The Influence of Soil Moisture Stress on Growth, Water Relation and Fruit Quality of *Hibisicus sabdariffa* L. Grown Within Different Soil Types.

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Abstract: Two pot experiments were carried out during two successive seasons 2008 and 2009. The experiments aimed to study the effect of different soil moisture stress levels (70%, 50% and 30% depletion of the available soil water) on vegetative growth, Yield, essential oil, N, P, K, protein and anthocyanins contents of *Hibiscus subdariffa* L. grown within three soil types (clay, sandy and sandy clay loam soils). All growth and yield attributes, as well as oil % were significantly increased under the moderate soil moisture level combined with sandy soil. Increasing soil moisture level caused an increase in RWC %, N, P, K, protein % and anthocyanins content, combined with mixed soil in case of RWC%, N, P, K, and protein % and combined with sandy soil in case of anthocyanins content. While opposite trend obtained for osmotic pressure which revealed the highest significant increases under the lowest soil moisture level combined with clay soil.
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1. Introduction

Roselle plant (*Hibiscus sabdariffa* L.) belongs to family *Malvaceae.* It is well known in Egypt with the name of "Karkaddeh", and is mainly cultivated for its sepals which contain anthocyanine, which are responsible primarily for red colour and were defined 3-glucoside and cyanidin 3- glucoside.

The sepals are the most important economic parts of the plant which is used in food (Jam and Jelly) and cosmetic industry as a source of natural colouring agents ,Raifa *et al*., (2005). Karkadeh is considered a very popular beverage and valuable medicinal plant due to its effect on lowering and/ or adjusting the blood pressure (anti-hypertension) without production of any side effects (Faraji and Tarkhani, 1999). Also has effect on stomach function, and can resist various infections of intestinal disease (Owolabi *et al.*, 1995). Obiefuna *et al.* (1994) added that *Hibisicus sabdariffa* flowers can be used to relax the pain muscles of uterus and intestine. It has highly antibacterial properties .As well as, considered cardiotonic. It is useful as laxatives (Hayat, 2007). Tanaka *et al*. (1993) also stated that protocatechuic acid (a simple phenolic compound) detected in *Hibisicus sabdariffa* could be used to fight pyrexia and liver disorders. Also, it has been demonstrated that this compound is an effective agent in reducing the carcinogenic action of di-ethylnitrosamine in the liver. Furthermore, Roselle seeds contain about 17% fixed oil which is similar in its properties to cotton seed oil (Metwally *et al*., 2002).

Water is imperative for plant growth and development. Water deficit stress, permanent or temporary, limits the growth and distribution of natural vegetation and the performance of cultivated plants more than any other environmental factor (Kramer, 1983). Although research and practices aimed at improving water stress resistance and water use efficiency have been carried out for many years. The mechanism involved is still not clear, Smith and Griffiths, (1993). Further understanding and manipulating plant water relations and water stress tolerance can significantly improve plant productivity, tuff grass management, and environmental quality (Soha *et al.*, 2010). Water stress is characterized by reduction of water content, turgor, total water potential, wilting, closure of stomata, and decrease in cell enlargement and growth. Severe water stress may result in arresting of photosynthesis, disturbance of metabolism, and finally dying (Mckersie and Leshem, 1994). In Egypt, there is a tendency for cultivation of more newly reclaimed desert areas in the front of population increment problem. Research on the response of plants to drought is therefore necessary for improving plant growth and crop production in these regions.

Different plant species vary enormously in their soil and nutritive requirements. This aspect had not received sufficient attention for most medicinal plants. The three important characteristics of soils are their physical, chemical and microbiological properties. The effects of soil on plant growth are greatly dependent on the relationship between air and water in the soil pores. Metwally *et al.* (1972) stated that soil pores play an important role not only on the soil aeration and water movement but also on the availability of plant nutrient and microbiological activities (Abou-Leila *et al.*, 1993).

Therefore, the main target of the present work is to improve agricultural and productivity of *Hibisicus sabdariffa* L. plant under different soil moisture levels and within different lands.

2. MATERIAL AND METHODS:

Treatments:

Water Treatments:

The following three water treatments were applied throughout the entire growth period of the crop:

W1= water stress maintained around 70% depletion of the available soil water and the soil water is maintained to field capacity when this depletion level is reached.

