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Effects of irrigation rate and leaf harvest intensity on multi-purpose pumpkin (*Cucurbita moschata* duch.) growth and quality

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Abstract

Pumpkin (*Cucurbita moschata* Duchsene) is rapidly gaining popularity in dishes in Kenya. The fruits, leaves and seeds are becoming popular due to their nutritional and medicinal properties. However, water stress and irregular leaf harvesting constrain optimal yields. The present study determined effects of irrigation rate and leaf harvest intensity in sustaining enhanced growth and quality. A split-block embedded in Randomized Complete Block Design with four replications was set up in a rain shelter that blocked rain from plots. Irrigation was applied to main plots and leaf harvest intensity to split-blocks. The treatments were 1, 2, 3 and 4 litres applied once per week through drip tubes and 0, 1, 2 and 3 leaves harvested once per fortnight per branch. One plant spaced at 2mx2m and replicated four times formed a treatment. The variables measured were: leaf and fruit growth; male and female flowers; fruit quality; seed number, weight, germination and vigour. Data were subjected to analysis of variance using JMPIN 5.1 software. Tukey's Studentized Range Test at P=0.05 was used to separate means. Leaf harvest intensity had a significant (P<0.05) decreasing effect on flower, leaf and fruit growth and quality. Irrigation rate had a significant (P<0.05) increasing effect on branches, flowers and seedling vigour. Interaction had a significant (P<0.05) increasing effect on leaves, seeds and male flowers. Irrigating with 3 L sustained the best performance and hence is recommended. Harvesting two leaves is recommended for producing many edible leaves, and one or no leaf for high quality fruits and seeds.

Keywords: Climate, Defoliation, Fruit, Vegetable, Sink, Source

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1. Introduction

Worldwide, pumpkin is used in a variety food dishes that are cherished by consumers for their nutritional and health benefits. The pumpkin species (*Cucumis moschata*) is a crop, whose leaves, flowers and fruits are eaten as vegetables, while snacks are made from roasted seeds (Ndoro et al., 2007). This consumption of many parts of the plant qualifies it to be referred to a multipurpose fruit-vegetable. Pumpkin leaves are harvested during the vegetative growth period of the plant, while harvesting of mature fruits occurs during the later growth stages (Isutsa and Mallowa, 2013; Mwaura et al., 2014). The emergence of multi-purpose pumpkin as an important vegetable in Kenya has attracted great attention due to its adaptation to a wide range of climates and high-yielding potential (Ondigi et al., 2008). In Kenya, pumpkin production increased from 316 ha in 2006 to 979 ha in 2010 (Horticulture Report, 2010). International trade of edible pumpkin leaves, fruits and seeds is very minor or non-existent, but at national level, leaves, fruits and often seeds are important products in local markets. It has been reported that pumpkin grows well in almost any part of East Africa since it is hardy and can store for over 8 months post-harvest when the fruit stalk is left intact (Grubben and Chigumira-Ngwerume, 2004). Due to these features, multi-purpose pumpkin is a suitable food security crop for resource-poor households (Horticulture Report, 2010). Currently, there is an increase in production and consumption due to medicinal properties in pumpkins (Horticulture Report, 2010). Pumpkins are rich in beta-carotene, which improves immune function (Ghanbari et al., 2007, Ondigi et al., 2008). Pumpkin contains many mineral nutrients, vitamins, oils and nutritional properties (Stevenson et al., 2007; Provesi et al., 2011; Woomer and Imbuni, 2005; Caili et al., 2006).

Pumpkin contains 80%-90% water and hence uses a lot of water during growth. Watering should be done in the morning to help reduce occurrence of fungal diseases. Sprinkling should not be done in mid-morning during bloom when bees are active for it reduces bee activity, resulting in poor fruit set and small and misshapen fruits (Marr et al., 2004). There are, however, three critical growth stages when moisture stress can be a major problem: seedling emergence, early bloom, and 10 days before harvest (Marr et al., 2004). Water shortage during flowering results in poor fruit set and misshapen fruits. When leaves wilt, blossoms drop rather than set fruits. Moisture stress 10 days before harvest can result in a rapid decline of vines and reduction in fruit size (Walker, 2011). According to Marr et al. (2004), it is best to water plants at the roots rather than sprinkling from above. Pumpkins require uniform irrigation for optimum growth and yield. The quantity of water required varies with agroecological conditions. Asoeqwue (1988) observed irrigation frequencies of 3, 6, and 9 days intervals compared to no irrigation on fluted pumpkin (*Telfairia occidentalis* Hook.) prolong productive life of the crop and enhance leaf and pod yields. Irrigation at 3 days interval had the best leaf and pod yield and the highest percentage of plant survival. Yi-jie Li *et al*. (2011), reported that muskmelon plant development and fruit production were significantly affected under different irrigation amounts with higher soil water content enhancing vegetative growth, increasing plant height and stem diameter; variation in soil water content affected fruit size and yield. The highest fruit yield and irrigation water use efficiency was obtained from employing the greatest irrigation threshold and quantity. Amer (2011) found that squash fruit and seed yields and quality were significantly affected by irrigation method and quantity.

Plant leaves play an important role in growth, development and production by functioning as centers of photosynthesis and sources of metabolic processes assimilates (Ibrahim et al., 2010). Plant leaves form the photosynthetic machinery and their removal constitutes a reduction in photosynthetic tissue and photo-assimilates needed in growth. Ibrahim *et al.* (2010) reported that defoliation alters hormone balance, starch, sugar, and protein and chlorophyll contents of source leaves, as well as stomatal resistance and senescence rate. The present paper presents results on increase of multi-purpose pumpkin growth and quality through optimum irrigation rate and leaf harvesting intensity, and follows the one on leaf and fruit yields from the same study (Mwaura et al., 2014).

2. Materials and methods

2.1. Experimental sites

The research was conducted on-station in two different sites at Kabete and Embu. Kabete site was located at 36°41'E and 01°15'S and 1737 m above sea level (Jaetzold et al., 2005). The site is sub-humid with 23.8^{o}C and 12.6^{o}C average annual maximum and minimum temperatures, respectively. It has a bimodal rainfall pattern and 980 mm average annual rainfall. The rains range from 600 mm to 1800 mm in two distinct seasons (Jaetzold et al., 2005). The long rains fall between March and June, while the short rains between October and December (Jaetzold et al., 2005). Kabete soil is well-drained, very deep dark-reddish brown to dark-red, friable clay classified as a humic Nitisols, according to the Soil Map of the World (Jaetzold et al., 2005). Embu site was located at latitudes 0° 08' to 0° 35' South and longitudes 37° 19' to 37° 40' East and 1000-1500 m above sea level (Jaetzold et al., 2005). Embu soils are deep Nitisols of moderate to high fertility. Embu site has a bimodal rainfall pattern and 1250 mm average annual rainfall, divided into two distinct seasons. The long rains fall between March and June, and the short rains between October and December (Jaetzold et al., 2005).

