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Effect of Potassium Sulfate Fertilization on Vegetative Growth, Yield, Fruit Quality and Leaf Mineral Composition of Some Pomegranate Cultivars

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Abstract. This investigation was carried out during 1997 and 1998 growing seasons to study the effect of potassium sulfate as soil application (at rates of 0, 1, 1.5 and 2 kg/tree/year) on the vegetative growth, yield, fruit quality and leaf mineral composition of Mellasy, Taeifi and Khob El-Jamil pomegranate cultivars grown at Dirab Experimental and Research Station, College of Agriculture, King Saud University.

The results revealed that the vegetative growth of Mellasy and Taeifi pomegranate cultivars slightly affected by potassium sulfate treatments. Whereas, Khob El-Jamil cultivar, data showed that trunk diameter, in the second season, and tree circumference, in both seasons, were significantly increased in trees received 1.5 kg of potassium sulfate comparing to the control. However, the tree height did not affect by the different potassium sulfate treatments.

In general, increasing the rate of potassium sulfate applications up to 2 kg/tree/year markedly increased the yield and the most of physical and chemical fruit properties. In addition, results indicated that higher rates of potassium sulfate gave not only increase in fruit yield, but also higher leaf potassium content. Furthermore, number, weight of fruits and the yield per tree responded positively to the different potassium sulfate applications in the second season than in the first one.

The results also showed that there were no correlation could be observed between potassium sulfate application and leaf nitrogen and phosphorus contents. Meanwhile, leaf iron, zinc, manganese and copper contents were slightly affected by the potassium applications.

Introduction

Pomegranate fruits are considered as one of the most important fresh fruits in Saudi Arabia and other Arab countries. During the last few years many local and introduced pomegranate cultivars were planted in the Experimental and Research Station at Dirab, College of Agriculture, King Saud University. In addition, soils of the central region of Saudi Arabia being a part of arid and semi-arid regions are coarse-textured, high in $CaCO_3$ content and low in organic matter (Modaihsh, 1992 and Sabbah & Bacha, 1996). Furthermore, nutritional problems arose seriously in such soils due to high content of $CaCO_3$ and their properties that affect the fertility of these soils (Moustafa *et al.,* 1992).

It is well recognized that the mineral nutrient status of the leaves is a significant factor determining the substantial losses in the fruit quality at harvest (Kassem, 1991). Although potassium is one of the most important essential elements, which is commonly in short supplied in the soil, it plays a dominant role in the mineral nutrition of fruit crops. The need for potassium may be more widespread than it is generally believed, because the fruits remove more potassium than any other nutrient element. About 2.1 kg of potassium is removed from every ton of fruits harvested (Chapman, 1968 and Koo, 1985). It is likely that some potassium fertilizer will be needed on most soils after years of intensive cultivation of pomegranate.

In addition, the need for potassium varies according to soil condition prevailing in each orchard. For instance, the percentage of lime in naturally calcareous soils are known to have relatively high capacities for fixing applied potassium into non-exchangeable forms (Sabbah *et al.,* 1995). Potassium availability in soils could also be influenced by moisture content, plant withdrawal rates, temperature and other factors (Koo, 1985),

Our investigation carried out to determine whether soil application of potassium sulfate to the soil could increase leaf potassium content and thereby improve the yield and quality of fruits from Mellasy, Taeifi and Khob El- Jamil pomegranate grown in Riyadh under calcareous soil condition. In addition, vegetative growth and leaf mineral compositions of the treated trees were also determined.

Materials and Methods

The present study was carried out during 1997 and 1998 growing seasons on 20-year-old trees of three pomegranate cultivars (*Punica granatum,* L) namely Mellasy, Taeifi, and Khob El-Jamil grown at Dirab Experimental and Research Station, College of Agriculture, King Saud University. The soil of the experimental orchard was classified as sandy loam calcareous. Data presented in

Table 1 show some physical and chemical properties of such soil in the experimental orchard.

TABLE 1. Chemical and physical properties of the soil profile in the experimental orchard.

Depth (cm)	pH	EC dS/m	O.M. (%)	$CaCo_3$ (%)	Available N (mg/kg)	K (mg/kg)			Particle size distribution (%)			Texture
						Total	Sol.	Exch.	Sand	Silt	Clay	
0-3	7.80	1.50	0.98	29.1	21.3	1500	4.9	196.2	47	34	19	loam
30-60	8.03	0.94	0.27	33.7	20.2	1367	3.2	182.5	52	29	19	loam

Sixteen trees, at approximately the same vigor planted at 5 × 5 m apart, were selected from each of the three pomegranate cultivars. All management practices were the same as those usually followed in the commercial orchards. Prior to the establishment and throughout this experiment, annual fertilizer applications per tree were 20 kg organic manure added in December with 2 kg of ammonium sulfate (21% N) and 1 kg of superphosphate (18-26% P_2O_5) divided into three equal doses and applied in March, May, and July in each year. The trees were irrigated by bubblier irrigation system using about 90-120 m^3/tree/year sewage water. Table 2 shows the analysis of final effluent from Riyadh sewage treatment plant.

TABLE 2. Analysis of final effluent of Riyadh sewage water.

Determination		Mean	Determination		Mean
pH		7.4	Cl	(meq / l)	4.9
E.C.	(mmhos)	1.6	SO_4	(meq / l)	6.9
NH_4-N	(ml / l)	20.6	HCO_3	(meq / l)	3.2
PO_4-P	(ml / l)	7.0	Fe	(ug / l)	251
K	(ml / l)	15.5	Zn	(ug / l)	135
Ca	(ml / l)	130	Mn	(ug / l)	40
Mg	(ml / l)	28	Pb	(ug / l)	< 2
Na	(ml / l)	146	Co	(ug / l)	< 2

A complete randomized block design with four replicates of one-tree-plot for the three pomegranate cultivars were used. Soil application of potassium sulfate (48-52% K_2O) treatments were at rates of: 0 (control), 1, 1.5, and 2 kg per tree each year. Each potassium sulfate fertilizer rate was divided into three equal doses and applied at first before bloom in March 1st, second after fruit set in May 1st , and third during fruit development in July 1st in both seasons.

Vegetative growth properties such as trunk diameter (cm), tree circumference (m), and tree height (m) of the trees were measured and recorded in the first week of June during both seasons for each of the three cultivars.

Yield was recorded (as number and weight of fruits per tree) at harvest time (August 15th for Taeifi, September 10th for Khob- El-Jamil and September 15th for Mellasy) in both seasons. For determination of the physical and chemical properties of the fruits, 10 fruits were taken randomly from each tree (replicate). Fruit volume (ml), length (cm), diameter (cm), peel weight (g), peel thickness (cm), and volume of juice per fruit (ml) were measured. In juice, total soluble solids (TSS %) were determined using Abbe refractometer, percentage of acidity (as citric acid) by titration with 0.1 N sodium hydroxide, and vitamin-C by titration with 2,6-dichlorophenol indophenol blue dye (A.O.A.C., 1980).

To determine the mineral composition, leaf samples were collected during the last week of July in both seasons. Each sample was composed of 50 leaves taken randomly from the non-fruiting shoots. The leaves were washed several times with tap water, distilled water and then oven dried at 70^{o}C. The dried leaves were ground and digested with hydrogen peroxide and sulfuric acid for nutrient element determinations (Evanhuis and DeWaard, 1980). Total nitrogen was determined colorimetrically according to Evanhuis (1976). Phosphorus was determined colorimetrically by the ascorbic acid method (Murphy and Riley, 1962). Potassium was measured using air propane flame photometer (Chapman and Pratt, 1961). Iron, zinc, manganese and copper were measured using Perkin-Elmer atomic absorption spectro- photometer Model 2380.

