ha (GH¢ 8,813.60) soil amendments. Application of 5 t/ha of poultry manure produced the highest average net revenue (GH¢ 15,435.90) from the two experiments followed by 15 t/ha Pm (GH¢ 15,363.95) and 10 t/ha + 2.5 t/ha + 2.5 t/ha Pm (GH¢ 15,302.70).

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Table 4.30: Cost-Benefit analysis of 'Bawku Red' onion cultivar production for experiment 1

Treatments	Total Cost (GH¢)	Total Revenue (GH¢)	Net Revenue (GH¢)
T_1: Pm at 20 t/ha	10,646.40	16,712.50	6,066.10
T_2: Pm at 15 t/ha	9,503.55	24,115.00	14,611.45
T_3: Pm at 10 t/ha	8,360.70	20,912.50	12,551.80
T_4: Pm at 5 t/ha	7,217.85	21,822.50	14,604.65
T_5: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	9,503.55	24,867.50	15,363.95
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	8,360.70	21,560.00	13,199.30
T_7: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	9,152.70	21,717.50	12,564.80
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	8,009.85	16,852.50	8,842.65
T_9: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	7,527.00	8,417.50	890.50
T_{10}: Control (No fertilizer)	6,075.00	5,810.00	(265.00)

Table 4.31: Cost-Benefit analysis of 'Bawku Red' onion cultivar production for experiment 2

Treatments	Total Cost (GH¢)	Total Revenue (GH¢)	Net Revenue (GH¢)
T_1: Pm at 20 t/ha	10,646.40	19,460.00	8,813.60
T_2: Pm at 15 t/ha	9,503.55	25,620.00	16,116.45
T_3: Pm at 10 t/ha	8,360.70	24,552.50	16,191.80
T_4: Pm at 5 t/ha	7,217.85	23,485.00	16,267.15
T_5: Pm at 10 t/ha + 2.5 t/ha+2.5 t/ha	9,503.55	24,745.00	15,241.45
T_6: Pm at 5 t/ha + 2.5 t/ha +2.5 t/ha	8,360.70	22,680.00	14,319.30
T_7: Pm at 10 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	9,152.70	24,955.00	15,802.30
T_8: Pm at 5 t/ha + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha	8,009.85	22,592.50	14,582.65
T_9: NPK 15-15-15 at 600 kg/ha + Urea at 60 kg/ha	7,527.00	15,050.00	7,523.00
T_{10}: Control (No fertilizer)	6,075.00	12,827.50	6,752.50

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CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of fertilizer on soil chemical properties

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 depicting the poor fertility status of the soil. Magnesium, organic carbon, nitrogen and organic matter content were limiting in the soil. The application of fertilizers, especially the poultry manure, remarkably improved the fertility status of the soil when the soil was analysed after harvesting.

There was an increase in the organic carbon and organic matter content of the soil with the application of soil amendments. This observation is in agreement with the work by Young (1997), who reported that incorporation of poultry manure into the soil increases its organic status. Similarly, Zhang *et al.* (2009), 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 poultry manure had an increase in soil organic carbon and other nutrients compared to those treated with only NPK fertilizer.

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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 conforms to earlier reports by other researchers (Adekiya *et al.*, 2014; Onwu *et al.*, 2014: Ojeniyi *et al.*, 2013; Ayeni and Adetunji, 2010; Dikinya and Mufwanzala, 2010 and Ewulo *et al.*, 2008). It was reported by Snyman *et al.* (1998) and Young (1997), that the addition of poultry manure to the soil enhanced the cation exchange capacity of the clay-humus complex. Baffour (1985), also indicated that organic manure when applied to the soil is

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capable of supplying about 90 - 99% of the soil nitrogen, phosphorous and potassium. Furthermore, Uwah *et al.* (2014), reported 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 buttress the point that soils amended with organic manure have improved cation ion exchange capacity, organic matter content, total nitrogen, potassium and phosphorus. Even though the current study was conducted in moderately acidic soil, the phosphorus levels in the soil were improved. This is consistent with findings by Young (1997), who reported improved phosphorous availability in acid soils with the application of poultry manure.

5.2 Effect of fertilizer 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 fact that 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.

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5.2.2 Plant height and leaf length

The results from the two experiments showed increased plant height with soil amendments compared to the control at both bulb appearance and harvesting stage. 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 Bungard *et al.* (1999), who reported that nitrogen forms the basis of cell components and as a result promotes vigorous plant growth. 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. An increase in the plant height of onion with the application of poultry manure and NPK/poultry manure is consistent with the results by Rizk (1997). Similarly, Blay *et al.* (2002), reported that the plant height of shallots grown on sandy soils was significantly increased with the addition of poultry 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. Also, 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 poultry manure amendments resulted in higher plant height compared to the NPK treatment. This result is in harmony with the work of Abou El- Magd *et al.* (2012) who found that poultry manure produced the tallest garlic plants compared to the conventional chemical fertilizer. 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.

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The different treatments investigated had a significant effect on the leaf length, at the bulb appearance stage and at harvest 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. The findings of Gupta *et al.* (1999) which showed that the application of FYM improved the growth of onion also supports the current results. In agreement with the current findings, Sultana *et al.* (2014), Jilani (2004), Singh and Chaure (1999) and Kumar *et al.* (1998) have all reported increased leaf lengths of onion with the application of N from organic and inorganic sources.

5.2.3 Leaf diameter

Poultry manure and NPK amendments resulted in an increase in the leaf diameter of the 'Bawku Red' onion cultivar, at the bulb appearance stage and at harvest, over the control in both experiments. The increase in the leaf diameter could be due to the availability of N in the fertilizer which is responsible for proper vegetative growth (Bungard *et al.*, 1999). The results from the study is in conformity with the results obtained by Kumar *et al.* (1998) who reported a significant increase in leaf diameter with the application of 150 kg/ha of N. The results from the experiment further showed that the poultry manure and combination of NPK and poultry manure treatments produced plants with wider leaf width compared to the NPK treatment. Similar observations were made by Suresh *et al.* (2004). The results from the current study contradict that of Yohannes *et al.* (2013) and Abdissa *et al.* (2011) who reported that application of N did not affect the leaf diameter of onion.

