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RESPONSE OF MATURE WASHINGTON NAVEL ORANGE TREES TO IRRIGATION SYSTEM CONVERSION: 1. EFFECT ON FLORAL, FRUIT CHARACTERISTICS AND YIELD

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ABSTRACT : During 2003, 2004 and 2005 seasons, 44-year-old flood irrigated Washington Navel orange trees grown in sandy loam soil in Belbis district, Sharkia Governorate were converted to pressurized irrigation using GR (line or ring), microsprinkler, bubbler and drip (line or ring) systems. The tested pressurized irrigation systems supplied the experimental trees with 127.60, 116.21, 68.36 and 54.68 % from the estimated water requirements, respectively, in comparison with the conventional flood irrigation method through which the trees received 130.95 % of their calculated requirements. Trees converted to bubbler and microsprinkler systems and those flood irrigated exhibited the highest yield / tree, number of harvested fruits / tree, cropping efficiency, ratio between leafy inflorescences to both total and leafless ones as well as fruit set and fruit retention percentages in comparison with those converted to trickle irrigation systems. The previous parameters of the trees converted to the tested pressurized irrigation systems were gradually increased with increasing trees adaptation to the new irrigation systems.

Drip line converted trees produced the lowest total and average tree yield over the three-year period as well as the smallest fruit weight and size, whereas the highest corresponding values were recorded for flood irrigated trees, followed by those converted to bubbler and microsprinkler ones. Moreover drip line gave the highest TSS in the first two seasons and TSS / acid ratio in the third

season only. In the final year, water use efficiencies of bubbler, drip ring, microsprinkler and drip line irrigation systems were 51.10, 36.33, 20.81 and 16.13 % higher than that of flood irrigation system, respectively. Overall, results of this work indicated that mature Washington Navel orange trees can be converted to pressurized irrigation systems with minimal effects on yield and fruit quality especially in the first two seasons. Bubbler irrigation system was the best in this respect.

Key words: Citrus, irrigation conversion, microirrigation, cropping efficiency, flood border.

INTRODUCTION

The areas grown with citrus in Egypt have enormously increased through the last few decades, reaching about 359,703 feddans in 2004, most of them; 256,292 fed. (71.3 % of the total citrus acrage) grown in clay soils and usually flood irrigated. The remainder acrage, 103,411 fed. (28.7 %) grown in the newly reclaimed soils and mostly drip or sprinkler irrigated.

Increased competition between agricultural and nonagricultural water users has created a need for more efficient irrigation technologies such as low volume irrigation. Therefore, the current trend in citrus industry is a steady rate of conversion from flood irrigated orchards to microirrigation. Several investigations have shown improved irrigation efficiency with low volume pressurized systems. In addition, trickle-irrigated young trees grew more vigorously than trees irrigated by border flood (Rodney *et al.*, 1977). Records of Walker *et al.* (1991) on citrus and grapes showed that conversions have typically increased yields about 10 – 40 % and enhanced harvest and marketability. Roth *et al.* (1995) indicated that mature Valencia orange trees can be converted to pressurized irrigation systems with minimal effects on fruit yield and quality.

Recently, several microirrigation systems have been developed that deliver relatively small volumes of water at fairly frequent intervals mainly because more limited root volume is wetted, thus minimizing the large diurnal variations in soil and plant water status that commonly occur with flood irrigation (Swietlik, 1992; Spiegel-Roy and Goldschmidt, 1996).

Parsons (1993) recommended that microsprinkler and drip irrigation systems for young and mature citrus trees grown in soils of various textures and water contents should be designed to cover a large area under the tree; tables should be used to determine irrigation frequency and duration, and percolation must be reduced by increasing frequency and decreasing time of irrigation.

With escalating costs and lack of availability of high quality water, microirrigation is becoming widely used throughout the world and will continue to be the method of choice in many citrus growing regions, especially in the newly reclaimed areas (Davies and Albrego, 1994).

In arid or semiarid regions, citrus tree roots are usually concentrated in areas where irrigation water is applied. More than 50% of the root system should be irrigated for mature trees in well – drained, sandy soils (Smajstrla and Koo,1984) .Similarly, Koo and Smajstrla (1985) found that yields of mature Shamouti orange trees were greater when 70 - 90 % of the root zone was irrigated compared with 35%.

However, limited information exist on the performance of mature citrus (Navel orange var.) orchards converted from border-flood to low volume pressurized systems. Therefore, the objectives of this study were to: 1) determine responses of mature orange trees to conversion flood irrigation micro-irrigation systems via their effects on tree yield, fruit characteristics and water use efficiency, and 2) identify the optimum irrigation system and requirements needed to convert flood irrigated mature citrus trees to one of the pressurized micro-irrigation systems.

MATERIALS AND METHODS

The present investigation was carried out in the three successive seasons of 2003, 2004 and 2005 on about 44-year-old Washington Navel orange [*Citrus sinensis* L. Osbeck] trees originally worked on sour orange rootstock. The experimental trees were healthy, approximately uniform in size and vigor and grown in a sandy loam soil at 6 m apart in a private citrus orchard at Belbis district, Sharkia Governorate. The physical and chemical properties of the tested orchard soil and the used irrigation water are shown in Table 1 a, b and c. The orchard had been border-flood irrigated during its entire 44-year history. Fertilization, pruning and control of insects, diseases, and weeds were conducted according to the current commercial recommendations.

