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OPTIMIZING WATER PRODUCTIVITY, YIELD AND QUALITY OF GRAPEFRUIT IRRIGATED BY BUBBLER AND SURFACE IRRIGATION UNDER KHARTOUM STATE SUDAN CONDITIONS

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ABSTRACT

The experiment was carried out in the private orchards at Tayba Alhasnab area of south Khartoum State, in Sudan during 2012 and 2013 to evaluate the water productivity, yield and quality of foster grapefruit irrigated by bubbler and surface irrigation system. Irrigation interval was 5 days in bubbler irrigation system and every 7 to12 days in surface irrigation system depending on the prevailing weather conditions. The results revealed that higher yield and number of fruits was obtained on bubbler irrigation system compared to surface irrigation system. Moreover, bubbler irrigation system increased the total yield of foster grapefruit by 28% and 25%, respectively as compared to surface irrigation system. Applying irrigated water under bubbler irrigation system improved the quality parameters of foster grapefruit such as fruit diameter recorded significant differences on bubbler irrigation system compared with surface irrigation system in both years, fruit weight and peel thickness recorded significant differences ($P \leq 0.001$) between bubbler irrigation system and surface irrigation system on finger weight, but on differences in peel thickness in both years, total soluble solids of foster grapefruit irrigated by bubbler irrigation system were significantly higher ($P \leq 0.001$) compared with surface irrigation system in both years.

However, bubbler irrigation system saved irrigation water by 68% and 71% and had highest water productivity (2.9 and 2.7 kg/m^3) compared to surface irrigation system (0.67 and 0.68 kg/m^3). Also highest marginal rate of return was obtained with bubbler irrigation system compared to surface irrigation.

Keywords: *grapefruit, Bubbler irrigation, surface irrigation, water productivity, crop evapotranspiration.*

INTRODUCTION

Citrus is an important cash crop in the Sudan. It is one of the major sources of human diet due to its high nutritive value, especially vitamin C (Bedri, 1984). Its cultivation is native to tropical and subtropical regions. Total area of citrus in the Sudan is estimated as 45650 ha (National Horticulture Administration, 2013).

Irrigation is one of the most important factors in the improvement of yield and quality of citrus. Poor irrigation and water stress significantly depress root elongation and reduce fruit number, size and weight (Saeed *et al*., 1990). Bubbler irrigation is a combination of surface and drip irrigation that needs a small basin because the discharge is too high, 50 to 225 liters per hour, to infiltrate. It is usually used for orchard and big trees (Ismail, 2002). Ibrahim *et al*. (2012) reported that bubbler irrigation gave the highest mean values of growth parameters on date palm, while the basin irrigation gave the lowest values. On the other hands, Amiri*et al*. (2007) investigated the response of date palm (cultivar Zahdi) under three irrigation systems: basin, bubbler and sprinkler. They found that the maximum vegetative growth was obtained on bubbler irrigation followed by basin and sprinkler irrigation. The use of modern irrigation systems became essential due to the high demand for water especially in arid and semiarid regions. Modern irrigation systems have some advantages over conventional ones with respect to improved fruit quality, lower labour costs and economic use of irrigation water (Brown, 1999). Research work on proper water managements on fruit trees is very little in the Sudan. Hence, studies on design, implementation and management of water application methods on citrus and other fruits crops are highly needed. The objective of this research work was to optimize the water productivity, yield and quality of foster grapefruit irrigated by bubbler compared to surface irrigation under Khartoum State (Sudan) conditions.

MATERIALS AND METHODS

The experiment was established in a private orchard at Tayba Alhasnab area, Khartoum, Sudan during 2012 and 2013 to evaluate performance of the bubbler irrigation system in comparison with surface irrigation on grapefruit, variety foster. The climate is semi desert with low humidity and daily mean maximum temperature of 40^{o}C in summer and 30^{o}C in winter. Summary of the meteorological data is shown in table (1).

