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The Influence of Nitrogen and Phosphorus on Vegetative Growth, Yield Components and Yield of Watermelon

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Authors' contributions

This work was carried out in collaboration between all authors. Author EVE designed the study, did the data analysis, wrote the protocol and edited of the manuscript. Author TM did the data collection, managed the experimental processes and wrote the first draft of the manuscript. Author SOT managed the literature searches. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Two field experiments were undertaken to evaluate the effects of nitrogen and phosphorus on vegetative growth, yield components and yield of watermelon. The treatments were five levels of nitrogen (0, 50, 100, 150 and 200 kg/ha) and four levels of phosphorus (0, 25, 50 and 75 kg/ha). The results showed that there were no interactions between nitrogen (N) and phosphorus (P) treatments on all the dependent variables determined. With application of 50, 100 and 150 kg N/ha watermelon plants had significantly (*P* = .05) increased vegetative growth, yield components and fruit yield of watermelon compared to plants in which N was not applied. Application of N above 150 kg/ha decreased vegetative growth, yield components and fruit yield of watermelon. Application of 25 and 50 kg P/ha to watermelon plants increased vegetative growth, yield components and fruit yield of watermelon compared to plants in which P was not applied. Application of 75 kg P/ha had no significant (*P* = .05) effect on vegetative growth, yield components and fruit yield of watermelon. The positive response of watermelon plants to N and P was attributed to the role of N and P on

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growth, development and efficient utilization of carbohydrates to form protoplasm and more cells, and the increase in dry matter. The authors concluded that in order to optimize watermelon growth, yield components and fruit yield, N and P should be applied at 150 and 50 kg/ha, respectively.

Keywords: Watermelon; fertilizers N and P; field performance; fruit yield.

1. INTRODUCTION

Watermelon (*Citrullus lanatus* (Thumb) belongs to the family of cucurbitaceae, which is among plant families that supply humanity with edible products and useful fibers. Watermelon accounts for 6.8% of the world's cultivated area devoted to vegetable production [1]. The world production of watermelon was estimated at 105, 722,000 ton [1]. To date the world's largest producer of watermelon is China producing 70,000,000 ton, 66.43% of the total world production [1]. Turkey is the second largest world producer of watermelons (4,044,184 tons, 3.84% of world production). Iran, Brazil, Egypt and USA are the next largest world producers of watermelon each country producing 3,800,000, 2,079,547, 1,874,710 and 1,770,630 tons, respectively, representing 3.60, 1.97, 1.78 and 1.68% of the world production [1]. Although the origin of watermelon is in Southern Africa, no country in the region falls among the top 10 of the world largest producers. In Africa, Egypt and Algeria are the largest watermelon producers each producing approximately 1.78 and 1.42% of the total world production and are ranked 5th and 7th in the world, respectively [1]. Botswana, which is a center of diversity, only produces 254 tons of watermelon on an area of 76.19 ha [2].

The effects of plant mineral nutrition on fruit yield and quality are important and should be taken into consideration by growers and production managers to increase profitability and enhance sustainability and worldwide competiveness. It is important to design a balanced nutrition program formulated to provide specific needs for expected yields and fruit quality. With adequate nutrition, fruit crops grow stronger, have better tolerance to pests and stresses, yield more consistently and produce good quality fruit [3]. Mineral nutrition is of great significance in fruit crop production as it affects metabolic activity (strength) of source and sinks. For optimum yields, developing fruits need to attract photosynthetic assimilates, phytohormones, mineral nutrients and water [4,5].

Botswana soils are deficient in P and low in N and organic matter [6]. The fertility of soils in the savanna are reported to be low in organic matter, N and P, but crops respond well to fertilization because of their favourable base exchange properties [7,8]. Watermelon is highly demanding in N, which is essential for plant development and boosts both plant growth and crop yield [9]. However, excess N increases vegetative growth, and reduces fruiting and fruit quality of watermelon [9,10]. Moreover, high N content in plants is reported to reduce the production of phenolic compounds (fungistatic) and lignin in leaves, lessening the resistance to pathogens [9]. Nitrogen also increases amino acids and amines concentration in the apoplast and leaf surface than sugars in conidia germination, therefore favouring the development of fungal diseases [11]. Therefore, there is need to find a balance in N application in watermelon that enhances fruit yield and quality, but does not reduce resistance to pathogens. The objective of this study was to evaluate the effects of N and P on growth, yield and yield components of watermelon.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted in the Botswana University of Agriculture and Natural Resources (BUAN), Notwane Farm in Glen Valley Gaborone, Botswana. The climate is semi-arid with average annual rainfall of 538 mm. Most rains falls in summer, which generally starts in late October and continues to March or April. During the rainy season, prolonged dry spells are common and rainfall trends are localized. The soils are deficient in P, have low levels of N and organic matter [6]. 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 [12].

2.2 Experimental Design

Two field experiments were carried out between September 2012 and May 2013. The experimental design was split-plot 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 200 kg 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 samplings were done at a depth of 0-30 cm for the determination of physico-chemical properties, and total N and P.

