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Full Length Research Paper

Supplemental irrigation effects on yield of two watermelon (*Citrulus lanatus*) cultivars under semi-arid climate in Kenya

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The objectives of this study were to determine the effect of the supplemental irrigation using drip, sprinkler and furrow methods on two watermelon cultivars (Charleston grey, and Sugar baby) by studying their growth, yield and quality (Brix index) and economic feasibility under semi-arid climate in Kenya. Cultivars irrigated with drip produced significantly more fruits than those under either sprinkler or furrow. The highest total economic yield of 4.05 Mg/ha in the short rain season (SRS) and 4.95 mg/ha in the long rain season (LRS) was obtained in 'Charleston grey' irrigated by drip. The average fruit weight was 6.07 kg in the SRS and 7.42 kg in the LRS. The highest net benefit was US$ 493.3/ha in the SRS and 706.1/ha in the LRS. A 2 or 4-week starter irrigation, drip supplemental irrigation boosted 'Charleston grey' yields by 1.78-fold, if water stress occurred during the late vegetative growth. Supplemental irrigation during late vegetative growth decreased the total soluble solids in fruits. Total soluble solids concentration was 5.93°Brix in the SRS and 8.16°Brix in the LRS. The furrow irrigation supplied the most water to the crop resulting in the lowest total soluble solids of watermelons.

Key words: Drought management, irrigation methods, watermelon cultivar.

INTRODUCTION

Droughts within a rainy season limit crop production in arid and semi-arid regions contributing to poor crop growth, yield and quality. The annual rainfall in the semi-arid areas which, is about 600 mm, is often poorly distributed and it is a major constraint to crop production in Kenya (Mati, 2000), where 80% of the land is either arid or semi-arid (Jaetzold et al., 2007). Early maturing and drought-escaping or tolerant cultivars have traditionally been used as strategies for crop production in the arid and semi-arid regions. However, these strategies are now threatened by the shifting rainfall patterns due to climate change. For example, Mati (2000) in a simulation study of the influence of climate change on maize production in the semi-humid and semi-arid areas of Kenya predicted lower rainfall levels during the main growing season. Consequently, it was recommend-ded that traditional growing season must be shifted to continue with crop production. However, shifting of the crop growing season is still likely to be met with the unreliability of rainfall; a characteristic of semi-arid areas (Jaetzold et al., 2007). A strategy to mitigate shifting of the growing season and coping with the adverse effects of climate change is to apply supplemental irrigation (Fox and Rockstrom, 2003) or intermittent irrigation (Abbasi and Sepaskhah, 2011). Supplemental irrigation, in general, requires that the crop be of high value in order to pay for the extra investment. Horticultural crops like capsicum (Antony and Singandhupe, 2004) and watermelon (Cabello et al., 2009) have been found to respond favorably to supplemental irrigation.

Furthermore, studies have shown that supplementing irrigation water, when rainwater was lacking during the plant establishment and reproductive stages increased the water use efficiency (WUE) compared to applying irrigation water throughout the whole season (Kijne et al.,

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2003). Studies by Fox and Rockstron (2003) indicated that the WUE under farmers' traditional conditions averaged 0.9 kg/mm while the synergy effect of fertilizer application and supplemental irrigation resulted in WUE of 2.3 kg/mm, corresponding to 39% increase. In the Loess plateau of northwest China 45 and 68 mm of supplemental irrigation significantly increased watermelon yields and WUE by 36 and 46% respectively compared to non-irrigated treatment. However, WUE decreased when rainfall increased from 126 to 223 mm (Wang et al., 2004) and larger amounts of irrigation resulted in lower total soluble solids concentration (Sensoy et al., 2007). Watermelon (*Citrullus lanatus*) is a horticultural crop (Dane et al., 2007; Tóth et al., 2007) that provides a high return and has relatively low water requirement compared to other crops (Wang et al., 2004). The crop prefers a hot, dry climate with mean daily temperatures of 22 and 30°C. Maximum and minimum temperatures for growth are about 35 and 18°C respectively (FAO, 2010), making it an excellent crop of choice for the semi-arid areas.

