Effects of Nitrogen and Phosphorus Nutrition on Growth, Yield, Yield Components and Fruit Quality of Watermelon (*Citrullus lanatus* Thunb)

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EFFECTS OF NITROGEN AND PHOSPHORUS NUTRITION ON GROWTH, YIELD, YIELD COMPONENTS AND FRUIT QUALITY OF WATERMELON (*Citrullus lanatus Thumb*).

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STATEMENT OF ORIGINALITY

The work contained in this dissertation was compiled by the author at the University of Botswana, Botswana College of Agriculture between October 2012 and October 2014. It is original except where references are made and it will not be submitted for the award of any other degree or diploma of any other university.

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ABSTRACT

An experiment was conducted in the Botswana College of Agriculture, Notwane farm in Gaborone North to evaluate the effect of nitrogen and phosphorus on growth, yield, yield components and quality of watermelon (*Citrullus lanatus* thumb var. Crimson Sweet). Five levels of nitrogen (0, 50, 100, 150 and 200) and four levels of phosphorus (0, 25, 50 and 75) were laid in a split- plot design with five replications. There was no interaction between nitrogen and phosphorus fertilizer applications on all the dependent variables determined. Application of nitrogen at 50, 100 and 150 N kg/h increased vegetative growth, fruit yield, yield components and fruit quality. Application of N beyond 150 kg/ha decreased all the above dependent variables. Phosphorus application at 25 and 50 kg/ha increased vegetative growth, yield and yield components of watermelons. The positive response of watermelon plants to N and P was attributed to the role of N and P on growth, development and efficient utilization of carbohydrates to form protoplasm and more cells, and the increase in dry matter. It was concluded that in order to optimize watermelon fruit yield and quality, N and P should be applied at 150 and 50 kg/ha, respectively. The author recommends that for wider application of these fertilizer rates in Botswana, N and P trials be undertaken in various parts of the country under different soil types, irrigation regimes and rain-fed agriculture to confirm the current findings.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
K	Potassium
LAN	Limestone ammonium nitrate
MoA	Ministry of Agriculture
N	Nitrogen
Na	Sodium
P	Phosphorus
SAS	Statistical Analysis System
SSP	Single superphosphate
Zn	Zinc

CHAPTER 1

1.0 INTRODUCTION

1.1 General introduction

Watermelon (*Citrullus lanatus* (Thunb) belongs to a family of Cucurbitaceae, which is among plant families that supply man with edible products and useful fibers. The family Cucurbitaceae, consists of 115 genera, of which four are of economic importance: *Citrullus, Cucumis, Cucurbita* and *Lagenaria* (Wein, 2006). The family Cucurbitaceae consists of various squashes, melons and gourds which include crops such as cucumber, pumpkins, luffas and watermelons. The family is predominantly distributed around the tropics, where those with edible fruits were amongst the earliest cultivated plants both in the Old and New worlds (Wein, 2006). Cucumbers are thought to have been cultivated in India where their use has been dated back far as 3000 years ago (Pitrat *et al.*, 2008). *Cucumis melo* is thought to have originated in the central part of Africa, but spread rapidly to Asia, where many cultivars have since been selected. Watermelons originated in the Southern dry parts of Africa, particularly the Kalahari desert, which occupies some parts of Botswana, South Africa and Namibia and also has South Asia as its center of diversity (Camichael, 2011; Kawasaki *et al.*, 2000) . It is in the Southern African region, where watermelon is found growing in the wild, reaching maximum genetic diversity resulting in sweet, bland and bitter forms. Both the cultivated and the wild watermelons appear to have diverged independently from *Citrullus ecirrhosus* from Namibia (Janssens *et al.*, 2003).

Tsamma melon (*Citrullus lanatus* var tastius) found in Southern Africa is believed to be the ancestor of watermelon (Van Wyk and Gericke 2000). David Livingstone is reported to have seen Districts where the entire country side was literally covered by watermelon vines, while the Khoi-san and several kinds of animals devoured the fruit (Moradi and Younesi, 2009). The indigenous people, in search of water containing foods, selected varieties with low glycoside content (Razavi and Milani, 2006). Watermelon accounts for 6.8% of the world's cultivated area devoted for vegetable production. The world production of watermelon was estimated at 500,000 MT (FAO, 2005). To date the world's largest producer of watermelon is China producing 69, 315 000 MT (FAO, 2005). China, Turkey, Iran and USA produce about 50% of the world production of watermelon. Although the origin of watermelon is in Southern Africa, no country in this region falls among the top five largest producers let alone top 20 of the world production. Egypt in Africa is the fifth largest producer with 1,500,000 MT followed by Morocco in the 15th position. Botswana, where the fruit is a center of diversity, only produces 254 MT of watermelon on an area of 76.19 Ha (MoA, 2010).

1.2 Uses of watermelon

Watermelon contains 95% water, 0.5% ash, 0.01 % oil, 0.5% fibre, 5% carbohydrates, 250,000 mg vitamin A, 0.04 mg thiamine, 0.03 mg riboflavin, and 8.0 mg Ca, iron 0.02 mg, niacin 0.6 mg, ascorbic acid 15.0 g and potassium 6.0 mg have 0.6 mg per 100 g edible portion (Inuwa *et al.*, 2011).

Watermelon flesh is refreshing in hot summer keeping the body cool and calm. It prevents sun and heat stroke (Clenard *et al.*, 2005). It may help reduce inflammation associated with conditions of asthma, atherosclerosis, diabetes, colon cancer and arthritis (Clenard *et al.*, 2005). It contains high levels of lycopene which is an antioxidant that may help reduce the risks of diseases related to oxidative stress, that arise as a result of imbalance in the human antioxidated status implicated in aging and a number of diseases such as cancer, atherosclerosis and rheumatoid arthritis (Edwards *et al.*, 2003). Lycopene is a highly efficient oxygen radical scavenger and has been implicated in many epidemiological studies as providing protection against cancers especially in men (Edwards *et al.*, 2003). The fruit juice of watermelon has a radical scavenging effect which is maintained 90 minutes after consumption (Edwards *et al.*, 2003).

Watermelon rind contains citrulline, an amino acid that removes nitrogen from the blood and converts it into urine in the human body. Citrulline is a precursor in the biosynthesis of arginine. Citrulline reacts with body enzymes and is changed to arginine. Arginine boosts nitric oxide, which relaxes the blood vessels, thus having the same effect as viagra, which is used to treat erectile dysfunction. Arginine has also been observed to significantly increase the production of sperms in humans (Edwards *et al.*, 2003). About six cups of watermelon are enough to boost arginine level. Of recent, a dietary supplement made of watermelon rind has been made that can be used in the treatment of sickle cell anemia related afflictions (Benes, 1999).

Watermelon fruit can be used to make fresh salads and desserts, pies, vegetable entrees, snack foods and ornamental decorations. Often, watermelon is the only source of water in the desert in the dry season when no standing water is available (Moradi and Younesi, 2009; Wani *et al.*, 2006). In Asian countries such as India, watermelons are used to make preserves and pickles. Due to its high content of pectin, the fruit is a popular constituent of jams and jellies (Van Wyk and Gericke, 2000). Watermelon seeds may be roasted and eaten as snacks especially in Africa and Southern China (El-Aday and Tana, 2001; Wani *et al.*, 2006). The seeds may also be grounded and added into bread flour. Watermelon seeds contain 20-45% edible oil and 30-40% protein (Wani *et al.*, 2006). The husks of the seeds can be used as poultry feed. The leaves and young fruits are utilized as vegetables. The peel of the fruit is used for making jam (VanWyk and Gericke, 2000). In drought, the fresh watermelon and watermelon peels are used as livestock feed in South Africa and Botswana (VanWyk and Gericke, 2000).

1.3 Plant nutrition

In fruit production, the effects of nutrition on fruit quality are important and should be taken into consideration by growers and production managers to increase profitability and enhance sustainability and worldwide competiveness (Agrios, 1997). It is therefore, important to design a balanced nutrition program formulated to provide specific needs for expected yields and fruit quality (Bok *et al.*, 2006). With adequate nutrition, fruit crops grow stronger, have better tolerance to pests and stresses, yield more consistently and produce good quality fruit (Zekri *et al.*, 2003). Mineral nutrition is of great significance in fruit crop production as it affects metabolic activity (strength) of source and sinks. Good quality flowers and subsequent fruit growth is ultimately dependent on the presence of carbohydrates produced by past or current photosynthesis in the leaves, and on water and nutrients transported from the soil via the roots (Jackson and Looney, 1999). A severe limitation of mineral nutrients during flower initiation and development, leads to the development of the pollen grains with poor viability (Jackson and Looney, 1999). For maximum yield, developing fruits need to attract photosynthetic assimilates, mineral nutrients and water (Jackson and Looney, 1999).

There are 13 mineral nutrients that are needed by the plant which are taken from the soil or must be added as fertilizers. Nitrogen (N) is one of the mineral nutrients that are required in larger quantities than any other element for the completion of the plant's life cycle. Nitrogen is one of the most important nutrients affecting the growth, development, yield and fruit quality of fruit crops (Eckert, 2010). In addition, N is found in important molecules such as purines, pyrimidines, porphyrins and coenzymes. Purines and pyrimidines are found in nucleic acids (ribonucleic acid and deoxyribonucleic acid), which are essential for protein synthesis (Raven *et al.*, 1999). Nitrogen is an integral constituent of protein structure and thus of apoenzymes

(Marschner, 2005). Nitrogen is also a constituent of the porphyrin structure which is found in metabolically important compounds such as chlorophyll pigments and the cytochromes, which are essential for photosynthesis and respiration (Heidari and Mohammad, 2012). As an important part of the chlorophyll and cytochromes, N promotes rapid growth. Therefore, N is important in promoting vegetative growth of plants. In fruit production, N is essential in promoting effective pollination and fertilization of the flower, and subsequently promoting fruit set (Walters and Taylor, 2005).

Phosphorus (P) is another mineral element that plays an important role in plants. It is an essential nutrient that is a constituent of macromolecular structures (DNA, RNA and adenosine triphosphate (ATP) and phospholipids of biomembranes) (Marschner, 2005; Raven *et al.*, 1999). In both DNA and RNA, P forms a bridge between ribonucleoside units to form macromolecules (Marschner, 2005). Phosphate esters and energy-rich phosphates (ATP) represent the metabolic machinery of cells (Marschner, 2005; Mengel and Kirby, 2001). Phosphorus also plays a key role in modulation of enzyme activities and compartmentation which is essential for the regulation of metabolic pathways in the cytoplasm and chloroplasts (Raven *et al.*, 1999; Marschner, 2005). Phosphorus is also important in the general health of the plant because it stimulates root development, increases stalk and stem strength, enhances seed germination and early growth, stimulates blooming, enhances bud set and aids in seed formation (Aldana, 2005). Phosphorus further promotes more uniform plants, hastens maturity of crops, and improves crop quality and resistance to plant diseases (Adebooye *et al.*, 2010).

Having such a significant role in the crop growth and development, N and P are always present in comparatively small amounts in mineral soils. Moreover, a large proportion of these two elements are at one time held in combinations unavailable to plants. In Botswana, the soils are low in N and P (Bok *et al.* 2006; Emongor and Mabe, 2012). The soils in Botswana are aridisols of alluvial and/or colluvial (Burgess, 2006). To enhance yield and quality of watermelons is only possible with the external use of organic and inorganic fertilizers in this kind of soils. An application of N and P fertilizers to the arid soils is therefore essential to achieve high crop yields and good fruit quality (Samaila *et al.,* 2011). Biomass and carbohydrate content of fruit are manipulated by agronomic practices (fertilizer application, fruit thinning, plant growth regulator application, pollination and irrigation that increase assimilate partitioning to fruit in a number of crops (Basak, 2002; Stover *et al.*, 2001; Byers *et al.*, 2003; Long *et al.*, 2004).