W2= water stress maintained around 50% depletion of the available soil water and the soil water is maintained to field capacity when this depletion level is reached.

W3= water level maintained around 30% depletion of the available soil water and the soil water is maintained to field capacity when this depletion level is reached.

Soil types:

The following three soil types were used during the experiment:

Table (1): The three soil types were used during the experiment

Tret.	Sand %	Silt %	Clay %	Soil texture	pH	E.C. dsm^{-1}	O.M %	Total N%	Total P%	Total K %	F.C. %
S1	17.75	22.10	60.15	Clay	7.8	1.42	1.25	13.73	5.38	81.8	30
S2	93.66	3.97	2.37	Sandy	8.49	2.30	0.05	3.85	2.29	49.2	16
S3	52.63	10.32	37.05	Sandy Clay loam	8.01	1.89	0.67	6.32	4.162	60.3	26.4

S1=Clay soil. S2=Sandy soil. S3=Sandy clay loam soil.

Planting and watering procedure:

Seeds of *Hipisicus sabdariff* L. (deep red sepals cultivar) provided from the Medicinal and Aromatic Research Station, Agricultural Research Centre, Ministry of Agriculture, Egypt. The experiment was carried out at the green house of National Research Centre, Dokki, Egypt, during the summer seasons of 2008 and 2009. The seeds were directly planted on 15th of April in earthenware pots 40 diameter and 40 cm height with perforated bottoms, and were filled with 10 kg of the three different soil types. Five seeds were planted in each pot and thinned down to two plants after emergency, the number of plants per pot was determined on the basis of the area of the pot at a recommended seed rate of 50 plant/ m^2 (Soub, 1984). Each pot was fertilized with 2g Calcium superphosphate (15.5% P_2O_5), 1.5g potassium sulphate (48% K_2O) and 1.5g ammonium sulphate (20.5 % N). Calcium superphosphate was added during the preparation of soil, while both amounts of potassium and ammonium sulphate were added to the plants as three sides dressing at monthly intervals starting one month from the planting. Such plants were equally irrigated with tap water for six weeks, before starting soil moisture treatments. All pots were weighted every 1 to 3 days on a beam balance. The pots were then irrigated to restore the soil to the appropriate moisture regime by adding a calculated amount of water. The general principal stated by Boutraa and Sanders (2001) was used for the water treatment application.

Design of the Experiments:

This experiment included 9 treatments which were the combination between three soil moisture levels (70, 50 and 30% depletion of the available soil water) and three soil types (clay, sandy and sandy clay loam soil), treatments were arranged in a split plot design with three replicates, different soil moisture levels were assigned at random in the main plots, while sub-plots were devoted too the different soil types.

Data Collection:

The following characters were either measured or computed on three Roselle plants: Plant height (cm), number of leaves/plant, number of branches /plant, root length (cm), leaf area (cm^2), fresh weight of total plant (g), dry weight of total plant (g), RWC% and osmotic pressure (Atm) were taken on 15^{th} of September. Number of fruits/plant, fresh weight of sepals/plant, dry weight of sepals/plant, seeds wt/plant and chemical analysis were recorded on the first of December during maturity. The relative water content percent was measured also on fresh leaves according to Weatherly (1962). The determination of total soluble solids concentration in the cell sap of fresh plant was also estimated by using refracto-meter, the corresponding values of osmotic pressure (Atm) were then obtained from tables given by Gusev (1960). Proline content was determined on dry leaves according to Troll (1995). Total anthocyanin content in the dried sepals was determined by using of Fuleki and Francis (1968) and developed by Du and Francis (1973). N and K percentages were determined in dried sepals by using atomic absorption on spectrophotometer according to the method described by Bremner and Mulvaney (1982), Olsen and Sommers (1982) respectively. While P (%) was measured photometically according to the method described by Jackson (1970), and then the protein (%) was also calculated using the equation of Alsmeyer *et al.* (1974). Fixed oil percent in the seeds was determined according to A.O.A.C. method (1980).

Statistical analysis:

The collected data were subjected to statistical analysis of variance using the normal (F) test and the means separation were compared by using Least Significant Difference (LSD) at 5% level according to Snedecor and Cochran (1980).