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5.2.4 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 higher number of leaves compared to the control (no fertilizer). It has been reported that the number of leaves of a plant is dependent on the rate of vegetative growth which is influened by nutrient availabiltiy in the soil (Sekhon and Meelu, 1994). 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 poultry manure led to higher 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 improved the number of onion leaves over the control. The increase in the number of leaves per plant was plausible because fertilizers supply the soil with high nutrients especially nitrogen which significantly supports vegetative growth (Blay *et al.*, 2002). Results of this current study is in agreement with the work by Al-Fraihat (2016), Mutetwa and Mtaita (2014), Rabari *et al.* (2014), Singh and Ram (2014), Yohannes *et al.* (2013), Abdel-Mawgoud *et al.* (2005) and Khalil *et al.* (2002), 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), Kandil *et al.* (2013) and Tukur *et al.* (2009), reported that the application of poultry 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 other researchers (Abdissa *et al.*, 2011, Ibrahim, 2010, Nasreen *et al.*, 2007 and Vachhani and Patel 1993). Similar results were obtained in shallots (Blay *et al.*, 2002).

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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 600 kg/ha + Urea at 60 kg/ha in experiment two. 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 and 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.

5.2.5 Number of days to 50% bulb appearance

Results from the current study revealed that there were shorter number of days to 50% bulb appearance in the poultry manure amended plots compared to the other treatments for both experiments. This may be attributed to the fact that poultry 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; Agyenim-Boateng *et al.*, 1997; Sinnadurai 1992 and Baffour, 1985). This might have contributed to the early bulb formation and appearance as observed in the sole poultry manure treatment plots. The finding of Bungard *et al.* (1999) that nitrogen forms the basis of cell components and as a result promotes vigorous plant growth is consistent with the outcome of this study.

The study further showed that on average, it took fewer number of days to 50% bulb appearance in experiment two than in experiment one. This occurrence may be linked to the higher average photoperiod received by the onion plants during the bulbing stage in experiment two compared

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to experiment one. The current findings agree with that of Lancaster *et al.* (1996), who reported that bulbing in onion occurs only when the photoperiod required by the plant is reached.

5.2.6 Number of days to physiological maturity

Findings from this study indicate that poultry manure and a combination of poultry manure and NPK fertilizer amendments resulted in significantly longer number of days to physiological maturity compared with plants from the control plots in both experiments. This outcome may be attributed to the role nitrogen plays in promoting vegetative growth (Bungard *et al.*, 1999) and as a result delayed the number of days to physiological maturity. This finding supports the work of Abdissa *et al.* (2011), who noted that nitrogen fertilization was able to increase the period to physiological maturity by six days compared to the control irrespective of the N rate applied. In accordance with the current finding, Yohannes *et al.* (2013), asserted that increase in N application is associated with prolonged physiological maturity period of onion.

5.2.7 Dry and fresh biomass

There were variations in the fresh and dry weight of biomass among the different treatments with the amended plots having higher weight of biomass compared to the control. In agreement with the current results, Meena *et al.* (2015) reported that application of 5 t/ha of poultry manure saw a significant increase in the weight of the fresh shoot biomass of onions over the check. The finding of Mousa and Mohamed (2009) that the application of chicken manure increased the total dry biomass of onion over the control also confirms this current study. An increase in the fresh weight of shoot biomass of onion with the application of poultry manure observed in this current study has also been documented by Eliakira and Yohana (2013) and Kandil *et al.* (2013).

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The results from this study further showed that the NPK amendment had lower biomass weight compared to poultry manure and a combination of poultry manure and NPK amendments. Similar findings were reported by Yassen and Khalid (2009), who reported 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). In agreement with the current study, Dapaah *et al.* (2014) affirmed that poultry manure application increased the weight of the total dry biomass of onion over the NPK treatment.

Application of nitrogen fertilizer from inorganic source is capable of increasing the total dry biomass of the onion plant. The results from experiment one of this current study showed that the weight of the total dry biomass from the NPK plots was significantly higher compared to the control (no fertilizer). Similar findings have been made 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 results that the weight of the total fresh and dry biomass from the plots amended with a combination of poultry manure and NPK fertilizer was significantly higher than the control (no fertilizer) maybe due to the fact that both poultry manure and NPK have abundant nitrogen needed for the growth and development of the onion. On the other hand, the control plot solely relied on nitrogen available in the soil which was inadequate. It has been reported by Norman (2004), that soils in their natural state do not have adequate nutrients to support the growth and development of crops. The findings of Dapaah *et al.* (2014), that the application of poultry 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

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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 a combined application of compost and mineral N significantly increased the total fresh and dry biomass of onion.

5.3 Effect of fertilizer on yield and yield components

5.3.1 Bulb diameter and grades

The outcome of the study clearly indicates that the sole application of poultry manure and a combination of poultry manure and NPK fertilizer produced higher percentage of large and medium size bulbs compared to the control (no fertilizer) and the recommended NPK treatment. The highest percentage of the small bulbs came from the control plot followed by the NPK treatment. Poultry manure is said to increase the bulb diameter of onion depending on the rate applied. The finding of Yassen and Khalid (2009) that poultry manure increased the bulb diameter of onion over the recommended NPK treatment is confirmed by this study. The result is also consistent with those of Mousa and Mohamed (2009) that the application of chicken manure significantly increased the bulb diameter of onions.