1.4 Justification of the study

Food is an essential commodity that separates prosperous nations from struggling ones. It is one of the essential needs of social security. One of the most important questions facing the global society is how to produce enough food to feed the increasing human population in the world. Another parallel question is how much fertilizers should be applied to crops for optimal growth and development, and ultimately produce a good quality crop (Agrios, 1997). The world population has increased fourfold during the 20th century from about 1.5 billion to 6.1 billion (Agrios, 1997). The population is consistently increasing with world population estimated at 9.0 billion in 2050 (Agrios, 1997). During the 21stcentury, crop production has also increased dramatically by about 2-4 times and supported food for people, although 800 million people still live under severe malnutrition (Ohyama and Sueyoshi, 2010). The increase in food production has been due to the development and adoption of agricultural technologies such as use of hybrid seeds and fertilizers, and better crop management practices.

Botswana soils are deficient in P and low in N and organic matter (Emongor and Ramolemana, 2004; Bok *et al.*, 2006; Emongor and Mabe, 2012). The fertility of soils in the savanna are reported to be low in organic matter, N and P (Enwezor and Moore, 1966; Sanchez, 1976; Uwah *et al.*, 2010) but crops respond well to fertilization because of their favourable base exchange properties (Mokwunye, 1979). Watermelon production level was reported to be low in Kenya due to low soil fertility, especially low soil N and organic matter (Aguyoh *et al.*, 2010). Watermelon is reported to be highly demanding in N, which is essential to plant development and boosts both plant growth and crop yield (Santos *et al.*, 2009). However, N in excess increases vegetative growth, and reduces fruiting and fruit quality of watermelon (Norman, 1992; Santos *et al.*, 2009, Shaoping *et al.*, 2013). Moreover, high content of N in the plant is reported to reduce the production of phenolic compounds (fungistatic) and lignin in leaves, lessening the resistance to pathogens (Santos *et al.*, 2009). Nitrogen also increases the concentration of amino acids and amines in the apoplast and leaf surface than sugars in conidia germination, therefore favouring the development of fungal diseases (Marschner, 2005). Consequently, if the N rate applied to watermelon on one hand, it may increase fruit yield, on the other hand, it may enhance losses caused by diseases. The search for a balance in N application in watermelon enhances the need for more research. Furthermore, to meet crop N and P requirements including watermelon, farmers in Botswana and worldwide have to apply nitrogenous and phosphatic fertilizers. In order to develop an effective fertilizer program that will apply the right amount of nutrients to achieve high fruit yield and quality fruit, the nutritional status of the fruit crops and soil needs to be determined, which requires research. In Botswana, no published research on watermelon mineral nutrition is available. Elsewhere, positive yield responses to N and P fertilizers have been reported (Brantley and Warren, 1960; Knysh and Vakulenko, 1976; Bhosale *et al.*, 1978; Som *et al.*, 1986; Uwah and Solomon, 1998; Uwah *et al.*, 2010). Fertilizer trials elsewhere in the world have revealed inconsistent results on yield and quality of watermelon fruit as a result of differences in agro-climatic conditions and agromomic practices (Leão *et al.*, 2008; Uygur and Yetisir, 2009; Uwah *et al.*, 2010; Liu *et al.*, 2014). In view of the conflicting information from different parts of the world and the lack of field studies on fertilizer requirements of watermelon in Botswana, therefore, this study intends to fill that knowledge gap in Botswana and add to the existing body of knowledge on the effects of N and P on the growth, yield, yield components and fruit quality of watermelon.

1.5 Objective of study

The objective of the study was to evaluate the effects of N and P on growth, yield and yield components, and fruit quality of watermelon.

1.6 Hypothesis

1) Nitrogen has no effect on growth, yield and yield components, and fruit quality of watermelon.
2) Phosphorus has no effect on growth, yield and yield components, and fruit quality of watermelon.
3) Nitrogen and P interaction has no effect on growth, yield and yield components, and fruit quality of watermelon.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Plant mineral nutrition

In view of the conflicting information from different parts of the world and the lack of field studies on fertilizer requirements of watermelon in Botswana and the SADC region, this review will cover general plant nutrition and effects of N and P nutrition on watermelon and cucurbits elsewhere in the world with emphasis on yield and yield components, and fruit quality of watermelon.

Various factors are required for plant growth such as light, CO_2, water and mineral nutrients. Increasing the supply of any of these factors from the deficiency range increases the growth rate and yield, though the response diminishes as the supply of the growth factor is increased (Marschner, 2005). Yield response is strongly influenced by interactions between mineral nutrients and other growth factors. For example, under field conditions the interaction between water availability and N supply are of particular importance (Marschner, 2005). The depressions in yield that accompany a large supply of N and other nutrients in combination with low soil moisture levels are presumably caused by several factors such as delay in stomatal response to water deficiency, the higher water consumption of vegetative biomass and the corresponding higher risk of drought stress in critical periods of economic yield formation, and increase in shoot-dry weight ratio with increasing N supply, an effect which seems to be more prominent in C_3 than in C_4 plant species (Hocking and Meyer, 1991).

Mineral nutrition of plants not only affects vegetative and reproductive organs, but also affects yield components of economic yield. In most crops, both quantity and quality are important yield components. For example, nitrate accumulation in spinach and sucrose accumulation in sugar beet with increasing levels of N applications; or with increase in mineral nutrient supply the number of either reproductive sinks or vegetative storage organs is increased (Marschner, 2005).

For a productive fruit crop, N and P should be within a range referred to as sufficient. Beyond this range the plant might be associated with excessive or deficiency of nutrients. Yield production in the annual herbaceous crops of the *Cucurbitaceae* are affected by both factors that influence plant productivity and those that determine the partitioning of assimilates to reproductive tissues (Wein, 2006). Fruit quality is an important criterion in the production of muskmelon, watermelon and winter squash. Production systems must provide conditions that allow fruit to develop acceptable sweetness and taste, and the size characteristics of the cultivar (Wein, 2006). Watermelon fruits should have a minimum sugar content of 9-10% to be considered acceptable (Mutton *et al.*, 1981; Peirce, 1987; Kader, 2002). As yields of fruits increase, soluble solid content (SSC) and fruit size decline (Mendlinger, 1994). Welles and Buitelaar (1988) reported that factors which shortened the period from flowering to fruit maturity reduced SSC of the fruit. Increasing the night temperature, reducing leaf area, and increasing the number of fruit per plant all reduced the maturation period of the sweet melons, and simultaneously lowered fruit quality (Welles and Buitelaar, 1988). Davis and Schweers (1971) also reported that fruit number per plant was inversely correlated with fruit SSC in melons. This implies that assimilate supply during the growth period is critical to determination of fruit quality. Thus factors that reduce the canopy photosynthetic rate, such as the extent of exposure of the leaf canopy to light or deficiency of mineral nutrients such as N, P and K may influence fruit quality and yield. Hygrotech (2004) reported that watermelon has a moderate nutrient requirement because of its deep rooting and efficiency in nutrient extraction from the soil. For higher watermelon yields 180kg N/ha and 168kg P/ha should be applied (Hygrotech 2004)

2.2 Nitrogen effects on watermelon yield and yield components

The nutrient requirements of crops depend on soil texture and clay minerals, types of previous vegetation cover, cropping intensity, temperature and soil moisture (Denton and Swarup, 1990; Mengel and Kirkby, 2001; Marschner, 2005). The N and P perform different physiological and biochemical roles in crops growth and development, therefore, there is a need for fertilizer application in order to obtain optimum yield. The quantity of nutrients which a crop takes up during growth depends on crop species and yield. Both crop yield and nutrient uptake also depend significantly on crop cultivar (Mengel and Kirkby, 2001).

In order to obtain high yield of watermelon, there is need to augment the nutrient status of the soil or growing medium to meet the crop's nutrient requirements and thereby maintaining the fertility of the soil or growing medium. The nutrient status of the soil can be increased by application of organic (animal manures, animal waste and compost) and inorganic fertilizers (Dauda *et al.*, 2008; Olaniyi, 2008; Aguyoh *et al.*, 2010, Uwah *et al.*, 2010). Norman (1992), Rice *et al.* (1993) and Schippers (2000) reported that watermelon is a heavy feeder of N and therefore requires application of 200 kg/ha of compound fertilizer (15-15-15) three weeks before planting time, followed by application of 21 kg N/ha at fruit set stage. Research on watermelon N requirements in Nigeria showed that application of 50 kg N/ha in two splits (30 kg N/ha at planting and 20 kg N/ha at fruit set) resulted in optimum watermelon yield, beyond which N induced vegetative growth at the expense of fruiting (Norman, 1992). However, in a three-year study with N fertilizer application at 0, 60, 120 and 180 kg/ha on watermelon in Samaru, Nigeria, N increased vegetative growth of watermelon (main vine/plant, leaf number, and branch number/plant and leaf area index) compared to control plants (Uwah *et al.*, 2010). Nitrogen application at 60, 120 and 180 kg/ha increased vine length, leaf number/plant and branch number by 29-158%, 66-523% and 56-160%, respectively, compared to control plants, depending on cultivar and year (Uwah *et al.*, 2010). On average, N application of 60, 120 and 180 kg/ha increased leaf area index (LAI) by 149, 318 and 387%, respectively, compared to control plants (Uwah *et al.*, 2010). The highest vegetative growth was observed in plants applied with 180 kg N/ha (Uwah *et al.*, 2010). In an earlier study in Samaru, Northern Nigeria, Uwah and Solomon (1998) reported that N application at 60, 120 and 180 kg/ha to watermelon cultivar 'Sugar baby', increased leaf number, number of branches, vine length and vine dry weight compared to control plants. In a study to determine the individual and combined levels of N and P fertilizers required for optimum growth and seed yield of egusi watermelon in Ogbomoso, Nigeria, Olaniyi (2008) reported that N at 40, 60 and 80 kg/ha increased primary vine, number of vines, leaf number and plant dry matter by 30-84, 71-191, 42-166 and 49-113%, respectively, compared to control plants, with the highest increase in vegetative growth variables obtained at 80 kg N/ha. Liu *et al.* (2014) reported that when the proportion of NH_4^+ was increased in watermelon, leaf number and area, plant height, net photosynthesis, biomass, and root growth were significantly decreased. However, when watermelon plants were supplied with mixed NO_3^- and NH_4^+ compared to NO_3^- or NH_4^+ alone, improved vegetative growth and uptake of N and P, but decreased uptake of K, Ca and Mg (Liu *et al.*, 2014). Shaoping *et al.* (2013) researching on the effects of nitrogen, density and nitrogen use efficiency of watermelon in China, reported that N application of 100, 200 and 300 kg/ha had significant effects on yield and fruit quality of watermelon. Application of 100 and 200 kg N/ha increased watermelon fruit yield by 10.6 and 22.3% compared to plants applied with no N, respectively. Application of 300 kg N/ha reduced watermelon fruit yield by 8.42 %.

In Spain, Castellanos *et al.* (2011) working with 11 rates of N (11, 30, 61, 85, 93, 95, 112, 139, 148, 243 and 393 kg N/ha) in a three-year study reported that N increased stem and leaf dry matter production, leaf area index and leaf area duration. The dry biomass of stems and leaves (vegetative growth) increased with increase in N application rate (Castellanos *et al.*, 2011). While, Abou El-Yazied *et al.* (2012) in Egypt reported that application of N at 64, 80 and 96 kg/ha increased the main vine length, number of branches, leaf number and area and plant dry matter of Cantaloupe melon hybrids.