Watermelon is a traditional food plant in Africa (Janick et al., 2007; Gyulai et al., 2011) with potential to improve nutrition, boost food security, foster rural development and support sustainable landcares (NRC, 2008). Small-holder farmers in the semi-arid eastern Kenya grow watermelon, mostly under rain conditions and to a lesser extent supplemental furrow irrigation. However, the yields remain low mainly due to erratic rainfall. For example, in 2007 the yield was a paltry 1.66 Mg/ha (MOA, 2008) compared to the expected 25 to 35 mg/ha in commercial fields (FAO, 2009). Watermelon has critical growth periods when irrigation is a necessity for optimal yield and quality (Hartz, 1997). Water deficit during the establishment period delays growth and produces a less vigorous plant. For example, when water deficit occurs during the early vegetative period, less leaf area is produced which reduces fruit yield. The late vegetative period or vine development stage, the flowering period and the yield formation period (fruit filling) are the most sensitive periods to water deficit. During the ripening period a reduced water supply improves fruit quality. Yields are little affected by water deficits immediately prior to harvest. Within certain water deficit limits, irrigation practices do not greatly affect the number of fruits per plant but affect the fruit size, shape, weight and quality (FAO, 2001). It is recommended that irrigation should take place when, depending on the level of evaporation, the soil water has been depleted some 50 to 70% of plant available water (FAO, 2001).

Past projects of agricultural water management in many semi-arid areas have focused primarily on maximizing rainfall infiltration through soil and water conservation activities. Unreliability of rainfall remains a major challenge to crop production because of water stress during the crucial stages of crop growth. Supplemental irrigation using appropriate methods and crops like watermelon which is adapted to arid and semi-arid climate can provide a suitable strategy for the small- holder farmers to manage water stress and increase crop production, thereby improving the rural livelihood and development. The goal of this study was to use supplemental irrigation to enhance watermelon production in a semi-arid region in Kenya. The objectives were to determine; (1) the effect of the supplemental irrigation and cultivars on watermelon growth, yield, quality and, (2) economic feasibility of watermelon production using supplemental irrigation in semi-arid climate.

MATERIALS AND METHODS

The study was carried out at Marimanti Rural Farmers' Training Centre farm in eastern Kenya. The site lies to the southeast of Mount Kenya between latitude 0°30'N and 0°30'S and longitude 38°E at an altitude of about 800 m. Rainfall is highly variable and unpredictable with a bimodal pattern, characterized by two well-defined rainy seasons that occur from March to June (long rain season, LRS) and from October to November (short rain season, SRS). The mean seasonal rainfall during the SRS and the LRS is approximately 300 and 350 mm respectively. The mean annual temperature is 26.2°C while the annual mean maximum and minimum temperatures are 33.2 and 20.0°C, respectively. The mean annual rainfall of 600 mm constitutes only 40 to 50% of the potential evapotranspiration. The soils are predominantly derived from basement system rocks and are moderately to well drained. The major soils include rhodic Ferralsols, chromic Acrisols and chromic Luvisols (Scholte, 1989). The soil at Marimanti (Kenya) is sandy loam with near neutral reaction in the upper 0.30 m. Some of the soil characteristics at the experimental site are presented in Table 1.

This study was conducted during the SRS in 2008 and the LRS in 2009. The land was ploughed and 60 kg/ha of phosphorus fertilizer applied as TSP at the start of each season. The treatments were arranged in a split-plot complete randomized design with supplemental irrigation methods as the main plots and watermelon cultivars as the minor plots. Furrow, sprinkler, and drip irrigation methods were applied to the main plots. The fourth main plot was not irrigated and served as the control. Two watermelon (*C. lanatus*) cultivars; "Sugar baby and Charleston grey", were grown. Each main plot was divided into two equal sub-plots measuring 4.2 × 7.5 m with three rows of plants spaced 2 m apart and 1 m between plants. Two guard rows that were spaced 2 m apart were planted surrounding each main plot. Treatments were replicated 3 times and 3 m buffer zone separated the irrigation treatments to minimize the effect of treatment on adjacent plots. On 20th September 2008 and 7th March 2009, the two watermelon cultivars were planted for the SRS and LRS respectively. After planting, all plots were irrigated using sprinklers for 2 and 4 weeks before the 1st rainstorm in the SRS and LRS respectively. This was done to minimize chance of crop failure due to the uncertain rainfall in this region, to target higher prices for the watermelon at the beginning of the harvest season and achieve uniform establishment. Kirnak and Dogan (2009) used basal irrigation in a similar experiment to achieve uniform root establishment without water stress.