2.3 Cultural Practices

Watermelon variety 'crimson sweet' was used in the study as plant material. The seeds were directly planted at two seeds per hill at a spacing of 2.0 m (between rows) × 0.5 m (within rows). Seedling thinning was done two weeks after emergence leaving one seedling per stand. Fertilizer application was done by side banding. Nitrogen was applied in two splits. The first application was done two weeks after seedling emergence and the second application was done at the onset of flowering. Phosphorus was applied two weeks after emergence [11]. 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, some insecticides (cypermethrin, chloropyrifos and methomyl) were sprayed interchangeably in the late afternoons not to coincide with bee visitations. Irrigation with over-head sprinklers was done when the soil water content was just below field capacity.

2.4 Dependent Variables Determined

The dependent variables that were determined included number of leaves/plant, length of the primary vine, number of branches/plant, leaf water and dry matter contents, female flower number/plant, fruit number/plant, fruit length and diameter, rind thickness and fruit yield.

2.4.1 Fruit maturity

The fruits were harvested at 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 had changed from white to cream, in association with the hollow sound produced by tapping fruit with a firm finger.

2.4.2 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.

2.4.3 Vine length

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

2.4.4 Leaf water content and dry matter determination

The water and dry matter content of watermelon plants were determined at harvest by destructive harvesting of five plants randomly chosen per replication per treatment. The stems and leaves of five plants were separated and put in paper bags already weighed. The fresh samples were weighed using Mettler PM 400 digital balance. The fresh mass were determined by subtracting the mass of paper bag from the mass of paper bag plus the sample. Then the fresh plant samples were oven dried at $66^{o}C$ to constant mass. Water contents of the stems and leaves were then determined by subtracting dry mass from their corresponding fresh mass, respectively. The dry matter and water contents were expressed as a percentage.

2.4.5 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.

2.4.6 Number of female flowers

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

2.4.7 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.

2.4.8 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 was 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.

2.4.9 Fruit rind thickness

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

2.5 Data Analyses

Due to the similarity of the data in the two trials, data were pooled during analysis [13]. The data collected were subjected to analysis of variance using the general linear 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 treatment means were done using Protected Least Significant Difference (LSD) at P = .05. Proc univariate procedure was carried out on residuals to support the assumptions of normality made.

3. RESULTS

3.1 Soil

The soil physico-chemical properties at the start of the study are shown in Table 1. From the results, the soil pH was moderately acidic with low N, P, organic carbon (OC) and cation exchange capacity (CEC). Application of the fertilizers LAN (limestone ammonium nitrate) and SSP (single super phosphate) had no significant influence on the soil pH, OC and CEC (Tables 2, 3). However, LAN application significantly (P < .0001) increased total soil N at the end of the experiment (Tables 2, 3). Increasing LAN application significantly (P < .0001) increased total soil N (Table 2). 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 (Tables 1, 3). However, the experimental plots applied with SSP had significantly (P < .0001) higher total soil P compared to plots where SSP was not applied (Table 3).

3.2 Vegetative Growth

Nitrogen and P application significantly (P = .05) increased vegetative growth of watermelon plants compared to control plants (Tables 4, 5). However, the interaction of N and P had no significant (P = .05) effect on vegetative growth of watermelon plants. Application of 50, 100 and 150 kg N/ha to watermelon plants significantly (P < .0001) increased vine number/plant and vine length compared to control plants (Table 4). However, application of N above 150 kg/ha decreased vine number/plant and vine length (Table 4). Nitrogen fertilizer application significantly (P = .05) increased leaf number of watermelon plants compared to plants where no N was applied (Table 4). Nitrogen application at 50, 100, 150 and 150 kg/ha significantly (P = .05) increased leaf number/plant than control plants (Table 4). There was no significant (P = .05) difference in leaf number in watermelon plants applied with 50, 100, 150 and 200 kg N/ha (Table 4). Nitrogen application had no significant (P = .05) effect on watermelon leaf water and dry matter contents (Table 4).

Phosphorus fertilizer application at 25 and 50 kg P/ha significantly (P = 0.05) increased watermelon vine number/plant and vine length compared to control plants (Table 5). Application of 50 kg P/ha to watermelon plants resulted in significantly (P = .05) higher vine number/plant and vine length than plants applied with either 25 or 75 kg P/ha (Table 5). However, application of P above 50 kg P/ha decreased the number of vines per plant and vine length (Table 5). Phosphorus application on watermelon crop significantly (P < .001) increased the leaf number/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/plant than control plants (Table 5).

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. Effect of nitrogen fertilizer LAN on soil physico-chemical properties

kg N/ha	pH	mg N/kg	mg P/ kg	OC (%)	CEC (cmol/kg)
0	5.19b	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	5.20b	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 P < .0001 and non-significant, respectively. Means separated using the Least Significant Difference (LSD) at P = .05; means within column(s) followed by the same letter(s) are not significantly different*

Table 3. Effect of phosphorus fertilizer SSP on the soil physico-chemical properties

kg /ha P	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 P = .05, .01, < .0001, and non-significant respectively. Means separated using the Least Significant Difference (LSD) at P = .05; means with the same letter are not significantly different from each other*

Table 4. Effect of nitrogen on number of vines, length of vines, leaf number, leaf moisture content and leaf dry matter content

Nitrogen (kg/ha)	Number of vines per plant	Length of vines (m)	Leaf number 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 P = .01, < .0001 or insignificant, respectively. Means separated using the Least Significant Difference (LSD) at P = .05; means with the same letter are not significantly different from each other*

Table 5. Effect of phosphorus on 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 < .001, respectively. Means separated using the Least Significant Difference (LSD) at P = .05; means followed with the same letter(s) are not significantly different from each other*

However, there was no significant difference in leaf number/plant of plants applied with either 25 or 75 kg P/ha. Applications of 25, 50 and 75 kg P/ha significantly (P = .05) reduced the leaf moisture content, but significantly (P = .01) increased leaf dry matter content compared to control plants in which P fertilizer was not applied (Table 5). However, there was no significant differences in leaf water and dry matter contents of watermelon plants applied with 25, 50 or 75 kg P/ha (Table 5).