In *Cucurbitaceae*, it is the female flower that develops into a fruit. Jalal (2000) reported that N application increased the total yield of the cucurbits crop with respect to the number of fruits and average fruit. The fruit number was attributed to the pistillate flowers that were pollinated and fertilized to develop into a fruit. Swaider *et al.* (1994) reported that in cucurbits, increasing the N application rates from 56 kg to 112 kg resulted in an increase in the number of flowers that reached anthesis. Oloyede *et al.* (2013) reported that application of the compound fertilizer 15-15-15 at the rate of 100, 150, 200 or 250 kg/ha to pumpkin (*Cucurbita pepo*), increased fruit number/ha by at least 42.9% compared to control plants in which no fertilizers was applied. While application of 50, 100, 150, 200 or 250 kg/ha of the compound fertilizer 15-15-15 increased pumpkin fruit yield by 34.2-171% compared to control plants (Oloyede *et al.*, 2013). For optimum fruit yield production, the leaf N content (6^{th} leaf from growing tip) should be 7,500 ppm N (sufficient), but deficient at $\leq$ 1,500 ppm (Maynard and Hochmuth, 2007).

2.3 Nitrogen effects on watermelon fruit quality

Few studies in literature have reported on the effects of N nutrition on watermelon fruit quality attributes such as fruit soluble solid content, titratable acidity, flesh firmness, rind thickness and fruit mineral content. Ferrante *et al.* (2008) reported that application of N from 0 to 165 kg/ha to watermelons did not have an effect on fruit flesh firmness, skin and pulp content, caretonoid content, total phenols and ascorbic acid content. However, Shaoping *et al.* (2013) reported that increasing the N application rate above 200 kg/ha decreased the fruit soluble solids content (sugar) from 13.9% (200 kg N/ha) to 8.42% (300 kg N/ha). Olaniyi and Tella (2011) reported that application of 60 kg N/ha and 25 kg K/ha significantly increased the seed protein, fat and mineral (P, K, Ca, Mg, Fe and Zn) contents of watermelon compared to seeds from fruits of control plants. Abdel-All and Seham (2013) reported that application of K to watermelon plants grown on clay loam soils (pH 8.2) at 62, 125 and 187 kg K/ha increased the fruit soluble solids content and reduced fruit rind thickness compared to fruit from control plants. Increasing K application from 0 to 187 kg/ha increased the fruit soluble solids content from 9.4% to 11% and decreased the rind thickness by 23.6%. Adequate K nutrition has been associated with increased yields, fruit size, soluble solids content, ascorbic acid (vitamin C) content, improved fruit colour, increased shelf-life and shipping quality of many horticultural crops (Lester *et al.*, 2006; 2010; Kanai *et al.*, 2007).

2.4 Phosphorus effects on yield, yield components and fruit quality of watermelon

Although several studies have been conducted on phosphorus effects on plant growth and development especially on cereals, vegetables and fruits, few are on cucurbits. In studies carried out in the guinea savanna zone of Southwestern Nigeria by Olaniyi (2008) found that application of 52.5 kg P_2O_5/ha was optimum for watermelon yield. While, Adeyemi (1991) reported that in soil of low and medium fertility application of 75 kg P_2O_5/ha resulted in optimum watermelon yield in Nigeria. Olaniyi (2008) reported that increasing application of P from 0 to 8.8, 13.2 or 17.6 kg/ha increased vegetative growth of watermelon (primary vine length, number of vines, leaf number and plant dry matter) however, there was no significant difference between 13.2 and 17.6 kg P/ha on their effect on vegetative growth. Olaniyi (2008) further reported that increasing P application from 0 to 8.8, 13.2 or 17.6 kg/ha reduced days to 50% flowering from 47 to 43.8, 44.5 and 40.3, respectively, but increased both the number of female and male flowers of watermelon. He further reported that increasing P application increased fruit diameter, number of fruits/plant, fruit weight, fruit yield, number of seeds/fruit, seed yield/fruit and seed yield/ha of watermelon plants. However, the optimum fertilizer application rate that optimized vegetative growth, yield and yield components of watermelon was interaction of 60 kg N/ha and 13.2 kg P/ha (Olaniyi, 2008). In a three-year study in Samaru, Nigeria by Uwah *et al.* (2010), P application at 17 and 34 kg/ha increased vegetative growth (vine length, leaf number/plant, branch number/plant, leaf area index and total dry matter), number of fruits/plant, fruit yield/ha and total fruit sugar content in two varieties of watermelon. Phosphorus application at 17 and 34 kg/ha increased total fruit yield by 25 and 33%, respectively compared to yield in watermelon plants without P application (Uwah *et al.*, 2010). The optimum total dry matter, fruit yield and fruit sugar content was obtained with the interaction of 120 kg N/ha and 34 kg P/ha (Uwah *et al.*, 2010). Earlier, Uwah and Solomon (1998) reported similar results when they found that application of 17 and 34 kg P/ha, increased total fruit yield by 32 and 39%, respectively, compared to watermelon plants not applied with P. In the Republic of South Africa, for high watermelon fruit yield and fruit of excellent quality, application of up to 180 kg N/ha and 73 kg P/ha in soils with lower than 20 ppm bicarbonate extractable P is recommended (Metho, 2011).

Olaniyi and Oyerele (1997) reported that watermelon plants applied with P had high fruit quality in terms of protein, P, K, Ca, Mg and Fe as compared with fruit from watermelon plants not fertilized with P. However, Fiskel *et al.* (1967) and Lee and Kader (2000) reported that with increase in P application up to 150 kg/ha, the absorption of Ca, Mg, Cu, Zn and Fe was inhibited which was directly correlated with the nutritional status of the watermelon fruit. They further stated that P application at 150 kg/ha increased the uptake of B, Mo, Mn and watermelon fruit had high vitamin C content.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental site

The study was conducted at the Botswana College of Agriculture.(BCA), Notwane Farm in Glen Valley Gaborone North (latitude 24°34'S and 25°57'N) at altitude of 994 above sea level. The climate is semi-arid with average annual rainfall of 538 mm. Most rain falls in summer, which generally starts in the late October and continues to March or April. During the rainy seasons, prolonged dry spells are common and rainfall trends are localized. The recorded minimum and maximum temperatures during the period of study was 19 °c and 31°c respectively. The soils are deficient in phosphorus, have low levels of nitrogen and organic matter (Emongor *et al.*, 2004; Emongor *et al.*, 2012). The soils are shallow, ferruginous tropical soils, mainly consisting of medium to coarse grains and sandy loams with low water holding capacity and subject to crusting after heavy rains (De Wilt and Nachtengale, 1996).

3.2 Experimental design

Two field experiments were carried out between October 2012 and April 2013. The experimental design used was a split - plot design laid down in randomized complete blocks with three replications. The treatments were N (main-plots) and P (sub-plots). Nitrogen in the form of limestone ammonium nitrate (LAN-28 % N) was applied at 0, 50, 100, 150, and 200kg N/ha. Phosphorus was applied as single superphosphate (SSP-10.5% P) at 0, 25, 50 and 75 kg P/ha. The main-plot size was 12 m × 12 m while the sub-plots were 6 m × 6 m each. Before the start of the study, soil sampling was done at a depth of 0-30 cm for the determination of physico-chemical properties, and total N and P.

3.3 Cultural practices

Watermelon seeds variety 'crimson sweet' were directly planted at two seeds per station with spacing of 2.0 m between rows and 0.5 m within row. Seedling thinning was done two weeks after emergence leaving one seedling per stand. Fertilizer application was done by side banding about 5 cm away from the seedling. Nitrogen was applied in two splits as LAN (28% N). The first applications was done two weeks after seedling emergence and the second application was done at the onset of flowering. Phosphorus was banded two weeks after emergence.

The soil was kept weed free by shallow cultivation between rows and around the watermelon plants with care to avoid root damage. The vines were trained to leave paths between the rows in order to give access for pest and disease control operations. Routine scouting of pests and diseases was done daily. Integrated pest management strategies such as sanitation, prevention, exclusion and elimination of pests and diseases were applied. To control fruit flies, aphids, thrips, leaf miners and cucurbit beetle, insecticides cypermethrin, chloropyrifos and methomyl were sprayed interchangeably on the late afternoons not to coincide with bee visitations. Irrigation with over-head sprinklers was only done when rain stopped and the soil water content was just below field capacity.

3.4 .0 Dependent variables determined

The dependent variables that were determined included number of leaves/plant, leaf area, length of the primary vine, number of branches/plant, leaf water and dry matter content, female flower number/plant, fruit number/plant, fruit length and diameter, rind thickness, fruit yield, fruit titratable acidity, soluble solids content, fruit water content, fruit dry matter content, lycopene content, and leaf and fruit N, P, K, and Mg.

3.4.1 Fruit maturity

The fruits were harvested manually, 85 days after planting. The maturity of the fruit harvested was indicated by the drying of the tendril, located at the insertion of the fruit peduncle into the stem and the colour of the side of the fruit which is in contact with the ground that changed from white to cream, in association with the hollow sound produced by tapping with a firm finger.

3.4.2 Leaf number

Leaf number was determined by counting the number of leaves of five plants randomly selected per treatment/replication. Leaf number was determined six weeks after emergence.

3.4.3 Vine length

Primary vine length was determined using a 50 m-tape measure six weeks after emergence from five randomly selected plants/treatment/replication.

3.4.4 Leaf water content and dry matter determination

The moisture and dry matter content of watermelon plant was determined at harvest by destructive harvesting of the five plants chosen at random per replication per treatment. The stems and leaves of five plants per replication per treatment were separated and put in paper bags already weighed. The fresh samples were weighed using Mettler PM 400 digital balance. The fresh weights were determined by subtracting the weight of paper bag from weight of paper bag plus the sample. Then the fresh plant samples (stems and leaves) were oven dried at 66° C to constant weight. The stems and leaves water contents was then determined by subtracting dry weight from their corresponding fresh weights, respectively. The dry matter (DM) content was expressed as percentage by dividing the dry weight with the fresh weight and the answer multiplied by 100.

Sample weight * 100 = % dry weight

Sample fresh weight

3.4.5 Branch number

Branch number was determined on five randomly selected watermelon plants/treatment/replication. The number of branches were counted at six weeks after emergence.

3.4.6 Number of female flowers

In each treatment and replication, five plants were randomly selected and the number of female flowers were counted at seven weeks after emergence.

3.4.7 Fruit number

Fruit number was determined on five watermelon plants randomly selected at the centre of the plots. Fruit number was determined by counting all the fruits on each plant at harvest (85 days after planting).

3.4.8 Fruit length and diameter

The fruit length and diameter per treatment per replication was determined on 10 randomly selected fruit at harvest (85 days after planting) representative of the treatment. The fruit length and diameter were determined by arranging the watermelon fruits end- to- end and side- to- side, respectively, and measuring total length and diameter using a 50 m-tape measure.

3.4.9 Fruit rind thickness

The rind thickness was determined on 10 randomly selected fruit representative of the treatment at harvest. Each fruit was sectioned equatorially and the rind thickness measured using electronic veneer calipers.