The daily supplemental irrigation was applied to bring the soil moisture to 60% water holding capacity and it was expressed as the daily volume of water applied through each method divided by the plot area (189 m^2). In both SRS and LRS, the daily supplemental irrigation was 5.7 mm in drip, 48.1 mm in sprinkler and 66.7 mm in furrow irrigation methods. Expressing the daily supplemental irrigation as equivalent rainfall allowed for a quick

Table 1. Soil characteristics at Marimanti (Kenya) during the short rain season (SRS) in 2008 and long rain season (LRS) in 2009.

Season (year)	Depth (m)	pH	TN	OC	P	K	Ca	Mg	Na	CEC	Sand	Silt	Clay	Textural class
			%		cmol$_c$/kg						g/kg			
SRS (2008)	0 - 0.18	6.5	0.04	0.41	36	0.36	4.80	3.22	0.70	14.53	760	100	140	SL
	0.18 - 0. 30	6.4	0.03	0.30	28	0.18	6.80	3.28	0.90	12.40	687	126	187	SL
LRS (2009)	0 - 0.18	7.6	0.05	0.40	144	0.41	3.40	3.51	0.32	14.53	760	100	140	SL
	18 - 0.30	6.4	0.06	0.33	84	0.24	2.40	3.51	0.24	12.40	687	126	187	SL

TN = Total nitrogen, OC = organic carbon, SL = sandy loam.

comparison of the methods assuming that the volume of water applied through each method was from rainfall. Supplemental irrigation was done each fourth day following three consecutive days of drought. Three day-irrigation interval was also used by Kirnak and Dogan (2009) in similar climatic conditions. The drip irrigation system consisted of polyethylene tubes with drip emitters placed at 1 m apart. The drip emitters discharged water at rate of 5 L per h. The sprinklers had orifices of 0.9 mm diameter. They covered a diameter of 4.6 m and were spaced 3.7 m apart in a row. The gross rate of application was approximately 0.41 cm per h. The furrow system consisted of furrows 2 m apart and across the plot in which water was allowed to flow slowly and continuously for about 3 h when all the water had infiltrated. The number of internodes produced in the longest branch per plant during the 5th week was determined by counting. Mature fruits were harvested on 30th November 2008 SRS and on 21st May 2009 LRS, each day in the morning.

Fruits weighing at least 1 kg, not cracked, deformed or affected by disease were considered marketable. Each of these fruits was counted and weighed. In each harvest, three marketable fruits from each replication were analysed for total soluble solids by hand held refractometer and expressed as °Brix. The data were subjected to analysis of variance using the general linear model for a split-plot completely randomized design (Steel et al., 1997) to obtain an F value of the significant effect of the model. Significance of treatment differences was examined using Duncan's new multiple range tests for $P \leq 0.05$. Cost-benefit analysis (Nas, 1996) was done by accounting for total cost as cash expenses for land preparation, seed, fertilizers, pesticides, water and harvesting. gross benefit was the product of fruit yield and the selling price.

RESULTS

There were ten and eleven daily rainstorms during the SRS and LRS respectively. The total rainfall during the two rain seasons was similar: it was 429 mm during the SRS and 478 mm during the LRS. However, the rainfall pattern and distributions showed marked differences (Figure 1). During the SRS, the daily supplemental irrigation was applied seven times in two splits: five applications between 19th September and 4th October and two applications between the first and second daily rainfall on 5th and 18th October. In the LRS, supplemental irrigation was applied 13 times in five splits: Nine applications before the onset of the rains (between 7th March and 3rd April) and once three times and twice one time between subsequent daily rainstorms. The rate of internodes production was determined as an index of the watermelon vegetative growth during the 5th week after planting in both SRS and LRS. The 5th week was chosen because vegetative growth was most vigorous and secondly, all the treatments were in place during this time. The number of internodes varied from 8.67 to 9.33 produced in the main branch during the 5th week under the various supplemental irrigation methods and each cultivar (Table 2). The differences in these numbers was not statistically significant ($P \leq 0.05$) in both SRS and LRS.