A two factor split-block design embedded in a completely randomized block design with four replications in each site was used (Figure 1). Individual plots in a block measured 2 m x 2 m, separated from each other by 1 m buffer. The two factors were four irrigation levels and four leaf harvest intensities. Irrigation was applied to main plots and leaf harvest intensity to split-blocks. Drippers were used to apply two liters of water per hour to each plant. To achieve the different irrigation rates, drippers were opened for half an hour, one hour, one and a half hours, and two hours per plant once per week. Leaf-harvesting involved manual picking of mature, edible leaves from each branch, starting from 8 to 10 weeks after emergence. Fruits were harvested when physiologically mature.

Soil analysis and testing was done to determine fertility and water conductance using the methods described below (Hinga et al., 2002). The < 2 mm soil samples were oven-dried at 40^{o}C. Available mineral nutrients P, K, Na, Ca, Mg and Mn were extracted using the Mehlich double acid method. The nutrients in the soil samples were extracted in a 1:5 ratio (w/v) of 0.1 N HCl and 0.025 N H_2SO_4. The Na, Ca and K mineral nutrients were determined using a flame photometer (M400, Corning 400, UK), while P, Mg and Mn were measured using UV/VIS spectrophotometer at 600 nm (SPEKOL 1500, Analytik Jena, Germany) (Hinga et al., 2002). The total organic carbon was determined using the calorimetric method. All organic C in the 0.5 mm soil sample oven-dried at 40°C was oxidized using acidified dichromate at 150°C for 30 minutes to ensure complete oxidation. Barium chloride was added to the cool digests. After mixing thoroughly, digests were allowed to stand overnight. The C concentration was read on UV/VIS spectrophotometer at 600 nm (SPEKOL 1500, Analytik Jena, Germany) (Hinga et al., 2002). Total nitrogen was determined using Kjeldahl method. The < 0.5 mm soil sample oven-dried at 40°C was digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrate at approximately 350°C. Total N was determined using distillation followed by titration with diluted standardized H_2SO_4 (Hinga et al., 2002). The Soil pH was determined in a 1:1 (w/v) soil-water suspension using a pH meter (3510 pH meter, Jenway, UK) (Hinga et al., 2002). The available trace elements Fe, Zn and Cu were extracted in a 1:10 ratio (w/v) with 0.1 M HCl in < 2 mm soil samples oven-dried at 40°C. The elements were measured using Atomic Absorption Spectrophotometer (Analyst 100, PerkinELMer, USA) (Hinga et al., 2002). The soil hydraulic conductivity was determined using constant head system that assesses water movement in the soil and indirectly indicates the soil texture stability (Hinga et al., 2002). The soil analysis results were as shown Figure 1.

The field was ploughed to a fine tilth and leveled. The plots were laid out and drip irrigation system installed. An overhead rain shelter was constructed to keep out rain water. Three seeds were sowed in each hole. All treatment plots received the same amount of basic fertilizer and farmyard manure according to the soil test results. After germination, seedlings were thinned to leave one per hole. Recommended phosphorus and one-third of potassium and ammonium nitrate fertilizers were applied just before sowing. The remaining nitrogen and potassium fertilizers were applied at two equal doses, at six weeks post-planting and at the beginning of flowering (Simsek et al., 2011). All plots were irrigated to 100% field capacity immediately after sowing, but subsequent irrigations were carried out according to the treatments. Weeding with a hoe was done when necessary. Vines were coiled when required but leaving them in contact with the soil so as to freely develop roots into the soil at nodes. Pest control was done when required using recommended pesticides. Seeds of *Cucurbita moschata* Duchsene landrace were used. This species is commonly cultivated in Kenya. It is predominantly multi-purpose, owing to edible leaves, fruits and seeds. Uniformly appearing pumpkin fruits were purchased from the local market, seeds extracted, air-dried and stored in a cool dry place.

2.2. Data collection

Each plant represented an experimental unit and hence measurements were done on all plants. Branches were counted and recorded every 2 weeks for 10 weeks starting from eight weeks after emergence. Four leaves per plant, each from a different branch at the 13th node, were used to determine the leaf area, using linear non-destructive measurements at one week after the onset of flowering. The formula leaf length x width x a constant used had A = 0.838x - 0.558, where A = area, and x = length × width (Gao, 1999). Counting of male and female flowers weekly for three weeks from the onset of flowering season was done and their ratio calculated to estimate the sex ratio. Three fruits were randomly selected from each treatment, the seeds extracted, air-dried, 1000 counted and weighed. Fruit size was determined using the average length × width of three randomly selected fruits per treatment. Three mature fruits randomly selected per treatment were cut and edible flesh thickness measured using a Vernier-caliper (Khattab et al., 2009). Four replicates of 10 seeds from each treatment were germinated, counted and expressed as percentage. Seedling growth rate was determined as growth rate of stem length, stem thickness, root length, and leaf number at 2 weeks post-emergence (AOSA, 1993).

No.	Analysis	Embu	Remark	Kabete	Remark
1	Soil pH	5.52	Medium acid	5.50	Medium acid
	Fe	22.8 ppm	Adequate	49.2 ppm	Adequate
2	Cu	4.13 ppm	Adequate	8 ppm	Adequate
	Zn	26.2 ppm	Adequate	11.0 ppm	Adequate
	P	9 ppm	Low	37 ppm	Adequate
3	Mg	3.65%	High	1.18%	Adequate
	Mn	0.87%	Adequate	0.65%	Adequate
	K	0.84%	Adequate	0.56%	Adequate
4	Ca	2.3%	Adequate	1.7%	Low
	Na	0.15%	Adequate	0.13%	Adequate