3.4.10 Titratable acidity

Fruit titratable acidity was determined by taking 10 randomly selected fruit/ treatment/ replication. The fruit pulp was cut and mixed to form a composite sample. Then 100 g of the composite sample was weighed and 100 ml of distilled water added to the sample. The sample was homogenized and filtered with five layers of cheese cloth. Then 20 ml of the filtrate was pipetted into a 50 ml conical flask and two drops of phenolphthalein indicator added. The sample was then titrated with 0.1 N NaOH to end point, and this was done in triplicates. The results were expressed as total titratable acidity equivalents.

$$\text{Total titratable acidity g/100 ml juice} = \frac{\text{ml base} \times \text{normality of base} \times 1 \times 100 \times 1}{\text{ml sample}}$$

3.4.11 Soluble solids content

Ten randomly selected fruit /treatment /replication was used. The fruits were cut into sections at stem end, centre and blossom end. The fruit sections were blended separately. A drop of juice from these blended fruits sections was put on the hand refractometer (0-32%).

3.4.12 Fruit mineral analysis

Ten randomly selected fruit per treatment per replication was cut (epidermis and mesocarp) and mixed to form a composite sample. A composite sample of 1 kg was weighed and oven dried at

66°C to constant weight (72 hours). The dried samples were ground using a sieve of size two and 1.25 g composite sample digested in 20 ml sulphuric acid (98%) and 4 ml hydrogen peroxide (30%) in a BD block at 330°C for 7 hrs.

Nitrogen (N) was determined through distillation and titration using the micro kjeldahl method (AOAC, 1996). Phosphorus (P) was determined calorimetrically using sodium phenol and ammonium molybdate plus ascorbic acid method (AOAC, 1996). The absorbance was read on the UV Visible Spectrophotometer (UV-160 IPC Shimadzu). Potassium (K) and sodium (Na) were determined by atomic absorption spectrophotometry (Varian SpectrAA 300). Data was expressed as percentage or mg/g on dry weight basis.

3.4.13 Fruit vitamin C content

Vitamin C content was determined using 2, 6-dichloroindophenol titrimetric method according to AOAC (1996). Ascorbic acid reduces oxidation-reduction indicator dye (2, 6-dichloroindophenol) to colourless solution. At end point, excess unreduced dye is rose pink in acid solution. Vitamin C was extracted and titration performed in the presence of metaphosphoric acid-acetic acid solution to maintain proper acidity for reaction and to avoid antioxidation of ascorbic acid at high pH (AOAC, 1996).

3.4.14 Lycopene content

Fruit lycopene content was determined according to the method of Davis *et al.* (2003). A composite sample of 2 g watermelon flesh was homogenized to a puree. Twenty five ml of hexane was then added to the watermelon puree and then placed on an orbital shaker to mix at 180 rpm for 15 minutes. The orbited watermelon puree containing hexane was left for 5 minutes to allow for phase separation. The absorbance of hexane (upper) layer was measured at 503 nm using a UV visible spectrophotometer (UV-160 IPC, Shimadzu). The lycopene content of tissu was calculated using the formula below:

Lycopene (mg / kg tissue) = (A 503 × 31.2) /Fruit weight

3.5 Data analysis

Due to the similarity of the data in the two trials, data was pooled during analysis (Cochran an Cox, 1992). The data collected was subjected to analysis of variance using the general linea model (Proc GLM) procedures of statistical analysis system (SAS) program package Appropriate regression models were used to examine the response of watermelon to increasing N and P application. Multiple comparisons among means was done using Protected Leas Significant Difference (LSD) at $p = 0.05$. Proc univariate procedure was carried out on residual to support assumptions of normality made.

CHAPTER 4

4.0 RESULTS

4.1 Soil data

The soil physico-chemical properties in Notwane farm, Sebele at the start of the study are shown in Table 1. From the results, the soil pH was moderately acidic with low nitrogen, phosphorus, organic carbon (OC) and cation exchange capacity (CEC). Application of the fertilizers limestone ammonium nitrate (LAN) and single super phosphate (SSP) had no significant influence on the soil pH, OC and CEC (Table 2, 3, 4). However, LAN application significantly ($P \leq 0.0001$) increased total soil N at the end of the experiment (Table 2, 3). Increasing LAN application significantly ($P \leq 0.0001$) increased total soil N (Table 3). Application of SSP fertilizer had no significant effect on total soil P at the end of the experiment compared to the start of the experiment (Table 1, 4). However, the experimental plots applied with SSP had significantly ($P \leq 0.0001$) higher total soil P compared to plots where SSP was not applied (Table 4).

Table 1: the physico-chemical properties of soil before the start of the study

pH	mg N/kg	mg P/kg	OC (%)	CEC(Cmol/kg)
5.53	1.02	2.67	0.061	1.96

Table 2: Summarized ANOVA table for dependent variables soil pH, soil nitrogen, soil phosphorus, organic carbon (OC) as well as the cation exchange capacity (CEC).

Dependent variable	Effects	F-value	P-value
Soil pH	N	2.27	0.0722
	P	0.99	0.4058
	N*P	0.61	0.8249
Soil nitrogen	N	1874.07	0.0001
	P	5.09	0.033
	N*P	1.18	0.3196
Soil phosphorus	N	7.58	0.0001
	P	20.06	0.0001
	N*P	0.84	0.6063
Soil organic carbon (OC %)	N	1.73	0.1553
	P	1.95	0.1305
	N*P	1.34	0.2222
Cation exchange capacity	N	28.97	0.0001
	P	3.20	0.0297
	N*P	1.90	0.0522

Table 3: Effect of nitrogen fertilizer limestone ammonium nitrate (LAN) on soil physico-chemical properties

kg N/ha	pH	mg N/kg	mg P/ kg	OC (%)	CEC(Cmol/kg)
0	5.19a	1.17e	2.30a	0.09ab	2.22c
50	5.43a	2.22d	2.21a	0.068b	2.52b
100	5.44a	7.47c	2.38a	0.064b	2.51b
150	5.52a	12.13b	2.08a	0.07ab	2.85a
200	5.20ab	17.74a	2.16a	0.12ab	2.25c
Significance	NS	****	NS	NS	NS
LSD	0.23	0.91	0.42	0.05	0.133

****, NS Significant at 0.0001 and non-significant, respectively. Means separated using the Least Significant Difference (LSD) at P = 0.05; means within column(s) followed by the same letter(s) are not significantly different.

Table 4: Effect of phosphorus fertilizer single super phosphate on the physico-chemical properties of soil

Kg P /ha	pH	mg N/kg	mg P/kg	OC (%)	CEC (Cmol/kg)
0	5.30a	7.87b	1.75b	0.06b	2.40b
25	5.40a	7.88b	2.13a	0.08ab	2.48ab
50	5.47a	8.50a	2.36a	0.11a	2.54a
75	5.40a	8.34a	2.39a	0.07ab	2.38b
Significance	NS	**	****	NS	*
LSD	0.20	0.52	0.37	0.04	0.12

*, **, **** and NS. Significant at 0.05, 0.01, 0.0001, and non-significant respectively. Means separated using the Least Significant Difference (LSD) at $P = 0.05$; means with the same letter are not significantly different from each other.

4.2 Vegetative growth

Nitrogen and phosphorus application significantly ($P < 0.05$) increased vegetative growth of watermelon plants compared to control plants (Table 5, 6, 7). However, the interaction of N and P had no significant ($P < 0.05$) effect on vegetative growth of watermelon plants (Table 5, 6, 7). Application of 50, 100 and 150 kg N/ha to watermelon plants significantly ($P< 0.0001$) increased number of vine /plant and length of vine compared to control plants (Table 5, 6). However, application of N above 150 kg/ha decreased number of vine /plant and length of vine (Table 6). Nitrogen fertilizer application significantly ($P < 0.01$) increased number of leaves of watermelon plants compared to plants where no N was applied (Table 5, 6). Nitrogen application at 50, 100, 150 and 150 kg/ha significantly ($P < 0.01$) increased number of leaves /plant than control plants (Table 6). There was no significant ($P > 0.01$) difference in number of leaves in watermelon plants applied with 50, 100, 150 and 200 kg N/ha (Table 6). However, plants applied with 150 kg N/ha had the highest number of leaves/plant (Table 6). Nitrogen application had no significant (P>0.005) effect on watermelon leaf water and dry matter contents (Table 5, 6).

Table 5: Summarized ANOVA table for dependent variables number of vines, length of vines, leaf number and leaf moisture and dry matter content

Dependent variable	Effects	F -value	P-value
Number of vines	N	12.83	0.0001
	P	6.51	0.0006
	N*P	0.56	0.8667
Length of vines	N	7.24	0.0001
	P	5.45	0.0019
	N*P	0.18	0.9988
Leaf number	N	3.58	0.0099
	P	7.16	0.0003
	N *P	0.53	0.8867
Leaf moisture content	N	0.89	0.4722
	P	4.78	0.0042
	N *P	0.46	0.9306
Leaf dry matter	N	0.91	0.4619
	P	4.75	0.0043
	N*P	0.46	0.9330

Table 6: Effect of nitrogen fertilizers on the dependent variables number of vines, length of vines, number of leaves , leaf moisture content and leaf dry matter content in watermelons

Nitrogen (kg/ha)	Number of vines per plant	Length of vines (m)	Number of leaves per plant	Leaf moisture content (%)	Leaf dry matter content (%)
0	4.90b	2.05c	24.50b	82.02a	17.97a
50	5.69a	2.23b	29.18a	82.03a	17.96a
100	5.60a	2.65ab	29.75a	82.71a	17.29a
150	5.40a	2.75a	32.05a	82.73a	17.24a
200	4.10c	2.50ab	29.02a	83.21a	16.78a
Significance	****	****	**	NS	NS
LSD	0.49	0.280	4.40	1.50	1.50

, **, NS. Significant at 0.01, 0.0001 or insignificant, respectively. Means separated using the Least Significant Difference (LSD) at P = 0.05; means with the same letter are not significantly different from each other.

Phosphorus fertilizer application at 25 and 50 kg P/ha significantly ($P \leq 0.01$) increased watermelon vine number/plant and vine length compared to control plants (Table 7). Application of 50 kg P/ha had significantly ($P \leq 0.05$) higher vine number/plant and vine length than plants applied with either 25 or 75 kg P/ha (Table 7). However, application of P above 50 kg P/ha decreased the number of vines per plant and length of vine (Table 7). Phosphorus application on watermelon crop significantly ($P < 0.0003$) increased the number of leaves per plant compared to the control plants (Table 5). Application of either 25 or 50 kg P/ha resulted in watermelon plants with higher leaf number per plant than control plants (Table 7). However, there was no significant difference in the number of leaves /plant of the plants applied with either 25 or 75 kg P/ha. Applications of 25, 50 and 75 kg P/ha significantly ($P \leq 0.0042$) reduced the leaf moisture content, but significantly ($P \leq 0.0043$) increased leaf dry matter content compared to control plants in which P fertilizer was not applied (Table 5). However, there was no significant ($P>0.005$) differences in leaf water and dry matter contents of watermelon plants applied with 25, 50 or 75 kg P/ha (Table 7).

Table 7: Effect of phosphorus fertilizer on the dependent variables number of vines, length of vines, leaf number, leaf moisture content and leaf dry matter content.

Phosphorus (kg/ha)	Number of vines	Length of vines (m)	Leaf number	Leaf moisture content (%)	Leaf dry matter content (%)
0	4.56c	2.23c	24.12c	83.70a	16.30b
25	5.08b	2.49b	29.44b	82.20b	17.79a
50	5.52a	2.77a	33.60a	81.27b	18.73a
75	4.96bc	2.48b	26.08bc	81.25b	18.75a
Significance	***	**	***	**	**
LSD	0.44	0.25	3.94	1.35	1.35

, *, significant at P = 0.01, or 0.001, respectively. Means separated using the Least Significant Difference (LSD) at P = 0.05; means followed with the same letter(s) are not significantly different from each other.