The yield components that were studied included the number of fruits produced per plant (Table 3) and the total marketable yield. There were no fruits in the control plots during the SRS; however, in the irrigated treatments during the SRS there were 4 to 6.6 fruits per plant. Cultivars receiving supplemental irrigation by drip produced significantly ($P \leq 0.05$) more fruits than those under either sprinkler or furrow (Table 3). During LRS, the number of fruits in the control plots was significantly ($P \leq 0.05$) low compared to plots receiving supplemental irrigation. The total marketable yield of watermelon per ha is shown in Table 4. In the SRS, the control treatment did not produce any yield. However, in the other plots receiving supplemental irrigation, the yield was significantly higher and between 3.54 and 4.28 Mg/ha. In the LRS, the yield varied from 2.73 in the furrow to 4.95 Mg/ha in the drip treatment. "Charleston grey" when irrigated with furrow method gave the highest total yields, when water deficit occurred in early vegetative growth (in SRS). Likewise, "Sugar baby" yielded most when irrigated with drip. However, when water deficit occurred during the late vegetative growth, flowering period and the yield formation period (as in LRS), it was drip method irrespective of the cultivar that contributed mostly to the increase in

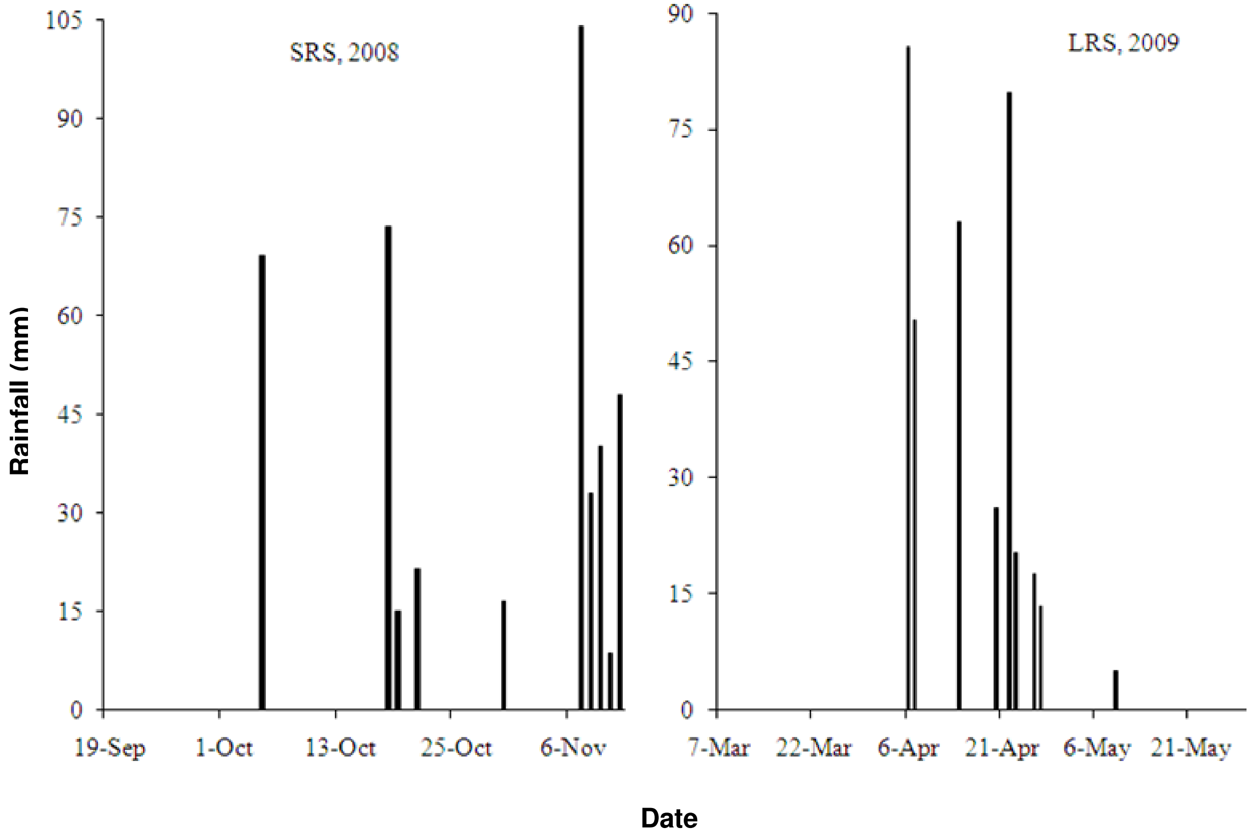

Figure 1. Distribution of daily rainfall for short rain season (SRS) and long rain season (LRS).