Statistical analysis was performed using SAS computer package (SAS, 1986) with Duncan's multiple range test for means comparison (Steel and Torrie, 1980).

Results and Discussion

1. Vegetative Growth

Results illustrated in Table 3 show the effect of soil application of potassium sulfate on some vegetative growth properties of the three pomegranate cultivars. In Mellasy cultivar, there were no significant differences in trunk diameter and tree height between treatments in both seasons. Whereas, adding 2 kg potassium sulfate/tree in the first season and 1.5 kg/tree in the second season caused significant decrease in the tree circumference as compared with those of the control. In Taeifi cultivar, there were no marked differences in the vegetative growth properties between treatments in both seasons. In Khob El-Jamil, adding 1.5 kg potassium sulfate/tree produced significant increase in the trunk diameter, in the second season, and the tree circumference, in both seasons, as

TABLE 3. Effect of potassium sulfate fertilization on vegetative growth of some pomegranate cultivars during 1997 and 1998 seasons*.

Potassium sulfate rates	Mellasy			Taeifi			Khob El-Jamil		
	Trunk diameter (cm)	Tree circumference (m)	Tree height (m)	Trunk diameter (cm)	Tree circumference (m)	Tree height (m)	Trunk diameter (cm)	Tree circumference (m)	Tree height (m)
1997									
Control	17.38 a	12.08 a	4.05 a	18.63 a	12.20 a	3.85 a	18.25 a	10.50 b	4.53 a
1 kg / tree	16.13 a	12.30 a	4.03 a	18.88 a	11.33 a	4.11 a	19.88 a	12.48 ab	4.43 a
1.5 kg / tree	16.25 a	10.58 ab	3.85 a	19.00 a	12.40 a	4.08 a	19.63 a	12.63 a	4.43 a
2 kg / tree	16.63 a	9.73 b	3.80 a	19.25 a	12.75 a	4.09 a	19.25 a	11.53 ab	4.33 a
1998									
Control	19.00 a	12.85 a	4.20 a	18.70 a	12.30 a	4.13 a	19.00 b	10.65 b	4.68 a
1 kg / tree	18.00 a	12.70 ab	4.11 a	18.95 a	12.15 a	4.13 a	20.13 ab	12.55 ab	4.73 a
1.5 kg / tree	17.25 a	10.65 b	4.00 a	20.50 a	13.05 a	4.36 a	21.50 a	13.38 a	4.84 a
2 kg / tree	18.25 a	10.85 ab	3.90 a	20.50 a	13.59 a	4.35 a	19.50 b	12.13 ab	4.78 a

*Means not sharing the same letter(s) within columns are significantly different ($P < 0.05$), by Duncan's multiple range test.

compared with the control. However, tree height did not affect by the different potassium sulfate applications.

In general, the results indicated that the vegetative growth of Mellasy and Taeifi pomegranate cultivars slightly affected by potassium sulfate treatments. Whereas, in Khob El-Jamil cultivar, data showed that trunk diameter, in the second season, and tree circumference, in both seasons, were significantly higher in trees fertilized with 1.5 kg of potassium sulfate as compared with the control. However, the tree height did not affect by the potassium sulfate treatments.

These findings were, somewhat, in agreement with those obtained by Singh & Patil (1989) and Bewoor *et al.* (1990) on pomegranate trees, and Deszyck *et al.* (1958) and Reese & Koo (1975), who measured several mature cultivars of orange trees in two potassium experiments. They found no differences in tree size except in K-deficient trees (< 0.7 K %), which were smaller and also had smaller leaves.

2. Yield

To achieve high yield of pomegranate trees, there are many factors beside nutrition that should be controlled. Thus, one must keep in mind that although mineral nutrition is a major factor; it is certainly not the only factor that responsible on the tree productivity.

Results in Table 4 show that, in the first season, adding 1.5 kg potassium sulfate/tree caused a significant increase in the weight of Mellasy fruits as compared with the control. Also, soil application of 2 kg potassium sulfate/tree produced a marked increase in the yield of Khob El-Jamil trees comparing with untreated control. No other significant differences could be observed between treatments in the first season. Whereas, in the second season, results in Table 4 indicated that increasing the rate of potassium sulfate applications to the trees gave significant increases in the number of fruits per tree, fruit weight and the yield per tree as compared with the control for the three pomegranate cultivars.

In general, increasing the rate of potassium sulfate application up to 2 kg tree/year was more effective and pronounced on the number of fruits/tree, fruit weight and the yield per tree for the pomegranate cultivars in the second season than in the first one. The present results might be supporting the notion that potassium sulfate fertilizer can often increase the yield especially under calcareous soil, which have potassium deficiency. This observations suggest that the yield influence with increasing fertilizer rates is a response to additional potassium. A more favorable macro nutrient balance is one possible explanation. These findings were in accordance with those obtained by Sen & Chauhan (1983), Singh *et al,* (1988) and *Peters et al.* (1993). They reported that the application of

TABLE 4. Effect of potassium sulfate fertilization on yield of some pomegranate cultivars during 1997 and 1998 seasons*.

Potassium sulfate rates	Mellasy			Taeifi			Khob El-Jamil		
	Number of fruits / tree	Fruit weight (g)	Yield / tree (kg)	Number of fruits / tree	Fruit weight (g)	Yield / tree (kg)	Number of fruits / tree	Fruit weight (g)	Yield / tree (kg)
1997									
Control	212.0 a	161.3 a	33.1 a	171.3 a	186.3 a	32.2 a	97.5 b	168.0 a	17.8 b
1 kg / tree	253.3 a	213.8 ab	54.3 a	200.0 a	166.3 a	33.8 a	157.5 a	243.8 a	34.0 ab
1.5 kg / tree	208.8 a	233.8 a	46.2 a	258.8 a	198.8 a	51.7 a	176.3 a	198.8 a	33.9 ab
2 kg / tree	225.0 a	217.5 ab	47.5 a	257.5 a	198.8 a	49.2 a	173.8 a	209.8 a	37.6 a
1998									
Control	66.8 a	170.5 b	11.6 c	131.8 a	133.1 c	17.4 b	98.5 b	175.8 b	17.4 b
1 kg / tree	89.8 a	181.8 ab	16.3 bc	124.5 a	154.8 bc	19.3 b	102.5 b	183.8 ab	19.1 b
1.5 kg / tree	91.0 a	186.1 ab	16.9 ab	243.0 a	167.9 ab	40.6 a	103.0 b	197.0 ab	20.2 b
2 kg / tree	110.8 a	197.8 a	21.9 a	266.3 a	182.6 a	48.4 a	136.3 a	206.7 a	28.2 a

*Means not sharing the same letter(s) within columns are significantly different ($P < 0.05$), by Duncan's multiple range test.

potassium sulfate gave better response in pomegranate. They also found that rising potassium rates increased the yield of pomegranate trees. Likewise, Deszyck *et al.* (1958), Reese & Koo (1975) and Sabbah *et al.* (1995) working on citrus trees, found that low potassium reduced fruit productivity by producing small size fruit and increasing fruit split and fruit drop. On the other hand, Haggag & El-Shamy (1987) found that pomegranate trees did not show a clear response with increasing potassium rates.