3.3 Reproductive Growth

Nitrogen and P fertilizer application significantly (P = .05) increased the yield and yield components of watermelon. However, the interaction of N and P had no significant (P = .05) effect on yield and yield components of watermelon.

3.3.1 Female flower number

The results showed that N application significantly (P < .0001) increased the number of female flowers/vine (Fig. 1). The response of increasing N fertilizer application by watermelon plants was quadratic with respect to number of female flowers (Fig. 1). The maximum number of female flowers was obtained with application of 150 kg N/ha, beyond which there was a decrease (Fig. 1). Phosphorus application did not significantly (P = .05) increase the number of female flowers/vine of watermelon plants compared to the control (Fig. 2). 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 (Fig. 2).

3.3.2 Fruit number

Watermelon plants applied with N and P fertilizer had significantly (P < .0001) higher fruit number/vine than plants without N and P fertilizer application. However, there was no N and P interaction on fruit number/vine of watermelon plants. Application of 50, 100, 150 and 200 kg N/ha significantly (P < .0001) increased fruit number/vine compared to control plants (Fig. 3). The response of watermelon plants to increasing N application was quadratic with respect to fruit number/vine (Fig. 3). Maximum fruit number/vine of watermelon plants was obtained with application of 150 kg N/ha, beyond which a decrease was observed (Fig. 3).

Phosphorus fertilizer application significantly (P < .0001) increased fruit number/vine of watermelon plants compared to the control plants (Fig. 4). Increasing P application from 0 to 75 kg/ha increased fruit number/vine of watermelon plants and the response was quadratic (Fig. 4). Maximum fruit number/vine was obtained with application of 50 kg P/ha, beyond which a decrease was observed (Fig. 4). There was a significant (P = .05) positive linear correlation (r = 0.80) between the number of female flowers/vine and number of fruit/vine (Fig. 5).

3.3.3 Fruit mass

Nitrogen and P significantly (P = .05) increased fruit mass of watermelon plants compared to the control. However, N and P interaction had no significant (P = .05) effect on the fruit mass. Application of N at 50, 100, 150 and 200 kg/ha significantly (P < .0001) increased fruit mass compared to fruit from watermelon plants applied with no N (Fig. 6). The response of fruit mass to increasing N application was quadratic, with maximum fruit mass obtained with application of 150 kg N/ha (Fig. 6).

Phosphorus application significantly (P = .05) increased the fruit mass of watermelon plants compared to control plants (Fig. 7). Phosphorus application at 25, 50 and 75 kg/ha significantly (P = .05) increased fruit mass compared to control and the response to increasing P application was quadratic (Fig. 7). Maximum fruit mass was obtained with application of 50 kg P/ha (Fig. 7).

3.3.4 Fruit size

Nitrogen and P fertilizer application to watermelon plants significantly (P < .0001) increased fruit size (length and diameter) (Table 6). However, N and P interaction had no significant (P = .05) effect on watermelon fruit size (Table 6). Watermelon plants applied with N at 50, 100, 150 and 200 kg/ha significantly (P < .0001) produced longer fruit than fruit from control plants (Table 6). There were no significant (P = .05) differences among the N rates of 50, 100 and 200 kg/ha with respect to fruit length (Table 6). Watermelon plants applied with 150 kg N/ha significantly (P = .05) produced more elongated fruit than fruit from watermelon plants applied with 50, 100, or 200 kg N/ha (Table 6). Application of N above 200 kg/ha resulted in reduced fruit length (Table 6). Application of N significantly (P < .0001) increased watermelon fruit diameter compared to fruit from plants where N was not applied (Table 6). Similar to fruit length, watermelon plants applied with N at 50, 100 or 200 kg/ha did not significantly (P = .05) differ in their fruit diameter (Table 6). But watermelon plants applied with 150 kg N/ha produced fruit with a higher diameter than from plants applied with 50, 100, or 200 kg N/ha (Table 6). Nitrogen fertilizer application had no significant (P = .05) effect on watermelon length-to-diameter (L/D) ratio (Table 6).

Phosphorus fertilizer application at 50 and 75 kg/ha significantly (P < .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 7). There was no significant (P = .05) difference in fruit length from plants applied with either 50 or 75 kg P/ha (Table 7). While application of 25, 50 and 75 kg P/ha to watermelon plants significantly (P = .05) increased fruit diameter compared to fruit from plants not applied P (Table 7). There was no significant difference in fruit diameter from watermelon plants applied with 25, 50, or 75 kg P/ha (Table 7). Application of P fertilizer at 25, 50, or 75 kg/ha to watermelon plants significantly (P = .05) produced fruit with higher fruit L/D ratio than fruit from control plants (Table 7). However, there was no significant difference in fruit L/D ratio among the P treatments of 25, 50, or 75 kg/ha (Table 7).