Table 2. Supplemental irrigation methods and cultivar effect on internodes formation per branch during the short rain season (SRS) and the long rain season (LRS) during the 5th week after planting.

Treatment	Internodes per vine*	
	SRS	LRS
Supplemental irrigation method		
None	8.67±0.19	9.17±0.18
Drip	9.00±0.19	9.33±0.18
Sprinkler	9.00±0.19	9.33±0.18
Furrow	9.00±0.19	8.83±0.18
Cultivar		
Charleston grey	9.08±0.17	9.08±0.19
Sugar baby	8.75±0.17	9.25±0.19

*Values were not significantly different (P ≤ 0.05).

total marketable yield. The quality of watermelon fruit was determined by measuring the weight of individual fruits and the total soluble solids. The individual fruit weight produced under the various supplemental irrigation methods during the SRS and LRS is shown in Table 5. In SRS, the control treatment did not yield any fruits.

However, all the supplemental irrigation methods increased fruit weight up to 6.07 kg. In the LRS fruit weight was 4 and 7.42 kg in the control treatment and drip supplementary irrigation treatment, respectively. The fruit weight was significantly (P ≤ 0.05) higher in "Charleston grey" than "Sugar baby" for all supplemental irrigation methods when water deficit occurred in early vegetative growth (in SRS). However, when water deficit occurred during the late vegetative growth, flowering period and the yield formation period (as in LRS), and fruit weight was higher in both cultivars when irrigated by drip. Furrow irrigation had the least increase in both cultivars. The soluble solids in °Brix in the watermelon fruits produced under the various supplemental irrigation methods during the SRS and LRS is shown in Table 6. In both SRS and LRS the °Brix was significantly (P ≤ 0.05) different for each supplemental irrigation method. In the SRS, the control treatment did not recover from the effects of the 13-day drought period that occurred in the 3rd week and so the crop withered before maturity (Table 6). However, in the irrigated plots, soluble solids were highest under drip and least in furrow. In the LRS, the crop experienced five drought periods after the 5th week (Figure 1); however, watermelon was able to recover from the effects of drought and survive to maturity. Fruits

Table 3. Supplemental irrigation methods and cultivar effects on fruits produced per plant during the short rain season (SRS) and the long rain season (LRS).

Treatment	Numbers of fruits per plant	
	SRS	LRS
Supplemental irrigation method		
None	0.00±0.00[d]	1.67±0.38[c]
Drip	6.66±0.57[a]	4.67±0.38[b]
Sprinkler	4.00±0.57[b]	7.10±0.38[a]
Furrow	4.83±0.57[ab]	6.10±0.38[a]
Cultivar		
Charleston grey	3.58±0.41[c]	4.92±0.25[b]
Sugar baby	4.17±0.41[c]	4.92±0.25[b]

Different letters following the standard errors in a column show a significant difference between the means (P ≤ 0.05).

Table 4. Effect of the various supplemental irrigation methods and cultivars on the total marketable yield of watermelon during the short rain season (SRS) and the long rain season (LRS).

Treatment	Total yield (mg/ha)	
	SRS	LRS
Supplemental irrigation method		
None	0.00±0.00[c]	2.77±0.41[b]
Drip	4.05±0.38[a]	4.95±0.41[a]
Sprinkler	3.54±0.38[a]	3.84±0.41[ab]
Furrow	4.28±0.38[a]	2.73±0.41[b]
Cultivar		
Charleston grey	4.03±0.24[a]	4.72±0.28[a]
Sugar baby	1.91±0.24[b]	2.42±0.28[b]

Different letters following the standard errors in a column show a significant difference between the means (P ≤ 0.05).

under drip, sprinkler and furrow methods had a significantly (P ≤ 0.05) less total soluble solids than those in the control. A simple cost-benefit analysis was done to assess the economic viability of watermelon production using supplemental irrigation in semi-arid climate. This analysis is presented in Table 7. "Charleston grey" responded well to all the methods tested in the SRS and gave economic yields. However, in the LRS, beneficial response was only in drip supplemental irrigation.