3. *Fruit Quality*

a) Physical properties of the fruits

Regarding Mellasy pomegranate cultivar, results in Table 5 indicated that, the influence of soil application of potassium sulfate on the physical properties of the fruits was more noticeable in the second season than in the first one. Fertilizing the trees with all potassium sulfate treatments, especially, 2 kg/tree, induced the highest values of fruit volume, length, and diameter and juice volume per fruit. Whereas, adding 1 kg potassium sulfate/tree caused a significant increase in the peel thickness as compared with 2 kg/tree and the control treatments. However, peel weight was not affected by the different potassium sulfate treatments.

As for Taeifi cultivar, results in Table 5 showed that there were no consistent trend between treatments regard to the most of the physical properties of the fruits. In the first season, the results indicated that fertilizing the trees with 1 kg potassium sulfate significantly increased the peel thickness of the fruits as compared with adding 2 kg/tree. Also, the fruit volume and the juice volume per fruit were significantly higher in trees fertilized with all potassium sulfate treatments, especially 2 kg/tree as compared with the control. No significant differences were also noted in the physical properties of the fruits between treatments, however.

Concerning Khob El-Jamil cultivar, the results in Table 5 showed that, in the first season, the soil application of 1 kg or/ and 2 kg potassium sulfate/tree gave a marked increase in the fruit volume and juice volume per fruit as compared with the control. Whereas, the application of 1.5 kg potassium sulfate/tree significantly reduced the peel thickness of fruits as compared with the control. In the second season, the results showed that all potassium sulfate treatments caused better effects on the physical properties of Khob El-Jamil fruits as compared with the control. The best results were, generally, obtained by adding 2 kg potassium sulfate/tree. It was also noted that increasing potassium sulfate rates markedly increased fruit volume, length, and diameter and peel weight and juice volume per fruit as compared with the control.

TABLE 5. Effect of potassium sulfate fertilization on the fruit physical properties of some pomegranate cultivars during 1997 and 1998 seasons*.

Potassium sulfate rates	**1977**						**1998**					
	Fruit volume (ml)	Fruit length (cm)	Fruit diameter (cm)	Peel weight (g)	Peel thickness (cm)	Juice volume (ml)	Fruit volume (ml)	Fruit length (cm)	Fruit diameter (cm)	Peel weight (g)	Peel thickness (cm)	Juice volume (ml)
Mellasy												
Control	172.3 a	6.4 a	6.9 a	69.0 a	0.37 a	60.5 a	147.8 b	6.1 b	6.5 b	38.3 a	0.24 b	52.8 c
1 kg / tree	220.3 a	6.8 a	7.7 a	92.4 a	0.39 a	76.8 a	188.8 a	6.5 ab	7.2 a	47.9 a	0.30 a	61.8 b
1.5 kg / tree	220.3 a	7.0 a	7.9 a	98.3 a	0.38 a	82.8 a	193.5 a	6.4 ab	7.3 a	42.1 a	0.28 ab	66.3 ab
2 kg / tree	216.0 a	6.8 a	7.7 a	88.9 a	0.29 a	73.0 a	203.5 a	6.8 a	7.7 a	43.4 a	0.24 b	72.8 b
Taeifi												
Control	197.5 a	6.9 a	6.8 a	77.6 a	0.36 ab	69.3 a	149. 5 b	6.0 a	6.7 a	33.3 a	0.24 a	48.3 b
1 kg / tree	182.0 a	6.6 a	6.9 a	70.5 a	0.42 a	60.8 a	165.6 ab	5.9 a	6.6 a	36.4 a	0.23 a	62.0 a
1.5 kg / tree	215.3 a	6.9 a	6.8 a	83.9 a	0.40 ab	77.0 a	171.5 ab	6.2 a	6.6 a	35.8 a	0.19 a	58.8 a
2 kg / tree	212.5 a	6.9 a	7.0 a	65.3 a	0.34 b	78.0 a	187.5 a	5.9 a	6.2 a	31.3 a	0.22 a	60.0 a
Khob El-Jamil												
Control	161.8 b	6.4 a	7.2 a	90.8 a	0.43 a	47.8 b	184.0 b	6.0 b	6.9 c	30.6 c	0.24 a	70.0 c
1 kg / tree	240.8 a	6.8 a	7.7 a	117.3 a	0.39 ab	71.5 ab	189.8 ab	6.6 a	7.5 b	36.5 bc	0.25 a	81.5 bc
1.5 kg / tree	208.8 ab	6.8 a	7.6 a	92.0 a	0.33 b	75.5 ab	200.8 ab	6.9 a	8.0 a	46.0 a	0.24 a	89.0 ab
2 kg / tree	224.8 a	6.9 a	7.9 a	96.9 a	0.35 ab	87.0 a	208.3 a	6.8 a	8.0 a	41.9 ab	0.26 a	100.0 a

*Means not sharing the same letter(s) within columns are significantly different ($P < 0.05$), by Duncan's multiple range test.

Although pomegranate trees grown for many years, little information is available on flowering and fruiting habits and fruit properties of local and introduced cultivars in Saudi Arabia. Recently, Bacha *et al.* (1994) studied the fruiting characteristics of some local and introduced pomegranate cultivars grown in Riyadh region. They reported that the physical properties of the fruits differed from one cultivar to another. Also, Singh *et al.* (1988) and Peters *et al.* (1993) found that pomegranate fruit size and other properties of the fruits were greatest in trees receiving the highest potassium rates. Meanwhile, Koo (1985), Miller & Hofman (1988) and Sabbah *et al.* (1995) indicated that the application of potassium to citrus trees, either to the soil or as foliar spray, had a marked effect on all aspects of fruit quality, particularly fruit size.

b) Chemical properties of the fruits

No significant differences were found in the chemical properties of Mellasy fruits between treatments, in the first season. Whereas, in the second season, fertilizing the trees with all potassium sulfate treatments caused a significant increase in TSS as compared with the control. Also, fertilizing the trees with 2 kg potassium sulfate markedly increased vitamin C in the fruits as compared with the control. However, no significant differences were found between potassium sulfate treatments in the percentage of acidity, Table 6.

Concerning Taeifi cultivar, results in Table 6 showed that the potassium sulfate treatments did not affect TSS or acidity of the fruits during both seasons. Whereas, increasing potassium sulfate rates, markedly, increased vitamin C in the fruits as compared with the control.

Regarding Khob El-Jamil cultivar, results in Table 6 indicated that TSS was unaffected by potassium sulfate levels during both seasons. Whereas, data of first season showed that the acidity of the fruits were significantly decreased in trees receiving 2 kg as compared with those receiving 1 kg potassium sulfate. However, in the second season, no significant differences were found in the percentage of acidity among treatments. Results of both seasons revealed that fertilizing trees with 2 kg potassium sulfate markedly increased vitamin C in the fruits as compared with the control.

These findings were, somewhat, in agreement with those obtained by Singh *et al.* (1988) and Peters *et al.* (1993). They reported that pomegranate fruit properties were greatest in trees receiving the highest rates of potassium. On the other hand, Sen and Chauhan (1983) found that rising potassium rates decreased TSS in pomegranate fruits.

The values of TSS, acidity and vitamin C of the experimental pomegranate fruits were generally similar to those obtained by Bacha & Ibrahim (1981) and Bacha *et al.* (1994) working on different pomegranate cultivars.

TABLE 6. Effect of potassium sulfate fertilization on the fruit chemical properties of some pomegranate cultivars during 1997 and 1998 seasons*.