3. Results and Discussion

3.1. Growth attributes:

Plant height, no of leaves, no of branches, root length, leaf area, fresh and dry weights of the whole plant were taken as indicator for the growth of Roselle plant. Data presented in Table 2 indicated that there was a significant effect due to the use of different soil moisture levels, where the lowest significant means of all growth characters observed under the lowest soil moisture level W1, except for number of branches. Also, all previously mentioned characters revealed significant increases under moderate W2 and the highest soil moisture W3 levels where the difference between the two moisture levels was insignificant in most cases, except for leaf area where the highest record observed under moderate soil moisture level W2. These results were in harmony with those reported by Abdel- Gawad *et al*. (1987); Wagner *et al.* (1989); Gad El-Rab *et al*. (1993); Abd El-Ati (2000); El-Tantawy and El-Beik (2007). The reduction in plant growth under low soil moisture condition may be due to that water stress caused losses in tissue water which reduced turgor pressure in the cell, thereby inhibited enlargement, division of cells and caused a reduction in the uptake of nutrient elements thus causing a disturbance in the physiological processes needed for plant growth, (Slatyer, 1969; Hsiao and Acevedo, 1974). The decrease in enlargement and division of cells led to decrease leaf area and hence the effective of photosynthetic surface and caused a reduction in CO_2 assimilation due to stomata close (Fisher and Hogan, 1965; Jain and Misra, 1970). Marchner (1995) reported also that water stress caused an increase in ABA/cytokine ratio, which in turn decreases plant growth; he also added that under sufficient water conditions, there were decrease in ABA and increase in cytokinin, GA and IAA reflecting good growth and dry matter content.

It can be also observed from the collected data that sandy soil increased all growth characters significantly compared with the other two media, followed by mixed soil which revealed insignificant difference with sandy soil in no. of leaves, leaf area and dry weight. While the lowest means observed in clay soil compared with the other two soil types. These results were on line with those obtained by Russell (1971) and Abou-Leila *et al*. (1993). This effect may be attributed to the physical properties of the soil, where sandy soil is porous and the ions absorption is easier while some of ions adhere on the clay soil particles. Plus root system may penetrates deeper and extending wider in sandy soil more than the other two soil types and make the plant established well in this kind of soil (Burman *et al.*, 1991; Uday *et al.*, 2001; and Azza *et al.*, 2010).

Concerning the effect of interaction between different soil moisture levels and different soil types, the data indicated that under the lowest soil moisture level W1 the highest records observed in mixed soil S3 except for root length compared with the other two soil types. This result may be due to that sandy soil does dry out very quickly specially under low water supply, while mixed soil hold moisture and nutrients well (Azza *et al*., 2010). Moreover, the data revealed that under the other two soil moisture levels (W2 and W3) the highest significant records obtained in sandy soil compared with the other two soil types. The data also illustrated that the highest significant means in growth attributes observed under the combined effect of moderate water supply and sandy soil W2XS2 compared with the other treatments, followed by the combined effect of W3XS2 where the difference between the two interactions was insignificant in most cases. While the lowest means observed under the combined effect of the lowest water supply and clay soil W1XS1.

3.2. Water relations:

3.2.1. Osmotic pressure:

Data in Table 3 showed that osmotic pressure of Roselle leaves was significantly increased with increasing the extent of stress so as to reach their maximum values in Roselle leaves under the lowest soil moisture level W1. These results were in great accordance with those obtained by Kandil (1994); Badr (1998) and Abo El-Kheir (2000). Such increase in osmotic pressure with decreasing in soil moisture level may be due to increasing the quantity of electrolytes and non electrolytes to create a water potential gradient to facilitate inward water movement and positive turgor leading to tolerance (Abo El-Kheir, 2000).

Recent research revealed also that clay soil showed the highest significant increase in osmotic pressure values compared with the other two soil types, followed by sandy one where the lowest significant means obtained in mixed soil. These results could be due to that clay soil was heavy and difficult to work sticky when wet and very hard when dry. Also, some of ions adhere on the clay soil particles which may causes plants exposed to more osmotic stress than that in mixed and sandy media. Moreover, nutrients are easily washed through sandy soils than in mixed media. These explanations were in parallel with those obtained by El-Khalifa (2003); El-Sallami (2003); Mohmood (2005); Kathiravan *et al.* (2008); James and Michael (2009); and Azza *et al.* (2010). It can be observed also from the collected data that the highest significant mean in osmotic pressure values obtained in plants grown under 70% depletion of the available soil water combined with clay soil W1XS1. While, the lowest means observed plants grown under 30% depletion of the available soil water combined with mixed soil W3XS3.