Table 1. Monthly average climatic parameters

Month	Temperature °C		Humidity%	Wind speed Kmday^{-1}	Sunshine hrs
	Max	Min			
January	30.8	15.6	33.9	345.6	9.71
February	33	17	25	388.8	10.67
March	36.8	20.5	18.2	388.8	10.49
April	40.1	23.6	16	345.6	10.86
May	41.9	27.1	19.2	311	10.42
June	41.3	27.3	26.1	345.6	9.78
July	38.4	25.9	46.7	345.6	9.03
August	37.3	25.3	54.8	345.6	8.66
September	39.1	26	42.7	311	9.19
October	39.3	25.5	32	267.8	9.19
November	35.2	21	29.9	345.6	9.67
December	31.8	17.1	35.1	345.6	9.9
Average	**37.1**	**22.7**	**31.6**	**340.6**	**9.8**

The orchard was established in 2008 and trees were transplanted in 1.5 m^2 holes which were filled by silty loam soil with high silt content (68%) and low clay (26.7%). The plot of each irrigation method was containing 3 trees planted at spacing of 7x7 m. The plot size of surface irrigation was 21m length and 4m wide and consisted of 3 parts each one was 4x7m. Treatments were replicated 5 times. Bubblers distributors were installed in the laterals at distances of 7 m apart and one distributor per tree with discharge of 100 lha^{-1}.

The daily meteorological data were recorded during the study period to compute the daily reference evapotranspiration by REF-ET software version 2.0 Allen (2000).

The crop water requirement was calculated according to Allen *et al*. (1998) using the following formula:

$ET_c = ET_o \times K_c$…… (1)

where ET_c is crop evapotranspiration (mm/day), K_c is crop coefficient(was taken from FAO-56 documentation Table 12 (Allen, *et al*., 1998))) ET_o is reference crop evapotranspiration (mmday^{-1}).

The crop water requirement (CWR) for every 5 days in bubbler irrigation was calculated using the following equation:

$CWR = ET_c \times 5$ …… (2)

The overalllosses in discharge at the gross depth (dg) were calculated using the following equation:

$$dg = \frac{ET_c \text{ mm}}{EU} \text{……..} \quad (3)$$

Where EU= emission uniformity (90%).

Volume of water for bubbler irrigation was applied in liter/plant using the following equation:

$V = A \times AW \times dg$…… (4)

Where V -volume of water in liter per plant, A - plant area (row spacing m × plant spacing m), Aw% - wetted area (0.3) and dg - net depth required, mm.

Time of irrigation was calculated using the following equation:

$$\text{Time of irrigation} = \frac{\text{Volume of water to be applied (liter)}}{\text{Bubbler discharge rate } (lha^{-1})} \quad \ldots\ldots\ldots (5)$$

Irrigation was applied every 5 days in the bubbler irrigation system while for the surface irrigation it was applied every 7 to 12 days depending on the prevailing weather conditions. The recommended dose of fertilizer was added by fertigation in bubbler irrigation and applied manually on the surface irrigation. The special horticultural practices were carried out as recommended.

Yield per tree was recorded in tons/fed. Ten fruits were collected randomly for determination of quality such as fruit diameter (cm), fruit weight (g), peel thickness (cm) and total soluble solids (TSS %).

Flowmeter was used for measurement of total water applied in both bubbler and surface irrigation systems.

Water productivity (WP) was calculated using the following equation:

$$WP = Yield/TWA \quad \ldots\ldots\ldots\ldots (6)$$

Where Yield in kg/fed and TWA is total water applied in m^3/fed.

Marginal rate of return was analyzed according to CIMMYT (1988) and used to evaluate the profitability of the bubbler irrigation system in comparison with surface irrigation based on the field information and data collected.

GraphPad statistical package (GraphPad Software, 2014) was utilized for analysis of data and t- test was used for means separation.