Regarding the combined effect of poultry manure and NPK fertilizer on the bulb diameter of onion, this study agrees with findings by Yoldas *et al.* (2011) and Akoun (2005) that the combined incorporation of organic and inorganic fertilizers into the soil significantly increased the diameter of shallot bulbs. The results of this study is in agreement with findings by Al-Fraihat (2016) and Mondal *et al.* (2004) that a combined application of organic manure and chemical fertilizer resulted in an increase in the bulb diameter of onion compared to the control and NPK only treatment.

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Other sources of organic manure can play a similar role as poultry manure and increase the bulb diameter of onion upon application as observed in this study. This is feasible because all forms of organic manure are able to improve the physical and chemical properties of the soil and maintain the productivity of the soil (Chandra, 2005; Tirol-Padre *et al.*, 2007; Bhattacharyya *et al.*, 2010 and Lasmini *et al.*, 2015). This was demonstrated by Yohannes *et al.* (2013) that application of farmyard manure gave the highest mean bulb diameter compared to the control plot (no fertilizer).

The no statistical differences obtained between the bulb diameter of onion from the control and NPK amended plot in both experiments contradicts findings by Mohammadi-Fatideh and Hassanpour-Asil (2012) and Abdissa *et al.* (2011) that the application of mineral N increased the bulb diameter of onion compared to the unfertilized plot. This occurrence may be attributed to the moderate acidic nature of the soil used for the experiment and the inability of the NPK fertilizer to reduce soil acidity. The resultant effect of this phenomenon is that the availability of nutrients in the soil would be reduced (Chao *et al.*, 2014 and Silveira, 2013). The observation by Raemaekers (2001) that onions are sensitive to soils low in pH is in agreement with the finding of this current study.

5.3.2 Bulb length

The study showed that the bulb length of onion from all the amended plots in experiment one were significantly higher than the control. In experiment two, poultry manure and a combined application of poultry manure and NPK fertilizer amendments had a significantly higher bulb length than the control. This outcome could be due to the availability of nitrogen in both the

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poultry manure and NPK fertilizer. In agreement with this finding, Sultana *et al.* (2014) reported increased bulb length with a combined application of N from organic and inorganic sources. Similar findings have also been documented by Yohannes *et al.* (2013), Yadav *et al.* (2003) and Reddy (2005) that N fertilization increased the bulb length of onion. Contrary to the results of this study, Abdissa *et al.* (2011) observed no effect of N fertilzation on the bulb length of onion.

The current study further revealed that the bulb length from the NPK treatment was lower than the control in experiment two. This could be linked to the low soil pH of the NPK amendment plot measured after harvest. The soil pH of the NPK plot was much lower compared to the control plot and this might have led to the shorter bulbs recorded. This claim is supported by the findings of Norman (1992) and Sinnadurai (1992) who asserted that onions are sensitive to low soil pH and can perform well when planted in less acidic soil.

5.3.3 Neck thickness and harvest index

There were variations in the neck thickness of onion bulbs among the different treatments. The study showed a higher neck width for bulbs from the amended plots compared to the control plot in both experiments. This finding is in agreement with the finding of Singh and Ram (2014), that the neck thickness of onion bulbs coming from poultry manure amended soil was significantly higher than those from the control plot.

The results from the study indicate a higher harvest index in the poultry manure and a combination of poultry manure and NPK amendments compared to the control in experiment one. Similarly, Yohannes *et al.* (2013), reported that the harvest index of onion was increased over the control with combined application of N and FYM. The finding of Abdissa *et al.* (2011)

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that harvest index of onion increased with the application N compared to the control treament is consistent with the current study. In experiment two of this study, there was no significant difference in the harvest index among the different treatments. This result is not 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.

5.3.4 Mean bulb weight

The mean bulb weight from the amended plot was higher than the control in both experiments. A combined application of poultry manure and NPK fertilizer had higher mean bulb weight compared to the control and NPK treatment. This outcome is in agreement with 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 combined 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. The findings of Agumas *et al.* (2014), Mohammadi-Fatideh and Hassanpour-Asil (2012) and Abdissa *et al.* (2011) that the mean bulb weight of onion was significantly increased with the application of mineral N is consistent with results of this study. The poultry manure amendment was found to perform better than the other amendments. Similar results have been documented by Kandil *et al.* (2013) and Mousa and Mohamed (2009), who reported an improved mean bulb weight for chicken manure amended plot over mineral fertilizer and other sources of organic manure. In line with the results of the current study, Yohannes *et al.* (2013)

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asserted 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.

5.3.5 Total and marketable bulb yield

There were significant differences in the total and marketable bulb yield among the different treatments in both experiments. The results from the study revealed that the total and marketable bulb yield from the poultry manure amendments was higher compared to the other treatments. Similar findings were documented by Bashir *et al.* (2015), Dapaah *et al.* (2014), Gwari *et al.* (2014), Eliakira and Yohana (2013), and Giardini *et al.* (1992) that the application of poultry manure led to an increase in the total bulb yield of onion compared to the control. Abbas *et al.* (2011) also demonstrated that poultry manure increased the yield and quality of eggplant when applied. In support of this current study, Mousa and Mohamed (2009), found that the application of poultry manure increased the yield of onion compared to animal manure and mineral fertilizer. Similar results were obtained by Abou El- Magd *et al.* (2012), in garlic. In addition, the findings of Kandil *et al.* (2013), that the total and marketable yield of onion was higher for the chicken

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manure plot than the compost and farmyard manure is in conformity with the current study. In contrast with the current finding, Kandil *et al.* (2013) and Seran *et al.* (2010) reported that plots treated with mineral fertilizer had higher total and marketable yields of onion compared to the poultry manure amendment. Application of other forms of organic manure can also improve the yield of onion over the control. This may be due to the fact that these other forms may contain significant amounts of nitrogen needed for growth and development. The work of Yoldas *et al.* (2011) showed that application of cattle manure significantly improved the bulb yield of onion over the control.