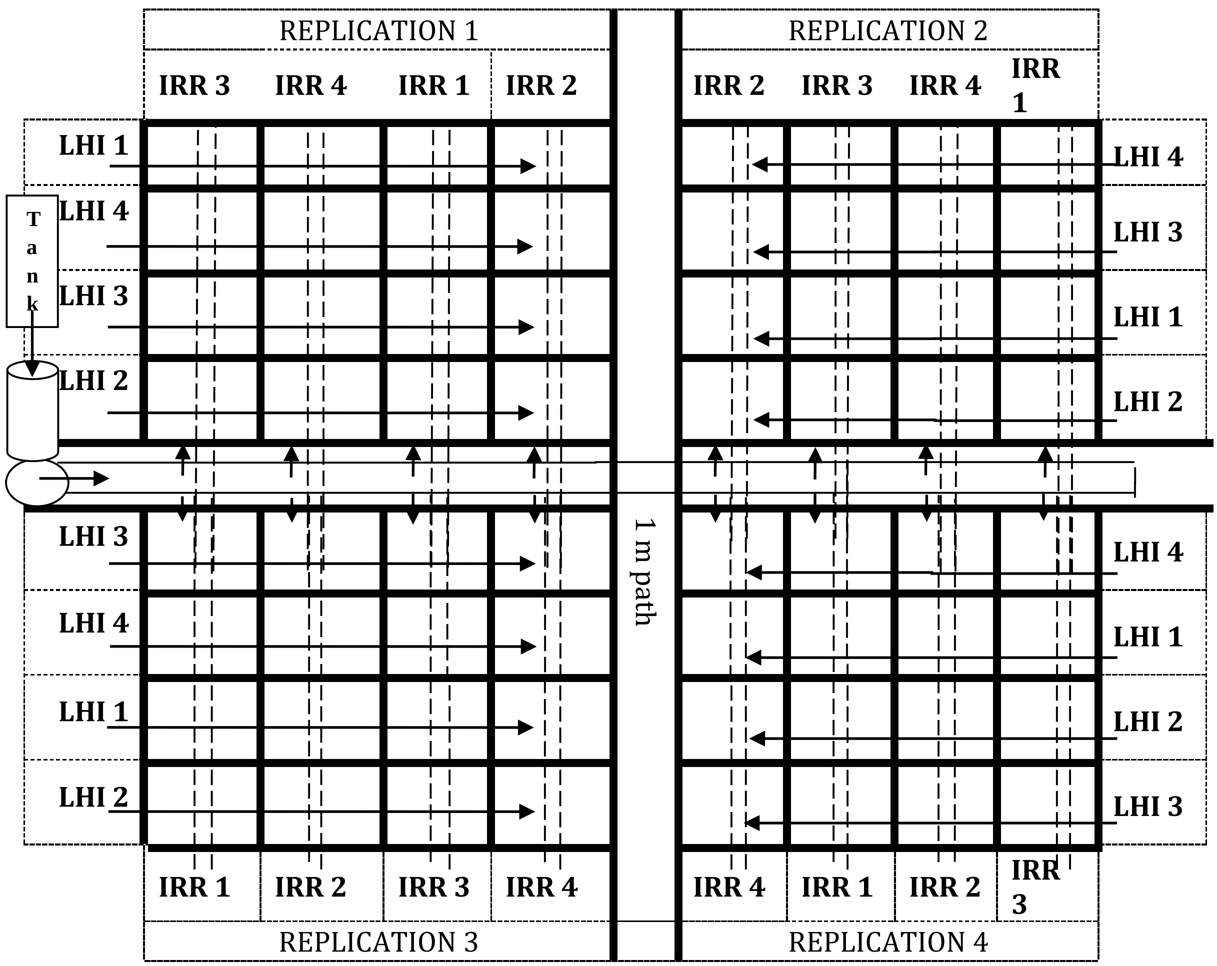

Figure 1. Experimental layout, where IRR = Irrigation rate; LHI = Leaf harvest intensity; 1, 2, 3, 4, refer to lowest to highest IRR or LHI rates, respectively

2.3. Data analysis

Data values were subjected to analysis of variance using JMP IN 5.1 (Sall et al., 2003) statistical software. Mean separation was done using Tukey's Studentized Range Test at P = 0.05. Data for the two experimental sites were analysed separately due to variable agro-ecological conditions.

3. Results

3.1. Effects of irrigation and leaf harvest intensity on number of branches and leaf area

Irrigation rate had no significant effect (P>0.05) on branches (Table 1). Application of 3 L per week produced the highest 214 and 178.5 branches at Embu and Kabete, respectively. In both sites, the branches increased with increase in irrigation rate up to 3 L. Application of 1 L per week produced fewest 189 and 161.3 branches at Embu and Kabete, respectively. Leaf harvest intensity had no significant effect (P>0.05) on branches (Table 1). Nonetheless, harvesting of one leaf had the highest 212 and 175.2 total branches at Embu and Kabete, respectively. Irrigation had no significant effect on the leaf area in Kabete but was significant (P<0.05) in Embu. Application of 3 L produced the highest leaf area in both sites (Table 1). The significant difference observed in Embu could have been by chance since the trend in both sites was similar. Leaf harvest intensity had a significant effect (P<0.05) on the leaf area in Embu, where harvesting of one leaf produced the largest leaf area (Table 1). However, leaf area was not significantly different for harvesting three leaves and no leaf. In Kabete, harvesting of three leaves had the highest leaf area, although it was not significantly different from the others.

Table 1. Effects of irrigation and leaf harvest intensity on branches and leaf area

	Number of branches		Leaf area (cm^2)	
Irrigation rate/plant	Embu	Kabete	Embu	Kabete
1 litre/week	189.0	161.3	502.3a	438.9
2 litres/week	199.8	172.2	440.5b	436.5
3 litres/week	214.0	178.5	524.0a	446
4 litres/week	210.8	169.9	497.3a	374.5
P-value	0.18	0.66	<0.0001*	0.1107
LHI/branch/fortnight				
0 leaf	196.2	174.9	491.1ab	421.1
1 leaf	212.0	175.2	511.8a	403.8
2 leaves	205.5	155.9	468.8b	410.5
3 leaves	199.9	175.1	492.4ab	460.3
P-value	0.60	0.44	0.0294*	0.3129

**Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05*

3.2. Effects of Irrigation and Leaf Harvest Intensity on Male, Female and Aborted Flowers

Irrigation had no significant effect (P>0.05) on the male and female flowers in Embu (Table 2). Application of 2 L per week produced the highest 61.7 male flowers and also stimulated early flowering. Application of 1 L per week produced the highest 21 female flowers and the least 56.2 male flowers, while application of 3 L produced the least 18.2 female flowers. Leaf harvest intensity had a significant effect (P<0.05) on total male and female flowers at Embu (Table 2). Harvesting of one leaf and not harvesting produced more male (68.1) and female (23.5) flowers in Embu (a ratio of 3:1), compared to the other leaf harvest intensities. Harvesting of three leaves produced the least 47.6 total male and 15.7 female flowers, although the ratio was the same 3:1.

Irrigation rate had no significant effect (P>0.05) on the male flowers in Kabete (Table 2). Application of 3 L produced the highest male (49.9) and female flowers (22.3) (ratio of 2:1), while 1 L produced the least male (39.8) and female (17.8) flowers (ratio of 2:1). Leaf harvest intensity had a significant effect (P<0.05) on male flowers (Table 3). Harvesting of three leaves produced the lowest male flowers (34.8), although this was not significantly different from harvesting of one leaf. Harvesting of three leaves produced more male (48.8) and female (22.4) flowers (ratio of 2:1) in Kabete compared to the other leaf harvest intensities.

