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Evaluating Water-stress as Flowering and Fruiting Stimulus to Sweet Orange (*Citrus sinensis*. L) in Tropical Conditions

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Abstract

This study aimed to find out the optimum water stress period to induce rest as stimulus after which irrigation should be resumed to obtain flowering and best fruit yield for sweet orange. The experiment was conducted at Kitayab, AlRaw and Central Zeidab Schemes in River Nile State, Sudan during 2014/15 and 2015/16 seasons. Mature orange trees (local Sinnari cultivar) grafted on sour orange root stock from farms where basin irrigation and different irrigation stopping periods after harvest were practiced. Nine trees spaced at 7×7 m. and with at least 10 years' age, were randomly selected for experimentation in four sites. The soil at the experimental sites is mostly homogenous representing Nile fluvent sediments of entisols with loamy to clay loam texture. The experimental design was randomized complete block design (RCBD) with three replicates. The periods for irrigation stress after harvest and before the new flowering season were 2, 3, 4, 5, 6, 7, 8 and 9 weeks. All intervals ending at the onset of winter season. Parameters taken were: time of flowering, number of flowers/ squire meter, number of fruits/tree, number of dry branches/tree, difference in maturity/tree as percentage of mature fruits over others. Results obtained indicated that early flowering noticed after 9 weeks of irrigation stress compared to short periods. Number of flowers per a square meter increased in both seasons by increasing irrigation-stress period. Irrigation stress period affected significantly number of fruits per tree in both seasons, but not following the same trend of number of flowers per square meter. In both seasons, the highest number of fruits was registered by 3-week dry period treatment. Increasing irrigation-stress period increased dry branches per tree and differences in fruit maturity.

Keywords: Sweet orange, flowering stimulus, water stress period, tropical conditions

تقييم الاجهاد المائي كمحث لإزهار واثمار البرتقال في ظروف المناطق المدارية

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المستخلص
هدفت هذه الدراسة لإيجاد الفترة المناسبة لا يقاف الري والتي يمكن بعدها ان تزهر شجرة البرتقال لإعطاء انتاجية جيدة من الثمار. استخدم الصنف سناري من البرتقال المطعوم على اللارنج في موسمي 15/2014 و 16/2015 بمناطق مشاريع الكتياب ووسط الزيداب والراو بولاية نهر النيل. يستخدم المزارعين الري الغمري بالحياض مع فترة تعطيش قبل موسم الازهار. تم اختيار تسعة من الاشجار المسافة بينها 7X7 متر بعمر عشرة اعوام في الأقل بكل من المناطق الاربع في تربة متجانسة تمثل الطمي و طمي الطين النيلي. استخدم تصميم المربعات كاملة العشوائية لثلاثة مكررات لتنفيذ التجربة. فترة التعطيش بعد الحصاد وقبل بداية موسم الازهار الشتوي كانت 2، 3، 4، 5، 6، 7، 8 و9 اسابيع لتنتهي كلها مع دخول الموسم الشتوي. القراءات المأخوذة تمثلت في الفترة حتى الإزهار، عدد الأزهار في المتر المربع، عدد الثمار في الشجرة، عدد الافرع الجافة في الشجرة، الفروق النسبية في نضج الثمار. أوضحت النتائج ان الإزهار الابكر نتج عن فترة التسعة اسابيع من ايقاف الري مقارنة مع الفترات القصيرة. عدد الأزهار في الموسمين زاد بزيادة فترة الاجهاد المائي و اثرت هذه الفترة معنويا على عدد الثمار في الشجرة في كلا الموسمين، ولكن لم تكن مماثلة لنمط التزهير في المتر المربع. أعلى انتاجية للثمار نتجت عن فترة الاجهاد المائي (التعطيش) لثلاثة اسابيع، كما نتج عن فترات الاجهاد المائي الطويلة زيادة في عدد الأفرع الجافة بالشجرة وزيادة في الفروق بنسبة نضج الثمار.
كلمات مفتاحية: البرتقال، محثات الإزهار، الاجهاد المائي ، البيئات المدارية.

Introduction

Sweet orange (*Citrus sinensis*) is the most important trading species of family *Rutaceae* and the genus Citrus. Most of citruses grow in the world between latitudes 20- 40 north and south where flowering is controlled by seasonal change in temperature degrees. The total world production is about 51.8 million metric tons (USDA, 2019). Citrus is very important for human health, rich in ascorbic acid and other antioxidants such as carotenoids and phenolic compound. It has may nutritional and medicinal benefits (Yarkwan and Oketunde, 2016).