Results from the study indicated that the combined application of poultry manure and NPK fertilizer improved the total and marketable yields of onion over the control and NPK fertilizer only treatments. This was demonstrated by Yohannes *et al*. (2013), who asserted that a combined application of mineral N and 30 t/ha FYM increased the total bulb yield of onion over the control plot. A similar finding was made by Sultana *et al.* (2014), who reported that an integrated application of N from organic and inorganic sources resulted in an increase in the total yield of onion compared to the control (no fertilizer). The results from this study is in line with the work of Rizk *et al.* (2014), Mondal *et al.* (2004), Sharma *et al.* (2003) and Jayathilake *et al.* (2002) who indicated that the highest yield of onion bulbs was observed with the combined application of organic and inorganic fertilizers compared to the application of chemical fertilizers alone.

Despite the acidic nature of the soil used for the experiment which might have contributed to the low yield from the NPK treated plots (Raemaekers, 2001, Norman, 1992 and Sinnadurai, 1992), the NPK amended plots had higher total and marketable bulb yield compared to the control plots (no fertilizer). In agreement with the current finding, Al-Fraihat (2016), Mohammadi-Fatideh

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and Hassanpour-Asil (2012), Abdissa *et al.* (2011) and Halvorson *et al.* (2008) observed an increase in the total and marketable yield of onion over the control treatment with nitrogen application.

5.4 Effect of fertilizer on soil pH

The results from the study showed significant differences in soil pH among the different treatments. The soil pH at the experimental site was improved with the addition of poultry manure and a combined application of poultry manure and NPK fertilizer. In support of the current finding, Agbede (2010) and Ano and Agwu (2006) reported that the rise in soil pH could be attributed to the application of poultry manure resulting in an increase in organic matter and calcium ions released into the soil solution during microbial decarboxylation of manure which is known to buffer change in soil pH. Similar findings were made by Uwah *et al.* (2014), Decutt (2012) and Snyman *et al.* (1998) who reported that the application of poultry manure led to a significant increase in soil pH. The current study is also consistent with the work of Chellemi and Lazarovits (2002) and Lombin *et al.* (1991), who observed an increase in soil pH and a reduction in the exchangeable acidity in the soil with the application of organic manure. The results from the study further indicated that application of NPK fertilizer reduced soil pH. The implications are that the continuous use of chemical fertilizers can increase the acidity of the soil. Similar results have been documented by Tirol-Padre *et al.* (2007) and Negassa *et al.* (2001), who asserted that long term use of chemical fertilizers can have negative effects on the chemical properties of the soil including the pH of the soil.

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5.5 Effect of fertilizer on the mineral composition of onion bulb

The results from the study showed that there was accumulation of N, P, K, Mg and Ca in the 'Bawku red' onion bulb. Application of poultry manure and a combined application of poultry manure and NPK fertilizer gave a higher percentage of N, P, K, Mg and Ca accumulation in the bulb compared to the NPK fertilizer and the control in both experiments. The finding of Yoldas *et al.* (2011) that the combined application of organic manure and NPK fertilizer significantly increased the K, Ca and Mg content of the onion bulb is consistent with the current study. Similar to the current finding, Yassen and Khalid (2009) and Abdelrazzag (2002), asserted that the application of poultry manure at different rates increased the concentration of nitrogen, phosphorus and potassium in the onion bulb over the control treatment (NPK). Coolong *et al.* (2005) also reported increased N, P, Ca and Mg content of onion bulbs with the application of N which agrees with this present study. Similarly, Meena *et al.* (2015), found the percentage of nitrogen and phosphorus in onion bulbs to be significantly higher in the poultry manure amended plot compared to the control plot. Sultana *et al.* (2014), also demonstrated that the combined application of organic and inorganic sources of fertilizers increased the concentrations of N, P and K in the bulbs of the onion at harvest.

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5.6 Effect of fertilizer on net revenue

The results from the study indicated that fertilizer application in onion production is profitable. The poultry manure amended plots and the combined application of poultry manure and NPK fertilizer had significant net revenue compared to the control and application of NPK fertilizer only treatments. The substantial profit made from the application of fertilizer could be attributed to the high marketable yield attained with the application of poultry manure and combination of

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poultry and NPK fertilizer treatments. The net revenue of onion production in the study using the different soil amendments was higher in experiment two compared to experiment one. This may be the result of the high marketable yields obtained in experiment two compared to experiment one which could be attributed to the high rainfall, temperature and photoperiod received by plants in experiment two. 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 with a negative net revenue in experiment one. This could be due to the low total and marketable bulb yield of the crop resulting from poor fertility and the acidic nature of the soil.

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CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Attention is currently shifting to the use of organic amendments due to the benefits it has over inorganic fertilizers. Inorganic fertilizers such as NPK 15-15-15 have over the years played an important role in improving the yields of vegetables including onions. The integrated use of organic and inorganic amendments is advocated for because of the added benefit of being able to maintain the fertility of the soil as well as protect the environment.

From this study, it was observed that all the soil amendments used increased the vegetative and yield parameters of the 'Bawku Red' onion variety over the control. On average, application of 15 t/ha of poultry manure gave the highest total and marketable yield, suggesting it to be the most effective amendment. Application of poultry manure, integrated application of poultry manure and NPK and the application of NPK only were shown to improve the yield and vegetative growth of onion over the control (no fertilizer).

It was observed from the study that with the exception of NPK 15-15-15 at 600kg/ha + Urea at 60kg/ha treatment all the other soil amendments investigated raised the pH of the soil over the control. Application of poultry manure alone or in combination with NPK reduced the acidity of soil.

The different soil amendments studied were found to improve the N, P, K, Ca and Mg content of onion bulb. Application of poultry manure and combined applications of poultry manure and

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NPK increased the mineral (N, P, K, Ca, Mg) content of onion bulbs over the control and NPK only treatment.