4.3.0 Reproductive growth and fruit quality

Nitrogen and phosphorus application significantly ($P \leq 0.05$) increased the yield and yield components of watermelon (Table 8). However, the interaction of N and P had no significant ($P \leq 0.05$) effect on yield and yield components of watermelon (Table 8).

4.3.1 Female flower number

The results showed that N application significantly ($P \leq 0.0001$) increased the number of female flowers/vine (Table 8, Figure 1). The response of increasing N fertilizer application in watermelon plants was quadratic with respective to number of female flowers (Figure 1). The maximum numbers of female flowers were obtained with application of 150 kg N/ha, beyond which there was a decrease (Figure 1).

Phosphorus application did not significantly (P > 0.005) increase the number of female flowers per vine of watermelon plants compared to the control (Table 8, Figure 2). However, there was a non-significant (P > 0.005) increase of female flowers as P was increased from 0 to 50 kg/ha, after which a decrease occurred (Figure 2).

Table 8: Summarized ANOVA for dependent variables female flower/vine, fruit number/plant, fruit weight, fruit length, fruit diameter, fruit length: diameter ratio and fruit yield of watermelons.

Dependent variable	Effect	F-value	P-value
Female flower number/plant	N	7.08	0.0001
	P	2.17	0.0984
	N*P	0.74	0.7109
Fruit number/plant	N	12.38	0.0001
	P	22.40	0.0001
	N*P	1.09	0.3823
Fruit weight	N	15.60	0.0001
	P	3.49	0.0197

	N*P	0.18	0.9989
Fruit length	N	17.94	0.0001
	P	14.49	0.0001
	N*P	0.49	0.4835
Fruit diameter	N	6.77	0.0001
	P	2.02	0.1186
	N*P	0.60	0.8318
Fruit length: diameter ratio	N	1.74	0.1500
	P	5.93	0.0011
	N*P	0.44	0.9421
Yield	N	27.49	0.0001
	P	18.43	0.0001
	N*P	0.7281	0.7281

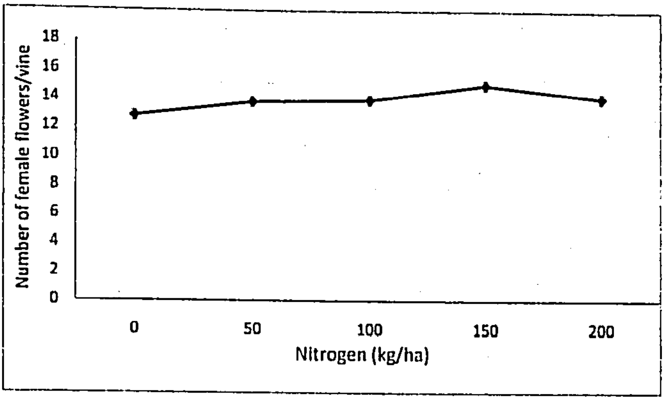

Figure1: Effect of nitrogen on the female flowers of watermelon

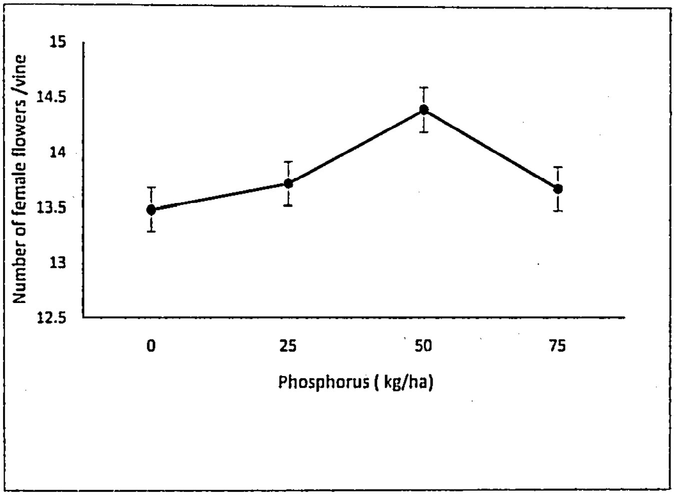

Figure 2: Effect of phosphorus on the number of female flowers of watermelon

4.3.2 Fruit number

Nitrogen and phosphorus application significantly ($P < 0.0001$) increased the fruit number per vine of watermelon plants compared to the control (Table 8). However, there was no N and P interaction on fruit number per vine of watermelon plants (Table 8). Application of 50, 100, 150 and 200 kg N/ha significantly ($P < 0.0001$) increased fruit number/vine compared to control plants (Table 8, Figure 3). The response of watermelon plants to increasing N application was quadratic with respect to number of fruits /vine (Figure 3). Maximum number of fruits/ vine of watermelon plants (6.5) was obtained with application of 150 kg N/ha, beyond which a decrease was observed (Figure 3).

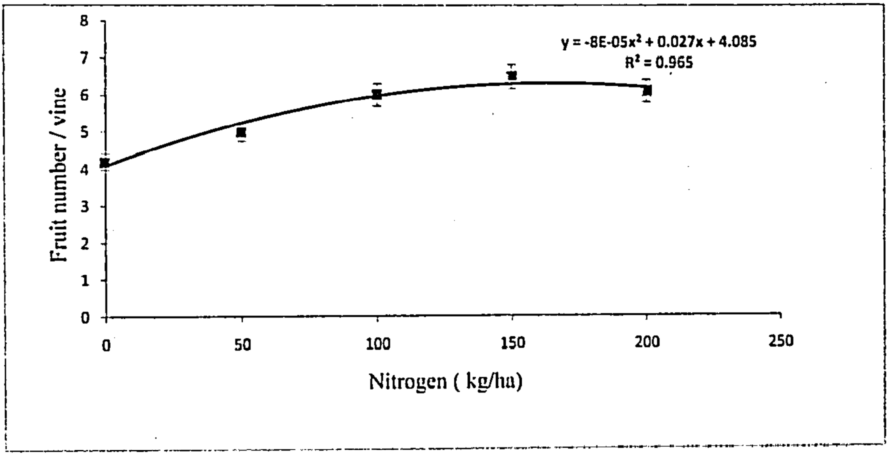

Figure 3: Effect of nitrogen on fruit number

Phosphorus application significantly ($P \leq 0.0001$) increased fruit number/vine of watermelon plants compared to the control (Table 8, Figure 4). Increasing P application from 0 to 75 kg/ha increased fruit number/vine of watermelon plants and the response was quadratic (Figure 4). Maximum fruit number/vine (5.2) was obtained with application of 50 kg P/ha, beyond which a decrease was observed (Figure 4).

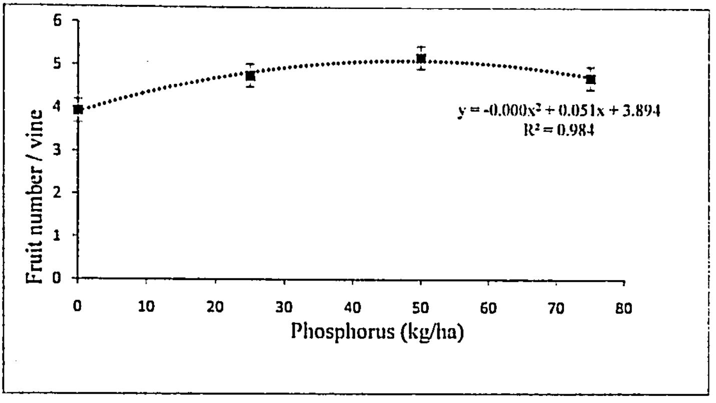

Figure 4: Effect of phosphorus on fruit number

There was a significant ($P \leq 0.05$) positive linear correlation ($r = 0.80$) between the number of female flowers/vine and number of fruit/vine (Figure 5).

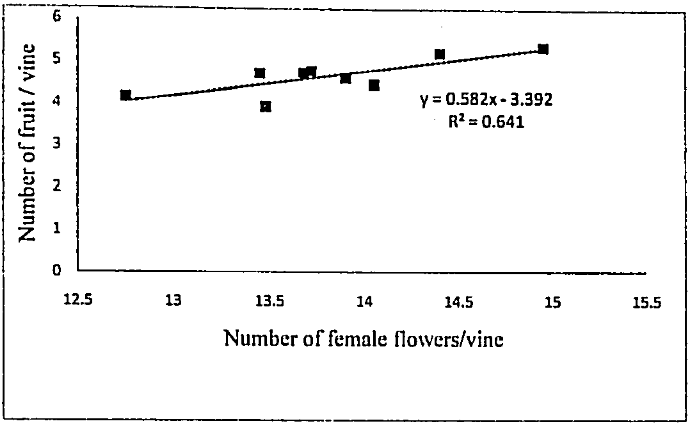

Figure 5: The correlation between the number of fruit/vine and number of female flowers/vine

4.3.3 Fruit weight

Nitrogen and P significantly ($P \leq 0.02$) increased fruit weight of watermelon plants compared to the control (Table 8). However, N and P interaction had no significant ($P > 0.05$) effect on the fruit weight (Table 8). Application of N at 50, 100, 150 and 200 kg/ha significantly ($P < 0.0001$) increased fruit weight compared to fruit from watermelon plants applied with no N (Table 8, Figure 6). The response of fruit weight to increasing N application was quadratic, with maximum fruit weight obtained at 150 kg N/ha (Figure 6).

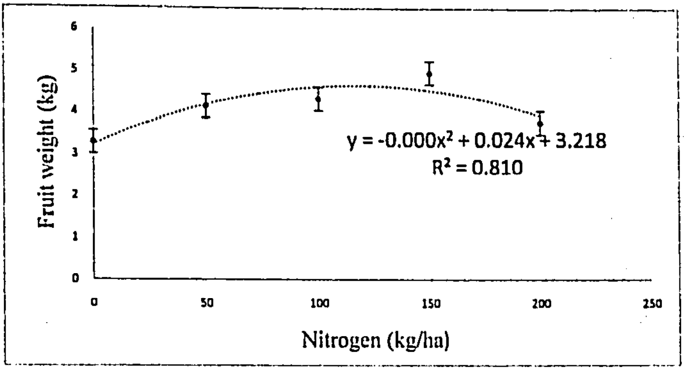

Figure 6: Effect of nitrogen on watermelon fruit weight

Phosphorus application significantly ($P \leq 0.02$) increased the fruit weight of watermelon plants compared to control plants (Table 8). Phosphorus application at 25, 50 and 75 kg/ha significantly ($P \leq 0.02$) increased fruit compared to control and the response to increasing P application was quadratic (Table 8, Figure 7). Application of P beyond 50 kg/ha decreased fruit weight (Figure7).