Sweet orange (*Citrus sinensis*) is a perennial tree crop that displays a very strange reproductive behavior. Regulation of fruit bearing in citrus is of complicated nature depending upon many internal and external factors that may interact or act individually. The mechanisms whereby endogenous and environmental stimuli affect reproductive growth are fully discussed by researchers to provide knowledge that allow optimizing flowering and fruit set (Banuet, 2001; Zhang *et al*., 2018).

Citrus species usually exhibit tremendous flowering over season. This floral behavior depends on the cultivar, tree age, environmental conditions, nutritional status and crop management practices (Monselise, 1986; Iglesias *et al*., 2007). Sweet orange (*Citrus sinensis*) may develop 250,000 flowers per tree in a bloom season although only a small amount of these flowers (usually less than 1%) becomes mature fruit (Erickson and Brannaman, 1960; Goldschmidt and Huberman, 1974). Thus, flowering behavior for citrus trees represents, as described by some researchers, as a waste of resources. However, this reproductive pattern may be linked to a survival strategy (Bustan *et al*., 1995; Bustan and Goldschmidt, 1998).

Citrus trees require a reasonable water management and a balanced nutrition to provide good yield in quality and quantity. Sufficiently irrigated and served trees grow stronger, with adequate tolerance to stresses, consequently giving more yield with good quality fruits. On the other hand, deficiency levels of these important production inputs will result in low fruit yield with poor quality.

In subtropical regions, where citruses are usually grown, flowering occurs during the spring flush along with the vegetative sprouting. Under such environments, flowering takes place after a period of bud dormancy and on exposure to low temperatures and short days of winter after which flower bud induction is stimulated in a time dependent manner. In tropical environment, as in Sudan, these conditions prior to flowering are not as ideal as in subtropical regions, citrus flowers in response to re-hydration after a period of water deficit rather than with low temperature stimuli (Banuet, 2001; Iglesias *et al*., 2011).

The need for water stress induced rest period to encourage flowering is anticipated, but its magnitude (in terms of a drought stress index or period) does not have been identified accurately.

Irrigation depend on type of soil, climatic condition and tree age and for bearing trees irrigation should continue in systemic way. Continuous irrigation helps in absorption of nutrients and decrease the flowers drops. Irrigation is an important factor determining yield and flowering in citrus, water stress impose different yield losses depending on the time that plant subjected to water stress (Ginestar and Castel, 1996; Pérez-Pérez *et al*., 2008; Hutton and Loveys, 2011). Water stress application depends mainly on the crop nature, and the different effects caused by it in different growth stages. Critical growth stages, in which water should not be reduced have to be considered (Chalmers *et al*., 1986). Moderate levels of stress can result in an inadequate flowering response. On the other hand, severe water stress involves negative effects, such as excessive leaf senescence, twig drying, root system damage and high percentages of flower abortion (Torrisi, 1952; Crescimanno, 1959). The correct amount of drought stress necessary to induce flowering is important, since excessive stress can be harmful. Some reports indicate that 64% of the flowers aborted after excessive drought stress, compared with only 20% after a moderate drought. Excessive drought stress also harms the development of fruits already on the trees and will reduce substantially regular yield (Levy, 1998).

The objectives of this study are to determine the effect of length of different periods of water stress to induce rest period as stimulus to citrus flowering with special emphasis on finding out the optimum stress period at which irrigation should be resumed to obtain best fruit yield.

Materials and Methods

The experiment was conducted at citrus growing areas in River Nile State (Kitayab, AlRaw and Central Zeidab Schems) during 2014/15 and 2015/16 seasons where citrus is considered as the main cash crop. Farmers used basin irrigation and practice different irrigation stopping periods after harvest thinking this practice will result in intense flowering and consequently high yield. The area is characterized by arid climate where potential evapotranspiration is very high (1806 mm meaning a water deficit by subtracting annual rainfall mainly during August of more than 1700 mm). Mean maximum and minimum temperatures in the hottest month (June) are 48-28 C^o, while the mean maximum and minimum during the coolest month (January) are 31 and 8 C^o.

Eight farms with mature orange trees (*Citrus sinensis* L. Local Sinnari cultivar) grafted on sour orange (*Citrus aurantium*, L.) root stock that use different irrigation stress periods was selected. Nine trees from each farm were randomly selected and tagged for further readings. The selected trees with at least 10 years' age, spaced at 7×7 m. The soil at the experimental sites is mostly homogenous representing Nile fluvent sediments of entisols with loamy to clay loam texture and water characteristics of 33-34% vol. as field capacity and 19-20% vol. as permanent wilting point and matric and osmotic potential of 14-15 bar. The experimental design was randomized complete block design (RCBD) with three replicates. The period for irrigation stress after harvesting and before the new flowering season was 2, 3, 4, 5, 6, 7, 8 and 9 weeks. All intervals ending at 30th of October to 15th November and the flowing parameters taken were:

1- Time of flowering.
2- Number of flowers/ squire meter (counted by naked eye).
3- Number of fruits/tree (counted at beginning of phase II, onset of fourth month).
4- Number of dry branches/tree.
5- Difference in maturity/tree as percentage of mature fruits over others counted at phase III based on fruit shape and colour.
6- Statistical analysis applied by using MSTT-C computer software

Results and Discussion

Results showed that time of flowering was affected by irrigation stress period and as this period increased, early flowering occurs. Early flowering noticed after 9 weeks of irrigation stress and late flowering noticed after 2 weeks' period (Table 1). Number of flowers per square meter was significantly affected by irrigation stress period and as this period increased, number of flowers per square meter increased in both seasons. Combined analysis showed that the highest number of flowers (67.4) resulted from 9 weeks 'dry period and the least number (49.1) resulted from 2 weeks' period (Table 2). Interaction between number of flowers and site was not significant.

Table 1: Effect of irrigation stress period on time of flowering of Sweet orange in River Nile State, season 2014/ 15 and 2015/ 16.

Irrigation stress period	Time of flowering
2 week	1st w Feb
3 weeks	1st w Feb
4 weeks	2th w Jan
5 weeks	4th w Dec
6 weeks	2th w Dec
7 weeks	1th w Dec
8 weeks	4th w Nov
9 weeks	4th w Nov

Table 2: Effect of irrigation stress period on number of flowers per square meter in Sweet orange in River Nile State, season 2014/ 15 and 2015/ 16.

Irrigation stress period	Flowers No. per square meter								
	Season 2014/2015				Season 2015/2016				
	Area1	Area2	Area3	Mean	Area1	Area2	Area3	Mean	Combine
2weeks	50.0	55.2	57.3	54.2	44.7	50.2	37.3	44.1	49.1
3weeks	50.0	47.4	48.9	43.2	56.2	56.8	48.0	53.6	51.2
4weeks	55.5	54.4	51.0	53.7	53.3	39.0	44.2	45.6	49.6
5weeks	50.3	52.5	44.2	49.0	63.7	56.1	48.0	53.5	51.3
6weeks	55.4	59.8	56.7	57.3	72.4	58.4	56.7	62.5	59.9
7weeks	63.4	61.0	63.4	62.5	78.3	71.2	62.7	70.6	66.6
8weeks	63.4	56.7	67.2	62.4	76.1	65.7	70.2	70.7	66.5
9weeks	61.8	70.3	69.3	67.2	89.0	72.3	71.7	67.7	67.4
Mean					62.9	58.7	53.9		
CV %				33.4					26.9
SE ±				6.4ns					4.0**
Interaction				11.4ns					6.3**

Number of fruits per tree was significantly affected by irrigation stress period in both seasons (Table 3) but not following the same trend of number of flowers per square meter. In both seasons the highest number of fruits was registered by 3-week dry period treatment (1683.5 and 1711.7 fruits per tree in the first and second season, respectively) and the least number was registered by the longest dry period (945.1 and 972.2 7 fruit per tree, respectively). This may be due to the fact that although long dry period stimulates abundant flowering, it may in the same manner adverse fruit set that means not all flowers set fruits. Interaction between number of fruit per tree and the area was not significant. Results obtained were in line with statement of Bustan *et al*. (1995) and Bustan and Goldschmidt (1998) when discussing intense flowering as a survival strategy following stress period so that citrus bloom abundantly and then also show high abscission of buds, flowers, fruitlets and fruits.

Table 3: Effect of irrigation stress period on number of fruits per tree on Sweet orange in River Nile State, seasons 2014/ 15 and 2015/ 16.

Irrigation stress period	Fruits No. per tree								
	Season 2014/ 15				Season 2015/ 16				
	Area 1	Area 2	Area 3	Mean	Area 1	Area 2	Area 3	Mean	Combined
2weeks	1546.8	1725.3	1086.0	1492.7	1518.2	1735.4	984.8	1412.0	1427.8
3weeks	1428.5	1266.2	959.9	1683.5	1423.4	2662.2	1049.6	1711.7	1697.6
4weeks	1389.0	1966.3	1103.2	1486.2	1330.2	1863.4	919.6	1371.1	1428.6
5weeks	1311.4	1170.7	998.1	1493.4	1378.8	1663.9	1003.2	1348.6	1218.7
6weeks	1363.6	1486.1	788.9	1212.9	1407.8	1419.4	846.1	1224.4	1145.7
7weeks	1064.1	1504.1	807.1	1125.1	1252.4	1504.1	742.5	1166.3	103.8.7
8weeks	985.4	1306.3	792.1	1027.9	1160.0	1232.0	756.6	1049.5	958.6
9weeks	1018.1	1031.4	785.7	945.1	1133.6	1100.9	682.2	972.2	
Area mean	1259.6	1731.6	915.1		1325.6	1647.7	873.0		
CV %				21.7				22.6	24.8
SE ±				44.3**				76.6**	45.1**
Interaction				57.7n.s				167.2sig	127.6ns