6.2 Recommendations

- Even though the application of 15 t/ha of poultry manure gave the highest yield suggesting it to be the most effect amendment; it is more economical to use 5 t/ha of poultry manure since it gave the highest net revenue.

- In order to sustain the fertility and productivity of the soil and obtain the best from organic and inorganic fertilizers, it is recommended that farmers practice Integrated Soil Fertility Management (ISFM) by adopting the 10 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha or 5 t/ha Pm + NPK 15-15-15 at 300 kg/ha + Urea at 60 kg/ha amendment, depending on the fertility status of their soil.

- As much as possible, acidic soils should be avoided in onion production when only chemical fertilizers are to be used. This is because the inorganic fertilizers can further reduce the soil pH and subsequently affect the total and marketable yield of the crop.

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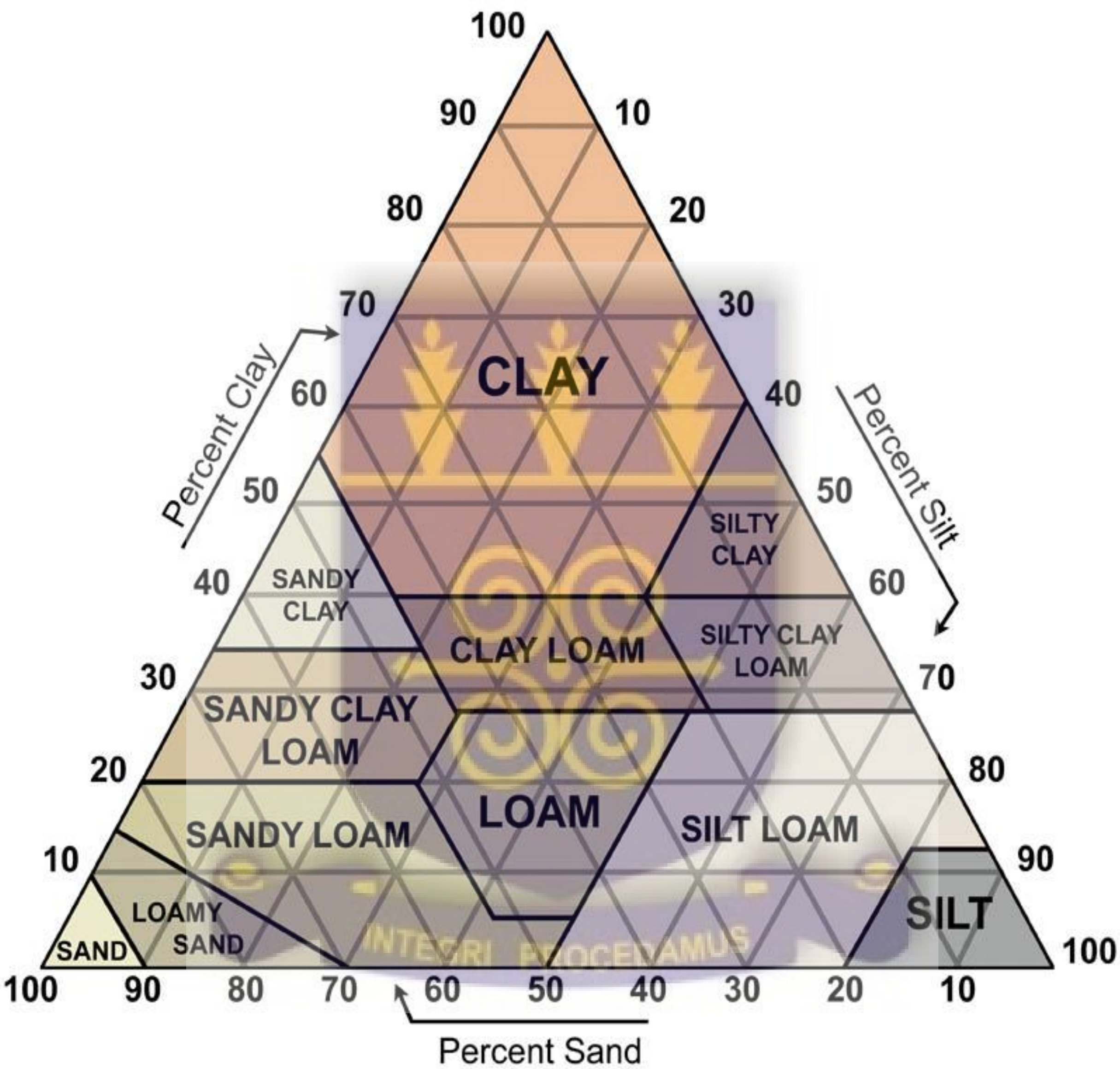
APPENDICES

Appendix 1: Soil texture triangle



Source: www.soilsensor.com/soil types

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Appendix 2: Analysis of variance (ANOVA) for experiment one

Variate: Crop establishment (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	16.25	5.417	0.55	
Treatments	9	190.625	21.181	2.13	0.062
Residual	27	268.125	9.931		
Total	39	475			

Variate: Plant height at bulbing (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	38.811	12.937	2.34	
Treatments	9	1181.275	131.253	23.72	<.001
Residual	27	149.372	5.532		
Total	39	1369.458			

Variate: Plant height at harvest (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	15.846	5.282	1.42	
Treatments	9	785.924	87.325	23.51	<.001
Residual	27	100.294	3.715		
Total	39	902.064			

Variate: Leaf length at bulbing (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	34.037	11.346	1.88	
Treatments	9	1288.519	143.169	23.72	<.001
Residual	27	162.943	6.035		
Total	39	1485.499			

Variate: Leaf length at harvest (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4.173	1.391	0.37	
Treatments	9	742.978	82.553	21.69	<.001
Residual	27	102.782	3.807		
Total	39	849.933			