3.2.2. Relative water content RWC %:

For the RWC % of Roselle leaves, results in Table 3 showed that during plant development, increasing stress caused an observed adverse action on relative water content. Plants subjected to the lowest soil moisture level W1 showed the lowest significant means of RWC %. Moreover, there was no significant difference between the moderate soil moisture level W2 and the highest soil moisture level W3. The present results agreed with those obtained by Tayagi *et al.*(2000);Choi *et al*.(2000); Phutela *et al.* (2000); Flexase *et al*. (2000); Garg *et al*.(2001); Sanchez-Blanco *et al.* (2006);Abdalla and El-Khoshiban (2007); Soha and Ezzat (2010). Such decrease in RWC % under the lowest soil moisture level may be attributed to decline in osmotic and water potentials with concomitant preliminary decrease in RWC %, also decreased water quantity caused decrease in relative turgidity is due to decreased photosynthesis as a consequence of stomata closure (Kramer, 1983); this caused reduced translocation and hence reduced turgor pressure.

Data in the same table revealed also that, plants grown in mixed soil recorded the highest significant values for the RWC % compared with the other two soil types, followed by sandy soil. This effect may be attributed to the physical properties of the soil, where mixed soil holds moisture and nutrients well plus free movement of water through it as a result of adequate pores which may reveal good growth and water status. These results were confirmed by El-Mesiry and Azza (2001); El-Sallami (2002); El-Khalifa (2003); Kathiravan *et al.* (2008).

Regarding the effect of interaction between different soil moisture levels and different soil types, the data indicated that plants grown under the lowest soil moisture level W1 revealed the lowest RWC % values in different soil types. Moreover, mixed soil revealed the highest significant means of RWC % under different soil moisture levels. While, the highest significant mean of RWC % obtained in plants grown under 30% depletion of the available soil water interacted with mixed soil W3XS3, and the lowest significant means obtained in plants grown under 70% depletion of the available soil water combined with clay soil W1XS1.

Table (2): Effect of different soil moisture levels, different soil types and their interactions on growth attributes of Roselle plant (Combined analysis of two seasons).

Treatments \ Charact.		plant height cm	no of leaves	no of branches	root length cm	leaf area cm^2	fresh weight g	dry weight g
Effect of water stress								
W1		105.556	38.777	3.000	14.111	41.302	232.690	56.803
W2		129.222	77.111	3.889	28.744	67.786	304.226	61.049
W3		128.333	76.555	3.889	28.144	50.110	295.991	60.125
$LSD_{0.05}$		1.083	1.433	0.685	1.391	0.701	9.066	2.067
Effect of soil types								
S1		97.333	37.889	3.000	12.000	45.664	209.458	55.501
S2		134.222	77.222	4.778	31.889	56.777	318.581	61.762
S3		131.556	77.333	3.000	27.111	56.758	304.868	60.714
$LSD_{0.05}$		1.242	1.027	0.559	0.873	0.475	3.531	1.354
Effect of interaction between water stress and soil types								
W1	S1	95.000	24.000	3.000	11.000	30.028	191.681	51.185
	S2	103.333	42.000	3.000	20.333	45.527	219.221	59.256
	S3	118.333	50.333	3.000	11.000	48.351	287.168	59.967
W2	S1	98.333	45.000	3.000	12.333	66.408	218.654	57.948
	S2	145.667	95.333	5.667	38.333	69.299	353.892	63.881
	S3	143.667	91.333	3.000	35.667	67.652	340.132	61.318
W3	S1	98.667	44.667	3.000	12.667	40.554	218.040	57.369
	S2	145.667	94.333	5.667	37.000	55.504	341.492	62.149
	S3	140.667	90.333	3.000	34.667	54.270	328.442	60.857
$LSD_{0.05}$		2.152	1.779	0.968	1.512	0.823	6.115	2.346

W1 = 70% depletion of the available soil water. W2 = 50% depletion of the available soil water. W3 = 30% depletion of the available soil water. S1=clay soil. S2=sandy soil. S3=sandy clay loam soil.