Irrigation rate had no significant effect (P>0.05) on the aborted flowers in both sites (Table 2). Nevertheless, application of 1 or 2 L resulted in more flower abortion compared with application of 3 and 4 L. Irrigation with 1 L had the highest flower abortion of 11.0 and 9.9 in Embu and Kabete, respectively. Application with 4 L had the lowest aborted flowers of 8.4 and 8.3 in Embu and Kabete, respectively. The aborted flowers decreased with the increase in irrigation rate. Leaf harvest intensity had a significant effect (P<0.05) on the aborted flowers in Embu (Table 2). The same trend was observed at Kabete site, although it was not significantly different. Flower abortion was higher in treatments where three leaves were harvested (14.0 and 10.8) in Embu and Kabete, respectively. Harvesting of one leaf had the least aborted flowers (5.7) in both sites. The number of flowers aborted increased with the increase in leaf harvest intensity.

Table 2. Effect of irrigation rate and leaf harvest intensity on male and female flowers

Irrigation rate/plant	Embu site total intact		Kabete site total intact		Total aborted	
	Male	Female	Male	Female	Embu site	Kabete site
1 litre/week	56.2	21	39.8	17.8	11	9.9
2 litres/week	61.7	19.3	41.4	20.3	9.9	8.8
3 litres/week	57.1	18.2	49.9	22.3	8.2	5.7
4 litres/week	58.3	18.4	41.8	19.5	8.4	8.3
P-value	0.68	0.623	0.2753	0.2938	0.5657	0.2797
LHI/branch/fortnight						
0 leaf	60.1ab	19.6ab	42.8	18.1	5.7c	5.7
1 leaf	68.1a	23.5a	46.6	21.8	8.1ab	6.8
2 leaves	57.5ab	18.1ab	34.8	17.8	9.7ab	9.3
3 leaves	47.6b	15.7b	48.8	22.4	14.0a	10.8
P-value	0.001*	0.014*	0.0800	0.1091	0.0052*	0.0938

*Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05

3.3. Effects of irrigation rate and leaf harvest intensity on fruit size and flesh thickness

Irrigation rate had no significant effect (*P*>0.05) on the mean fruit size (Figure 2). Application of 4 L produced larger fruits in Embu, while 1 L produced larger fruits in Kabete. Leaf harvest intensity had no significant effect (*P*>0.05) on the fruit size (Figure 1). Harvesting of one leaf produced larger fruits in Embu, while harvesting of three leaves produced larger fruits in Kabete. There was no significant effect (*P*>0.05) of irrigation rate had on edible flesh thickness in both sites (Figure 2). The lower water rates (1 and 2 L) produced thicker flesh thickness than 3 and 4 L in Kabete. Leaf harvesting intensity had no significant effect on edible flesh thickness (Figure 2). In both sites, harvesting of two leaves produced thicker edible flesh than the other treatments.

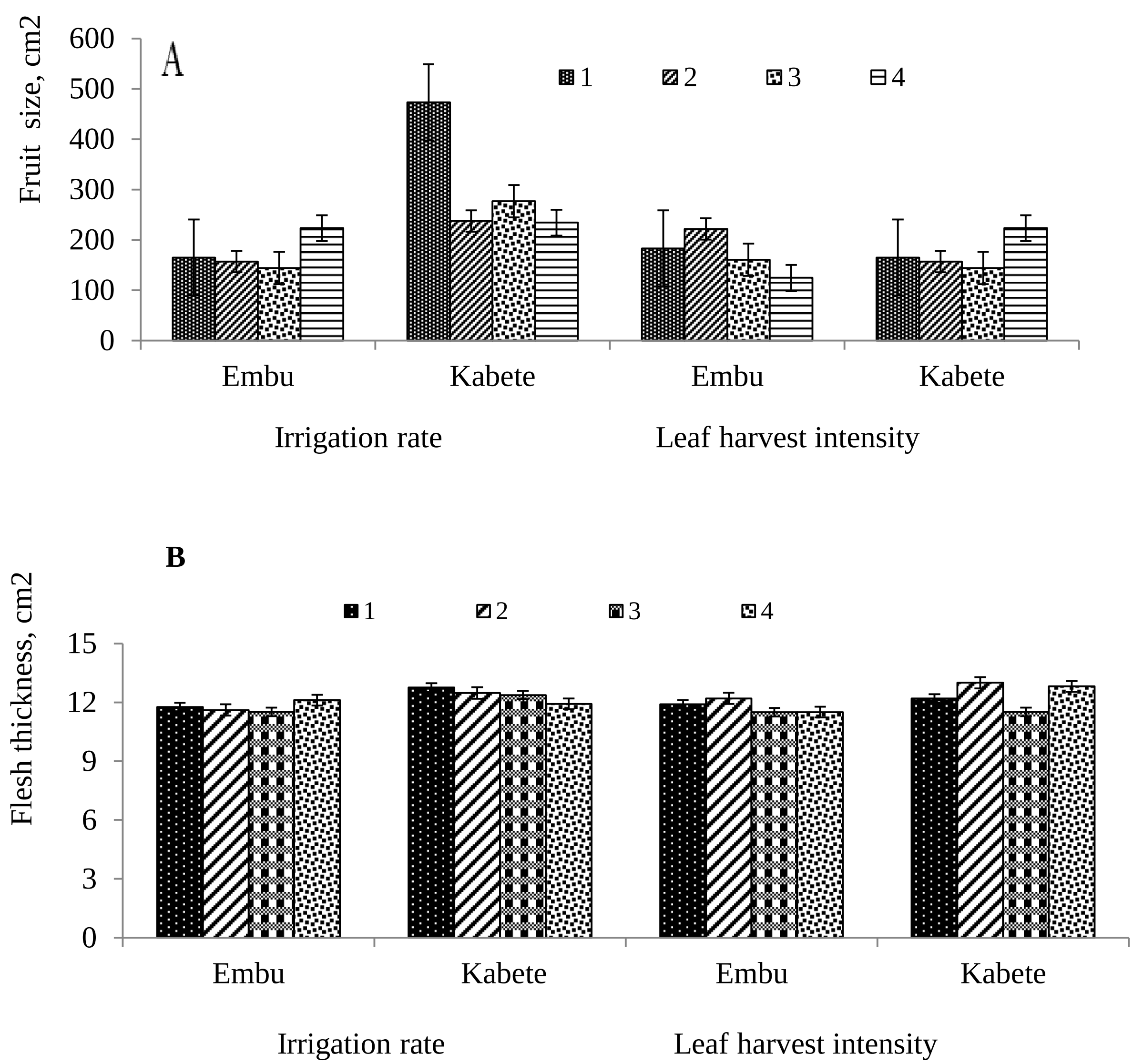

Figure 2. Effect of irrigation and leaf harvest intensity on the fruit size and edible flesh thickness. The 1, 2, 3, 4 represent irrigation rates or leaf harvest intensity. Bars = standard errors