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Variate: Leaf diameter at bulbing (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.7833	1.9278	6.14	
Treatments	9	44.5938	4.9549	15.78	<.001
Residual	27	8.4798	0.3141		
Total	39	58.8569			

Variate: Leaf diameter at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6.6951	2.2317	6.83	
Treatments	9	41.7726	4.6414	14.2	<.001
Residual	27	8.8282	0.327		
Total	39	57.296			

Variate: Number of leaves per plant at bulbing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.205	0.0683	0.67	
Treatments	9	17.221	1.9134	18.82	<.001
Residual	27	2.745	0.1017		
Total	39	20.171			

Variate: Number of leaves per plant at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.4068	0.4689	2.14	
Treatments	9	15.1363	1.6818	7.68	<.001
Residual	27	5.9108	0.2189		
Total	39	22.4537			

Variate: Fresh Bulb biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.16	0.38667	7.57	
Treatments	9	1.316	0.14622	2.86	0.017
Residual	27	1.38	0.05111		
Total	39	3.856			

Variate: Fresh Bulb biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	47.13	15.71	1.46	
Treatments	9	1121.86	124.65	11.61	<.001
Residual	27	289.89	10.74		
Total	39	1458.88			

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Variate: Fresh shoot biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	12.308	4.103	1.44	
Treatments	9	41.364	4.596	1.61	0.163
Residual	27	77.092	2.855		
Total	39	130.764			

Variate: Fresh shoot biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	60.731	20.244	2.11	
Treatments	9	564.481	62.72	6.54	<.001
Residual	27	259.019	9.593		
Total	39	884.231			

Variate: Total Fresh biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	17.732	5.911	1.84	
Treatments	9	50.544	5.616	1.75	0.126
Residual	27	86.648	3.209		
Total	39	154.924			

Variate: Total Fresh biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	196.2	65.4	2.48	
Treatments	9	2907.5	323.06	12.24	<.001
Residual	27	712.53	26.39		
Total	39	3816.23			

Variate: Dry Bulb biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.96216	0.32072	31.85	
Treatments	9	0.14616	0.01624	1.61	0.162
Residual	27	0.27184	0.01007		
Total	39	1.38016			

Variate: Dry Bulb biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.1009	1.7003	2.13	
Treatments	9	34.8661	3.874	4.86	<.001
Residual	27	21.5114	0.7967		
Total	39	61.4783			

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Variate: Dry shoot biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.31144	0.10381	3.39	
Treatments	9	0.75996	0.08444	2.75	0.02
Residual	27	0.82796	0.03067		
Total	39	1.89936			

Variate: Dry shoot biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.6296	0.2099	0.81	
Treatments	9	4.7701	0.53	2.06	0.071
Residual	27	6.9588	0.2577		
Total	39	12.3585			

Variate: Total Dry biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.48731	0.16244	3.85	
Treatments	9	1.03269	0.11474	2.72	0.021
Residual	27	1.13959	0.04221		
Total	39	2.65959			

Variate: Total Dry biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	8.159	2.72	1.61	
Treatments	9	63.002	7	4.14	0.002
Residual	27	45.653	1.691		
Total	39	116.814			

Variate: Number of days to 50% bulb appearance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	64.875	21.625	2.35	
Treatments	9	103.025	11.447	1.24	0.312
Residual	27	248.875	9.218		
Total	39	416.775			

Variate: Number of days to physiological maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	77.2	25.733	3.8	
Treatments	9	409.6	45.511	6.72	<.001
Residual	27	182.8	6.77		
Total	39	669.6			

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Variate: Neck diameter at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	7.5505	2.5168	8.02	
Treatments	9	24.7445	2.7494	8.77	<.001
Residual	27	8.4691	0.3137		
Total	39	40.7641			

Variate: Bulb diameter at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	37.47	12.49	0.75	
Treatments	9	2848.46	316.5	19.12	<.001
Residual	27	446.92	16.55		
Total	39	3332.85			

Variate: Bulb length at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	22.261	7.42	2.01	
Treatments	9	390.224	43.358	11.73	<.001
Residual	27	99.786	3.696		
Total	39	512.271			

Variate: Bulbing ratio

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.002287	0.000762	0.89	
Treatments	9	0.144509	0.016057	18.67	<.001
Residual	27	0.023218	0.00086		
Total	39	0.170014			

Variate: Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.016948	0.005649	1.24	
Treatments	9	0.147495	0.016388	3.6	0.005
Residual	27	0.122919	0.004553		
Total	39	0.287362			

Variate: Mean bulb weight (grams)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	13.2	4.4	0.64	
Treatments	9	3977.018	441.891	64.21	<.001
Residual	27	185.817	6.882		
Total	39	4176.035			

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Variate: Total bulb yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.5542	0.5181	0.64	
Treatments	9	468.2667	52.0296	64.21	<.001
Residual	27	21.8787	0.8103		
Total	39	491.6996			

Variate: Marketable bulb yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.351	0.7837	0.83	
Treatments	9	492.218	54.6909	57.62	<.001
Residual	27	25.6285	0.9492		
Total	39	520.1975			

Variate: Large bulbs grading (50 mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	56	18.7	0.17	
Treatments	9	3945.9	438.4	4.09	0.002
Residual	27	2892.9	107.1		
Total	39	6894.8			

Variate: Medium bulbs grading (30 - 50 mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	312.6	104.2	0.9	
Treatments	9	17831.7	1981.3	17.1	<.001
Residual	27	3128.1	115.9		
Total	39	21272.5			

Variate: Small bulbs grading (30 mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	267.18	89.06	1.49	
Treatments	9	26406.13	2934.01	49.12	<.001
Residual	27	1612.63	59.73		
Total	39	28285.94			

Variate: Soil pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.16459	0.05486	2.28	
Treatments	9	21.6625	2.40694	99.95	<.001
Residual	27	0.65019	0.02408		
Total	39	22.47728			