Table (3): Effect of different soil moisture levels, different soil types and their interactions on water relations of Roselle plant (Combined analysis of two seasons).

Treatments \ Charact.		Osmotic pressure (Atm)	RWC %
Effect of water stress			
W1		7.339	69.479
W2		6.596	81.305
W3		5.684	83.358
$LSD_{0.05}$		0.056	2.198
Effect of soil types			
S1		6.977	73.778
S2		6.423	77.860
S3		6.219	82.505
$LSD_{0.05}$		0.032	1.023
Effect of interaction between water stress and soil types			
W1	S1	8.030	64.675
	S2	7.020	71.214
	S3	6.967	72.548
W2	S1	7.020	77.306
	S2	6.637	80.157
	S3	6.130	86.453
W3	S1	5.880	79.352
	S2	5.613	82.209
	S3	5.560	88.514
$LSD_{0.05}$		0.056	1.773

W1 = 70% depletion of the available soil water. W2 = 50% depletion of the available soil water.
W3 = 30% depletion of the available soil water.S1=clay soil. S2=sandy soil. S3=sandy clay loam soil.

3.3. Yield attributes:

The data in Table 4 visualized that there was a significant effect due to the water stress, where the lowest significant means of the number of fruits/plant, fresh weight of sepals/plant, dry weight of sepals/plant and seeds weight/plant obtained under the lowest soil moisture level W1 compared with the other two levels. While, the highest significant means obtained by the moderate soil moisture level W2 followed by the highest one W3 where the difference between the two soil moisture levels was insignificant except for the seeds weight/plant. These results were in agreement with those obtained by Abdel- Gawad *et al*. (1987); Gad El-Rab *et al*. (1993); Elham and Ibrahim (2009). Such increase in yield values under moderate water supply may attribute to that this soil moisture level gave the plants its requirements of water, where water supply leads to the increase of the metabolism process and insufficient water can be deleterious for the yield and maturity (El-Telwany, 1987).

It was also evident from the data in the same table that sandy soil gave the highest significant means in weight of fruits/plant, fresh weight of sepals/plant, dry weight of sepals/plant and seeds weight/plant compared with the other two media followed by mixed media. These results were documented by researches done in this field e.g. Abou-Leila *et al.* (1993); El-Khalifa (2003)*;* Mohmood (2005). These results may be attributed to free movement of water through the soil particles as a result of adequate pores also this type of soil provided a continues system of air filled pores extending from the soil surface throughout the root zone, sandy soil also has high proportion of sand drain easily, so water logging is not a problem unless a "pan" or impervious layer has formed below the surface their open structure means that they are easy to work allowing earlier sowing and plating. Moreover, it is porous and the ions absorption is easier while some of ions adhere on the clay soil particles (Russel, 1971). The influence of various stress levels and various soil types on yield and yield attributes of Roselle plant indicated that mixed soil revealed highest means under the lowest soil moisture level W1, while under the other soil moisture levels W2 and W3 the highest significant means obtained in sandy soil. The data also visualized that the highest significant means of yield component appeared in plants grown under the moderate soil moisture level combined with sandy soil W2XS2, while the lowest means obtained under the lowest soil moisture level combined with clay soil W1XS1.

Table (4): Effect of different soil moisture levels, different soil types and their interactions on yield attributes of Roselle plant (Combined analysis of two seasons).

Treatments \ Charact.		no of fruits/plant	fresh wt of sepals/plant	dry wt of sepals/plant (g)	seeds wt/plant (g)
Effect of water stress					
W1		7.667	13.245	5.621	5.964
W2		16.333	36.173	8.474	18.566
W3		15.889	35.247	7.975	15.885
$LSD_{0.05}$		1.162	2.193	2.012	0.471
Effect of soil types					
S1		8.333	16.312	6.554	9.130
S2		16.777	37.123	8.157	17.208
S3		14.776	31.230	7.360	14.077
$LSD_{0.05}$		0.625	0.916	0.639	0.395
Effect of interaction between water stress and soil types					
W1	S1	5.667	8.899	4.259	5.410
	S2	8.333	14.607	5.832	6.107
	S3	9.000	16.229	6.772	6.376
W2	S1	9.667	20.433	8.067	10.476
	S2	21.333	48.993	9.649	24.824
	S3	18.000	39.095	7.708	20.398
W3	S1	9.667	19.603	7.336	11.505
	S2	20.667	47.770	8.990	20.693
	S3	17.333	38.368	7.601	15.458
$LSD_{0.05}$		1.082	1.586	1.107	0.684