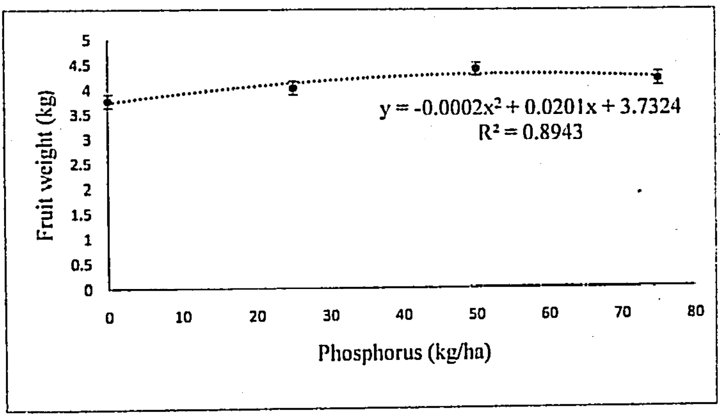

Figure 7: Effect of phosphorus on watermelon fruit weight

4.3.4 Fruit size

Nitrogen and P fertilizer application to watermelon plants significantly ($P < 0.0001$) increased fruit size (length and diameter) (Table 8). However, N and P interaction had no significant ($P > 0.05$) effect on watermelon fruit size (Table 8). Nitrogen fertilizer application at 50, 100, 150 and 200 kg/ha significantly ($P < 0.0001$) increased fruit length compared to the control (Table 8, 9). However, there was no significant ($P > 0.05$) among the N rates of 50, 100 and 200 kg/ha with respect to fruit length (Table 9). Watermelon plants applied with 150 kg N/ha, significantly ($P < 0.05$) produced elongated (longer) fruit than fruit from plants applied with either 50, 100, or 200 kg N/ha (Table 9). Application of N above 200 kg/ha resulted in reduced fruit length (Table 9). Application of N significantly ($P < 0.0001$) increased watermelon fruit diameter compared to fruit from plants where N was not applied (Table 8, 9). Similar to fruit length, watermelon plants applied with N at either 50, 100 or 200 kg/ha did not significantly ($P > 0.05$) differ in their fruit diameter (Table 9). But watermelon plants applied with 150 kg N/ha produced fruit with a greater diameter than from plants applied with either 50, 100, or 200 kg N/ha (Table 9). However, N fertilizer application had no significant ($P > 0.05$) effect on watermelon length-to-diameter (L/D) ratio (Table 9).

Table 9: Effect of nitrogen on watermelon fruit size

Nitrogen (kg/ha)	Fruit length (cm)	Fruit diameter(cm)	Fruit length: diameter ratio
0	18.69c	16.34c	1.14a
50	20.91b	17.81b	1.17a
100	20.95b	18.01b	1.16a
150	22.04a	18.88a	1.17a
200	20.15b	18.11b	1.11a
Significance	***	***	NS
LSD	0.82	0.85	0.05

, **, and NS. Significant at 0.01, 0.0001 and non-significant, respectively. Means separated using the Least Significant Difference (LSD) at P = 0.05; means with the same letter are not significantly different from each other.

Phosphorus fertilizer application at 50 and 75 kg/ha significantly ($P < 0.001$) increased the fruit length of watermelon plants compared to fruit length from plants not applied with P or applied with 25 kg P/ha (Table 10). However, there was no significant ($P > 0.05$) difference in fruit length from plants applied with either 50 or 75 kg P/ha (Table 10). While application of 25, 50 and 75 kg P/ha to watermelon plants significantly ($P \leq 0.05$) increased fruit diameter compared to fruit from plants not applied P (Table 10). However, there was no significant ($P > 0.05$) difference in fruit diameter from watermelon plants applied with either 25, 50, or 75 kg P/ha

(Table 10). The effect of P application on the fruit L/D ration followed a similar trend to that of fruit diameter (Table 10).

Table 10: Effects of phosphorus on the fruit size

Phosphorus(kg/ha)	Fruit length (cm)	Fruit diameter (cm)	Fruit L/D ratio
0	19.43b	17.03b	1.14b
25	20.06b	17.28a	1.16a
50	21.67a	17.87a	1.21a
75	21.03a	18.04a	1.17a
Significance	***	*	**
LSD	0.74	0.76	0.05

*, **, and ***, Significant at 0.05, 0.01 and 0.001, respectively. Means separated using the Least Significant Difference (LSD) at P=0.05; means with the same letter are not significantly different from each other

4.4 Fruit yield

Nitrogen and P fertilizer application significantly ($P \leq 0.0001$) increased the fruit yield of watermelon plants compared to the yield of control plants (Table 8). However, there was no significant ($P > 0.05$) effect of N and P interaction on watermelon fruit yield (Table 8). Application of N at 50, 100, 150 and 200 kg/ha significantly ($P \leq 0.0001$) increased watermelon fruit yield, and the response to increasing N application was quadratic (Figure 8). The point was deflection in N application with respect to fruit yield was 150 kg/ha, beyond which yield decreased (Figure 8).

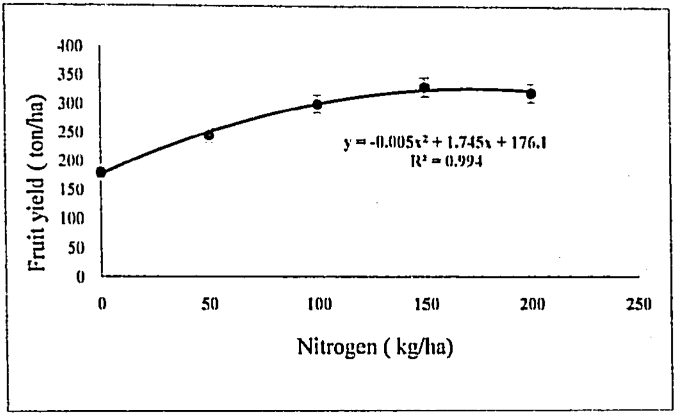

Figure 8: Effect of nitrogen on fruit yield of watermelon

Phosphorus fertilizer application significantly ($P \leq 0.0001$) increased the fruit yield of watermelon plants compared to fruit yield from control plants (Table 8, Figure 9). Applications of 25, 50 and 75 kg P/ha to watermelon plants significantly ($P \leq 0.0001$) increased fruit yield compared to fruit yield from watermelon plants not applied with P fertilizer, and the response to increasing P application was quadratic (Figure 9). Maximum watermelon fruit was obtained with application of 50 kg P/ha, beyond which a decrease occurred (Figure 9).

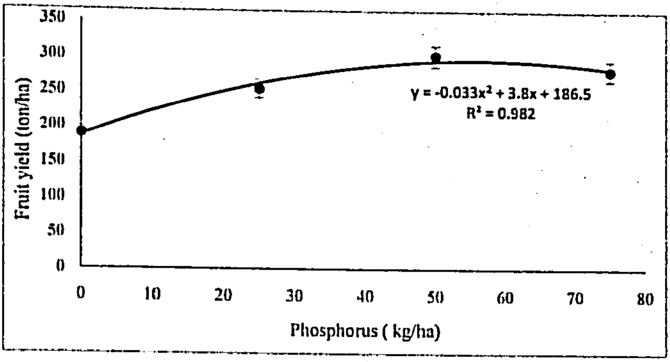

Figure 9: Effect of phosphorus on watermelon yield

4.5 Fruit sensory quality characteristics

Nitrogen significantly ($P \leq 0.0001$) influenced the fruit quality components (lycopene content, vitamin C, soluble solids content, titratable acidity and rind thickness) of watermelon (Table 11). However, P and the interaction of N and P had no significant ($P > 0.05$) effect on fruit quality components of watermelon (Table 11, 13). Application of N at 50, 100, 150 and 200 kg/ha significantly ($P \leq 0.0001$) increased fruit flesh lycopene (antioxidant) content compared to fruit from plants not applied with N (Table 12). However, there was no significant ($P > 0.05$) difference in the fruit flesh lycopene content of fruit applied either with 50, 100 or 200 kg N/ha (Table 12). The highest fruit flesh lycopene content (23.35 mg/kg) was in fruit applied with 150 kg N/ha (Table 12). Nitrogen fertilizer application at 50, 100, 150 and 200 kg/ha significantly ($P < 0.0001$) increased fruit vitamin C compared to fruit from plants not applied with N (Table 12). However, there was no significant ($P > 0.05$) difference in the fruit vitamin C content of fruit applied either with 50, 100 or 200 kg N/ha (Table 12). The highest fruit vitamin C content (15.17 mg/g) was in fruit applied with 150 kg N/ha (Table 12). Watermelon plants applied with 50, 100, 150 and 200 kg N/ha produced fruit with significantly (P < 0.0001) higher titratable acidity than fruit from control plants.

Table 11: Summarized ANOVA table for dependent variables for lycopene, vitamin c, and titratable acidity, soluble solid content at the stem, middle and blossom end as well as the rind thickness.

Dependent variable	Effects	F-value	P-value
Lycopene	N	17.80	0.0001
	P	2.82	0.0666
	N*P	0.42	0.9348
Vitamin C	N	61.61	0.0001
	P	0.29	0.8289
	N*P	0.13	0.9998
Titratable acidity	N	8.04	0.0001
	P	2.22	0.925
	N*P	0.95	0.5011
Soluble solid content(Stem)	N	1.61	0.1797
	P	1.11.	0.3501
	N*P	0.44	0.9436
Soluble solid content (middle)	N	1.03	0.3997

	P	0.25	0.8610
	N*P	0.40	0.9578
Soluble solid content (blossom)	N	1.84	0.1300
	P	0.13	0.9409
	N*P	0.28	0.9909
Rind thickness	N	7.50	0.0001
	P	1.35	0.2640
	N*P	0.51	0.9023

Table 12: Effect of nitrogen on fruit lycopene, vitamin C, soluble solids content and rind thickness.

Nitrogen kg/ha	Lycopene (mg/kg)	Vitamin C mg/g	Titratable acidity (g/100 ml juice)	Fruit soluble solids content (%)			Rind thickness (mm)
				Stem end	Middle	Blossom end	
0	11.85d	7.70c	0.12b	6.73a	8.94a	6.75a	9.12b
50	18.49bc	12.27b	0.15a	6.78a	8.25a	6.70b	12.32a
100	19.19b	13.24b	0.14a	6.74a	8.70a	6.60b	12.12a
150	23.35a	15.17a	0.14a	6.71a	8.83a	6.71a	12.80a
200	15.98c	12.96b	0.14a	6.69a	8.25a	6.61b	12.40a
Significance	****	****	****	NS	NS	NS	****
LSD	2.9	0.99	0.01	0.93	0.89	1.04	1.60

****, NS. Significant at 0.0001 or non-significant, respectively. Means separated using the Least Significant Difference (LSD) at P = 0.05; means with the same letter(s) are not significantly different.

not applied with N (Table 11, 12). However, there was no significant ($P > 0.05$) difference in titratable acidity of fruit from plants applied with either 50, 100, 150, or 200 kg N/ha (Table 12.)

Nitrogen fertilizer application had no significant (P > 0.05) effect on the fruit soluble solids content (SSC) of watermelons (Table 11, 12). However, the fruit SSC significantly (P < 0.05) differed within the fruit (Table 12). The SSC from the middle section (portion) of the fruit was significantly (P < 0.05) higher than SSC from either the stem end or blossom end of the fruit (Table 12). The fruit SSC from the stem end or blossom end of the fruit did not differ (Table 12). Nitrogen application significantly (P < 0.0001) increased the watermelon fruit rind thickness compared to fruit from control plants (Table 11, 12). However, there was no significant (P > 0.05) difference in fruit rind thickness among the N rates (Table 12).

Table 13: Effect of phosphorus on fruit lycopene content, titratable acidity, soluble solids content and rind thickness.

Phosphorus kg/ha	Lycopene (mg/kg)	Vitamin C (mg/g)	Titratable acidity (g/100 ml juice)	Fruit soluble solids content (%)			Rind thickness (mm)
				Stem end	Middle	Blossom end	
0	17.65a	12.01a	0.12a	5.82a	8.40a	6.09a	10.98a
25	17.73a	12.39a	0.13a	6.37a	8.66a	6.38a	11.63a
50	18.82a	12.34a	0.13a	6.47a	8.74a	6.24a	12.01a
75	18.88a	12.33a	0.12a	5.98a	8.58a	6.18a	10.73a
Significance	NS	NS	NS	NS	NS	NS	NS
LSD	2.66	0.89	0.01	0.83	0.80	0.93	1.42

NS, non-significant at P ≤ 0.05. Means separated using the Least Significant Difference (LSD) at P=0.05; means with the same letter (s) are not significantly different.