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Variate: % Nitrogen (N)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00714	0.00238	2.95	
Treatments	9	1.7459	0.193989	240.7	<.001
Residual	27	0.02176	0.000806		
Total	39	1.7748			

Variate: % Phosphorus (P)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.15994	0.05331	4.08	
Treatments	9	2.39001	0.26556	20.31	<.001
Residual	27	0.35311	0.01308		
Total	39	2.90306			

Variate: % Potassium (K)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.00709	0.3357	19.98	
Treatments	9	15.83796	1.75977	104.75	<.001
Residual	27	0.45361	0.0168		
Total	39	17.29866			

Variate: % Calcium (Ca)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.006936	0.002312	5.43	
Treatments	9	0.02662	0.002958	6.95	<.001
Residual	27	0.011491	0.000426		
Total	39	0.045046			

Variate: % Magnesium (Mg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.19149	0.06383	6.08	
Treatments	9	23.68298	2.63144	250.57	<.001
Residual	27	0.28355	0.0105		
Total	39	24.15802			

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Appendix 3: Analysis of variance (ANOVA) for experiment two

Variate: Crop establishment %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	146.25	48.75	0.67	
Treatments	9	958.75	106.53	1.46	0.214
Residual	27	1972.5	73.06		
Total	39	3077.5			

Variate: Plant height at bulbing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	41.246	13.749	2.11	
Treatments	9	724.741	80.527	12.38	<.001
Residual	27	175.649	6.506		
Total	39	941.636			

Variate: Plant height at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	76.166	25.389	3.21	
Treatments	9	432.086	48.01	6.07	<.001
Residual	27	213.544	7.909		
Total	39	721.796			

Variate: Leaf length at bulbing (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	70.286	23.429	2.96	
Treatments	9	650.934	72.326	9.14	<.001
Residual	27	213.604	7.911		
Total	39	934.824			

Variate: Leaf length at harvest (cm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	113.191	37.73	5.2	
Treatments	9	393.96	43.773	6.03	<.001
Residual	27	195.897	7.255		
Total	39	703.048			

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Variate: Leaf diameter at bulbing (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.8602	0.6201	2.46	
Treatments	9	14.0008	1.5556	6.18	<.001
Residual	27	6.7952	0.2517		
Total	39	22.6562			

Variate: Leaf diameter at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.8055	0.9352	3.13	
Treatments	9	13.4399	1.4933	4.99	<.001
Residual	27	8.0731	0.299		
Total	39	24.3185			

Variate: Number of leaves per plant at bulbing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.7928	0.2643	1.56	
Treatments	9	16.8773	1.8753	11.06	<.001
Residual	27	4.5798	0.1696		
Total	39	22.2497			

Variate: Number of leaves per plant at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.541	0.847	3.22	
Treatments	9	16.865	1.8739	7.12	<.001
Residual	27	7.109	0.2633		
Total	39	26.515			

Variate: Fresh Bulb biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.42979	0.4766	7.63	
Treatments	9	1.62381	0.18042	2.89	0.016
Residual	27	1.68671	0.06247		
Total	39	4.74031			

Variate: Fresh Bulb biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	57.46	19.15	0.54	
Treatments	9	2589.43	287.71	8.11	<.001
Residual	27	958.21	35.49		
Total	39	3605.1			

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Variate: Fresh shoot biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	37.74	12.58	0.73	
Treatments	9	478.73	53.19	3.07	0.012
Residual	27	468.06	17.34		
Total	39	984.53			

Variate: Fresh shoot biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	15.187	5.062	1.46	
Treatments	9	50.21	5.579	1.61	0.161
Residual	27	93.323	3.456		
Total	39	158.72			

Variate: Total Fresh biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	21.339	7.113	1.83	
Treatments	9	60.891	6.766	1.74	0.127
Residual	27	104.819	3.882		
Total	39	187.048			

Variate: Total Fresh biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	123.54	41.18	0.68	
Treatments	9	4832.51	536.95	8.8	<.001
Residual	27	1646.65	60.99		
Total	39	6602.71			

Variate: Dry Bulb biomass at bulbing (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.20307	0.40102	32.22	
Treatments	9	0.13548	0.01505	1.21	0.33
Residual	27	0.33604	0.01245		
Total	39	1.6746			

Variate: Dry Bulb biomass at harvest (g/plant)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.229	0.743	0.59	
Treatments	9	78.535	8.726	6.98	<.001
Residual	27	33.742	1.25		
Total	39	114.506			

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Variate: Dry shoot biomass at bulbing (g/plant)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.37869	0.12623	2.39	
Treatments	9	0.49563	0.05507	1.04	0.433
Residual	27	1.42484	0.05277		
Total	39	2.29917			

Variate: Dry shoot biomass at harvest (g/plant)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.4123	0.1374	0.73	
Treatments	9	5.2298	0.5811	3.07	0.012
Residual	27	5.1133	0.1894		
Total	39	10.7554			

Variate: Total Dry biomass at bulbing (g/pant)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.5145	0.1715	2.53	
Treatments	9	0.61099	0.06789	1	0.461
Residual	27	1.82765	0.06769		
Total	39	2.95314			

Variate: Total Dry biomass at harvest (g/plant)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	2.66	0.887	0.68	
Treatments	9	104.036	11.56	8.8	<.001
Residual	27	35.45	1.313		
Total	39	142.145			

Variate: Number of days to 50% bulb appearance

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	85.875	28.625	3.11	
Treatments	9	103.025	11.447	1.24	0.312
Residual	27	248.875	9.218		
Total	39	437.775			

Variate: Number of days to physiological maturity

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	77.4	25.8	4.08	
Treatments	9	415.6	46.178	7.31	<.001
Residual	27	170.6	6.319		
Total	39	663.6			