3.4. Effects of irrigation rate and leaf harvest intensity on seed components

Irrigation as well as leaf harvest intensity had no significant effect (*P*>0.05) on 1000-seed weight (Figure 3). In Embu, one or no leaf produced higher 1000-seed weight, compared to treatments where more leaves were harvested. In Kabete, the trend in 1000-seed weight was not consistent. Irrigation had no significant effect (*P*>0.05) on the number of seeds per fruit (Table 3). The trend indicated that higher water rates produced more seeds than those receiving lower water rates (Table 3). Application of 4 L produced the highest mean number of seeds in both sites (309.7 at Embu and 232.8 at Kabete). Application of 3 and 4 L produced more seeds than application of 1 and 2 L. Leaf harvest intensity had a significant effect (*P*<0.05) on the number of seeds at Kabete (Table 3). In treatments where no or one leaf was harvested, the seeds were higher compared to where more leaves were harvested. A similar trend was observed at Embu. Irrigation rate had no significant effect (*P*>0.05) on the viability of seeds in both sites (Table 3). Germination started on the 5th day after sowing. Seeds for 1 and 2 L had higher germination rate at 5, 6 and 7 days after sowing compared to those for 3 and 4 L.

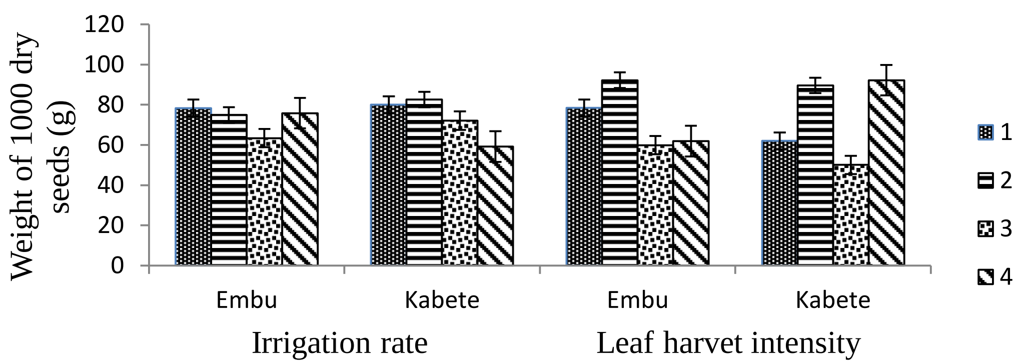

Figure 3. Effect of irrigation rate and leaf harvest intensity on 1000-seed weight. The 1, 2, 3, 4 represent irrigation rates or leaf harvest intensity. Bars represent standard errors

Most germination occurred by the 6th and 7th day and was completed by the 12th day after sowing. Although there was no significant effect, the trend was that treatments that received low water had a higher germination rate than those that received high water. There was no significant effect (*P*>0.05) of leaf harvesting intensity on the germination rate (Table 3) although seeds for one harvested leaf in Embu and no harvested leaf in Kabete had the highest germination percentage (Figure 4).

There was a significant effect (*P*<0.05) of irrigation on seedling stem diameter at Kabete (Table 4). The 3 L produced the thickest stem girth (1.1 cm) compared with the other rates. Similarly, the 3 L in Embu produced the thickest stem, although it was not significantly different from the other rates. Irrigation had a significant effect (*P*<0.05) on seedling root length, with 2 L producing the longest roots, 7 cm and 4.5 cm in Embu and Kabete, respectively. Higher water rates resulted in shorter roots compared to the lower rates. Application of higher rates increased seedling stem length in both sites, although not significantly. Leaf harvest intensity had a significant effect (*P*<0.05) on seedling stem diameter in Kabete (Table 4). The no leaf harvest produced the thickest stems.

Table 3. Effect of irrigation rate on seed number and viability

	Number of seeds per fruit		Germination rate	
Irrigation rate/plant	Embu	Kabete	Embu	Kabete
1 litre/week	242.0	182.5	9.1	9.1
2 litres/week	212.7	195.1	8.5	8.5
3 litres/week	263.7	242.6	7.8	7.8
4 litres/week	309.7	232.8	9.1	9.1
p-value	0.6212	0.6375		
LHI/branch/fortnight				
0 leaf	274.6	282.7a	8.3	8.3
1 leaf	301.1	284.2a	8.9	8.9
2 leaves	243.5	140.1b	8.6	8.6
3 leaves	208.9	146.1b	8.8	8.8
p-value	0.5240	0.0078*		

**Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05*

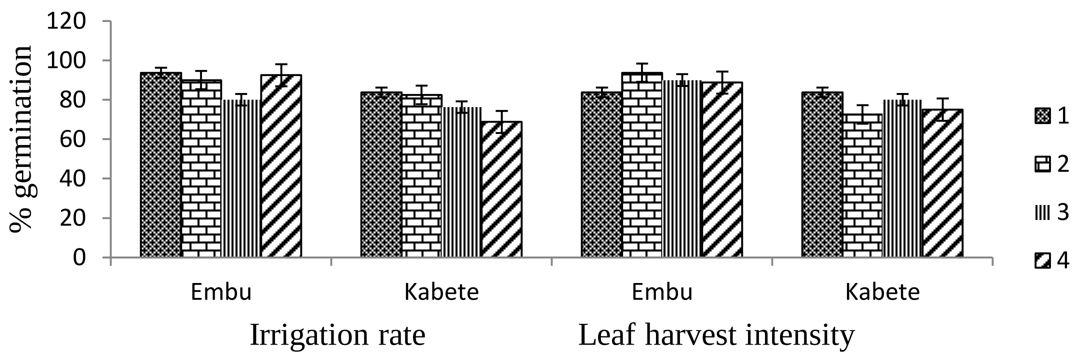

Figure 4. Effect of irrigation rate and leaf harvest intensity on germination percentage. The 1, 2, 3, 4 represent irrigation rates or leaf harvest intensity

3.5. Effects of interaction between irrigation and leaf harvest on branches and leaf area

Interaction between irrigation rate and leaf harvest intensity had no significant effect (*P*> 0.05) on branches (Table 5). The 3 L and no leaf harvest and 4 L with one leaf harvest produced the highest branches in Embu, although these results were not significantly different from the interactions. At Kabete 1 L and 2 leaves produced the highest branches, although the results were not significantly different from the other interactions. The results showed that applying 3 or 4 L combined with any leaf harvest intensity increased the branches in both sites.