4.6 Fruit mineral content

The interaction of N and P fertilizer application had no significant ($P > 0.05$) effect on the fruit mineral content (Table 14). Nitrogen fertilizer application significantly ($P < 0.0001$) increased the fruit N content compared to fruit from plants not applied with N (Table 14, 15). Application of N at 50, 100, 150 and 200 kg/ha increased the fruit N content (Table 15). The highest fruit N content (3.34%) was in fruit applied with 200 kg/ha (Table 15). Increasing N application from 50 to 200 kg/ha significantly ($P \leq 0.0001$) increased N accumulation into the fruit and response was linear (Table 15). However, N application had no significant ($P > 0.05$) effect on the partitioning of P, K and Na into the fruit (Table 14, 15).

Table 14: Summarized ANOVA table of dependent variables of fruit N, P, K and Na content of watermelon

Dependent variable	Effects	F-value	P-value
Fruit N	N	225.20	0.0001
	P	2.0	0.1212
	N*P	0.27	0.9927
Fruit P	N	1.13	0.3471
	P	83.94	0.0001
	N*P	0.99	0.4659
Fruit K	N	4.36	0.231

	P	3.36	0.230
	N*P	1.17	0.3228
Fruit Na	N	0.98	0.4230
	P	0.28	0.8363
	N*P	0.09	1.0000

Table 15: Effect of nitrogen on fruit N, P, K and Na content

kg N/ha	N (%)	P (%)	K (%)	Na (mg/g)
0	1.02e	0.32a	2.35a	1.15a
50	2.07d	0.34a	2.34a	1.29a
100	2.60c	0.32a	2.23a	1.34a
150	2.93b	0.31a	2.44a	1.14a
200	3.34a	0.29a	2.19a	1.10a
Significance	****	NS	NS	NS
LSD	0.17	0.17	0.26	0.30

****, NS significant at P = 0.0001 or non-significant. Means separated using the Least Significant Difference (LSD). Means within the column(s) followed by the same letter (s) are not significantly different at P = 0.05

Phosphorus fertilizer application had no significant (P > 0.05) effect on fruit mineral partitioning of N, K and Na, but significantly (P ≤ 0.0001) increased the fruit P content (Table 14, 16), Application of P at 25, 50 and 75 kg/ha, significantly (P < 0.0001) increased fruit P accumulation compared to fruit from control plants (Table 16). Application of P beyond 50 kg/ha resulted in a significant (P < 0.05) decrease in fruit P content (Table 16).

Table 16: Effect of phosphorus on fruit N, P, K and Na content

kg P/ha	N (%)	P (%)	K (%)	Na (mg/g)
0	2.28a	0.11d	2.20a	1.13a
25	2.41a	0.33c	2.32a	1.22a
50	2.43	0.44a	2.34a	1.23a
75	2.45	0.39b	2.35a	1.24a
Significance	NS	****	NS	NS
LSD	0.17	0.05	0.12	0.26

****, NS significant at P=0.0001 or insignificant. Means separated using the Least Significant Difference (LSD). Means within the columns followed by the same letter (s) are not significantly different at P=0.05

CHAPTER 5

5.0 DISCUSSION

5.1 Soil analysis

The soil analysis data at the start of the experiment showed that the soil pH was moderately acidic with low N, P, organic carbon (OC) and cation exchange capacity (CEC). Application of the fertilizers limestone ammonium nitrate (LAN) and single super phosphate (SSP) had no significant influence on the soil pH, OC and CEC. However, LAN application significantly ($P \leq 0.0001$) increased total soil N at the end of the experiment; this was attributed to the 28% N in the fertilizer LAN. Application of SSP fertilizer had no significant effect on total soil P at the end of the experiment compared to the start of the experiment. Emongor *et al.* (2004) and Emongor *et al.* (2012) reported that Sebele soils are deficient in P and N, but low in CEC and organic carbon. Ademba (2008) and Zhu *et a*l. (2015) reported that N fertilizers are not only enhances of the soil N when applied, but also beneficial to soil fauna which are important in the mineralization and nitrification of soil N.

5.2 Effects of N and P on vegetative growth

Nitrogen and P fertilizer application significantly increased the vegetative growth (number of vine /plant, length of vine and number of leaves) of watermelon crop compared to the control plants. Nitrogen increased vegetative growth of water because of the role of N in cell division, cell enlargement as well as photosynthesis. Nitrogen is also a major component of chlorophyll, amino acids; energy transfer compounds such as ATP, vitamins as well as other components needed for cell growth, development as well as yield (Mengel and Kirkby, 2001; Marschner, 2005). Olaniyi (2008) reported that N application at 40, 60 and 80 kg/ha increased the vegetative growth (vine length, number of vines and number of leaves) and productivity of watermelon by increasing the photosynthetic capacity through increased amounts of stromal and thylakoid proteins. Uwah *et al.* (2010) reported that application of N to watermelon plants at 60, 120 and 180 kg/ha in Samuru, northern Nigeria, significantly increased vine length, leaf number and leaf area, leaf area index, branch number and total dry matter. The increase in vegetative growth of watermelons as N application rate was increased has also been reported by other researchers (Anyim and Ayodele, 1983; Olaniyi *et al.*, 2008; Uwah and Solomon, 1998; Olaniyi and Tella, 2011). Nitrogen is an important plant nutrient which is absorbed primarily in the form of NO_3^- and NH_4^+ ions, and an adequate supply is associated with vigorous vegetative growth and deep green colouration, but deficiency of N results in stunted growth and chlorotic leaves (Tisdale and Nelson, 1990, Mengel and Kirkby, 2001; Marschner, 2005). The positive response of the vegetative growth variables to N application was attributed to the role of N in plant growth especially as the soil native N content was low.

In the current study, application of N above 150 kg/ha reduced vegetative growth. Uwah and Solomon (1998) and Uwah *et al.* (2010) reported similar results in Nigeria when they observed that increasing N application above 120 kg/ha reduced vegetative growth (number of vines /plant, length of vines, leaf number, leaf area index and total plant dry matter). The reduction in vegetative growth above 150 kg N/ha was attributed to N toxicity or N induced deficiency of other nutrients (Marschner, 2005; Mengel and Kirby, 2001). Application of N has been shown to increase vegetative growth of fruit plants due to N induced increase in the phytohormone zeatin which is a cytokinin (Buban *et al.*, 1978; Gao *et al.*, 1992). Cytoninins have been shown to increase vegetative growth of cucurbits due their role in increasing cell division and enlargement (Wisemer, 1994; Salisbury and Ross, 1996; Emongor; 2002; Batlang *et al.*, 2006).

Phosphorus significantly increased the vegetative growth and dry matter of watermelon plants compared to control plants because of its role as a constituent of macromolecular structures and transfer of through the plant in form of ADP and ATP thereby controlling processes in plants as photosynthesis, respiration, protein and nucleic acid synthesis as well as nutrient transport through the plant cells needed for the growth and development of the crop (Marschner, 2005; Mengel and Kirby, 2001; Eberl *et al.*, 1992). Westphal *et al.* (2008) reported that P inoculation at rates of 54 kg/ha improved vegetative growth of watermelon plants. The improved vegetative growth was attributed to the role of phosphorus in the enhancement of root growth and function leading to improved nutrient and water uptake needed for watermelon plant growth and development. Uwah *et al.* (2010) reported that application of 17 and 34 kg P/ha significantly increased vegetative growth and total dry matter of watermelon plants.

Adequate supply of N and P in watermelons has been reported to lead to efficient utilization of carbohydrate to form protoplasm and more cells hence increased vegetative growth and total dry matter (Uwah *et al.*, 2010). Similar findings have been reported by Som *et al.* (1989), Rice *et al.* (1993), Majia (1997), Lamido (1994), and Uwah and Solomon (1998). In the current study, application of more than 50 kg P/ha reduced vegetative growth of watermelon plants. Chen *et al.* (2014) reported that application of excess phosphate fertilizer to watermelon plants reduced vegetative growth due to reduced leaf chlorophyll content hence reduced crop photosynthesis; and there was also reduced the stem cellulose content and plant resistance to diseases induced by excess P. Excessive soil P is reported to reduce plant growth due to reduced up take of micronutrients especially iron and zinc (Marschner, 2005; Mengel and Kirkby, 2001).

5.3.0 Effects of N and P on yield components and yield of watermelon

5.3.1 Number of female flowers

Cucurbits are crop species that require insect pollination because they have separate male and female flowers. Therefore for successful pollination in order to maximize yield, both male and female or perfect flowers must open on the same day (Wein, 2006; Rylski and Aloni, 1990). The monoecious sexual type (male and female flowers are on the same plant) is most prevalent in watermelons, but cultivars differ in ratio of male to female flowers, and in the lowest node to bear female flowers (Wein, 2006). Low female flowers negatively impacts on fruit yield of cucurbits (Wein, 2006). Nitrogen significantly increased the female flower number of watermelons compared to control plants in the current study. The increase in number of female flowers was attributed to the vigorous vegetative growth and total plant dry matter induced by N application. High application of N has been reported to delay production of pistillate flowers, but promote male flower production (Loy, 2004; Wein, 2006). Sabo *et al.* (2013) reported that application of 20 or 30 kg N/ha to watermelon plants in Gombe State of Nigeria increased the number of female flowers per vine.

McArdle (1998) reported that N application at 200 or 400 ppm (fertigation) increased earliness in female flower development and femaleness in general when applied early than late to watermelon plants. The increase in female flower development was attributed to vegetative growth, since watermelon plant dry weight was significantly influenced by N. Umaru (2014) reported that N fertilizer application significantly increased watermelon flower numbers in Bauchi State of Nigeria. However, watermelon plants applied 50 kg N/ha did not significantly ($P > 0.05$) differ in flower number production. While Swiader *et al.* (1994) reported that application of 112 kg N and 112 kg K/ha in combination significantly increased the number of female flowers of pumpkin. Rajar-Kumar and Gopola-Rao (1980), Arya *et al.* (1999) and Ezzo *et al.* (2012) reported that application of N on early growth stages of cucurbits promoted femaleness. Umamaheswarappa *et al.* (2005) further reported that application of 120 kg/ha N promoted pistillate flowers in cucumbers. A further increase in fertilizer from 150 to 200 kg N/ha was not economic as it reduced the number of female flowers which when pollinated can set and develop into fruits.

Phosphorus application did not significantly ($P > 0.05$) increase the number of female flowers per vine of watermelon plants compared to the control in this investigation. However, there was a non-significant increase of female flowers as P was increased from 0 to 50 kg/ha, after which a decrease occurred. The P induced increase in the number of female flowers was attributed to the P induced increase in vegetative growth and dry matter accumulation. Mady (2009) reported that P and the type of P-fertilizer plus temperature during the growing season of winter squash (*Cucurbita pepo*) significantly influenced sex expression, with higher number of female flowers developing when P was applied at between 1000-1500 ppm and urea-phosphate fertilizer. Mady (2009) concluded that the increase in femaleness in winter squash due to P and type of P-fertilizer was due to cool conditions and vigorous growth leading to early flowering and increased carbohydrate accumulation in the P treated plants. Umamaheswarappa *et al.* (2005) also reported application of 50 and 100 kg P/ha to cucumber plants significantly increased the number of female and male flowers/vine compared to control plants. The increased male and female flowers per vine was attributed to the important role of P in respiration and flowering (Umamaheswarappa et al., 2005; Marschner, 2005). Similar results have also been reported by other researchers (Jassal *et al.*, 1972; Srinivas and Doijode, 1984; Arora and Satish, 1989; Forbes and White, 1986).