The experimental trees received their irrigation water requirements through seven irrigation systems namely:

1. Trickle irrigation using two lateral lines along tree rows (T1) or rings around the trees (T2) with four emitters / tree at 6 l/h flow rate for each dripper.
2. Trickle irrigation using GR laterals (3.5 l/h for each emitter) either along tree rows with two GR laterals / tree row (T3) or rings around the trees (T4).
3. Bubbler basin system with two bubbler heads / tree either was set on one lateral line on opposite sides under the canopy of each tree. Each bubbler head discharged water at 15 l/h. Since this water application rate exceeded infiltration rates. The water was contained inside a dike built around each tree (T5).
4. Microsprinkler (microjet) irrigation with one spray head (Rayjet) 360° / tree set on one lateral line and located under the tree canopy 1 m apart from the trunk base and about 50 cm above the ground. Approximately 75% of the area under the canopy was wetted at a total flow rate of 51 l/h. (T6).
5. Flood irrigation, the traditional irrigation system in the orchard as a control (T7).

Each of the pervious seven irrigation treatments (systems) has been supplied to six Washington Navel orange trees. The necessary flower and fruit samples were obtained from the medium four trees of each irrigation treatment representing four replicates (one tree for each replicate). The first and last tree of each treatment were discarded.

The experimental trees were irrigated for five hours by the pressurized irrigation systems (T1 through T6) daily in hot months (May – Aug.), in each other day in both spring (Mar. and April) and autumn (Sep. – Nov.) months and at two days intervals in winter (Dec. – Feb.). As such, the number of irrigations / year was the same for all treatments and reached 225

Table 1 a : Main physical properties of the orchard soil under the experimental trees during the study*

Depth (cm)	Particle size Distribution (%)			Textural class	Moisture content (%)				Available water (cm)
	Sand	Silt	Clay		Saturation point	Field capacity	Wilting point	Hygroscopic water	
0 - 30	43.3	50.4	6.3	Silty loam	52.3	26.1	13.1	3.6	4.3
31 – 60	60.1	27.3	12.6	Sandy loam	39.8	19.9	9.9	2.3	3.7
61 - 90	62.2	27.3	10.5	Sandy loam	37.8	18.9	9.4	1.8	3.2

Table 1 b : Main chemical constituents of the orchard soil extract under the experimental trees during the study*

Depth (cm)	pH	EC (mmhos/ cm)	Total nitrogen (%)	Organic matter (%)	Cations (meq./L)				Anions (meq./L)			
					Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}
0 - 30	8.35	1.41	0.020	0.50	6.72	2.24	3.56	1.06	Nil	3.80	7.90	2.40
31 – 60	8.63	0.70	0.018	0.17	2.80	1.12	2.35	0.73	Nil	3.20	2.60	1.20
61 - 90	8.59	0.77	0.018	0.15	1.08	2.76	3.12	0.74	Nil	3.00	3.70	1.00

Table 1 c: Main chemical constituents of the used irrigation water during the study*

pH	EC (mmhos /cm)	Equilibrium		Cations (meq./L)				Anions (meq./L)			
		SAR	Water class	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	Cl^{-}
8.6	3.05	9.3	$C_3 S_1$	7.0	2.8	20.5	0.2	Nil	10.0	15.8	4.7

* Average of three studied seasons.

irrigation along each year. The flood irrigated (control) trees received about 25 irrigation / year.

The consumed amount of irrigation water (l/tree /month) along year months through the tested irrigation systems are shown in Table 2.

The theoretical monthly water requirements (m^3/ fed.) were calculated according to Blany and Criddle (1950) equation since ETo = [1.8 x KP (T+18)] where: ETo reference crop evapotranspiration (m^3/fed.) for the month considered, K refers to crop coefficient, P is mean daily percentage of total annual day time hours calculated from the data obtained from a given month and latitude and T is mean daily temperate in °C over the month considered. Water requirements were calculated by multiplying ETo x leaching requirements (L). The theoretical water requirements of orange trees under the orchard conditions reached 5727.4 m^3 /fed./year.

The responses of the applied irrigation treatments on floral and fruit characteristics and yield were evaluated through the following fruiting characteristics of Washington Navel orange trees:

Fruit Set and Fruit Retention Percentages

To determine fruit set, fruit drop and fruit retention percentages along growth season, the emerged flowers on four branches at the different tree directions were counted at the balloon stage by the end of March of each season. After fruit set, the setted fruitlets were counted on the same branches at the end of April (25 – 30 April in the three seasons). Fruit set percentage and consequently the percentage of the dropped flowers (flower drop percentage) were calculated. The remaining fruitlets on the previous branches were counted. Thereafter, the remaining fruits were recounted by the end of December of each season to estimate fruit retention percentage.

At the commercial harvesting date of Washington Navel orange fruits (by the end of December) through each season, the remained fruits on each one tree (replicate) were picked and weighed. The average yield per trees (kg/tree) and the number of fruits / tree were recorded. The cropping efficiency was also calculated by: dividing the fruit yield (kg /tree) by the canopy volume (Whitney *et al.*, 1995). Water use efficiency (WUE) was also calculated by

Table 2: Amount of irrigation water (l / tree / month) applied to Washington Navel orange by the tested irrigation treatments

Month	Pressurized irrigation systems							Flood irrigation	
	Irrigation No.	T1	T2	T3	T4	T5	T6	Irrigation No.	T7
February	10	1200	1200	2800	2800	1500	2550	1	2586.20
March	15	1800	1800	4200	4200	2250	3825	2	5172.40
April	15	1800	1800	4200	4200	2250	3825	2	5172.40
May	30	3600	3600	8400	8400	4500	7650	3	7758.60
June	30	3600	3600	8400	8400	4500	7650	3	7758.60
July	30	3600	3600	8400	8400	4500	7650	3	7758.60
August	30	3600	3600	8400	8400	4500	7650	3	7758.60
September	15	1800	1800	4200	4200	2250	3825	2	5172.40
October	15	1800	1800	4200	4200	2550	3825	2	5172.40
November	15	1800	1800	4200	4200	2250	3825	2	5172.40
December	10	1200	1200	2800	2800	1500	2550	1	2586.20
January	10	1200	1200	2800	2800	1500	2550	1	2586.20
Total (l/tree/year)	225	27.000	27.000	63.000	63.000	33.750	57.375	25	64.655
Total (m^3 / fed.)		3132.0	3132.0	7308.0	7308.0	3915.0	6655.5		7500.0