Table 4. Effects of irrigation rate and leaf harvest intensity on the seedling growth

Irrigation rate/plant	Kabete			Embu		
	Stem length	Root length	Stem girth	Stem length	Root length	Stem girth
1 litre/week	6.3	4.4	1.0b	7.9	5.8ab	1.2
2 litres/week	6.4	4.5	1.0b	7.6	7.0a	1.6
3 litres/week	6.9	3.6	1.1a	8.0	4.5b	2.1
4 litres/week	7.3	3.5	1.0b	8.3	4.4b	2.1
P-value	0.1000	0.0554	<0.000*	0.6304	0.0046*	0.1677
LHI/branch/fortnight						
0 leaf	6.7	4.0	1.1a	8.0	5.1	1.7
1 leaf	6.8	3.6	1.0b	8.0	5.2	1.7
2 leaves	6.8	4.1	1.0b	7.6	5.8	1.7
3 leaves	6.6	4.3	1.0b	8.2	5.6	1.8
P-value	0.9835	0.5594	<0.000*	0.6893	0.6892	0.9878

**Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05*

Table 5. Effect of interaction of irrigation and leaf harvest on branches and leaf area

Irrigation rate x Leaf harvest intensity	Number of branches		Leaf area (cm^2)	
	Embu site	Kabete site	Embu site	Kabete site
1,0	177	180	517.5abc	471.2 ab
1,1	211	202	481.5bcde	418.4 ab
1,2	184	143	523.9abc	435.9 ab
1,3	184	155	486.3bcd	430.3 ab
2,0	199	176	416.1de	388.1a b
2,1	197	165	470.6bcde	434.2 ab
2,2	212	160	386.0e	359.3a b
2,3	191	194	489.3bcd	476.1a b
3,0	223	186	591.0a	564.4 a
3,1	218	195	529.6abc	478.6a b
3,2	211	160	483.8bcde	447.8a b
3,3	205	175	491.6abcd	381.5a b
4,0	186	174	439.8cde	348.0ab
4,1	222	166	565.6ab	284.0b
4,2	215	175	481.5bcde	399.2 ab
4,3	221	190	502.5abcd	465.1 ab
P-value	*P*>0.05	*P*>0.05	<0.0001*	0.0359*

**Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05*

Interaction between irrigation and leaf harvest intensity had a significant effect ($P<0.05$) on leaf area (Table 5). Application of 3 L and no leaf harvest produced the highest leaf area in both sites (591.0 cm^2 and 564.4 cm^2 in Embu and Kabete, respectively). These results were only significantly different for the interaction between 4 L and one leaf harvest in Kabete. In Embu, application of 2 L and 2 leaves harvest produced the least leaf area.

3.6. Effects of interaction between irrigation rate and leaf harvest intensity on flowers

The interaction between irrigation rate and leaf harvest intensity had a significant effect (P<0.05) on the male flowers (Table 6). The 2 L and one leaf harvest produced the highest 76 male flowers at Embu. The 3 L and one leaf harvest had the highest 64.3 male flowers at Kabete, although not significantly different from the other treatments. Harvesting of one or no leaf with any irrigation rate produced the highest male flowers in both sites, while harvesting three leaves produced the lowest flowers. Male flowers decreased with increase in leaves harvested. Interaction had no significant effect (P>0.05) on female flowers (Table 6). The showed 1 L and one leaf harvest produce the highest female flowers in Embu, while the 3 L and one leaf harvest in Kabete produced the highest female flowers. The female flowers increased up to two leaves harvest with any irrigation rate.

Table 6. Effect of interaction between irrigation rate and leaf harvest intensity on flowers

Irrigation rate x Leaf harvest intensity	Number of male flowers		Number of female flowers	
	Embu	Kabete	Kabete	Embu
1,0	59.5abcd	40.3	18	19
1,1	64.3abc	48.3	21	29
1,2	54.3bcd	31.3	17	21
1,3	46.8cd	39.3	16	16
2,0	59.0abcd	41	15	20
2,1	76.0a	38	21	25
2,2	57.5abcd	28.5	19	16
2,3	54.3bcd	58	26	16
3,0	64.5abc	52.5	23	22
3,1	65.0abc	64.3	27	19
3,2	57.8abcd	38	19	17
3,3	41.3d	45	21	16
4,0	57.5abcd	37.3	16	17
4,1	67.3ab	35.8	19	22
4,2	60.5abc	41.5	17	19
4,3	48.0cd	52.8	27	16
P-value	0.0445	0.29	>0.05	>0.05

**Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05*

3.7. Effect of interaction of irrigation and leaf harvest on fruit size and flesh thickness

The interaction had no significant effect (P>0.05) on fruit size (Table 7). However, application of 4 L and leaf harvest had a positive effect on fruit size in Embu. Application of 3 L interacted positively with leaf harvest to give the highest fruit size in Kabete. In interactions where more leaves were harvested (two and three) reduced fruit size more than interactions where one or no leaf was harvested and the same irrigation rate. Interaction had no significant effect on the edible flesh thickness (P>0.05) (Table 7). According to the results, the difference between the various combinations was negligible, although application of 4 L and one leaf harvest in Embu and 3 L and one leaf harvest in Kabete had a positive effect on the edible fruit flesh thickness.

3.8. Effects of interaction of irrigation and leaf harvest on seed weight and number

There was no significant effect ($P>0.05$) between interaction of irrigation rate and leaf harvest intensity on the 1000 dry seed weight (Figure 5). Interaction between 4 L and one leaf harvest had the highest mean weight (116.1 g) of 1000-seeds in Kabete. The interaction between 2 L and three leaf harvest had the highest mean weight (122.1 g) of 1000-seeds in Embu. Interaction of irrigation rate and leaf harvest intensity had a significant effect ($P<0.05$) on the number of seeds (Table 8). Application of 4 L and one leaf harvest produced higher number of seeds in Embu, while 3 L and one leaf harvest produced highest number of seeds in Kabete. The one leaf harvest and any irrigation rate produced more seeds than all the other treatments.

Table 7. Effects of interaction between irrigation and leaf harvest intensity on fruit size and flesh thickness

Irrigation rate x Leaf harvest intensity	Fruit size (cm^2)		Edible flesh thickness (cm^2)	
	Embu	Kabete	Embu	Kabete
1,0	110	227	11	13
1,1	208	315	13	13
1,2	224	175	12	12
1,3	118	117	12	13
2,0	174	126	12	12
2,1	162	226	12	12
2,2	189	288	12	13
2,3	103	310	12	14
3,0	220	182	13	12
3,1	156	484	11	14
3,2	71.6	110	11	11
3,3	130	331	12	13
4,0	227	182	12	12
4,1	361	383	14	13
4,2	157	86	14	11
4,3	147	286	11	12