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Variate: Neck diameter a harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.3734	0.4578	1.2	
Treatments	9	11.2875	1.2542	3.29	0.008
Residual	27	10.2798	0.3807		
Total	39	22.9407			

Variate: Bulb diameter at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	9.75	3.25	0.26	
Treatments	9	609.93	67.77	5.38	<.001
Residual	27	340.3	12.6		
Total	39	959.99			

Variate: Bulb length at harvest (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	16.015	5.338	0.93	
Treatments	9	241.835	26.871	4.7	<.001
Residual	27	154.205	5.711		
Total	39	412.054			

Variate: Bulbing ratio

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.000391	0.00013	0.36	
Treatments	9	0.005814	0.000646	1.79	0.116
Residual	27	0.009734	0.000361		
Total	39	0.015938			

Variate: Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.005133	0.001711	0.38	
Treatments	9	0.037714	0.00419	0.93	0.515
Residual	27	0.121532	0.004501		
Total	39	0.164379			

Variate: Mean bulb weight (grams)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	20.67	6.89	0.36	
Treatments	9	1644.16	182.68	9.58	<.001
Residual	27	515.02	19.07		
Total	39	2179.85			

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Variate: Total bulb yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.434	0.811	0.36	
Treatments	9	193.588	21.51	9.58	<.001
Residual	27	60.64	2.246		
Total	39	256.662			

Variate: Marketable bulb yield (t/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.797	0.599	0.17	
Treatments	9	230.212	25.579	7.08	<.001
Residual	27	97.531	3.612		
Total	39	329.539			

Variate: Large bulbs grading (>50 mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	295.71	98.57	1.23	
Treatments	9	1013.39	112.6	1.4	0.236
Residual	27	2167.65	80.28		
Total	39	3476.74			

Variate: Medium bulbs grading (30 - 50 mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1429.1	476.4	3.4	
Treatments	9	3571	396.8	2.83	0.017
Residual	27	3781.6	140.1		
Total	39	8781.7			

Variate: Small bulbs grading (< 30 mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	568.9	189.6	1.52	
Treatments	9	6822.5	758.1	6.08	<.001
Residual	27	3363.7	124.6		
Total	39	10755.1			

Variate: Soil pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.41023	0.13674	2.4	
Treatments	9	14.4219	1.60243	28.07	<.001
Residual	27	1.54115	0.05708		
Total	39	16.37328			

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Variate: % Nitrogen (N)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.007697	0.002566	2.93	
Treatments	9	1.862594	0.206955	235.95	<.001
Residual	27	0.023682	0.000877		
Total	39	1.893973			

Variate: % Phosphorus (P)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.04067	0.01356	0.92	
Treatments	9	2.54745	0.28305	19.3	<.001
Residual	27	0.39596	0.01467		
Total	39	2.98408			

Variate: % Potassium (K)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.03338	0.011127	1.66	
Treatments	9	15.89024	1.765582	263.93	<.001
Residual	27	0.18062	0.00669		
Total	39	16.10424			

Variate: % Calcium (Ca)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00106	0.000353	0.86	
Treatments	9	0.027785	0.003087	7.49	<.001
Residual	27	0.011135	0.000412		
Total	39	0.03998			

Variate: % Magnesium (Mg)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.05816	0.019387	2.17	
Treatments	9	23.9322	2.659133	297.37	<.001
Residual	27	0.24144	0.008942		
Total	39	24.2318			

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Appendix 4: Soil test interpretation guide

(a) Macronutrients (N, P, K)

	Nitrogen (N)		**Phosphorus (P)**		**Potassium (K)**		
Extraction method	Kjedahl	2N KCL	Bray	Olsen	Ammonium Acetate		Ammonium Bicarbonate
					Base	Available	DTPA
Units	%	ppm	ppm	ppm	meq/10g	ppm	ppm
Levels:							
High	0.23-0.30	41-75	40-100	>25	0.7-2.0	280-800	121-180
Adequate	0.13-0.23	20-41	20-40	15-25	0.45-0.70	175-280	61-120
Low	0.05-0.13	<20	<20	<15	<0.45	<175	<60

(b) Macronutrients (Ca, Mg, S)

	Calcium (Ca)		**Magnesium (Mg)**		**Sulphur (S-SO4)**
Extraction method	Ammonium Acetate		Ammonium Acetate		KCL 40
Units	meq/100g	ppm	meq/100g	ppm	ppm
Levels:					
High	>10	>2000	>1.5	>180	>10
Adequate	5-10	1000-2000	0.5-1.5	60-180	5-10
Low	<5	<1000	<0.5	<60	<5

(c) Micronutrients

	Iron (Fe)	**Manganese (Mn)**	**Zinc (Zn)**	**Copper (Cu)**	**Boron (B)**
Extraction method	DTPA	DTPA	DTPA	DTPA	DTPA
Units	ppm	ppm	ppm	ppm	ppm
Levels:					
High	>5.0	>2.0	>1.5	>2.0	>2.0
Adequate	2.5-5.0	0.6-2.0	1.0-1.5	0.6-2.0	0.5-2.0
Low	<2.5	<0.6	<1.0	<0.6	<0.5

(d) Soil properties (pH, organic matter, CEC, TEB, Base Saturation)

Parameter	**pH**	**Organic matter (%)**	**CEC**	**TED**	**Base Saturation (%)**
Levels:					
High*	>6.5	>2.5	>20	>20	>95
Adequate*	5.5-6.5	1.5-2.5	5-20	4-20	85-95
Low*	<5.5	<1.5	<5	<4	<85

** also depends on the crop*

Source: Council for Scientific and Industrial Research-Soil Research Institute (CSIR-SRI)

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Appendix 5: Descriptive terms commonly associated with certain 1:1 pH ranges

Term	pH
Extremely acid	<4.5
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Moderately acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral	6.6–7.3
Slightly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0
Very strongly alkaline	>9.1

Source: Soil Survey Division Staff, 1993