dividing average yield/tree (kg) (Y) by the amount of irrigation water (m^3) (Q),

$$WUE = \frac{Y}{Q} \ (kg/m^3 \ water)$$

Afterwards, 15 fruits were randomly collected from each replicate to determine the following fruit characteristics : Average fruit weight (g) and size (cm^3), average pulp and peel weights (g), pulp/fruit ratio and peel/fruit ratio. Fruit dimensions [height and diameter (cm)] and fruit shape index (L/D), average peel thickness (mm) and average juice volume / fruit (cm^3) were also determined. Titratable acidity in fruit juice was estimated as citric acid by titration against 0.1 *N* sodium hydroxide solution and the total acidity percentage was calculated as citric acid (A.O.A.C., 1970). Total soluble solids percentage (TSS %) was determined in fruit juice using a hand refractometer. TSS/acid ratio was also calculated. Vitamin C content as mg /100 ml juice was determined in fruit juice by titration against 2, 6–dichlorophenol-indophenol dye (A.O.A.C., 1970).

The obtained data were statistically analysed according to randomized complete blocks design with four replicates and one tree for each replicate. The individual comparisons between the obtained values were carried out using LSD at 5 % level (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

Amount of Applied Irrigation Water

Data in Table 2 show that the tested irrigation systems supplied the experimental trees with different volumes of irrigation water ranging from 27.00 – 64.655 m^3 water / tree / year (54.68 – 130.95 % of the estimated water requirements). Flood irrigated tress received the highest amount of water (64.655 m^3/ tree/year), followed in descendingly order by those converted to trickle system through line or ring GR laterals (63.00 m^3/ tree / year) and microsprinkler one (57.375 m^3 water / tree /year). The previous amounts of water represent 130.95, 127.60 and 116.21 % from the theoretically estimated requirements for flood, GR and microsprinkler systems, respectively. The least volumes of irrigation water were supplied through bubbler (33.75 m^3 water / tree / year) and drip either in line or ring laterals (27.00 m^3 water / tree /year), representing 68.36 and 54.68 % only of calculated water requirements, respectively. The amounts of irrigation water delivered through the tested pressurized systems (GR, microsprinkler, bubbler and drip) were 97.44, 88.74, 52.22 and 41.76 % from those applied through flood irrigation, respectively.

Effect of Irrigation Systems Conversion on Fruit Set and Fruit Retention Percentages and Cropping Efficiency

As shown in Table 3, the tested irrigation systems significantly affected fruit set and fruit retention percentages as well as cropping efficiency of Washington Navel orange trees in the three experimental seasons. However, trees converted to bubbler and microsprinkler systems and those flood irrigated recorded the highest values of the considered parameters in comparison with those converted to trickle irrigation systems, especially GR either through line or ring laterals which gained the lowest percentages of fruit set, fruit retention and cropping efficiency during the three seasons of study. Flood irrigated trees exhibited the highest cropping efficiency in the first two seasons, but in the third one it ranked third after those converted to microsprinkler and bubbler systems. The tested pressurized irrigation systems markedly increased the percentages of fruit set, fruit retention and cropping efficiency of the studied orange cv. from season to another. Since, fruit retention percentage ranged between 0.25 – 1.10, 1.02 – 2.50 and 1.76 – 2.51 % in the first, second and third seasons, respectively. Whereas, those of cropping efficiency ranged between: 0.17 – 0.90, 0.40 – 1.21 and 1.37 – 3.30 in the three seasons, respectively. It is worthy to mention that, fruit retention percentage of flood irrigated Washington Navel orange trees in the third season was 26.06 and 6.66 % lower than those of bubbler and microsprinkler converted trees, respectively. Similarly, cropping efficiency was 6.13 and 26.44 % also lower, respectively. The cropping efficiency of trickle irrigated trees either through line or ring laterals was significantly lower than those of flood irrigated trees in the three seasons due mainly to less ground coverage by irrigation water.

In this concern, Gonzales-Altozano and Castel (1999) subjected 10-year-old Clementine trees to regulated deficit irrigation (RDI) treatments by reducing irrigation requirements to 25 or 50% ETlys (evapotranspiration measured in a weighing lysimeter) either during the whole year or during flowering and fruit set, initial fruit enlargement phase or final fruit growth and maturation phases. They reported that the 25 and 50 levels, in spring, increased fruit drop in June and consequently reduced the number of harvested fruit per tree. Lal *et al.* (2003) revealed that irrigating Kinnow mandarin trees with 80 mm CPE improved fruit setting compared to 0, 160 and 240 mm CPE.

Table 3 : Effect of irrigation system conversion on fruit set, fruit retention and cropping efficiency of Washington navel orange trees (2003, 2004 and 2005, seasons)

Irrigation system	First season (2003)			Second season (2004)			Third season (2005)		
	Fruit set (%)	Fruit retention (%)	Cropping efficiency	Fruit set (%)	Fruit retention (%)	Cropping efficiency	Fruit set (%)	Fruit retention (%)	Cropping efficiency
Drip line	12.81	0.35	0.17	27.22	1.02	0.40	20.50	2.51	1.37
Drip ring	17.42	1.10	0.43	44.71	2.50	0.61	21.65	1.82	1.61
GR. line	8.65	0.34	0.37	28.84	1.65	0.63	22.01	1.79	1.69
GR. ring	4.86	0.27	0.32	30.89	1.51	0.58	20.46	1.94	1.68
Bubbler	19.05	0.81	0.90	37.94	1.96	1.21	29.46	2.08	2.77
Microsprinkler	13.69	0.25	0.44	37.12	2.08	0.90	24.78	1.76	3.30
Flood	16.02	1.19	1.45	36.94	1.78	1.37	24.19	1.65	2.61
L.S.D at 0.05	2.46	0.11	0.12	3.87	0.77	0.19	4.48	0.61	0.83

The effect of irrigation systems on cropping efficiency of citrus trees was of no previous reports in the available literature.