Potassium sulfate rates	**Mellasy**			**Taeifi**			**Khob El-Jamil**		
	Total soluble solids (%)	Acidity (%)	Vitamin C (mg / 100 ml juice)	Total soluble solids (%)	Acidity (%)	Vitamin C (mg / 100 ml juice)	Total soluble solids (%)	Acidity (%)	Vitamin C (mg / 100 ml juice)
1997									
Control	15.3 a	1.54 a	2.92 a	15.2 a	0.59 a	2.69 bc	15.5 a	1.36 ab	2.34 b
1 kg / tree	15.3 a	1.51 a	2.81 a	15.1 a	0.59 a	2.39 c	15.4 a	1.61 a	2.81 ab
1.5 kg / tree	15.0 a	1.42 a	3.21 a	15.1 a	0.58 a	3.66 ab	15.7 a	1.35 ab	3.17 ab
2 kg / tree	15.8 a	1.33 a	3.38 a	15.8 a	0.59 a	4.14 a	16.2 a	1.14 b	3.61 a
1998									
Control	15.3 b	1.03 a	3.02 b	15.5 a	0.52 a	2.58 c	17.9 a	1.20 a	2.03 b
1 kg / tree	16.5 a	1.01 a	3.03 b	16.0 a	0.46 a	3.03 bc	18.1 a	1.12 a	2.20 ab
1.5 kg / tree	16.3 a	1.06 a	3.46 ab	15.6 a	0.49 a	3.38 ab	18.1 a	1.23 a	2.20 ab
2 kg / tree	16.5 a	0.96 a	3.89 a	15.9 a	0.45 a	3.95 a	17.6 a	1.16 a	2.32 a

*Means not sharing the same letter(s) within columns are significantly different ($P < 0.05$), by Duncan's multiple range test.

4. Leaf mineral composition

a) Macronutrients

Concerning Mellasy pomegranates, results in Table 7 showed that the potassium sulfate treatments did not affect the leaf nitrogen or phosphorus contents during both seasons. Meanwhile, fertilizing the trees with 1 or 2 kg potassium sulfate, in the first season, and with all potassium sulfate rates, in the second season, significantly increased the leaf potassium composition as compared with the control.

Regarding Taeifi cultivar, results of the first season in Table 7 showed that the leaf nitrogen content was significantly higher in trees received 1.5 and 2 kg potassium sulfate as compared with the control. Also, fertilizing trees with 2 kg potassium sulfate, markedly, increased the leaf potassium composition as compared with the control. However, no significant differences were noted in the leaf phosphorus content among potassium sulfate treatments.

Results concerning Khob El-Jamil cultivar indicated that, in the first season, leaf nitrogen content did not affect by the potassium sulfate treatments as compared with the control. Whereas, leaf phosphorus content was markedly higher in trees receiving 2 kg potassium sulfate as compared with those receiving 1.5 kg. However, in the second season, no significant differences were found in the leaf nitrogen or phosphorus contents between treatments. Meanwhile, data of both seasons, showed that leaf potassium composition was significantly higher in trees received 2 kg potassium sulfate as compared with those of the control.

Generally, the results of among pomegranate cultivars indicated that, the potassium sulfate treatments caused a slight effect on the leaf nitrogen and phosphorus composition. Whereas, the potassium sulfate treatments, especially, 2 kg/tree gave a marked increase in the leaf potassium content as compared with the control. Sutandzhanov & Egamberdiey (1977) and Haggag & El-Shamy (1987) found that increasing potassium rates in pomegranate trees raised leaf potassium content. Such findings are in line with the results of the current study. Likewise, Koo (1985), Miller & Hofman (1988) and Sabbah *et al.* (1995) reported that the potassium application to citrus trees, either to the soil or as foliar spray, caused major changes in leaf macro-nutrient contents. Moreover, increasing potassium rates markedly increased leaf potassium content, but the magnitude of the responses may vary due to local soil and climatic conditions.

b) Micronutrients

The results in Table 8 show that there were no significant differences in the leaf iron, zinc, manganese, and copper contents due to potassium sulfate treatments in Mellasy and Taeifi pomegranate cultivars during both seasons.

TABLE 7. Effect of potassium sulfate fertilization on some leaf macronutrient compositions for some pomegranate cultivars during 1997 and 1998 seasons*.

Potassium sulfate rates	Mellasy			Taeifi			Khob El-Jamil		
	% on dry weight basis								
	N	P	K	N	P	K	N	P	K
1997									
Control	1.90 a	0.16 a	0.95 b	2.10 b	0.19 a	0.77 b	2.92 a	0.20 ab	1.09 b
1 kg / tree	1.93 a	0.19 a	1.14 a	2.29 ab	0.24 a	0.92 ab	2.77 a	0.20 ab	1.30 ab
1.5 kg / tree	2.09 a	0.17 a	1.05 ab	2.75 a	0.23 a	0.95 ab	2.84 a	0.18 b	1.30 ab
2 kg / tree	1.92 a	0.14 a	1.22 a	2.69 a	0.22 a	1.01 a	2.66 a	0.22 a	1.45 a
1998									
Control	2.02 a	0.22 a	0.81 b	2.11 a	0.22 a	0.88 a	2.25 a	0.22 a	0.87 b
1 kg / tree	2.53 a	0.23 a	1.20 a	1.12 a	0.24 a	0.88 a	2.30 a	0.24 a	1.04 ab
1.5 kg / tree	2.12 a	0.22 a	1.22 a	2.10 a	0.23 a	0.95 a	2.25 a	0.23 a	0.99 ab
2 kg / tree	2.40 a	0.21 a	1.29 a	2.38 a	0.26 a	1.05 a	2.19 a	0.25 a	1.11 a

*Means not sharing the same letter(s) within columns are significantly different ($P < 0.05$), by Duncan's multiple range test.

TABLE 8. Effect of potassium sulfate fertilization on some leaf micronutrient compositions of some pomegranate cultivars during 1997 and 1998 seasons*.

Potassium sulfate rates	Mellasy				Taeifi				Khob El-Jamil			
	ppm on dry weight basis											
	Fe	Zn	Mn	Cu	Fe	Zn	Mn	Cu	Fe	Zn	Mn	Cu
1997												
Control	267.5 a	32.8 a	58.5 a	31.3 a	305.0 a	44.3 a	68.3 a	29.3 a	300.0 a	43.5 a	57.8 a	29.5 a
1 kg / tree	334.5 a	45.3 a	76.0 a	40.5 a	310.8 a	43.3 a	73.3 a	25.5 a	310.8 a	39.3 a	63.8 a	26.8 a
1.5 kg / tree	312.8 a	33.5 a	66.0 a	30.0 a	352.5 a	41.5 a	72.5 a	23.0 a	273.8 a	39.5 a	57.5 a	27.3 a
2 kg / tree	329.5 a	33.8 a	58.5 a	26.3 a	323.8a	47.5 a	68.8 a	27.3 a	297.0 a	37.8 a	65.3 a	24.3 a
1998												
Control	310.5 a	44.5 a	67.0 a	24.5 a	306.8 a	42.5 a	62.3 a	20.5 a	254.3 a	40.0 a	7.28 b	22.5 ab
1 kg / tree	346.5 a	48.5 a	68.0 a	27.5 a	232.0 a	33.8 a	62.8 a	17.3 a	312.3 a	52.0 a	96.8 a	28.3 a
1.5 kg / tree	340.0 a	48.3 a	70.5 a	24.3 a	227.8 a	41.5 a	62.0 a	20.3 a	236.5 a	41.0 a	75.5 ab	21.0 b
2 kg / tree	315.5 a	49.3 a	65.3 a	29.0 a	250.0 a	40.5 a	65.8 a	22.0 a	215.3 a	38.8 a	76.0 ab	18.3 b

*Means not sharing the same letter(s) within columns are significantly different ($P < 0.05$), by Duncan's multiple range test.