3.3.5 Fruit yield

Nitrogen and P fertilizer application significantly (P < .0001) increased the fruit yield of watermelon plants compared to the yield of control plants (Figs. 8, 9). However, there was no significant (P = .05) effect of N and P interaction on watermelon fruit yield. Application of N at 50, 100, 150 and 200 kg/ha significantly (P < .0001) increased watermelon fruit yield, and the response to increasing N application was quadratic (Fig. 8). The point of deflection in N application with respect to fruit yield was 150 kg/ha, beyond which yield decreased (Fig. 8).

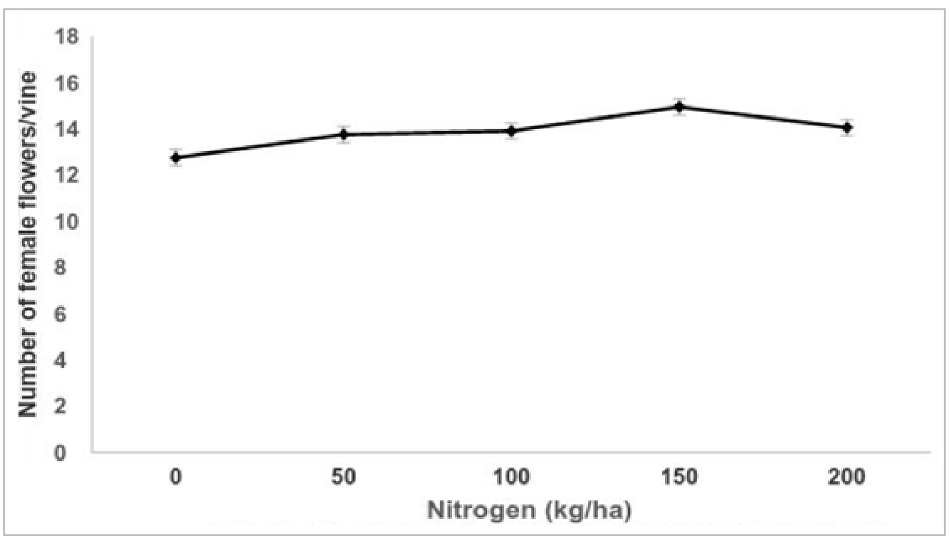

Fig. 1. Effect of nitrogen on the female flowers of watermelon

Table 6. 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 P = .01, < .0001 and non-significant, respectively. Means separated using the Least Significant Difference (LSD) at P = .05; means with the same letter are not significantly different from each other*