Effect on Inflorescence Types

It is quite evident from Table 4 that, trees converted to drip line irrigation system exhibited the highest ratio between leafless/ total inflorescence numbers and the lowest ratios between leafy and both total and leafless inflorescences throughout the three seasons, due mainly to citrus trees usually tend to produce more leafless inflorescences than leafy ones when subjected to any type of stress, especially water stress. Flood irrigated Washington Navel orange trees produced higher ratios between number of leafy inflorescences and each total and leafless inflorescences and lower leafless/total inflorescences ratio than those produced by pressurized irrigated trees in the first season. This trend was obviously adversed in the second and third seasons after the irrigated trees had been adapted to the new irrigation systems. Leafy/ leafless inflorescences ratio recorded for flood irrigated trees was 56.96 and 37.91 lower than those gained by trees converted to bubbler and microsprinkler irrigation systems. The corresponding percentages for leafy/total inflorescences were 29.93 and 20.69 %, respectively. At contrast, leafless/ total inflorescences ratio for flood irrigated trees was 17.42 and 12.04 % higher than those of bubbler and microsprinkler converted trees, especially in the second season.

As the trees adaptation to the new irrigation systems improved, especially in the third season, the trees tended to produce leafy inflorescences more than leafless ones. On the average of each season, leafless/ total inflorescences ratio in the last two seasons was 24.96 and 50.97 % lower, whereas leafy/ total inflorescences ratio was 37.83 and 50.90 % higher than their values in the first season, respectively. The corresponding percentages for leafy/ leafless inflorescences were 48.44 and 66.88 % higher, respectively.

The effect of irrigation systems on the number of leafy and leafless inflorescences and the ratio between them on citrus trees was of no previous reports in the available literature.

Effect on Yield / Tree

Data in Table 5 clearly show that the average yield / tree as well

Table 4 : Effect of irrigation system conversion on the ratio between leafy/total inflorescences, leafless/total inflorescences and leafy/leafless inflorescences of Washington navel orange trees (2003, 2004 and 2005, seasons)

Irrigation system	First season			Second season			Third season		
	Leafy / total inflorescences (%)	Leafless / total inflorescences (%)	Leafy / leafless inflorescences (%)	Leafy / total inflorescences (%)	Leafless / total inflorescences (%)	Leafy / leafless inflorescences (%)	Leafy / total inflorescences (%)	Leafless / total inflorescences (%)	Leafy / leafless inflorescences (%)
Drip line	20.05	79.95	26.03	31.20	68.80	45.58	53.41	46.60	116.68
Drip ring	27.58	72.42	38.98	38.54	61.46	62.92	51.94	48.06	112.36
GR. line	26.07	73.93	37.73	41.20	58.80	70.33	45.48	54.52	85.53
GR. ring	20.55	79.45	28.15	44.18	55.82	79.46	44.96	55.05	94.36
Bubbler	27.94	72.06	34.90	47.79	52.21	91.62	55.10	44.90	124.73
Microsprinkler	24.84	75.16	33.15	44.39	55.61	80.53	53.77	46.23	128.06
Flood	29.06	70.94	44.72	36.78	63.22	58.39	50.90	49.35	120.19
L.S.D at 0.05	6.64	6.67	8.73	4.32	5.58	8.86	4.96	4.96	9.58

as total and average tree yields over the three-year period were significantly affected by the studied irrigation treatments (systems) in the three seasons of study. However, converting flood irrigated Washington Navel orange trees to the pressurized irrigation systems (drip, GR, bubbler and microsprinkler) slightly shocked the trees until the root system adapted in terms of reducing yield of converted trees in comparing with flood irrigated ones, especially in the first season.

The yield of drip ring converted trees was 62.65, 37.75 and 24.19% higher than those converted to drip line system which produced the lowermost yield/tree throughout the three seasons, respectively in spite of the amount of irrigation water was the same in both systems. The GR ring and line converted trees produced *statistically* similar yields, especially in the last two seasons. Bubbler converted trees produced significantly higher yields than those converted to microsprinkler system in the first two seasons. But in the third season, both treatments produced the highest yield / tree without significant differences between them with the superiority to microsprinkler one. The yield of pressurized irrigation converted trees was match lower in the first season (ranged between 8.74 – 48.01 kg / tree), then increased markedly in the second (28.71 – 84.91 kg / tree) and third season (50.14 – 113.19 kg / tree) seasons, indicating that the converted mature Washington Navel orange trees began to adapte to the new irrigation systems one year after flood irrigation conversion. Furthermore, the yield of flood irrigated trees was 8.60, 3.15 and 2.00 folds that of drip line converted ones in the first, second and third seasons, respectively. Drip line converted trees produced the lowest total and average tree yield over the three-year period, whereas the highest corresponding values were recorded for flood irrigated trees followed in descendingly order by those of bubbler and microsprinkler converted trees. There was a gradual reduction in yield / tree as the amount of water was decreased.