Regarding Khob El-Jamil cultivar, results revealed that the leaf iron and zinc contents were unaffected by potassium sulfate treatments during both seasons. While, leaf manganese content was markedly higher, only in the second season, in trees receiving 1 kg potassium sulfate as compared with the control. Also, in the second season, leaf copper content was significantly higher in trees receiving 1 kg as comparing with 1.5 or 2 kg potassium sulfate/tree.

Generally, results of the pomegranate cultivars showed that the leaf micro-nutrient composition, slightly, affected by the different potassium sulfate treatments. In contrast, Haggag & El-Shamy (1987) found that increasing potassium application rates decreased leaf manganese and zinc in pomegranate trees. Whereas, Koo (1985), Miller & Hofman (1988) and Sabbah *et al.* (1995) working on citrus trees, reported that the potassium application, slightly, affected leaf micro-nutrient composition.

Conclusion

Regular potassium application was necessary to obtain high yield and best fruit quality of pomegranate cultivars. Increasing the rates of potassium sulfate applications markedly increased the yield and the most of physical and chemical fruit properties. The best results were obtained by adding 2 kg potassium sulfate/tree/year. In addition, increasing the rates of potassium sulfate as a potassium source caused a marked increase in leaf potassium content as compared with the control. No consistent trends were found in leaf nitrogen and phosphorus contents with regard to potassium sulfate fertilization. However, leaf iron, zinc, manganese and copper were slightly affected by the potassium sulfate applications.

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تأثير التسميد بكبريتات البوتاسيوم على النمو الخضري والمحصول ، وجودة الثمار ، والمحتوى المعدني للأوراق في بعض أصناف الرمان

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الريـــــاض - المملكة العربية السعودية

المستخلص. أجري هذا البحث خلال عامي ١٩٩٧و ١٩٩٨م بغرض دراسة تأثير التسميد الأرضي بكبريتات البوتاسيوم (بمعدلات صفر، ١، ١,٥، ٢ كجم/ شجرة/ عام) على النمو الخضري ، والمحصول ، وجودة الثمار ، والمحتوى المعدني للأوراق في أصناف الرمان المليسي والطائفي وخب الجميل ، النامية بمحطة الأبحاث والتجارب الزراعية بمزرعة كلية الزراعة ، جامعة الملك سعود بديراب .

أظهرت النتائج أن النمو الخضري لأصناف المليسي والطائفي قد تأثر بدرجة بسيطة بمعاملات التسميد البوتاسي المختلفة . بينما أدى تسميد الأشجار بكبريتات البوتاسيوم في صنف الرمان خب الجميل بمعدل ١,٥ كجم/ شجرة إلى زيادة معنوية في قطر الجذع ، خلال الموسم الثاني ، ومحيط الشجرة ، خلال موسمي التجربة ، وذلك مقارنة بالمعاملة القياسية. وعلى العكس من ذلك ، فإن ارتفاع الشجرة في الأصناف الثلاثة لم يتأثر بدرجة كبيرة بالمعاملات المختلفة .

وبوجه عام ، أظهرت النتائج أيضا في أصناف الرمان الثلاثة أن زيادة معدل التسميد بكبريتات البوتاسيوم حتى ٢ كجم/ شجرة/ عام قد أدى إلى زيادة معنوية في محصول الأشجار ، وفي معظم الصفات الطبيعية والكيميائية للثمار. وبالإضافة إلى ذلك، فإن المعدل العالي من سماد كبريتات البوتاسيوم لم يعط زيادة في المحصول فقط ، ولكن زاد أيضًا من محتوى أوراق الأشجار من عنصر البوتاسيوم ، وهذا يوضح أن تأثر المحصول بزيادة معدلات التسميد ما هو إلا استجابة للإضافات من

البوتاسيوم . كما أوضحت النتائج أيضًا أن عدد ووزن الثمار ومحصول أشجار الرمان قد استجابت بطريقة إيجابية لإضافات كبريتات البوتاسيوم المختلفة ، وذلك في الموسم الثاني من التجربة بمقارنتها بالموسم الأول .

وأوضحت النتائج أيضًا أنه لا توجد علاقة واضحة بين معدلات التسميد بكبريتات البوتاسيوم ومحتوى أوراق أشجار الرمان من عنصري النتروجين والفوسفور ، بينما تأثر محتوى الأوراق من عناصر الحديد والزنك والمنجنيز والنحاس بدرجة بسيطة بتسميد الأشجار بكبريتات البوتاسيوم .

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Evaluation of Some Factors Influencing the Weight of Lamb and Placenta at Lambing in Local Sheep Under Arid Environment of Saudi Arabia

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Abstract. Data of the present study were collected from 105 lambing from 7 breeding groups. The sheep flocks were raised at Hada El-Sham Experimental Station of King Abdulaziz University, KSA. The aim of the study was to evaluate the effect of breed, season of lambing, parity, weight of ewe and sex of lamb on lamb birth-weight and placental weight at lambing. The average lamb birth weights (LBWT) of different breed groups were 3.01, 2.95, 2.77, 3.29, 2.82, 3.34 and 2.97 kg for Naeemi (NAE), Sawakni (SAW), Najdi (NAJ), Harri (HAR), and crosses of (HAR × NAJ), (HAR × SAW) and (HAR × NAE), respectively. Difference between the two averages was significant. The average placental weights (PWT) of the same breeds were 488, 507, 481, 447.94, 457.57, 491.25 and 527.21 g respectively. Difference between the two averages was significant. The average fluids weight (FWT) of the different groups were 2.12, 2.25, 2.31, 1.81, 2.05, 2.22 and 1.91 kg, respectively. Differences between NAJ and HAR were significant (2.31 and 1.81 kg, respectively). No consistent pattern was observed with regard to parity effects on LBWT, PWT. LBWT was heavier for male lambs than for female lambs, however, PWT of female lambs was heavier than males. Sex difference was found to have significant effect on LBWT and PWT. Estimates of linear regression revealed that the increase in ewe weight was associated with an increase in LBWT, PWT and decrease in FWT.

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Introduction

Birth weight is an economically important feature in sheep flock. Lamb birth weight has been shown to be the most important factor affecting lambing difficulty (Sobiraj, 1994 and Cloete *et al.,* 1998). Weight at lambing is positively associated with placenta weight (Galan *et al.,* 1999 and Risam *et al.,* 1999). Accordingly, the factors affecting birth weight of lamb are mostly the same factors influencing placental weight at lambing. Lamb birth weight and/or placental weight in a flock of sheep appears to be affected by maternal factors (Omar, 1990; Abiola & Onwuka, 1998; Chaiwatanasin *et al.,* 1998; Hassan *et al.,* 1998, Mbap & Ikechi, 1998; Malik *et al.,* 1998; Arora *et al.,* 1999; Risam *et al.,* 1999 and Combellas & Combellas, 1999), direct genetic effects (Malik *et al.,* 1998; Eskandary & Kashan, 1998; Chaiwatanasin *et al.,* 1998; Hassan *et al.,* 1998; Singh *et al.,* 1998; Risam *et al.,* 1999 and Yazdi *et al.,* 1999), sex (Omar, 1990; Osinowo *et al.,* 1993, Abba, 1997; Yazdi *et al.,* 1998; Gill *et al.,* 1996 and Al-Merestani *et al.,* 1999), and the physiological state of the dam as associated by age, parity or weight (Omar, 1990; Jenkin *et al.,* 1995; Ozturk, 1996; Abba, 1997; Abiola & Onwuka, 1998; Hassan *et al.,* 1998; Mbap & Ikechi, 1998; Malik *et al.,* 1998; Singh *et al.,* 1998; Yazdi *et al.,* 1998; Risam *et al.,* 1999; Arora *et al.,* 1999; Thieme *et al.,* 1999; and Combellas & Combellas, 1999).