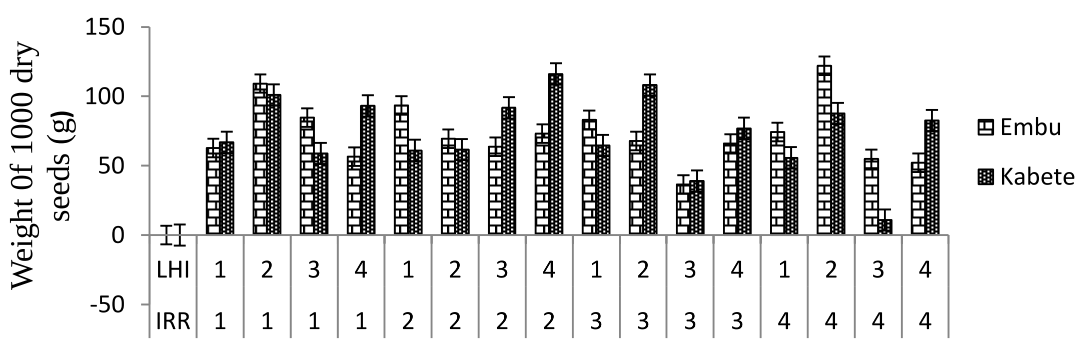

Figure 5. Effects of the interaction between irrigation and leaf harvest on 1000-seed weight

Table 8. **Effects of the interaction between irrigation and leaf harvest on seed number**

Irrigation rate x Leaf harvest intensity	Embu	Kabete
1,0	214.5 cde	132.3 h
1,1	224.3 cde	342.8 b
1,2	302.5 bc	181.0 g
1,3	226.8 cde	275.0 cd
2,0	303.5 bc	134.5 h
2,1	294.5 bc	127.3 h
2,2	296.3 bc	224.5 ef
2,3	160.5 ef	294.5 c
3,0	333.0 b	196.5 fg
3,1	214.0 cde	433.3 a
3,2	118.3 f	85.3 ij
3,3	185.5 def	255.3 de
4,0	247.5 bcde	121.3 hi
4,1	471.5 a	233.3 ef
4,2	257.0 bcd	69.5 j
4.3	262.8 bcd	306.0 bc

**Means followed by the same letters or no letters within a column are not significantly different according to the Tukey's Studentized Range Test at P = 0.05*

4. Discussion

4.1. Effects of irrigation rate on growth and quality

High irrigation rate promoted higher growth probably through enhancement of both the uptake of nutrients from the soil and the translocation of assimilates to the growing areas (sinks). The branches are essential in leaf production and treatments that promote their growth are highly valued in pumpkin. The highest irrigation rate of 4 L may have been too much, leading to anaerobic soil conditions that impede root respiration, nutrient uptake and translocation. This condition is in some crops manifested in stunted overall plant growth. For example, the high soil moisture content resulted in reduction of the number of male and female flowers produced.

Lack of significant difference in leaf area agreed with the findings of Fandika et al. (2011), who concluded that leaf area of pumpkin cultivars remains constant even under different treatments. Thus with or without irrigation, different cultivars of pumpkin differed in leaf area, while a cultivar maintained its leaf area. Water is essential in promotion of flower development into fruits. The heavy abortion of female flowers in treatments receiving low water rates indicated that more water was required to sustain development of the flowers into fruits. This was probably because water is used in keeping flowers turgid to prevent abscission. These results agreed with those of Walker (2011), who noted that irrigation is crucial during flowering, fruit set and fruit fill. If plants are stressed at these times, flowers and young fruits abscise prematurely.

Although irrigation rate had no significant effect on the edible flesh thickness, the trend showed that higher irrigation rates produced higher edible flesh thickness in both sites, implying that water availability facilitated translocation of photosynthates to the fruits, resulting in slightly thicker edible flesh. The results were similar to those of Searle (2003), who concluded that fruit size is generally controlled by genetics, but any factor that limits plant growth adversely affects fruit size. The factors include water, temperature, insects, diseases, pollination, fertility, soil type, plant population and weeds, among others. While irrigation is needed in high value crops, when plants are under moisture stress, extra water can help maintain or improve good fruit size. The trend shown on the number of seeds per fruit was similar to that reported by Ghanbari et al. (2007) that irrigation interval had significant effect on the number of seeds per fruit, with fruits receiving weekly (7 days) application having more seeds. The 7 day frequency can be equated to the 4 L in the present study. In crop physiology, hormonal activity in the growing fruits causes the fruit mesocarp to act as a stronger physiological sink than the other organs for photosynthetic materials. Most likely under higher irrigation levels, higher transmission rate of assimilates and dry matter to the fruit mesocarp could result, thereby expanding the fruit pericarp. Ultimately, excessive growth of the fruit decreases the number of seeds per fruit (Yousefi, 2012). However, Jahan et al. (2010), stated that pumpkin is a sink-limited herb and there is no link between increase in fruit dimension and higher seed production. Irrigation rate did not affect 1000-seed weight, similar to findings of Ghanbari et al. (2007). The lack of significant difference in germination indicated that seed quality is not determined by the level of soil moisture and leaf harvest intensity, but by other factors that were not considered in this study. This result agreed with the findings of Ghanbari et al. (2007).

4.2. Effects of leaf harvest intensity on growth and quality

Leaf harvesting reduced the photosynthetic area needed to drive branch growth, resulting in lower total number of branches in treatments where more leaves were harvested. The leaves form the photosynthetic machinery of the plant and their removal constitutes a reduction in photosynthetic tissue and photo-assimilates needed in crop growth. Ibrahim et al. (2010), reported that defoliation alters hormone balance, starch, sugar, protein and chlorophyll contents of source leaves, as well as stomatal resistance and senescence rate. Similarly, the negative effect of leaf harvesting on the number of male and female flowers was attributed to reduced photosynthetic process. The significance of leaf harvest intensity on flower abortion was attributed to the fact that leaf harvesting reduced photosynthetic area resulting in less assimilates being partitioned to the flowers for development. These results agreed with those of Ibrahim et al. (2010), who concluded that leaf-harvest can directly and indirectly affect growth, biomass production and partitioning. Leaf harvesting reduced photosynthetic area resulting in less assimilates being partitioned to the flowers.

Pumpkin belongs among monoecious plants, which can separate allocation to male and female functions more easily (Thomson et al., 2004). Depletion of resources through leaf harvesting which can be likened to folivory (leaf herbivory) differentially influences male and female functions. In the present study, pumpkin produced a lot of male flowers. A variety of factors must interact to determine how folivory alters the relative allocation of resources to male and female functions (Diggle and Miller, 2004). It was observed by Diggle and Miller (2004) that if pistillate and staminate flowers are produced at different positions on a plant, they compete and one of the flowers may receive more or less resources than the other, depending on the position occupied. Furthermore, production of pistillate flowers earlier than staminate flowers results in the latter suffering exhaustion of resources during re-allocation processes (Diggle and Miller, 2004). The abortion of female flowers may therefore have been caused by plant regulatory systems to shed off excess fruits and leave only few that it could manage to feed.