The obtained results are in harmony with those reported by Smajstrla and Koo (1984), Koo and Smajstrla (1985), Khalil *et al.* (2000) and El-Wazzan *et al.* (2001), who cleared that yields of mature Valencia and Washington

Navel orange trees were not affected by the amount of water applied, but were strongly related to the application methods. The spray irrigation systems which covered 28 – 51 % of the area under the tree canopy increased yields by 65% compared with nonirrigated controls, whereas drip system which irrigated 5 – 10 % of the canopy area increased yields by 41 – 44 %. The increase in yield was directly related to the increase in ground coverage by the irrigation treatments. Also, Germana *et al.* (1994) and Intrigliolo *et al.* (2000) found that yield of mature Valencia orange trees was higher with drip ring than with the line system and with five drippers than with three where the largest soil area was wetted. Kanber *et al.* (1996) reported that trickle or micro-sprinkler systems increased yields of Washington Navel orange trees, but this increment was significantly higher with sprinkler than drip irrigation. This trend was traced by several workers on different citrus species and varieties. (Zekri, 1989; Eliades, 1998; Daneshnia and Rastegar, 1998; Firoz *et al.*, 1999; Foguet *et al.*, 1999; Manjunatha *et al.*, 2000 and Shirgure *et al.* (2003).

At contrast, several authors working on different citrus species and varieties demonstrated that drip irrigated trees at full rate gave larger fruits and higher yields compared with flood or microsprinkler irrigated ones (Kumar and Bojappa (1994); Pankaj-Barua *et al.*, 2000; Satyendra-Kumar *et al.*, 2003 and Subhas-Balaganvi and Kumathe, 2004).

Meanwhile, several studies demonstrated that microirrigation uses less water than flood or sprinkler irrigation systems without compromising tree yield (Swietlik, 1992 and Roth *et al.*, 1995). Hutton (2000) stated that no significant reduction in yield of mature Navel orange trees was obtained when irrigation input was reduced by up to 65 % of district averages by changing flood irrigation to trickle irrigation.

Effect on Number of Harvested Fruits / Tree

It is clear from Table 5 that, irrigation conversion treatments significantly affected the number of harvested fruits / tree in three seasons. This effect followed similar trend to that of yield / tree. Drip line converted trees gave the least number of fruits / tree in the three seasons, whereas the highest fruit number / tree was recorded for flood irrigated trees in the first two seasons, followed by bubbler and microsprinkler converted trees, which produced the highest fruit number / tree in the third season. Drip ring converted trees exhibited significantly higher number of fruits / tree than those of drip line converted ones throughout the three seasons, in spite of using equal amounts of irrigation water in both, which represent the least amount of irrigation water among the tested systems (41.76 % only from those of flood irrigation). GR converted trees followed similar trend, especially in the last two seasons. Bubbler and microsprinkler converted trees produced higher number of fruits / tree than the other tested pressurized systems in the three seasons, with the superiority for bubbler in the first two seasons only. The average number of fruits / tree produced by the pressurized irrigation systems increased gradually for years 1 through 3, reaching its maximum value at the third season after the trees had been adapted to the new irrigation systems.

These findings are in agreement with those reported by Chartzoulakis *et al.* (1999), Gonzalez-Altozano and Castel (1999) who reported that the yield reduction at lower irrigation rates was accounted for increasing fruit drop and consequently reduced the number of harvested fruits per tree. Also, Pankaj-Barua *et al.* (2000) on lemon and Lal *et al.* (2003) on mandarin cleared that number of fruits per Assam lemon and Kinnow mandarin trees were significantly better with drip irrigation compared to rainfed or non-irrigated trees.

Effect on Fruit Weight and Size and Pulp Weight

As shown in Tables 5 and 6, fruit weight and size of Washington Navel orange trees significantly responsed to the tested irrigation systems in the three seasons. The smallest fruit weight and size were produced by drip line converted trees in the first two seasons and GR ring converted ones in the third one. The largest corresponding values were recorded for flood irrigated trees, followed in descendingly order by bubbler and microsprinkler converted trees in

Table 5 : Effect of irrigation system conversion on yield (kg / tree) and yield components of Washington navel orange trees (2003, 2004 and 2005 seasons)

Irrigation system	First season (2003)				Second season (2004)				Third season (2005)				Total and average tree yield over the three years (kg /tree)	
	Yield / tree (kg)	No. of fruits / tree	Fruit weight (g)	Water use efficiency (W.U.E)	Yield / tree (kg)	No. of fruits / tree	Fruit weight (g)	Water use efficiency (W.U.E)	Yield / tree (kg)	No. of fruits / tree	Fruit weight (g)	Water use efficiency (W.U.E)	Total	average
Drip line	8.74	72.25	120.97	0.32	28.71	127.50	225.37	1.07	50.14	213.50	234.67	1.86	87.59	29.20
Drip ring	23.40	137.25	170.55	0.87	46.12	201.25	229.15	1.71	66.14	297.00	222.90	2.45	135.63	45.21
GR. line	25.05	125.50	199.59	0.40	56.01	237.50	235.78	0.89	88.51	384.50	226.09	1.41	169.57	56.53
GR. ring	19.84	100.50	197.45	0.32	57.23	252.50	226.85	0.91	92.74	443.00	209.50	1.47	169.81	56.60
Bubbler	48.01	234.50	204.73	1.43	84.91	329.75	257.65	2.54	107.42	460.50	232.99	3.19	240.37	80.12
Microsprinkler	24.73	127.00	194.76	0.43	75.56	298.75	252.44	1.32	113.19	494.25	229.00	1.97	213.47	71.16
Flood	75.18	339.00	221.70	1.16	90.50	330.00	274.50	1.40	100.52	430.00	233.87	1.56	266.19	88.73
L.S.D at 0.05	3.06	9.15	10.92	0.07	3.59	14.22	12.87	0.09	10.23	28.24	12.83	0.21	10.78	3.59

Table 6 : Effect of irrigation system conversion on physical characteristics of Washington Navel orange fruits (2003, 2004 and 2005, seasons)