Since the sheep placenta is known to produce sufficient amounts of prostaglandin (PGE_2), it seems that the placenta controls fetal thermogenic responses to some extent. This transforms the fetus into an ectothermic organism, and yet allows the newborn a full exploitation of thermoregulatory responses typical to endothermic animals (Schroeder & Power, 1997).

The objectives of this study were to evaluate the nongenetic maternal and some environmental influences on lamb, placental and fluids weights at lambing and to clarify the relationship between placental weight and the weight of lamb produced at lambing under arid land environment.

Materials and Methods

Data from 105 ewes were collected from 7 different breed groups and their crossbreds namely Naeemi (NAE); Sawakni (SA); Najdi (NA); Harri (HA); ♀Harri)♂MNajdi (HA × NA),♀Harri) × ♂Sawakni (HA × SA) and ♀Harri × ♂ Naeemi (HA × NA), raised at Hada El-Sham Experimental Research Station belonging to the Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University.

This experimental station, covering an area of 100 acres, was established in an area located hundred and ten kilometer to the Northeast of Jeddah, in Hada Al-Sham area in Jamoum Governorate, which is rich of underground fresh water. Its climate is characterized by a long, hot and dry summer with increased humidity and a relatively short winter. The maximum temperature could reach 47°C in summer and about 10°C in winter. The average annual rainfall is below 10 cm and occurs mostly during winter.

All sheep were housed in open sheds, grazed on pasture from 7 to 11 in the morning and from 3 to 6 afternoon. Dry ewes and ewes in early pregnancy were offered ½ kg of concentrated feed/head/day (18% CP). This amount was increased to 0.75 kg during the last month of pregnancy. After lambing, the ewes with their lambs were transferred to individual pens, measuring 1.5 × 1.0 m in size, for one week and then transferred again to a larger enclosure with another 15-25 ewes and their lambs. All animals including had free access to fresh water and mineralized salt blocks.

Intensive sheep production system criteria were used (3 lambing/2 years). Ewes were bred in three breeding seasons over the year (January-February), (May-June) and (September-October). Consequently, there were three lambing seasons (June-July), (October-November) and (February-March).

Ewes were normally inseminated by rams. All ewes delivered normally, weight of lamb at birth (LBWT) and ewe weight immediately before (WTEB) and after (WTEA) lambing were recorded after expulsion of placenta (3-5 h) after parturition. Placental weight (PWT) was recorded to the nearest g. Weight of placental fluids was calculated from the following formula

$$FWT = WTEB - (WTEA + LBWT + PWT)$$

whereas

FWT = Fluids weight

WTEB = Weight of EWE just before lambing

WTEA = Weight of EWE after lambing

LBWT = Lamb birth weight

PWT = Placental weight

Data of lamb birth weight, placental and placental fluids weights at lambing were analyzed by the least squares and maximum likelihood program of Harvey (1990). A linear model including the fixed effects of parity, sex and season of lambing weight of ewe just before lambing was considered as a covariant.

Meteorological data for the total duration of the experiment (from May 1998 to June 1999) were obtained from the Department of Meteorology in Hada El-Sham Experimental Research Station.

Results and Discussion

Meteorological data

Figure 1 indicated that environmental temperature and relative humidity percent fluctuated among the different months. The highest ambient temperature was attained during May and September (46.15 and 46.00ºC, respectively), while the least was recorded during January (10ºC). Daily photoperiod length showed the longest day during May, June and July (11, 11 and 11 h, respectively) while the shortest day was recorded during December (8.5 h).

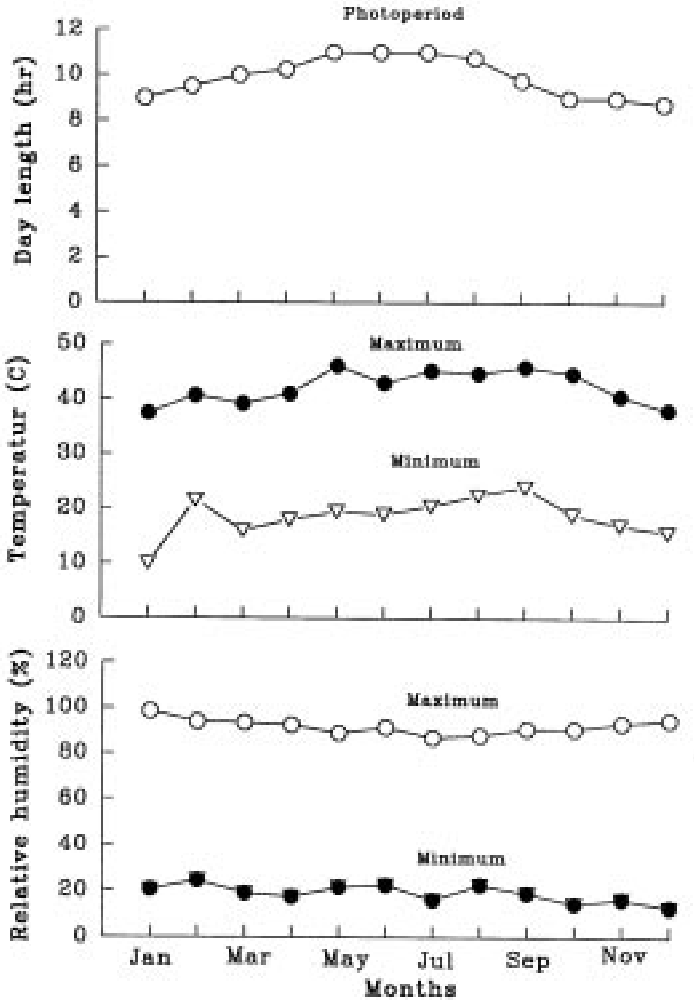

FIG. 1. Average monthly variations in day length, environmental temperature and relative humidity throughout the study.

Means and Variation of Uncorrected Records

The means, standard error and coefficient of variation (CV%) of ewes weight immediately before lambing (WTEB), after lambing (WTEA), lamb birth weight (LBWT), number of lambs (NOL), placental weight (PWT) and fluids weight (FWT) are given in Table 1.

TABLE 1. Means, standard errors (SE) and coefficient of variation (CV%) of unadjusted records.

Variable		Mean ± SE	CV%
Weight of ewe before lambing (WTEB)	(kg)	41.49 ± 0.37	9.18
Weight of ewe after lambing (WTEA)	(kg)	36.26 ± 0.36	9.90
Lamb birth weight (LBWT)	(kg)	2.90 ± 0.05	19.20
Number of lambing (NOL)		1.12 ± 0.03	29.45
Placental weight (PWT)	(g)	461.71 ± 7.43	16.50
Fluids weight (FWT)	(kg)	1.97 ± 0.05	23.66

*Number of observations = 105.

For the traits studied LBWT and PWT, CV relatively are nearly similar in magnitude (19.20 and 16.50), respectively. These higher coefficients of variation are more likely to be due to higher maternal effects on growth of lamb during the prenatal period.