RESULTS AND DISCUSSION

Number of fruits per tree and total yield

There were very highly significant differences in the number of fruits per tree and total yield (t/ha) of the foster grapefruit irrigated by bubbler irrigation than those irrigated by surface irrigation in both years (Table 1). The highest yield ranged from 18.33 to 20.47 t/ha under bubbler irrigation system in the two years compared to 14.33 and 16.42 t/ha under surface irrigation. For the bubbler irrigation system, the percentage increase in total yield was equal to 22% and 19% in season one and two, respectively, as compared to the surface irrigation (Table 1). The result revealed that higher yield was produced under bubbler irrigation compared to surface irrigation. Similar results were reported by Hussien *et al*. (2013) on orange who found that trees irrigated by bubbler yielded greater amounts of fruits than those irrigated by surface for two seasons.

Table 2. Number of fruits per tree and yield (ton/ha) of foster grapefruit irrigated by bubbler and surface irrigation.

Irrigation treatments	Number of fruits/tree		Yield ton/han	
	Year 2012	Year 2013	Year 2012	Year 2013
Bubbler irrigation system	167	175	18.33	20.47
Surface irrigation system	137	148	14.33	16.42
$SE^{\pm}$	4.5	5.4	***	***
Significance level	***	***	***	***

*** Significance at P≤ 0.001.

Fruit diameter

The results on fruit diameter showed significant differences under bubbler irrigation system compared with surface irrigation in both years (Table 3). These results are in conformity with those obtained byShashidhara*et al*. (2007).

Table 3. Fruit diameter of foster grapefruit irrigated by bubbler and surface irrigation.

Irrigation treatments	Fruit diameter (cm)	
	Year 2012	Year 2013
Bubbler irrigation system	9.2	10.6
Surface irrigation system	8.9	10.1
$SE^{\pm}$	0.124	0.104
Significance level	*	**

* and ** Significance at P≤ 0.05 and P≤ 0.01, respectively.

Fruit weight and peel thickness

The results showed significant differences (P≤ 0.001) between bubbler irrigation and surface irrigation on finger weight, but on differences in peel thickness in both years (Table 4). The highest fruit weight was obtained under bubbler irrigation system. These results are in agreement with those on orange trees (Hussien *et al*., 2013).

Table 4. Fruit weight and peel thickness of foster grapefruit irrigated by bubbler and surface irrigation.

Irrigation treatments	Fruit weight (g)		Peel thickness (cm)	
	Year 2012	Year 2013	Year 2012	Year 2013
Bubbler irrigation system	540	570	0.70	0.9
Surface irrigation system	510	545	0.65	0.8
$SE^{\pm}$	0.68	2.67	0.05	0.05
Significance level	***	***	NS	NS

*** and NS significance at P≤ 0.001 and not significant, respectively.

Total soluble solids

Total soluble solids of foster grapefruit irrigated by bubbler were significantly higher (P≤ 0.001) compared with surface irrigation in both years (Table 5). This result is in agreement with the findings of El-Gindy*et al*. (2000) who reported that bubbler irrigation system improved the quality of mango fruits compared with gated pipe irrigation system. The best total soluble solids were obtained when muskmelon was irrigated by drip irrigation compared to furrow irrigation system as reported by Bogle and Hartz (1986).

Tab. 5. Total soluble solids of foster grapefruit irrigated by bubbler and surface irrigation

Irrigation treatments	Total soluble solids (%)	
	Year 2012	Year 2013
Bubbler irrigation system	9.0	9.4
Surface irrigation system	8.6	9.0
$SE^{\pm}$	0.09	0.1
Significance level	***	***

***: indicated significance at P≤ 0.001.

Total water applied

The quantity of water applied to foster grapefruit was 6321 m^3/ha and 7586 m^3/ha under bubbler irrigation compared to 21429 m^3/ha and 24000 m^3/ha for surface irrigation in season one and two, respectively (Table 6). Therefore, the percentages of applied water saving by bubbler irrigation system were 71% and 68% for season one and two, respectively, as compared to surface irrigation. Similar results of irrigation water saving by bubbler irrigation system were reported by Hussien*et al*. (2013). They found that bubbler irrigation increased water utilization efficiency (59.4 %) compared to surface irrigation.

Table 6. Total water applied (m^3/ha) on foster grapefruit irrigated by bubbler and surface irrigation.