Irrigation system	Fruit characteristics				Pulp fresh weight (g)	Peel thickness (mm)	Juice volume (cm³)
	Size (cm³)	Length (cm)	Diameter (cm)	Fruit shape index (L/D)			
First season (2003)							
Drip line	141.00	5.71	6.01	0.95	89.61	4.37	68.00
Drip ring	193.75	6.06	6.32	0.96	124.96	4.46	96.50
GR. line	238.85	7.53	7.36	1.03	149.64	4.38	109.75
GR. ring	226.88	7.42	7.39	1.01	146.93	4.54	117.50
Bubbler	234.50	7.47	7.48	1.00	161.57	4.48	122.50
Microsprinkler	221.00	7.41	7.52	1.03	150.61	4.00	106.75
Flood	240.58	7.59	7.50	1.02	157.05	4.94	127.00
L.S.D at 0.05	10.57	0.44	0.29	0.07	9.04	0.41	11.90
Second season (2004)							
Drip line	220.67	7.41	7.31	1.01	160.74	3.93	111.00
Drip ring	225.00	7.62	6.69	1.02	158.29	2.48	106.75
GR. line	260.00	8.17	7.69	1.03	189.47	3.73	126.75
GR. ring	256.50	8.02	7.71	1.04	184.03	3.40	125.50
Bubbler	285.17	8.27	7.62	1.09	202.75	3.60	147.50
Microsprinkler	279.00	7.98	7.82	1.06	196.82	4.08	141.75
Flood	291.83	8.15	7.78	1.05	205.56	3.88	132.50
L.S.D at 0.05	10.32	0.43	0.86	0.05	9.62	0.39	8.26
Third season (2005)							
Drip line	245.00	7.92	7.61	1.04	187.12	3.28	144.75
Drip ring	234.08	7.73	7.51	1.03	174.04	3.45	124.75
GR. line	242.50	7.74	7.52	1.03	172.39	3.80	129.50
GR. ring	208.50	7.48	7.32	1.02	154.00	3.90	111.25
Bubbler	252.25	7.83	7.66	1.02	182.16	3.70	131.50
Microsprinkler	244.00	7.92	7.63	1.04	173.55	4.05	128.50
Flood	249.35	7.79	7.68	1.02	183.29	3.95	133.25
L.S.D at 0.05	9.66	0.40	0.28	NS	8.45	0.45	6.91

the three seasons due mainly to adequate amount and efficient distribution of irrigation water. GR converted trees produced fruits with larger weight and size than drip converted ones, especially in the first two seasons. Drip line converted trees, in the third season, gained comparable fruit weight and size to those of flood irrigated ones.

These results are in line with those reported by Zekri (1989) who found that fruit size and weight of 21-year-old Marsh grapefruit trees was 9 to 20 % greater in the overhead sprinkler treatment than in the corresponding drip or non-irrigated treatments. Responses to microsprinkler were intermediate between the overhead sprinkler and the drip treatments. With mature trees, irrigation systems providing greater soil area coverage gave better fruit growth than systems providing less soil coverage. Fruit size was the most sensitive quality indicator of poor irrigation practices. Several investigators working on different citrus species and cultivars reported the same trend (Josan *et al*., 1993 on Baramassi lemon trees; Eliades, 1998 on Washington Navel orange trees; Hutton, 2000 on mature Navel orange trees).

In addition, Germana *et al.* (1994) reported that fruit size of mature Valencia orange trees was higher with the ring than with the line drip system.

The highest and the lowest weights of fruit pulp were recorded for bubbler and drip irrigation systems, respectively. Weight of fruit pulp produced by bubbler converted trees was 22.66, 21.93 and 4.46 % higher than those of drip ring converted ones in the first, second and third seasons, respectively. In this respect, GR (ring or line) converted trees came in between. Flood irrigated trees gained higher pulp weight without significant difference with those of bubbler converted trees in the three seasons.

In this concern, Kumar and Bojappa (1994) irrigated Sathgudi orange trees with drip irrigation at 6 l / tree daily with one emitter (T1) or 2 emitters (T2) and at 12 l / tree daily with 1 emitter (T3) or 2 emitters (T4) in comparison with flood irrigation with 250 l/ tree at fortnightly intervals. They stated that drip irrigated trees produced fruits with a significantly higher pulp weight compared with those of flood irrigated ones.

Effect on Water Use Efficiency (W.U.E)

It is evident from Table 5 that WUE the highest and the lowest water use efficiencies were recorded for bubbler and GR converted trees either through line or ring laterals in the three seasons, respectively. In the third season, water use efficiency was 3.19, 2.45, 1.97, 1.86 and 1.56 kg fruits / m^3 water for bubbler, drip ring, microsprinkler, drip line and flood irrigation systems, respectively. Line irrigation systems either through drip or GR laterals induced lower water use efficiency than ring system of both methods in the three seasons. In the final season, water use efficiency of bubbler, drip ring, microsprinkler and drip line irrigation systems were 51.10, 36.33, 20.81 and 16.13 % higher compared with flood irrigation systems, respectively. Water use efficiency of the tested pressurized irrigation systems was low in the first season (ranged between 0.32 – 1.43 kg fruit / m^3 water), intermediate in the second season (0.89 – 2.54 kg fruit / m^3 water) and high in the third one (1.41- 3.19 kg fruit / m^3 water). This gradual increment in water use efficiency was parallel to the gradual adaption of the trees to the new irrigation systems.

These findings are in harmony with these obtained by Kumar and Bojappa (1994), Roth *et al.* (1995), Kanber *et al.* (1996), Intrigliolo *et al.* (2000) and Satyendra- Kumar *et al.* (2003). Their, working on different citrus species and cultivars, reported that water applied by drip irrigation was used more efficiently. Since, water use efficiency was 4.50 – 6.56 kg fruit / m^3 water with trickle irrigation, compared with 1.6 kg fruit m^3 only with sprinkler irrigation. The most economically profitable system was under-tree sprinkler irrigation. Shirgure *et al.* (2003) evaluated the effect of drip, microjet 300 and microjet 180 degrees in comparison with basin irrigation and found that the highest water use efficiency was recorded for microjet 180 system, followed by microjet 300 degrees, drip and basin methods of irrigation.