W1 = 70% depletion of the available soil water. W2 = 50% depletion of the available soil water. W3 = 30% depletion of the available soil water. S1=clay soil. S2=sandy soil. S3=sandy clay loam soil.

3.4. Effect on some chemical constituents:

3.4.1. Mineral ions content:

It is evident from the data in Table 5 that minerals content of Roselle sepals were gradually decreased with decreasing the water supply. The decreased levels of each of N, P and K in response to stress were ascertained by the work of each of Razi and Sen (1996), Schier and McQuattie (2000);Bie *et al*. (2004); Koyro (2006); Wu and Xia (2006). Such reductions in the contents of these elements in different tissues were attributed primarily to soil water deficiency which markedly reduces the flow rates of elements in soil, their absorption by stressed root cells and also its ability to translocate through the different organs and tissues. This situation resulted in an interruption in the various metabolic pathways carried out by plants respiration, photosynthesis, biosynthesis of phospholipids, nucleic acids, plastids, enzymes..etc, disorders in both plasma membrane permeability and stomatal osmotic regulations, thus plants seized growth and eventually died (El-Telwany, 1987; Rodriguez *et al*., 1996; and Saxena and Nautiyal, 2001).

The maximum increases in N, P and K content of Roselle sepals obtained in mixed soil followed by sandy soil, while the lowest records obtained in clay media. In this respect, El-Gamal *et al.* (1983); Abou-Leila (1991a) ;Abou-Leila *et al.* (1993) recorded similar results. Such increase in N, P and K content of Roselle sepals in mixed soil may attributed to the presence of adequate supply of available nutrients in this type of soil, also sandy soil is porous and the ions absorption is easier while some of ions adhere on the clay soil particles (Abou-Leila *et al.*, 1993).

With regards to the effect of interaction between the studied factors the data revealed that the best values for N, P and K content of Roselle sepals obtained in plants grown under the highest soil moisture level combined with mixed soil W3XS3, followed by sandy soil under the same soil moisture level W3XS2 where the difference between the two treatments was insignificant except for N%, while the lowest means obtained under the lowest soil moisture level combined with clay media W1XS1 compared with the other treatments.

3.4.2. Protein percent:

Results in table 5 indicated also that protein % of Roselle sepals was significantly increased with increasing soil moisture level till reach their maximum value under the highest soil moisture level W3. This result was supported by several authors such as Singh *et al*. (1985); Hurkman and Tanaka (1987); King *et al*. (1988); Ben–Hayyim *et al*. (1989). The decrease in protein % under low soil moisture level may be due to that water stress causes a reduction in hydrostatic pressure and can cause an increase in accumulation of abscisic acid in plant tissues which resulted in the inhibition of protein synthesis (Chandler and Robertson, 1994).

Current study showed also that the maximum protein % mean obtained in mixed soil and with significant difference compared with the other two media, followed by sandy soil. While, the lowest significant means obtained in clay soil compared with the other soil types. These results were in great accordance with that recorded by El-Gamal *et al.* (1983); Abou-Leila (1991a); Abou-Leila *et al.* (1993). These results might be due to the presence of adequate supply of nitrogen and therefore uptake by plant in mixed soil compared with the other two media, which therefore resulted in the an increase in protein %.

Regarding the effect of interaction the data revealed that the highest significant means obtained under the combined effect of the highest soil moisture level and mixed soil W3XS3. While, the lowest means obtained under the combined effect of the lowest soil moisture level and clay soil W1XS1 compared with the other treatments.

3.4.3. **Oil Percent:**

It is clear from the data in table 5 that the highest oil % means obtained under the moderate soil moisture level W2 and with significant difference compared with the other two soil moisture levels. This result was in parallel with that obtained by Chanirar *et al.* (1989); El- Sabbagh (2003); Elham and Ibrahim (2009).