5.3.2 Fruit number, weight and size

Application of N and P fertilizer independently increased fruit number/vine, fruit weight and fruit size (length, diameter and length-to-diameter) ratio compared to control plants in which N and P were not applied. The increase in the fruit number, fruit weight and size due N and P was attributed to the integral roles of N and P as constituents of protein structure, nucleic acids (DNA and RNA), apoenzymes, coenzymes (adenosine triphosphate-ATP and flavin adenine dinucleotide-FAD) and prosthetic groups (chlorophyll, cytochromes and nitrogenase) (Marschner, 2005; Mengel and Kirkby, 2001). Nitrogen promotes growth and development of crops, and suboptimal supply of N (< 2% dry weight depending on crop) to crops retards growth and development (Marschner, 2005). The increase in fruit number, weight and size due to N application was also attributed to the role of N in promoting cell division and expansion, stimulation of RNA and protein synthesis, induction of enzymes and delay in protein degradation necessary for watermelon fruit growth and development via biosynthesis of fruit growth promoting phytohormones auxins, gibberellins and cytokinins (Marschner, 2005). Cytokinins increase cell division by regulating D-type cyclin gene *CYcD3*, which is important in regulating the G1/S-transition of the cell synthesis cycle (Schmülling, 2004). Cytokinins also increases the number of replication origins during S-phase and they play a role in regulating G2/M transition (Schmülling, 2004). Cytokinins have been shown to increase cell division in fruits leading to increase in fruit weight and size (Wisemer, 1994; Emongor, 1995; Salisbury and Ross, 1996; Schmülling, 2004). Nitrogen is also reported to stimulate cytokinins which are important for sink strength of the developing flowers and fruits for the import of growth substances necessary for fruit development (Lovatt and Salazar-Garcia, 2006).

The increase in fruit yield components (flower number per vine, fruit number and weight, and fruit size) due to N and P application was also attributed to independent N and P increase in vegetative growth and total dry matter. Nitrogenous compounds make up a significant part of total dry weight of plants and increase in N and P supply leads to efficient utilization of carbohydrate to form protoplasm hence increase in fruit weight and size (Lamido, 1994; Marschner, 2005). Sabo *et al.* (2013), Agba and Enga (2006) and Lawal (2000) reported that improved supply of nutrients to cucurbits leads to better utilization of carbon and subsequent synthesis of photoassimilates leading higher fruit weight, size and yield. Umaru (2014) reported that application of 75 kg N/ha in Nigeria significantly increased the fruit number/vine of watermelons. The decline in fruit number/vine, fruit weight and size after 150 kg/ha N and 50 kg P/ha was attributed to a number of factors such toxicity of N and P per se or induced deficiency of other nutrients due to high N and P (Marschner, 2005; Mengel and Kirkby, 2001). The critical deficiency content of N increases as the P content increases and vice versa (Marschner, 2005). For example, at low P content an increase in N content to 2.1-2.9% had little effect on yield, but at high P content yield continued to increase as N content rose to above 3% (Sumner and Farina, 1986).

5.4 Effects of N and P on fruit yield

Nitrogen and P fertilizer application significantly increased the fruit yield of watermelon plants compared to the yield of control plants. The increase in watermelon fruit yield due N and P fertilizer application was attributed to the independent N and P induced increase in vegetative growth, plant dry matter, number of female flowers, fruit number/vine, fruit size and fruit weight (yield components). Similar results have been reported by other researchers in watermelon (Uwah *et al.*, 2010; Umaru, 2014; Khan *et al.*, 2000). Uwah *et al.* (2010) reported that application of 120 kg N/ha and 34 kg P/ha significantly increased total dry matter and fruit yield of watermelon plants. Uwah *et al.* (2010), Van der Vossen (2004) and Som (1986) attributed the high fruit yield of watermelon induced by high N application rates to increased vegetative growth. Nitrogen and P are reported to increase vegetative growth of cucurbits (Eifediyi and Remison, 2009). More leaves translates to better chlorophyll development and higher stomatal conductance hence enhanced photosynthesis. This implies more photosynthates synthesized, therefore it is possible that more photosynthates were translocated to the sinks (fruits) leading heavier and larger watermelon fruits subsequently leading to higher fruit yield. While Umaru (2014) reported that application of 75 kg N/ha increased watermelon fruit yield/ha and marketable yield/ha. Marschner (2005) reported that N enhanced the uptake of P by plants and the influence of P on the plant in turn results in a more efficient utilization of N. Gartner (1969), Heathcote (1972), Khan *et al.* (2000) and Marschner (2005) reported that without the application of P and K fertilizers, the yield response to increasing levels of N was smaller than when adequate amounts of P and K were applied.

When the nutrient supply is optimal in crops, the leaf growth rate, thus the leaf area index (LAI) is maximized and net photosynthesis is high and there is sufficient cell expansion resulting in high yields (Chapin *et al.*, 1988; MacAdam *et al.*, 1989; Mengel and Kirkby, 2001, Marschner, 2005). Watermelon is a heavy feeder of N and therefore application of 200 kg/ha of the NPK fertilizer (20:20:20) was recommended before planting, followed by application of 40 kg N/ha at five weeks intervals up to flowering stage (Rice *et al.*, 1993; Schippers, 2000). Adequate supply of N was associated with high photosynthetic activity, vigorous vegetative growth and a dark green colour of the leaves due to high chlorophyll content leading to high yields (John *et al.*, 2004, Dauda *et al.*, 2008). While Shaoping *et al.* (2013) reported that N application of 100, 200 and 300 kg/ha had significant effects on yield and fruit quality of watermelon. Application of 100 and 200 kg N/ha increased watermelon fruit yield by 10.6 and 22.3% compared to plants applied with no N, respectively. Application of 300 kg N/ha reduced watermelon fruit yield by 8.42 (Shaoping *et al.*, 2013). Brantley and Warren (1960) showed that N rates higher than 120 kg/ha depressed the fruit yield of watermelon. While, Uwah *et al.* (2010) reported that application of 180 kg N/ha to watermelon plants decreased fruit yield. The results of Brantley and Warren (1960) and Uwah *et al.* (2010) were confirmed in the current study because application of more than 150 kg N/ha decreased watermelon fruit yield.

Phosphorus significantly increased the watermelon fruit weight and yield. This was also attributed to the effects of P on plant growth which has a positive role in stimulating healthy root growth which helps in the better utilization of water and nutrients (Mengel and Kirkby, 2001). In leaves, photosynthesis and carbon partitioning in the light-dark cycle are strongly affected by P concentration in the stroma of chloroplasts and the compartmentation between chloroplasts and cytosol (Marschner, 2005). For optimal photosynthesis P is required in the range of 2.0-2.5 mM, hence explaining the high plant dry matter and fruit yield in the current study (Robinson and Giersch, 1987; Heber *et al.*, 1989). However, the photosynthetic efficiency per unit of chlorophyll is much lower in P deficient leaves (Lauer *et al.*, 1989).

5.5 Effects of N and P on watermelon fruit quality (lycopene, vitamin C, soluble solid content and rind thickness)

Nitrogen fertilizer application significantly increased the watermelon fruit quality (lycopene content, vitamin C and rind thickness) compared to control plants. Lycopene is a carotenoid under the group of compounds known as isoprenoids. Isoprenoids are biosynthesized from acetyl-CoA via mevalonic acid and isopentenyl pyrophosphate (McGarvey and Croteau, 1995;

Luisa *et al.*, 2000). Plastid isoprenoids (gibberellins, abscisic acid, photosynthesis-related pigments such as carotenoids and the phytol moiety of chlorophylls, and the side chain of electron carriers such as plastoquinone K1, α-tocoquinone, and α-tocopherol) are derived from isopentenyl pyrophosphate (Rohmer, 1999; Lichtenthaler, 1999). The increase in watermelon fruit lycopene content was attributed to the role of N in many compounds and enzymes involved in the mevalonate and isopentenyl pyrophosphate pathway. Phosphorus application in the current study had a non-significant increase in the fruit lycopene content because P is a component of the isopentenyl pyrophosphate which is an important macromolecular in the synthesis of carotenoids. Ferrante *et al.* (2008) reported that application of N from 0 to 165 kg/ha to watermelons did not have an effect on fruit flesh lycopene content and total phenols. Kobryn and Hallmann (2005) observed that application of 140 and 210 mg N/dm of rockwool increased the lycopene content of tomato.

The watermelon fruit consists of the exocarp, mesocarp and endocarp. The endocarp is the seed-containing part that is consumed as food, and the mesocarp and exocarp make the rind. The rind is used to make pickles after removing the thin exocarp, leaving the crisp, white mesocarp (Gusmini *et al.*, 2004). Rind thickness is genetically controlled (quantitative trait with a larger contribution to its inheritance from additive than dominant genetic components (Sharma and Choudhury, 1988), but can also be influenced by cultural practices such as plant nutrition (Marschner, 2005). Nitrogen increased the watermelon rind thickness because of the role of N in fruit growth and development. Swiader *et al.* (1992) reported that N and P were important in vegetative growth of watermelons, which is fundamental to the productivity and quality of watermelons. Maluki *et al.* (2015) reported that N, P and the interaction of N and P at different rates had no significant effect on watermelon fruit rind thickness.

Nitrogen application increased the watermelon fruit vitamin C and titratable acidity contents, but it had no significant effect on fruit soluble solids content. The increase in fruit quality was attributed to the role of N and P in photosynthates biosynthesis which are converted into organic acids and starch during fruit growth and development. Subsequently during fruit ripening the starch is converted to soluble solids content. The interaction of sugars and organic acids are important in the flavor of fruits. In general, the concentration of acids decline during ripening, but the total number of acids increase (Emongor, 2015). Maluki *et al.* (2015) reported that N and P interaction increased watermelon fruit quality by increasing fruit soluble solids content, low acidity and firmness. While Aguyo *et al.* (2010) reported that increased nutrient application enhanced fruit quality of watermelons. Uwah *et al.* (2010) reported that application of 120 and 180 kg N/ha increased the watermelon fruit soluble solids content (sugars) by 80 and 108%, respectively, compared to fruits from plants where N was not applied. Similar results have been reported (Bhosale *et al.*, 1978; Umaru *et al.*, 1996; Majia, 1997; Uwah and Solomon, 1998).

5.6 Effect of N and P on fruit mineral content

Nitrogen and P fertilizer application independently increased fruit N and P contents, but had no effects on fruit K, and Na contents. Application of N and P fertilizer increased the uptake and partitioning of N and P to the watermelon fruit hence explaining the increase in fruit N and P content in fruits from plants applied with fertilizers. Inorganic and organic fertilizers are sources of essential mineral nutrients such as N and P (Mengel and Kirkby, 2001; Marchner, 2005). Nitrogen and P fertilizer application improves the uptake and partitioning of these nutrients within plants (Mengel and Kirkbery, 2001; Marschner, 2005; Emongor *et al.*, 2012).

6.0 CONCLUSION AND RECOMMENDATIONS

Based on vegetative growth, yield, yield components and quality of watermelon fruits, it was concluded that under sandy loam soils of Botswana, the optimal N and P fertilizer application rate to optimize watermelon fruit yield and quality is 150 kg N/ha and 50 kg P/ha. Application of N and P beyond 150 and 50 kg/ha, respectively, resulted in decrease in yield, yield components and fruit quality of watermelons. The author recommends the fertilizer application rates of 150 kg N/ha and 50 kg P/ha for optimum watermelon fruit yield and quality under Botswana sandy loam soils. Furthermore, for wider application of these fertilizer rates in Botswana, N and P trials be undertaken in various parts of the country under different soil types, irrigation regimes and rain-fed agriculture to confirm the current findings.

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