DISCUSSION

During the SRS, rainfall started on 5th October 2008; 14 days after planting. During the following 13 days (~ 2 weeks) there was no rain and supplemental irrigation was applied twice. On 18th October there was 73.5 mm of rain and thereafter daily rainfall became more frequent but decreased in amount until 7th November when a surge of 104.1 mm daily rainfall was recorded followed by a repeating sequence of more frequent but decreasing amount of daily rainfall. In general, the pattern of main peaks of daily rainfall increased with the advance of the SRS. During the LRS, rainfall started on 6th April 2009 which was 28 days (4 weeks) after planting. There were three other extended periods of drought during the LRS when supplemental irrigation was applied. In general, the pattern of main peak daily rainstorms decreased with the advance of the LRS. It was 86 mm on 6th April, 80 mm on 22nd April, and 45 mm on 11th June (Figure 1). During the SRS, the total equivalent rainfall was 40 mm for drip, 337 mm for sprinkler and 466.7 for the furrow methods respectively. During the LRS, the respective total equivalent rainfall was 80 mm for drip, 678.7 mm for sprinkler and 937.1 mm for the furrow methods. The equivalent rainfall that was applied by the drip irrigation

Table 5. Effect of the various supplemental irrigation methods and cultivars on watermelon fruit weight during the short rain season (SRS) and the long rain season (LRS).

Treatment	Fruit weight, kg	
	SRS	LRS
Supplemental irrigation method		
None	0.00±0.00[c]	4.00±0.62[b]
Drip	6.07±0.41[a]	7.42±0.62[a]
Sprinkler	5.32±0.41[a]	5.77±0.62[ab]
Furrow	5.65±0.41[a]	4.1±0.62[b]
Cultivar		
Charleston grey	5.66±0.27[a]	7.01±0.42[a]
Sugar baby	2.86±0.27[b]	3.63±0.42[b]

Different letters following the standard error in a column show significant difference between the means (P ≤ 0.05).

Table 6. Effect of the various supplemental irrigation methods and cultivar on the fruit total soluble solids during the short rain season (SRS) and the long rain season (LRS).

Treatment	°Brix	
	SRS	LRS
Supplemental irrigation method		
None	0.00±0.00[f]	9.58±0.01[a]
Drip	9.10±0.01[a]	9.43±0.01[b]
Sprinkler	8.45±0.01[b]	8.55±0.01[c]
Furrow	7.85±0.01[c]	8.00±0.01[d]
Cultivar		
Charleston grey	5.93±0.02[d]	8.16±0.02[d]
Sugar baby	6.77±0.02[e]	9.63±0.02[a]

Different letters following the standard error in a column show significant difference between the means (P ≤ 0.05).

method was significantly lower while that applied by sprinkler and furrow irrigation methods exceeded the long term annual average for this semi arid area, which is about 600 mm (Jaetzold et al., 2007). From planting to the 1st rainstorm 71 and 64% of the respective total supplemental irrigation was applied in the SRS and LRS. In both SRS and LRS, the amount of the daily rainfall and the total seasonal rainfall were similar but the distribution of the daily rainfall was different (Figure 1). In the SRS there was only one drought period and so supplemental irrigation was applied in two splits. In the LRS, there were four drought periods and supplemental irrigation was applied in five splits.