The data in the same table revealed also that sandy soil produced the highest significant means of oil % compared with the other soil media, followed by mixed soil. While the lowest means obtained in clay soil. Similar results were recorded by Penka (1978); Abou-Leila *et al*. (1994). This result may be due to that the formation and accumulation of essential oil were directly dependent upon perfect development and growth of the plant (Penka, 1978).

It is apparent from the same table also that under the lowest soil moisture level the best oil % records obtained in mixed soil, while in the other two soil moisture levels the best records obtained as a response to the combined effect of these two levels with sandy soil. The data also revealed that the highest record of oil % obtained in the combination effect of W2XS2 as compared with the other treatments.

3.4.4. Total anthocyanins:

It is evident from Table 5 that increasing soil moisture level caused significant increase in total anthocyanin content of Roselle sepals, where the maximum increase was recorded under the highest soil moisture level W3 and with significant difference compared with the other two soil moisture levels. While, the lowest anthocyanins mean obtained in plants grown under the lowest soil moisture level. These results were in harmony with Sidky *et al*. (1998); Metwally *et al*. (2002); Hayat (2007). Therefore, the shortage of water supply usually led to many disturbances in physiological characters of the plant, such as the reduction in leaf number and area or leaf yellowishing which followed by decrease in the quantity of the photocynthates which influenced the formation of coloring pigments such as chlorophyll and carotenoids. Consequently, the stimulation of anthocyanins under high water supply conditions resulted from the increase of soluble sugars which were transferred to the vegetative organs then to the developing fruits. In this connection, some workers found that there was a positive relationship between red pigmentation and soluble sugars, e.g., Filippov (1959); Downey (1971); Metwally *et al*. (2002); Hayat (2007).

As for the effect of soil type, the data in the same table cleared that the maximum anthocyanins record obtained in plants grown in sandy soil and with significant difference compared with the other two soil media, followed by mixed soil. While the lowest records obtained in clay soil. Such increase in anthocyanin content in sandy soil may due to the increase in photosynthate content as a result of increase in photosynthesis due to easier water uptake in this kind of soil which influenced the formation of coloring pigments.

Moreover, the maximum increases in anthocyanin means were more pronounced in response to the combination effect of the highest soil moisture level and sandy soil W3XS2 and with significant difference compared with the other treatments. While the lowest means obtained under the combined effect of the lowest soil moisture level and clay soil W1XS1.

Table (5): Effect of different soil moisture levels, different soil types and their interactions on fruit quality of Roselle plant (Combine analysis of two seasons).

Treatments \ Charact.		N %	P %	K %	Protein%	Oil %	Antho Cyanine mg/100g
Effect of water stress							
W1		2.210	0.408	2.184	13.668	9.342	6.694
W2		2.299	0.431	2.411	14.370	18.936	6.992
W3		2.445	0.447	2.406	15.284	17.048	8.031
$LSD_{0.05}$		0.097	0.080	0.040	0.859	0.552	0.097
Effect of soil types							
S1		2.182	0.400	2.165	13.548	13.779	6.677
S2		2.311	0.443	2.387	14.442	16.062	7.820
S3		2.462	0.454	2.449	15.333	15.485	7.220
$LSD_{0.05}$		0.046	0.032	0.065	0.380	0.274	0.073
Effect of interaction between water stress and soil types							
W1	S1	2.056	0.357	2.048	12.585	8.404	6.115
	S2	2.207	0.421	2.209	13.796	9.176	7.114
	S3	2.367	0.447	2.295	14.623	10.448	6.854
W2	S1	2.162	0.410	2.201	13.509	17.313	6.483
	S2	2.322	0.439	2.477	14.508	20.252	7.500
	S3	2.415	0.444	2.557	15.094	19.244	6.993
W3	S1	2.328	0.433	2.248	14.550	15.620	7.433
	S2	2.403	0.444	2.475	15.021	18.760	8.847
	S3	2.605	0.465	2.496	16.281	16.765	7.813
$LSD_{0.05}$		0.080	0.056	0.113	0.659	0.474	0.126

W1 = 70% depletion of the available soil water. W2 = 50% depletion of the available soil water. W3 = 30% depletion of the available soil water.S1=clay soil. S2=sandy soil. S3=sandy loam soil.

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