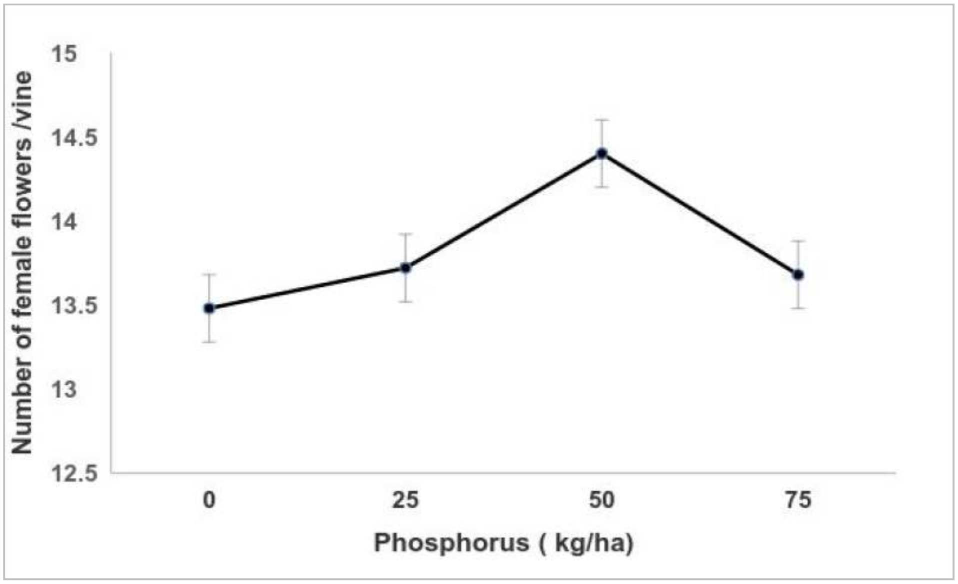

Fig. 2. Effect of phosphorus on the number of female flowers of watermelon

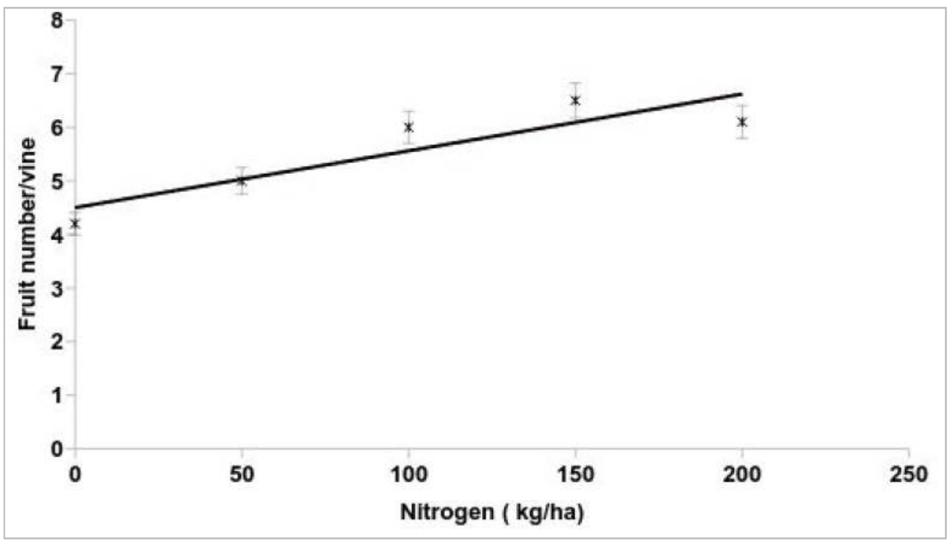

Fig. 3. Effect of nitrogen on fruit number

Table 7. 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 P = .05, .01 and < .001, respectively. Means separated using the Least Significant Difference (LSD) at P = .05; means with the same letter are not significantly different from each other*

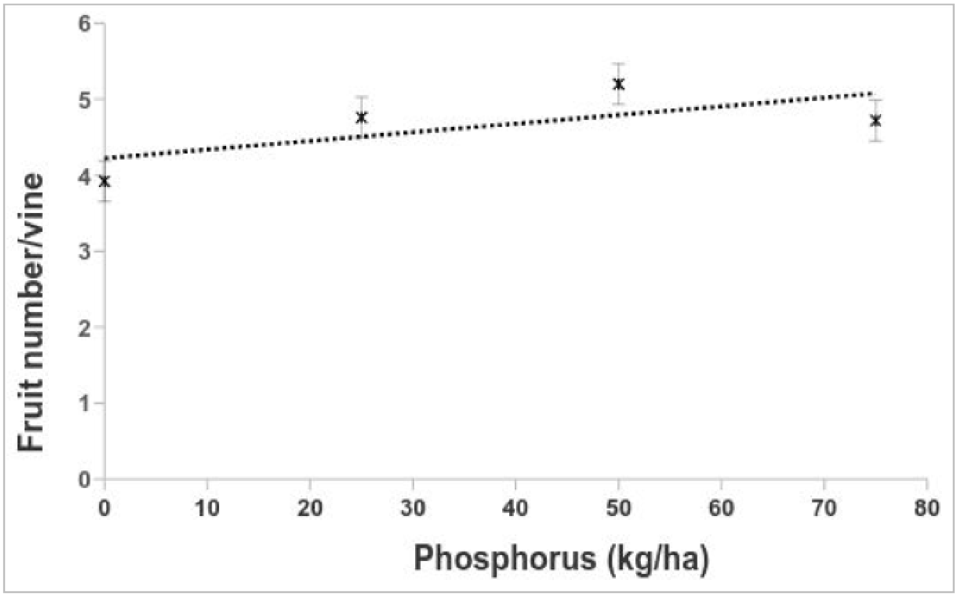

Fig. 4. Effect of phosphorus on fruit number

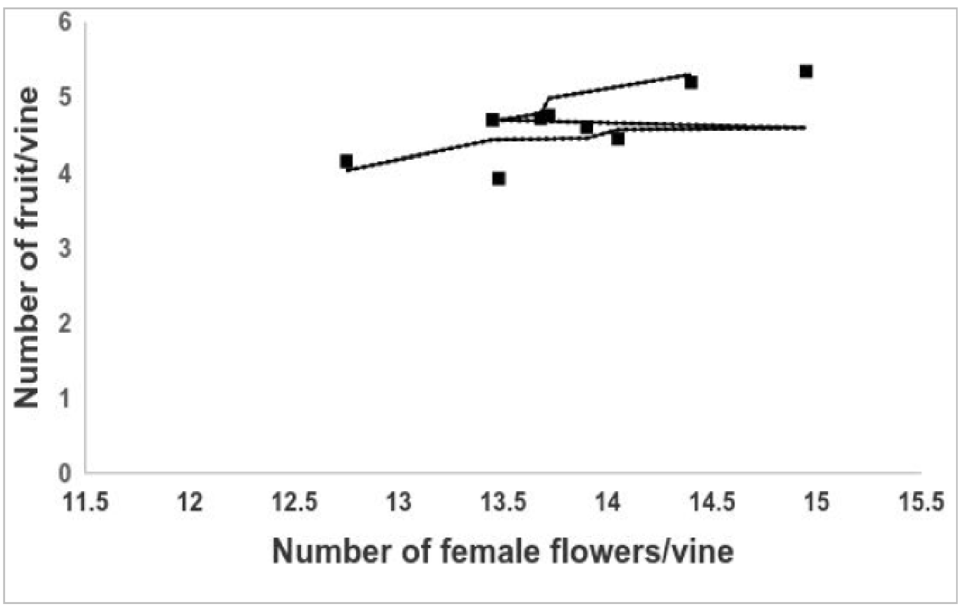

Fig. 5. The correlation between the number of fruit/vine and number of female flowers/vine

Phosphorus fertilizer application significantly ($P <$ .0001) increased the fruit yield of watermelon plants compared to fruit yield from with no added P (Fig. 9). Applications of 25, 50 and 75 kg P/ha to watermelon plants significantly ($P <$ .0001) increased fruit yield compared to fruit yield from watermelon plants not applied with P fertilizer. The response of watermelon fruit yield to increasing P application was quadratic (Fig. 9). Optimum watermelon fruit yield was produced by application of 50 kg P/ha to watermelon plants, beyond which a decrease in fruit yield occurred (Fig. 9).