Effect on Fruit Dimensions and Fruit Shape Index

Data in Table 6 show that fruit length, diameter and fruit shape index were significantly affected by the tested irrigation treatments in the three seasons, except fruit shape index in the third one. Drip line or ring converted trees produced fruits with smaller dimensions than other irrigation systems which exhibited higher fruit length and diameter without significant differences between them in the three seasons. Irrigation system which increased the wetted area led to increase fruit length and thereby produce fruits with more spherical shape than those of less area coverage such as drip systems.

These results are in partly parallel with those reported by Germana (1994) and Foguet *et al.* (1999) who cleared that fruit dimension increased by frequent irrigation.

Effect on Peel Thickness

Peel thickness of Washington Navel orange fruits was significantly affected by the tested irrigation systems, but this effect did not follow constant trend during the three seasons (Table 6). Since, peel thickness sometimes increased with irrigation systems delivering small amounts of irrigation water such as drip line or ring systems, especially in the third season. Moreover, peel was thick in the first season, through which the trees did not completely adapte to the new irrigation systems in comparison with the last two seasons. So, peel thickness was ranged between 4.00 – 4.94 mm, 2.48 – 4.08 mm and 3.28 – 4.05 mm in the first, second and third seasons, respectively. This trend was reported by Kumar and Bojappa (1994) and Eliades (1998) who stated that peel thickness tended to increase with decreasing amount of water applied. Nevertheless, flood and microsprinkler irrigation systems which deliver high volume of water increased peel thickness, especially in the last two seasons. In this respect, Foguet *et al.* (1999) irrigated Valencia orange trees with drip or microsprinkler systems in comparison with no irrigation and found that rind thickness was increased by irrigation. Meanwhile, Roth *et al.* (1995) after evaluating the performance of mature Valencia orange trees converted to pressurized irrigation systems, i.e. trickle, bubbler, spray and sprinkler, reported that differences in peel thickness due to irrigation treatments were minimal.

At contrast, Nakhla *et al.* (1998) irrigated Washington Navel orange trees with four annual irrigation rates (1500, 3000, 4500 or 6000 m^3 / feddan) and reported that rind thickness was not affected.

Effect on Juice Volume/Fruit

It is clear from Table 6 that the tested irrigation systems significantly affected juice volume / fruit in the three seasons. Drip converted trees either through line or ring laterals which delivered the lowest amount of irrigation water, induced the least juice volume / fruit, especially in the first two seasons in comparison with other studied irrigation systems. This indicate that juice volume / fruit decreased with decreasing amount of irrigation water and vice versa. These results were confirmed with those of Josan *et al.* (1993) on Baramassi lemon, Nakhla *et al.* (1998) on Washington Navel orange.

Moreover, at the third season, drip line converted trees exhibited significantly higher juice volume / fruit than flood irrigated ones, whereas those converted to GR line, bubbler and microsprinkler irrigation systems induced statistically similar juice volume / fruit to those of flood irrigated ones.

These findings are in line with those reported by Kumar and Bojappa (1994), Foguet *et al.* (1999) and Subhas-Balaganvi and Kumathe (2004) who declared that drip irrigated trees produced fruits with significantly higher juice content compared with flood irrigated trees. Shirgure *et al.* (2003) reported that juice percentage of Nagpur mandarin and acid lime fruits was significantly superior in microjet 180 and microjet 300 degrees compared to those of drip and basin irrigation systems.

Meanwhile, Chartzoulakis *et al.* (1999) stated that fruit juice content of Bonanza orange trees, grown under different soil water potentials (- 0.01, - 0.05 and – 1.5 MPa), was not affected by the soil water regime.

Juice volume of Washington Navel orange fruits ranged between 68.0 – 127, 106.75 – 147.50 and 111.25 – 144.75 cm^3/ fruit in the first, second and third seasons, respectively. On the average, the juice volume / fruit in the first season was markedly lower, then increased during the last two seasons after the trees had been adapted to the new irrigation systems.

Effect on TSS, Total Acidity Percentage, TSS / Acid Ratio and Vitamin C Content

The obtained data in Table 7 clarify the effect of irrigation system conversion on TSS, total acidity (%), TSS / ratio and Vit. C content of Washington Navel orange fruits.

In a general, tested irrigation conversion treatments significantly affected chemical fruit quality of Washington Navel orange trees in terms of TSS and total acidity percentages as well as TSS / acid ratio and Vit. C content in the three experimental seasons but the trend of this effect was different from season to another. Since, the percentages of TSS and total acidity in fruit juice were gradually reduced for years 1 through 3 when the trees became more adapted to the new irrigation systems, whereas TSS / acid ratio was gradually increased through the same period due mainly to marked reduction in juice total acidity percentage in the final year. Drip line and ring converted trees exhibited TSS percentage 27.17 and 5.56 % and 16.45 and 1.83 % higher than those of flood irrigated ones in the first and second seasons, respectively. Percentages of total acidity were also 42.85 and 28.57 % and 50.00 and 35.71 % higher than those of flood irrigated trees in the same tow seasons, respectively. The corresponding values of TSS / acid ratio for drip line and ring converted trees were 17.10 and 21.34 and 29.63 and 29.43% lower in the tow seasons, respectively. This means that both TSS and total acidity percentages in fruit juice were markedly increased, while TSS / acid ratio was reduced with decreasing the amount of irrigation water in the first two seasons.