The lack of a significant effect of leaf harvest intensity on 1000-seed weight probably implied that leaf harvesting indirectly reduced the amount of assimilates partitioned into seed production through reduction of photosynthetic area. According to KÓpondo et al. (2005), seed production in most indigenous leafy vegetables is low since most of the production is for leaf consumption and not seed production. Achieving a balance between leaf and seed yields in plants where the leaves are eaten requires both sound cultural practices and good leaf harvesting practices that do not reduce the active photosynthetic area of the plant to jeopardize seed yields. The significant effect of leaf harvest intensity on number of seeds was in agreement with Madakadze et al. (2007), who reported that more frequent harvesting at 7-day interval significantly reduced seed yields to 1.2, compared to 2.7 tonnes/ha obtained for 14- and 21-day intervals. When leaves are harvested, the plant concentrates on recovering the lost leaf area that is essential for photosynthesis rather than reproduction, resulting in reduced seed yields. Older leaves left on the plant are less efficient in photosynthesis, thereby reducing seed yields. The high interval (21 days) in the cowpea experiment is equivalent to harvesting of 3 leaves, which was the highest intensity in the present study (Isutsa and Mallowa, 2013). Ibrahim et al. (2010, concluded that cowpea leaf-harvest can directly and indirectly affect growth, biomass production and partitioning into sinks. Intense leaf harvesting reduced photosynthetic surface area resulting in less assimilates being partitioned into cowpea flowers.

4.3. Effect of interaction on growth and quality

Interaction had no significant effect on the number of branches, although the trend revealed that irrigation with 3 or 4 L combined with any leaf harvest intensity increased the number of branches in both experimental sites. This meant that water is essential for crop growth and higher soil moisture can give the plant the ability to withstand stress subjected through high leaf harvest intensity. The results on male flowers showed that application of 2 or 3 L and low (none or one) leaf harvest intensity produced more male flowers. Male flowers are essential in fruit and seed production and development through production of pollen for pollination. According to Marr et al. (2004), the more the pollination takes place, the more seeds develop, producing growth regulating compounds that enhance fruit size. Interaction between irrigation rate and leaf harvest intensity had no significant effect on the number of female flowers, although the trend showed that they increased up to harvesting 2 leaves in combination with any irrigation rate, after which the number reduced. The high leaf harvest intensity negatively affected the production of female flowers probably by reducing photosynthetic area. Sex allocation theory predicts that folivory decreases female function because it is more expensive in terms of plant resource allocation (Charlesworth and Morgan, 1991).

Lack of significant effect of interaction on the weight of 1000 dry seeds meant that the seed weight may be determined by other factors other than ones considered in this study. Nevertheless, the results showed that higher irrigation rates favoured production of heavier seeds and these high irrigation rates gave the plants ability to sustain seed production even if more leaves were harvested. The present results showed that the fruit edible thickness depends on the amount of photosynthates produced and partitioned during the fruit development stage. According to Yousefi (2012), higher irrigation rates have presumably higher transmission rate of assimilates and dry matter to the fruit mesocarp that expands the fruit pericarp. Interaction of 3 or 4 L with harvesting one or no leaf produced more seeds than the other treatments. Results have shown that the number of seeds produced is determined by the rate of photosynthesis and the ability of the plant to partition assimilates to the seed sinks. Thus increased irrigation rates combined with large photosynthetic area results in more seeds.

5. Conclusions and recommendations

5.1. Effects of irrigation rate conclusions

Irrigation rate affected the growth where higher irrigation rate (2 and 3 L) facilitated production of more branches probably through accelerated uptake of nutrients from the soil, increased photosynthetic process and also more efficient translocation of assimilates to the growing areas (sinks). Too much water may have caused reduced branch production as a result of anaerobic soil conditions which interfere with various plant growth functions. Low water levels could have caused reduced branching through adverse water stress effects. The irrigation water affected the number of male and female flowers produced in that low rates stimulated earlier commencement of flowering, whereas high rates delayed flowering by three days. High water levels caused production of many female flowers but most of them aborted within the first 3 weeks after flower initiation. Irrigation rate did not affect the leaf area, indicating that leaf area is determined by other factors other than the ones tested in the present study. Irrigation rate slightly affected pumpkin quality components. Higher irrigation rates favoured partitioning of assimilates to leaves leading to production of larger size. Amount of water applied did not affect 1000-seed weight. The fruit edible flesh thickness and the number of seeds increased with increased water rates. Irrigation affected seedling stem diameter with higher rates producing thicker stems. Low irrigation rates produced seedlings with longer roots. Irrigation rate had no effect on germination.

5.2. Effects of leaf harvest intensity conclusions

Leaf harvest intensity influenced growth by significantly affecting the number of branches in that treatments where only one or no leaf was harvested produced the highest number of branches. Few branches were recorded in treatments where more leaves were harvested. Leaf harvest intensity also affected the time to commencement of flowering and number of male flowers in that harvesting two leaves initiated flowering three days earlier than the other treatments. Leaf harvest intensity also affected the total number of male and female flowers, with higher leaf harvest intensity decreasing the number of both male and female flowers. Leaf harvest intensity affected quality in that harvesting of three leaves produced the highest number and weight of leaves but their sizes were small and un-attractive compared with those of harvesting one leaf, which resulted in few, large and attractive leaves. Low leaf harvest intensity (one leaf or none) favoured development of thicker edible fruit flesh and production of higher number of seeds per fruit. Leaf harvest intensity did not affect 100-seed weight. Low leaf harvest intensity produced seedlings with thicker stems than seeds from treatments where more leaves were harvested.

5.3. Effects of interaction between irrigation rate and leaf harvest intensity conclusions

Interaction between higher irrigation rates and any leaf harvest intensity increased the number of branches with harvesting of only one leaf giving the highest number of branches. Harvesting of more leaves combined with any rate of irrigation produced few flowers, meaning that flowering is affected by the level of photosynthesis and assimilates that are translocated. This was more evident with male flowers. The higher the photosynthetic area the higher the number of flowers produced. This result proved that leaves are sources of photosynthates for flowers, which in this case are the sinks. Higher water rates favoured production of many female flowers, but many of them aborted a few weeks after initiation. Interaction between irrigation and leaf harvest intensity affected leaf area with 3 L and no leaf harvest producing the highest leaf area in both sites. This result meant that the 3 L was optimal for leaf area development. Interaction between higher irrigation rates combined with harvesting one or no leaf produced higher number of seeds, fruit size and edible flesh thickness. This means that water and sufficient number of leaves are essential for improved quality of fruits and seeds. This may be as a result of increased photosynthesis and partitioning of assimilates to these sinks unlike where water is limiting.

5.4. Recommendations

Leaf harvesting should be avoided or if harvesting is to be done only one leaf should be harvested per branch once per week in a system where the goal is to produce seeds. Application of 3 L is recommended for production of the highest number of branches and the longest production period. It is therefore recommended during the dry season for optimal yields.

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