The average LBWT and PWT at lambing in native sheep included in the present study are relatively low (2.90 kg and 461.71 g, respectively) compared to other estimates for the same breed reported in the literature. In this respect, higher average birth weight for the same or different breeds of sheep have been reported by some investigators (Omar, 1990; Mbap & Ikechi, 1998; Arora *et al,.* 1999 and Abba, 1997). While the contrary was observed by others (Abiola & Onwuka, 1998; Mbap & Ikechi, 1998; Singh *et al.,* 1998; Chaiwatanasin *et al.,* 1998 and Combellas & Combellas, 1999). The evidence from the differences between the estimates for the traits studied and those reported by other investigators for the same and/or different breeds of sheep could possibly by attributed to possible differences in genitical criteria, climate, nutritional and/or managerial aspects.

Breed Effect

Least squares means of factors affecting lamb birth weight (LBWT), placental weight (PWT), fluids weight (FWT) and weight of ewe just before lambing are presented in Table 2. The average LBWT was 3.01, 2.95, 2.77, 3.29, 2.82, 3.34 and 2.97 kg. For NAE, SAW, NAJ, HAR, (HAR × NAJ), (HAR × SAW) and (HAR ×NAE) crossbreds respectively. The heaviest LBWT average was observed in HAR × SAW crossbred (3.34 kg), and the lightest LBWT average was observed in NAJ lambs (2.77 kg). Difference between the two averages was significant. The average PWT of the same breeds was 488, 507, 481, 447.94, 457.57, 491.25 and 527.21 g, respectively. The heaviest PWT average was detected in HAR ×NAE crossbred (527.21 g) and the lightest PWT average was observed in HAR (447.57 g). Difference between the two averages was significant. The average FWT of the different groups mentioned above was 2.12, 2.25, 2.31, 1.81, 2.05, 2.22 and 1.91 kg, respectively. Again difference between NAJ and HAR was significant (2.31 vs. 1.81 kg, respectively).

Breed in this study was found to exert a significant influence on LBWT, PWT and FWT. This result is in agreement with those obtained by Omar (1990); Ozturk (1996); Hassan *et al.* (1998); Mbap & Ikechi (1998); and Malik *et al.* (1998).

Parity Effect

Parity failed to exert a significant influence on LBWT and PWT (Table 2). Differences between FWT due to parity effect, however, were significant. Results on LBWT and PWT are in agreement with those obtained by Abba (1997) who concluded that lambs born to multiparous ewes were heavier than those born to primiparous ewes.

TABLE 2. Least squares-means ($\bar{x}$) of factors affecting lamb birth weight (LBWT), placental weight (PWT), fluids weight (FWT) and weight of ewe just before lambing (WTEB).

Independent variable	N	LBWT (kg)		PWT (g)		FWT (kg)		WTEB	
		$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
Breed		*		*		*		*	
1. Naeemi (NAE)	20	3.01	0.12	488.60	17.79	2.12	0.10	44.27	0.64
2. Sawakni (SAW)	10	2.95	0.16	507.37	24.79	2.25	0.14	46.01	0.86
3. Najdi (NAJ)	5	2.77	0.21	481.68	32.60	2.31	0.19	38.73	1.26
4. Harri (HAR)	30	3.29	0.10	447.94	15.35	1.81	0.09	38.76	0.54
5. (HAR × NAJ)	20	2.82	0.10	457.57	16.70	2.05	0.10	43.72	0.62
6. (HAR ×SAW)	10	3.34	0.16	491.25	23.60	2.22	0.15	39.59	0.91
7. (HAR ×NAE)	10	2.97	0.15	527.21	23.29	1.91	0.13	39.85	0.91
Parity		ns		ns		*		ns	
1st	31	3.04	0.09	462.63	14.39	1.69	0.08	41.89	0.57
2nd	33	2.94	0.09	489.02	13.88	2.05	0.08	41.60	0.55
3rd	24	3.04	0.10	494.81	15.75	2.24	0.09	41.26	0.63
4th	18	3.06	0.12	497.32	18.445	2.40	0.11	41.50	0.73

TABLE 2. Contd.

Independent variable	N	LBWT (kg)		PWT (g)		FWT (kg)		WTEB	
		$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
Season of lambing		ns		*		*		ns	
Feb-March	35	3.09	0.09	458.07	13.31	1.95	0.08	42.05	0.53
Jun-July	30	2.94	0.09	480.82	14.42	2.21	0.08	41.59	0.57
Oct-November	40	3.03	0.09	518.94	13.37	2.13	0.08	41.06	0.53
Sex		*		*		ns		ns	
1. Male (M)	45	2.81	0.08	462.32	11.54	2.06	0.07	41.84	0.46
2. Female (F)	2.6	2.76	0.07	465.28	11.06	2.11	0.06	40.90	0.44
3. Twins	12	3.49	0.04	530.24	20.90	2.11	0.12	41.95	0.83
Linear regress on ewe weight at lambing		0.072^{**}	0.017	1.750^{ns}	2.673	-0.673^{ns}	0.015	–	–

* = P < 0.05
ns = Not significant

From another point of view, the present result indicated that lambs born in the 4th parity or more were heavier than those born at earlier parities, this conclusion agrees with those reported by Yazdi *et al.,* (1998) who revealed that lambs were born at parities 4-6 had heavier birth weight than those born at earlier or later parties. However, the effect of parity could result as a combination of increased nutritional supply to the embryo, increased placental size, physical effects, ... etc. Therefore, findings of the present and reviewed studies can be expected because ewes in their first parity have just reached sexual maturity. Difference between least square means of the first and second parities in LBWT can be neglected biologically (3.04 vs. 2.94 kg), and consequently their efficiency in providing their fetus with nourishment and intrauterine environment during the prenatal mothering ability increase with the advancement of parity until a certain age, then it remained constant for a period and decreased thereafter due to aging (Abba, 1997).

FWT at lambing increased linearly as parity advanced (Tables 2 and 3). During the first pregnancy, the ewes still growing (*i.e.,* there is a competition between the ewe and its fetus concerning the use of nutrition) and consequently their body size (relevant to placental weight) are increased with advancement of parity.

Season of Lambing Effect

Least-squares means given in Table 2 indicated that the effect of season on LBWT was not significant. Seasons, however, were significant on PWT and FWT. There was a general tendency for LBWT and PWT at lambing to be low, when lambing took place in hot month (June). This tendency increased however with lambing during the months of February and October. The results of the analysis of variance in Table 3 showed that a significant relationship existed between PWT, FWT and season of lambing. This conclusion was observed by other investigators (Mbap & Ikechi, 1998; Hassan *et al.,* 1998 and Malik *et al.,* 1998). These results could be attributed to the fact that, during June and July (summer season) and October and November (autumn season), grazing on green fodder for pregnant ewes was not available in sufficient quantity, and was lower in nutritive value as well as the weather was not favorable. But during February (winter season), fodder became more abundant and of high nutritive value as the weather becomes milder. These results were in agreement with those obtained by Malik *et al.* (1998).

TABLE 3. Analysis of variance and coefficient of determination (r^2) of factors affecting lamb birth weight (LBWT), placental weight (PWT) and fluids weight (FWT) at lambing.