These results were confirmed by those of Josan *et al*. (1993), Foguet *et al*. (1999), Chartzoulakis *et al*. (1999) and Khalil *et al*. (2000). They working on several citrus species reported that the levels of soluble solids, acidity and sugars in the fruit juice decreased in the treatments that used more water, mainly because a dilution effect. In other words, the fruits of the stressed trees had higher sugar and acid content, whereas TSS / acid ratio and ascorbic acid content were positively correlated with quantity of irrigation water.

At contrast, Chartzoulakis *et al*. (1999) drip irrigated Bonanza orange trees when soil water potential reached -0.01, -0.05 and -1.5 MPa and declared that vitamin C content was not affected by the soil water regime.

Table 7 : Effect of irrigation system conversion on TSS, total acidity (%), TSS/ratio and Vit. C content of Washington navel orange fruits (2003, 2004 and 2005, seasons)

Irrigation system	First season (2003)				Second season (2004)				Third season (2005)			
	T.S.S. (%)	Total acidity (%)	T.S.S./ acid ratio	Vit.C. (mg/ 100 ml)	T.S.S. (%)	Total acidity (%)	T.S.S./ acid ratio	Vit.C. (mg/ 100 ml)	T.S.S. (%)	Total acidity (%)	T.S.S./ acid ratio	Vit.C. (mg/ 100 ml)
Drip line	16.38	0.20	82.24	75.66	14.38	0.18	79.88	52.42	12.88	0.11	123.13	59.50
Drip ring	15.00	0.21	74.27	62.66	13.88	0.19	74.89	68.87	12.88	0.12	108.05	57.80
GR. line	12.38	0.15	84.10	62.01	13.13	0.18	75.64	66.04	12.63	0.12	108.04	60.52
GR. ring	14.00	0.18	80.17	61.02	14.38	0.16	91.14	65.42	13.75	0.15	95.24	65.28
Bubbler	13.50	0.15	90.00	65.33	13.38	0.19	73.21	66.03	12.63	0.13	100.18	57.12
Microsprinkler	13.63	0.15	89.90	64.97	13.38	0.17	83.28	64.07	13.13	0.12	109.58	60.86
Flood	12.88	0.14	96.28	69.51	13.63	0.14	96.93	58.90	13.38	0.14	101.53	57.72
L.S.D at 0.05	1.25	0.03	7.62	3.41	0.89	0.04	14.32	4.97	0.78	0.01	10.75	6.98

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إستجابة أشجار البرتقال بسره واشنجطون البالغة لتغيير نظام الري

١ – التأثير علي الصفات الزهرية والثمرية والمحصول

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أجريت هذه الدراسة خلال ثلاثة مواسم متتالية (٢٠٠٣، ٢٠٠٤، ٢٠٠٥) علي أشجار برتقال بسره واشنجطون عمر ٤٤ سنة ومنزرعة في تربة رملية طميية بمركز بلبيس بمحافظة الشرقية. والتي تم تغيير نظام ريها بالغمر إلي الري الدقيق عن طريق الري بالتنقيط باستخدام خراطيم GR الخطي أو الحلقي، الرش الدقيق، البابلر أو التنقيط باستخدام خراطيم عادية (خطية أو حلقية). وقد أمدت هذه الطرق أشجار التجربة بكميات مياه تعادل ١٢٧,٦٠، ١١٦,٢١، ٦٨,٣٦، ٥٤,٦٨ % من الاحتياجات المائية المقدرة بمعادلة بلاني وكردل تحت

الظروف البيئية للمنطقة علي التوالي، بالمقارنة بالأشجار التي تروي بالغمر بكمية تعادل ١٣٠,٩٥ % من الأحتياجات المائية المقدرة ، وفيما يلي أهم النتائج:

- أعطت الأشجار التي تم تغييرها إلي نظامي البابلر و الرش الدقيق وتلك التي رويت بالغمر أعلي محصول وعدد ثمار/ شجرة ، وأعلي كفاءة إنتاج ، وأكبر نسبة بين النورات الورقية وكل من النورات الكلية وغير الورقية، وأعلي نسبة للعقد والثمار المتبقية، بالمقارنة بمثيلتها التي تم تغييرها إلي الري بالتنقيط.
- زادت الخصائص السابقة للأشجار التي تم تغيير ريها إلي نظم الري الدقيق تحت الدراسة تدريجيا بزيادة تأقلم الأشجار علي النظم الجديدة للري.
- أنتجت الأشجار التي تم تغييرها إلي الري بالتنقيط الخطي أقل كمية للمحصول ومتوسط محصول/ شجرة خلال فترة المواسم الثلاثة وكذا أقل وزن وحجم للثمرة، في حين سجلت أعلي القيم للصفات السابقة للأشجار التي رويت بالغمر تلتها الأشجار التي تم تغييرها إلي نظامي البابلر والرش الدقيق، بالإضافة إلي ذلك أعطي التنقيط الخطي أعلي نسبة TSS في الموسم الأول والثاني ، وكذلك TSS / acid ratio في الموسم الثالث فقط.
- خلال الموسم الثالث، كانت كفاءة استخدام الماء لنظم البابلر والتنقيط الحلقي والرش الدقيق والتنقيط الخطي ٥١,١٠ ، ٣٦,٣٣ ، ٢٠,٨١ ، ١٦,١٣ % أعلي عن مثيلتها للري بالغمر علي التوالي.
- تشير نتائج هذه الدراسة أنه يمكن تغيير نظام ري أشجار البرتقال بسره واشنجطون التي تروي بالغمر إلي أحد نظم الري الدقيق مع وجود تأثيرات محدودة علي المحصول وجودة الثمار خاصة خلال السنتين الأولي والثانية فقط، وقد حقق الري بالبابلر أفضل النتائج في هذا الصدد.