Consequently, about twice the amount of irrigation water was applied in the LRS compared to the SRS, to mitigate drought as a result of poor distribution of daily rainfall. This study showed that the duration and frequency of drought periods between the daily rainstorms in a rainy season influence the amount of supplemental irrigation water irrespective of the method of application. Moreover, with frequent periods of drought, drip method applied the least amount of water. In this study, all plots including the control were initially irrigated for 2 and 4 weeks in the SRS and LRS respectively. This initial supplemental irrigation most likely contributed to the uniform vegetative growth that was observed (Table 2). Moreover, initial supplemental irrigation has been used in other studies to achieve uniform root establishment without water stress (Kirnak and Dogan, 2009). Nevertheless, it was observed that "Charleston grey" formed more internodes than "Sugar baby" during the SRS while "Sugar baby" formed more internodes than "Charleston grey" during the LRS (Table 2). By the 5th week there was one drought period in the SRS but none in the LRS (Figure 1). Therefore, drought in early vegetative growth phase depressed internodes formation in "Sugar baby" but not "Charleston grey". Conversely, in the absence of drought during the early vegetative growth phase, internodes formation was greater in "Sugar baby" compared to "Charleston grey" (Table 2). It appeared that "Sugar baby" was more responsive to drought than "Charleston grey," although these differences were not significant. In the SRS, supplemental irrigation was applied only once after the first daily rainfall (Figure 1). The crop in the control treatment did not recover from the effects of the 13-day drought period and so no fruits were formed (Table 3). In the LRS, the crop experienced five drought periods after the 5th week, which was within the vegetative growth or the fruit filling period. Watermelon is most sensitive to drought during the late vegetative growth, flowering and yield formation (Hartz, 1997; FAO, 2010). Therefore, the drought periods were responsible for the low number of fruits per plant in the control treatment during the LRS.

The effects of watermelon cultivars on the number of fruits produced were not significant (P ≤ 0.05).

Table 7. Cost-benefit analysis of Charleston grey and sugar baby production.

Season	Supplemental irrigation method	Cost				Benefit	
		Installation	Production	Water	Total	Gross	Net
		US$/ha					
		Charleston grey					
SRS, 2008	None	0.0	1196.5	0.0	1196.5	0.0	(1196.5)
	Drip	333.3	1196.5	100.8	1630.7	2124.0	493.3
	Sprinkler	211.6	1196.5	196.0	1555.2	1912.0	356.8
	Furrow	806.7	1196.5	147.1	2199.2	2412.0	212.8
LRS, 2009	None	0.0	1196.5	0.0	1196.5	1684.0	487.5
	Drip	333.3	1196.5	216.0	1745.9	2452.0	706.1
	Sprinkler	211.6	1196.5	420.0	1723.2	1820.0	96.8
	Furrow	806.7	1196.5	315.1	2423.2	1600.0	(823.2)
		Sugar baby					
SRS, 2008	None	0.0	1196.5	0.0	1196.5	0.0	(1196.5)
	Drip	333.3	1196.5	100.8	1630.7	1112.0	(518.7)
	Sprinkler	211.6	1196.5	147.1	1555.2	924.0	(631.2)
	Furrow	806.7	1196.5	196.0	2199.2	2212.0	12.8
LRS, 2009	None	0.0	1196.5	0.0	1196.5	532.0	(664.5)
	Drip	333.3	1196.5	216.0	1745.9	1504.0	(241.87)
	Sprinkler	211.6	1196.5	315.1	1723.2	1252.0	(471.2)
	Furrow	806.7	1196.5	420.0	2423.2	588.0	(1835.2)

Although the total yields in this experiment are above the 1.6 mg/ha farmers' average in eastern Kenya (MOA, 2008), they were below the expected 25 to 35 mg/ha in commercial fields (FAO, 2009). A possible reason for this discrepancy in this study was the pest and disease attack that made many fruits to rot and fail to meet the market standards. In the SRS, the control treatment did not recover from the effects of the 13-day drought period that occurred in the 3rd week and so the crop withered before maturity (Table 4). In the LRS the crop experienced five drought periods after the 5th week (Figure 1); however, watermelon was able to recover from the effects of drought and survive to maturity. Supplemental irrigation by drip produced the highest yield (Table 4). "Charleston grey" yield was higher than "Sugar baby" (Table 4). Watermelon is commonly irrigated using furrow but under conditions where soils are light textured, drip irrigation has been successfully applied (FAO, 2010). The soil at the experimental site was sandy loam (Table 1). The basic infiltration rate in sandy loam is high and only second to sand (Hillel, 1980). During the SRS, the total equivalent rainfall was 40 mm for drip, 337 mm for sprinkler and 466.7 for the furrow method. During the LRS, the respective total equivalent rainfall was 80 mm for drip, 678.7 mm for sprinkler and 937.1 mm for the furrow method.