In this table and the flowing ones, ns = not significant and ** highly significant, sig = significant

As stated by Banuet (2001) and Malik *et al*. (2015) flower bud induction after the rest period has been extensively studied in various plants, and it is well known that several internal and external factors (e.g., day-length, temperature conditions, water stress, nutritional and internal carbohydrate level) play important role in controlling bud break. Majority of studies on bud break in citrus are related to flowering and are thoroughly discussed in various review articles. It is clear then, in tropical condition of Sudan, prolonged dry period induced rest period which can enhance abundant flowering upon rehydration but may not enhance flowers to set fruits. Many factors control fruit set, among them environmental condition and tree nutritional status are the most important. Despite abundant flowering, carbohydrate supply for the flower or fruit load may be some times insufficient and environmental conditions may become too adverse for normal fruit set to the majority of the tree bloom.

Result also indicated that number of dry branches per tree and differences in fruit maturity per tree were significantly affected by irrigation stress period. They were increased with increasing irrigation stress period and vise verse. More dry branches per tree resulted from 9 weeks' period (7.3) and the least number (1.0) resulted from 2 weeks' period (Table 4). Similarly, differences in fruit maturity follow the same trend, more percentage of early maturing fruits (10.3) resulted from 9 weeks' period and the least percentage resulted from 2 weeks' period (0.0) (Table 5). The interaction between area and maturity differences and area and dry branches was not significant in both seasons.

Table 4: Effect of irrigation stress period on number of dry branches per tree in Sweet orange in River Nile State, season 2014/ 15 and 2015/ 16.

Irrigation stress period	Dry branches per tree								
	Season 2014/ 15				Season 2015/ 16				
	Area 1	Area 2	Area 3	Mean	Area 1	Area 2	Area 3	Mean	Combined
2weeks	2.0	1.7	0.3	1.7	1.0	1.7	0.3	1.0	1.2
3weeks	2.3	2.7	2.0	2.3	1.0	1.0	0.0	1.7	2.0
4weeks	2.7	3.7	3.4	3.3	1.3	2.7	4.0	2.7	2.9
5weeks	4.1	3.9	4.7	4.2	4.1	3.7	6.1	4.6	4.4
6weeks	5.5	4.7	3.7	4.8	5.2	4.7	5.3	5.1	4.9
7weeks	6.7	5.7	4.2	5.5	6.0	5.6	5.3	5.7	5.6
8weeks	8.2	6.8	7.1	7.3	6.9	6.4	7.8	7.0	7.2
9weeks	8.7	8.3	7.9	8.3	7.5	7.1	7.4	7.3	7.8
Mean	5.0	4.7	4.2		4.1	4.3	4.7		
CV %				25.5				30.7	
SE ±				0.39**				0.57**	
Interaction				0.07ns				0.98n.s	

Table 5: Effect of irrigation stress period on percentage of fruit maturity differences per tree in Sweet orange in River Nile State, season 2014/ 15 and 2015/ 16.

Irrigation stress period	Percentage of fruit maturity differences per tree								
	Season 2014/ 15				Season 2015/ 16				
	Area 1	Area 2	Area 3	Mean	Area 1	Area 2	Area 3	Mean	Combine
2weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3weeks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4weeks	0.4	0.0	0.007	0.124	0.0	0.02	0.7	0.22	0.2
5weeks	1.4	0.3	5.33	2.4	3.7	1.2	0.4	1.7	2.1
6weeks	5.5	5.9	9.0	6.8	9.0	7.4	6.0	7.4	7.1
7weeks	7.6	8.9	9.3	8.6	6.2	8.3	8.0	8.7	8.7
8weeks	8.0	10.03	9.33	9.13	9.1	10.3	9.0	9.4	9.3
9weeks	9.5	11.33	9.7	10.2	9.3	10.5	10.2	10.13	10.3
CV %				39.9				36.9	34.1
SE ±				618**				0.58**	0.45**
Interaction				14ns				1.006ns	0.65ns

Conclusion

For citrus in tropical conditions, long water stress period may enhance abundant flowering but may not lead to good yield and may induce more twig and branch dryness.

Homogeneity in soil types didn’t reflect any difference in results in this study, but different soil types may need different water stress periods, Accuracy in dry period to stimulate flowering without harming the tree or its yield need more research work.

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