4. DISCUSSION

4.1 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 LAN and SSP had no significant influence on the soil pH, OC and CEC. Application of LAN fertilizer significantly ($P < 0.0001$) increased total soil N at the end of the experiment due to N (28%) in the fertilizer. Nitrogen fertilizers do not only enhance the soil N when applied, but are also beneficial. 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 and Mabe [6] reported that Sebele soils are deficient in P and N, but low in CEC and organic carbon. Nitrogen 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 [11,14].

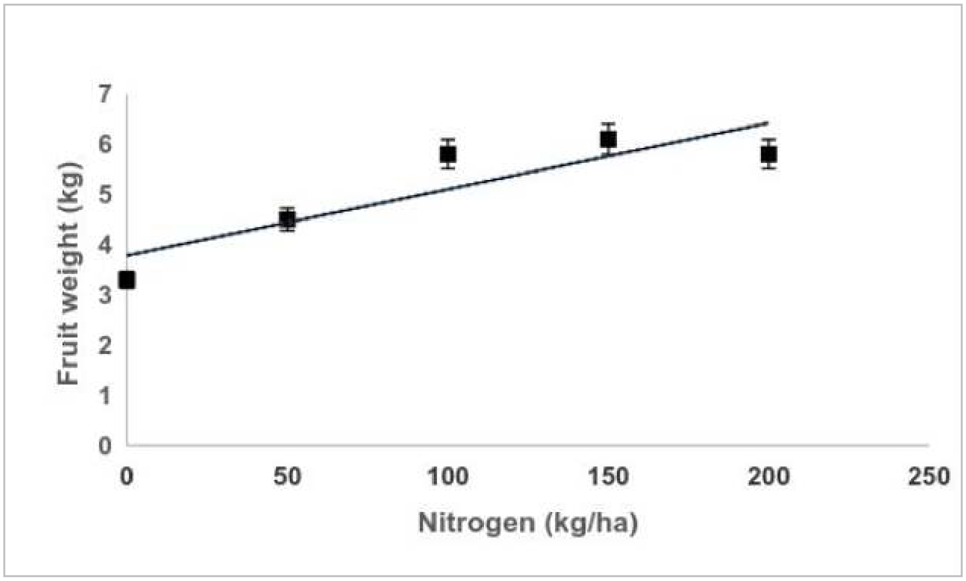

Fig. 6. Effect of nitrogen on watermelon fruit weight

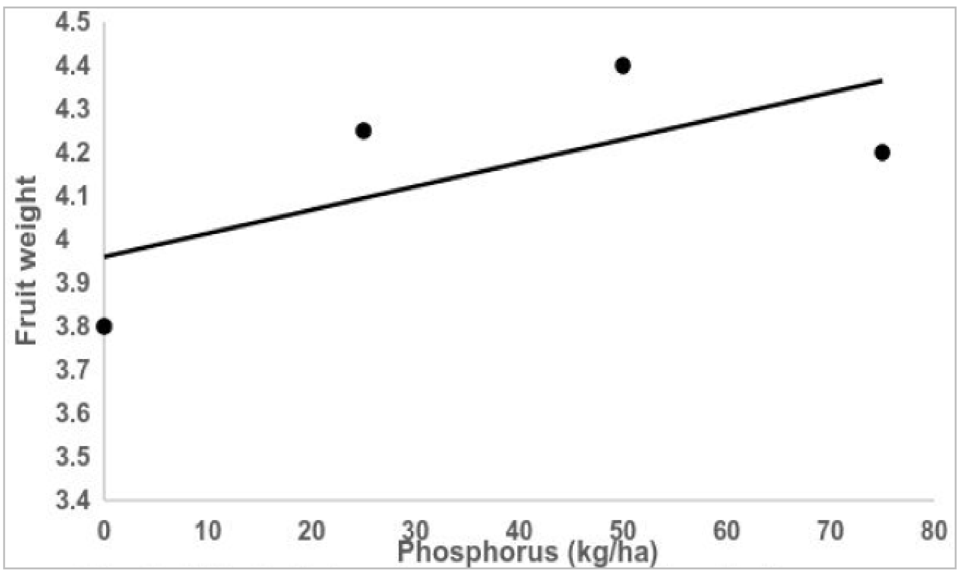

Fig. 7. Effect of phosphorus on watermelon fruit weight

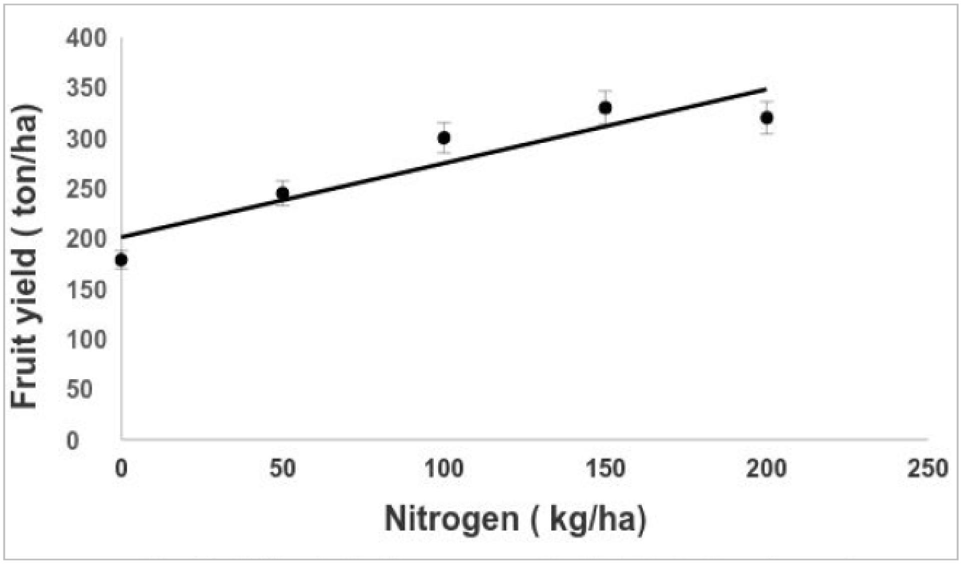

Fig. 8. Effect of nitrogen on fruit yield of watermelons

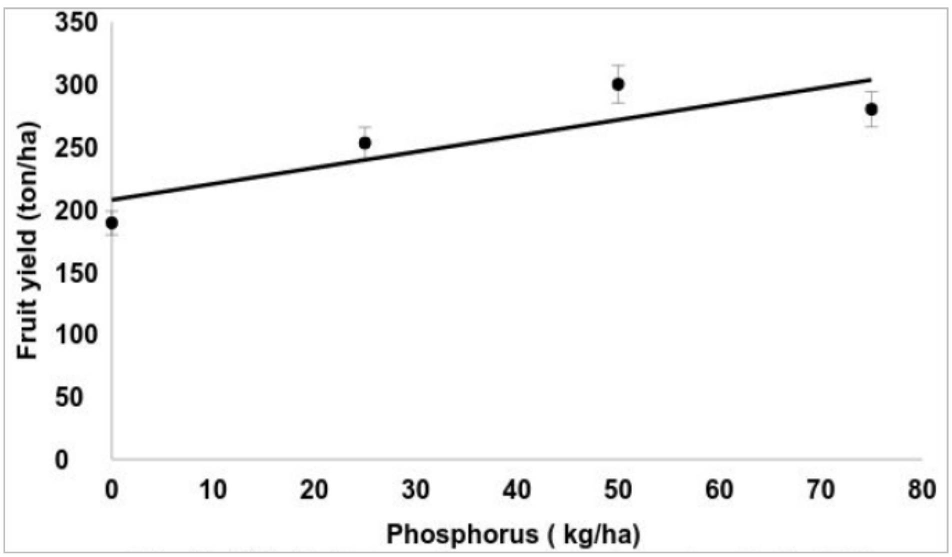

Fig. 9. Effect of phosphorus on watermelon fruit yield

4.2 Effects of N and P on Vegetative Growth

Nitrogen and P fertilizer application significantly increased the vegetative growth (vine number/plant, vine length and leaf number) of watermelon crop compared to the control plants in the current study. Nitrogen increased vegetative growth of watermelon because of the role of N in cell division, cell enlargement as well as photosynthesis. Nitrogen is 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 [11,15]. Olaniyi [16] reported that application of N at 40, 60 and 80 kg/ha increased the vegetative growth and productivity of watermelon by increasing the photosynthetic capacity through increased amounts of stromal and thylakoid proteins. Uwah et al. [8] reported that application of N to watermelon plants at 60, 120 and 180 kg/ha in Samuru, Northern Nigeria, significantly (P < 005) increased vine length, leaf number and area, leaf area index, branch number and total dry matter. The increase in vegetative growth of watermelons due to N-fertilizer application has also been reported in literature [16-18]. Application of N has been shown to increase vegetative growth in fruit plants due to N induced increase in the phytohormone zeatin which is a cytokinin [19]. Cytokinins have been shown to increase vegetative growth of cucurbits due to their role in increasing cell division and enlargement [20].

In the current study, application of N above 150 kg/ha reduced vegetative growth. Similar results have been reported in Nigeria when they observed that increasing N application above 120 kg/ha reduced vegetative growth [8,17]. The reduction in vegetative growth above 150 kg N/ha in the current study was attributed to N toxicity or N- induced deficiency of other nutrients [11,15].