Month	Bubbler irrigation		Surface irrigation	
	2012	2013	2012	2013
Jan	402	483	1545	1712
Feb	505	605	1743	1950
Mar	605	726	1938	2183
Apr	643	771	2010	2269
May	636	764	1998	2255
Jun	638	767	2002	2262
Jul	517	621	1767	1979
Aug	467	560	1669	1860
Sep	507	610	1748	1955
Oct	495	595	1726	1929
Nov	490	588	1714	1917
Dec	412	495	1564	1736
Total	**6321**	**7586**	**21429**	**24000**

Water productivity

The highest water productivity (2.9 and 2.7 kg/m^3) was obtained on grapefruit irrigated by bubbler irrigation system compared to surface irrigation (0.67 and 0.68 kg/m^3) in both years (Fig.1). These results are in agreement with those reported by Khalifa (2012) and Khalifa *et al*. (2013). Morever, Hussien*et al*. (2013) stated that the maximum water productivity was obtained on orange irrigated by bubbler irrigation compared to surface irrigation.

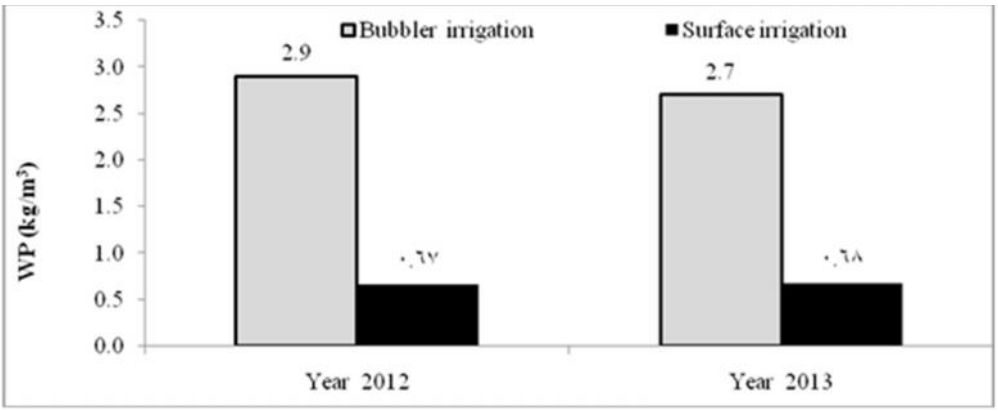

Figure 1. Water productivity (WP) (kg/m3) of foster grapefruit irrigated by bubbler and surface irrigation.

Economic analysis

Economic analysis showed that the bubbler irrigation had the highest net return of (38663.8 SDG/ha) and marginal rate of return 18%, which indicates that every monetary unit (SDG) invested in bubbler irrigation system would be returned back plus additional amount of 0.18 SDG (Table 7). These results are in agreement with those reported by Khalifa (2012) and Khalifa*et al*. (2013). Moreover, Khalifa*et al*. (2014) who found that the highest net returns and benefit cost ratio were obtained in the drip irrigation and the lowest were obtained in the surface irrigation.

Table 7. Marginal analysis of foster grapefruit irrigated by bubbler and surface irrigation.

Treatments	Variable cost (SDG/ha	Marginal cost (SDG/fed)	Net return (SDG/fed)	Marginal net return (SDG/fed)	Marginal rate of return (%)
Surface irrigation	2845.0		29405.0		
Bubbler irrigation	2336.5	-508.5	38663.5	9258.5	18.2

CONCLUSION

- The highest yield and yield components of foster grapefruit were obtained by bubbler irrigation system.
- Bubbler irrigation system increased the total yield of foster grape fruit by 19% and 22%, and saved irrigation water by 68% and 71%, respectively, as compared to surface irrigation.
- The highest irrigation water productivity (2.9 and 2.7 kg/m^3) was obtained on bubbler irrigation and the lowest (0.67 and 0.68 kg/m^3) on surface irrigation.
- The highest marginal rate of return was obtained on bubbler irrigation system.

RECOMMENDATION

Based on the above findings, were commend the use of bubbler irrigation for foster grapefruit production under Khartoum state conditions.

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