Therefore, yield increase was achieved when furrow method applied the largest amount of water compared to the other supplemental irrigation methods in early vegetative growth (in SRS). However, during this time the actual yield increase depended on the cultivar. Sensitivity of yield to water stress by watermelon cultivars was also observed by Ban et al. (2006). In contrast, watermelon prefers dry soils during ripening period (FAO, 2010). So when the water deficit occurred during the late vegetative growth, flowering period and the yield formation period (as in LRS), it was drip method that applied the least water thereby increasing total marketable yields in both "Charleston grey and Sugar baby". These weights were similar to the 4.9 and 10.8 kg obtained by Gusmini and Wehner (2005) at the Horticultural Crops Research Station at Clinton in North Carolina USA for the two cultivars. During the SRS, all supplemental irrigation methods significantly ($P \leq 0.05$) increased the individual fruit weight compared to the control. During the LRS, the fruit weight was highest ($P \leq 0.05$) in the drip treatment compared to the control. The effect of watermelon cultivars on fruit weight were significantly different ($P \leq 0.05$). "Charleston grey" yield was higher than "Sugar baby" in both SRS and LRS (Table 5). Fruit weight was mainly affected by cultivar when water deficit occurred in early vegetative growth. Conversely, when supplemental irrigation was done during the late vegetative growth, flowering period and the yield formation period (as in LRS), it was drip method that caused most of the increase in fruit weight in “Charleston grey and Sugar baby”. Moreover, furrow irrigation caused the least increase in fruit weight in “Charleston grey and Sugar baby”. These findings are consistent with that reported by Fabeiro et al. (2002) and Sensoy et al. (2007), which showed that larger amounts of irrigation water resulted in lower soluble solids concentrations in the plant tissues.

Furthermore, other studies have shown that relatively dry soils are preferred to increase sugar content (FAO, 2010; Cabello et al., 2008). In this study, the furrow treatment supplied the most water to the crop resulting to the lowest total soluble solids compared to the other methods. During the SRS, the total equivalent rainfall was 40 mm for drip, 337 mm for sprinkler and 466.7 for the furrow methods, respectively. During the LRS, the respective total equivalent rainfall was 80 mm for drip, 678.7 mm for sprinkler and 937.1 mm for the furrow methods. “Charleston grey” sugar had significantly ($P \leq 0.05$) less total soluble solids than “Sugar baby” in both SRS and LRS (Table 6). Whether supplemental irrigation is done in early vegetative growth (as in SRS) or in the late vegetative growth, flowering period and the yield formation period (as in LRS), drip method contributed most to the total soluble solids in the fruits. Likewise, furrow method contributed most to the decrease in total soluble solids. During the SRS the total equivalent rainfall was 40 mm for drip, 337 mm for sprinkler and 466.7 mm for the furrow method. During the LRS, the respective total equivalent rainfall was 80 mm for drip, 678.7 mm for sprinkler and 937.1 mm for the furrow method.

Therefore, soluble solids increase was achieved when drip method applied the least amount of water compared to the other supplemental irrigation methods; depending on the cultivar. In contrast, furrow irrigation resulted in the decrease in soluble solids because it applied most water. Indeed it has been observed that watermelon prefers to dry soils during ripening period (FAO, 2010). Supplemental irrigation of “Sugar baby” in both SRS and LRS was not beneficial except under furrow irrigation in the SRS. Studies on economic feasibility of watermelon production using different methods of supplemental irrigation are rare. However, some studies show that drip method can have huge economic benefits especially when N fertilizer is applied (Brees, 2002; Pier and Doerge, 1995).

Conclusion

Growth, yield and quality of watermelon cultivars were found to be affected by supplemental irrigations. Economic yields were achieved in “Charleston grey” using furrow, sprinkler and drip irrigation when water deficit occurred in the early vegetative growth. Drip supplemental irrigation was most suited when water deficit occurred in the late vegetative growth or fruit setting stage. It was not beneficial to produce “Sugar baby” except under furrow when the water deficit occurred early.

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