Phosphorus significantly increased vegetative growth and dry matter of watermelon plants compared to control plants in the current study possibly because of its role as a constituent of macromolecular structures and transfer through the plant in the forms of ADP and ATP, thereby controlling processes in plants such as photosynthesis, respiration, protein and nucleic acid synthesis as well as nutrient transport through the plant cells needed for growth and development of the crop [11,15]. Westphal et al. [21] reported that P inoculation at rates of 54 kg/ha improved vegetative growth of watermelon plants. The improved vegetative growth due to P fertilizer application 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. [8] 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 was reported to promote efficient utilization of carbohydrates to form protoplasm and more cells hence increased vegetative growth and total dry matter in watermelon [8]. In the current study application of more than 50 kg P/ha reduced vegetative growth of watermelon plants. Chen et al. [22] 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 stem cellulose content and plant resistance to diseases induced by excess P. Excessive soil P is also further reported to reduce plant growth due to reduced up take of micronutrients such as iron and zinc [11,15].

4.3 Effects of N and P on Yield Components and Yield of Watermelon

4.3.1 Number of female flowers

Cucurbits are crop species that require insect pollination because they have separate male and female flowers. For successful pollination in order to maximize yield, both male and female or perfect flowers must open on the same day [23]. The monoecious sexual type is most prevalent in watermelons, but cultivars differ in ratio of male to female flowers, and in the lowest node to bear female flowers [23]. Low female flowers negatively impacts on fruit yield of cucurbits [23]. Nitrogen significantly increased the female flower number of watermelons compared to control plants in the current study. The increase in number of female flowers due to N-fertilizer application was attributed to the N-induced vigorous vegetative growth and total plant dry matter. High application of N has been reported to delay production of pistillate flowers, but promote female flower production [24]. Sabo et al. [25] 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 [26] reported that N application at 200 or 400 ppm increased earliness in female flower development and femaleness in general when applied early than late to watermelon plants.

4.3.2 Fruit number, mass and size

Application of N and P fertilizer independently increased fruit number/vine, fruit mass and fruit size compared to plants in which N and P was not applied. The increase in the fruit number, fruit mass and size due to N and P was attributed to the integral roles of N and P as constituents of protein structure, nucleic acids, apoenzymes, coenzymes and prosthetic groups [11,15]. Nitrogen promotes growth and development of crops, and suboptimal supply of N (< 2% dry weight depending on crop) to crops retards growth and development [11]. The increase in fruit number, weight and size due to N-fertilizer 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 [11]. 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 [27]. Cytokinins also increases the number of replication origins during S-phase and they play a role in regulating G2/M transition [27]. Cytokinins have been shown to increase cell division in fruits leading to increase in fruit weight and size [4,27,28,29]. Nitrogen is also reported to stimulate cytokinins which are important for increasing sink strength of the developing flowers and fruits for the import of growth substances necessary for fruit development [4,29,30].

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 [11]. Sabo et al. [25] reported that improved supply of nutrients to cucurbits leads to better utilization of carbon and subsequent synthesis of photoassimilates leading to higher fruit weight, size, yield and quality. Application of 75 kg N/ha in Nigeria significantly increased the fruit number/vine of watermelons [31]. 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 as toxicity of N and P per se or induced deficiency of other nutrients due to high N and P [11,15].

4.3.3 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 to 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. Similar results have been reported in literature [8,31]. Uwah et al. [8] reported that application of 120 kg N/ha and 34 kg P/ha significantly increased total dry matter and fruit yield of watermelon plants. The high fruit yield of watermelon induced by high N application rates was attributed to the N-induced increase in vegetative growth observed in the current study. The higher leaf number observed in the current study due to N and P fertilizer application translated to better chlorophyll development and higher stomatal conductance hence enhanced photosynthesis. This implied more photosynthates was synthesized and translocated to the sinks (fruits) leading to heavier and larger watermelon fruits subsequently leading to higher fruit yield. Nitrogen enhances the uptake of P in plants and the influence of P in the plant in turn results in a more efficient utilization of N [11]. When the nutrient supply is optimal in crops, 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 [11,15,32,33]. 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 5 weeks intervals up to flowering stage [34,35]. 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 [36,37]. While application of N-fertilizer at 100, 200 and 300 kg N/ha had significant effects on yield and fruit quality of watermelon [10]. Application of 100 and 200 kg N/ha increased watermelon fruit yield by 10.6 and 22.3% compared to plants where N was not applied, respectively. Application of 300 kg N/ha reduced watermelon fruit yield by 8.42% [10]. Brantley and Warren [38] showed that N rates higher than 120 kg/ha depressed the fruit yield of watermelon, while, Uwah et al. [8] reported that application of 180 kg N/ha to watermelon plants decreased fruit yield. The results of Brantley and Warren [38] and Uwah et al. [8] were confirmed in the current study because application of more than 150 kg N/ha decreased watermelon fruit yield.

Phosphorus fertilizer application significantly increased the watermelon fruit weight and yield. This was 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 [15]. 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 [11]. 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 [39]. However, the photosynthetic efficiency per unit of chlorophyll is much lower in P deficient leaves [40].

5. CONCLUSION

Based on vegetative growth, fruit yield and yield components of watermelon plants, the authors concluded that under sandy loam soils, the optimal fertilizer application rate to optimize watermelon fruit yield was 150 kg N/ha and 50 kg P/ha. For wider application of these fertilizer rates in Botswana, southern Africa, African continent and the rest of the world, further trials should be undertaken under different soils types, irrigation regimes and rain-fed agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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