Source of variation	DF	LBWT (kg)	PWT (kg)	FWT (g)
		Mean squares	Mean squares	Mean squares
Breed	6	0.49^{*} ($r^2 = 0.091$)	10948^{*} ($r^2 = 1.088$)	0.40^{*} ($r^2 = 0.108$)
Parity	3	0.08^{ns} ($r^2 = 0.007$)	5795^{ns} ($r^2 = 0.288$)	1.90^{**} ($r^2 = 0.253$)
Linear	1	0.03^{ns}	10688^{ns}	4.85^{**}
Quadratic	1	0.09^{ns}	3307^{ns}	0.23^{ns}
Cubic	1	0.09^{ns}	391^{ns}	0.02^{ns}
Season of lambing	2	0.18^{ns} ($r^2 = 0.001$)	30079^{**} ($r^2 = 0.997$)	0.60^{*} ($r^2 = 0.053$)
Sex	2	2.50^{**} ($r^2 = 0.155$)	21910^{*} ($r^2 = 0.726$)	0.03^{ns} ($r^2 = 0.003$)
Linear regression on ewe weight	1	3.65^{*} ($r^2 = 0.113$)	2435^{ns} ($r^2 = 0.040$)	0.14^{ns} ($r^2 = 0.006$)
Residual	90	0.20	4584	0.015

$^{*}P < 0.05$ and $^{**}P < 0.01$.

The present results also indicated that, FWT in June (hot summer season) were significantly higher than that in October and November season of lambing. Findings of the present and reviewed studies, as well, can be expected because the fact that 'engine' of fetal metabolism generates heat (3-4 W kg-1 in fetal sheep), which has to be dissipated to the maternal organism. Because resistance to heat flow is larger than zero, fetal temperature exceeds maternal temperature by about 0.5°C (0.3-1°C). Schroeder and Power (1997) who added that since the sheep placenta is known to produce sufficient amount of prostaglandin E-2 (PG E-2), it seems that the placenta controls fetal thermogenic responses to some extent. This transforms the fetus into an ectothermic organ and yet allows the newborn a full exploitation of thermoregulatory responses typical to endothermic animals.

Since the fetus is considered as ectothermic, the effect of environmental heat on the thermoregulatory responses is expected to be more pronounced. Due to the fact that the present study revealed a non-restricted placental growth during hot seasons, this means that the sheep were thermoregulating well when exposed to hot environment. This conclusion is in agreement with the work of McCrabb and Bortolussi (1996). The sheep included in the present study are native of the arid land environment of Saudi Arabia. This might explain their observed thermoregulatory response.

Sex Effect

Male lambs were heavier in birth weight and PWT than female lambs (Table 2). In this respect, many investigators working in the different breeds of sheep observed that male lambs and their placenta were heavier in weight at lambing than female lambs (Omar, 1990; Osinowo *et al.,* 1993; Abba, 1997; Yazdi *et al.,* 1998; Gill *et al.,* 1996 and Al-Merestani *et al.,* 1999). These results are expected because LPWT was significant and positively correlated with PWT at lambing. The trends in sex differences in LPWT and PWT were statistically significant, respectively, while they were nonsignificant for fluids weight (Table 3).

Weight of Ewe before Lambing (WEBL)

LBWT was increased linearly with the increase of WTEBL (Tables 2 and 3) while PWT increased linearly, but did not reach statistical significance. Meanwhile, the relative size of F-values for the fixed effects included in the model of analysis (Table 3) indicated that weight of ewe effects contribute significantly to the variance of LBWT (Abba, 1997; Singh *et al.,* 1998 and Thieme *et al.,* 1999).

Estimates of linear regression (Table 2) revealed that the increase in ewe weight was associated with an increase in LBWT and PWT, and decrease in FWT. Each kg increase in ewe weight was associated with an increase of 0.072 kg, 1.75 g LBW and PWT respectively, and decreased 0.673 FWT.

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تقييم لبعض العوامل التي تؤثر على وزن الحملان ووزن المشيمة عند الولادة في الأغنام المحلية تحت ظروف البيئة الجافة بالمملكة العربية السعودية

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المستخلص . البيانات الموجودة في هذه الدراسة تم جمعها من عدد ١٠٥ ولادة شملت ٧ أنواع من قطعان الأغنام الموجودة بمحطة الأبحاث بهدى الشام التابعة لجامعة الملك عبد العزيز بالمملكة العربية السعودية . وكان الغرض من الدراسة تقييم تأثير النوع وموسم الولادة ، وعدد مرات الولادة ووزن الأم قبل الولادة وجنس الحمل على وزن الحملان ووزن المشيمة عند الولادة . ووجد أن متوسط أوزان الحملان عند الولادة في الأنواع المختلفة هو ٣,٠١، و٢,٩٥، و٢,٧٧، و٣,٢٩، و٢,٨٢، و٣,٣٤، و٢,٩٧ كجم لكل من النعيمي ، والسواكني ، والنجدي ، والحري ، وخلطان (الحري والنجدي) ، و (الحري و السواكني) ، و(الحري والنعيمي) على الترتيب . ووجد أن متوسط أوزان المشيمة في نفس الأنواع السابقة ٤٨٨، و٥٠٧، و٤٨١، و٤٤٧,٩٤، و٤٥٧,٥٧، و٤٩١,٢٥، و٥٢٧,٢١ جم بالترتيب . ووجد أن أثقل متوسط لوزن المشمية في خليط (الحري والنعيمي = ٥٢٧,٢١ جم) ومتوسط أخفها وزنًا في خليط أغنام (الحري = ٤٤٧,٥٧ جم) وكان الاختلاف بين المتوسطين معنوي . ولقد لوحظ أن متوسط أوزان السوائل الجنينية لمختلف الأنواع المدروسة ٢,١٢، و٢,٢٥، و٢,٣١، و١,٨١، و٢,٠٥،

* العنوان الدائم : قسم الإنتاج الحيواني ، كلية الزراعة ، جامعة عين شمس ، ص. ب ٦٨ حدائق شبرا ، ١١٢٤١ القاهرة – مصر.

و٢٢,٢، و٩١,١ كجم بالترتيب . ووجد أن الاختلاف بين أثقلها وزنا وأخفها وزنًا معنويا . ولم تظهر النتائج تأثيرًا معنويًا لعدد مرات الولادة على الصفات المدروسة ، ولكنها أظهرت زن متوسط وزن الميلاد للحملان الذكور أثقل من متوسط وزن الحملان الإناث ، بينما كانت متوسطات أوزان المشيمة للحملان الإناث أثقل من الذكور . ووجد أن جنس المولود له تأثير معنوي على الصفات المدروسة .

وبتقدير الانحدار الخطي أوضحت النتائج أن هناك علاقة طردية بين وزن الأم مع كل من وزن الحملان ووزن المشيمة عند الولادة ، وعلاقة عكسية مع وزن السوائل الجنينية .

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Seminal Plasma Induced Ovulation in the One Humped Arabian Camel (*Camelus Dromedrius*)

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Abstract. Fifty females and six males one-humped Arabian camels were used in the breeding season to determine factors inducing ovulation. After insemination ovaries were checked for ovulation by rectal palpation. The results indicated that ovulation was induced by seminal plasma but not by the spermatozoa, and the incidence of ovulation after insemination was 80%. Sixty percent of the females ovulated by 36 h after insemination and the rest by 48 h. The least amount of semen required to elicit ovulation was about 1.0 ml. Intramuscular injection of LH, hcG and LHRH also caused ovulation, even in females that did not ovulate in response to insemination.

Introduction

Reproduction is often the key to improved livestock performance. Reproduction in the camel is not as well understood as in more common species of domestic animal (Merkt *et al.,* 1990). Puberty in females occurs at 3 to 4 years of age and the first calf is born when the mother is 5 to 6 years old. Females remain sexually active for 20 to 30 years (Yagil, 1985). It is a common practice to withhold female camels from breeding until they are 4 to 6 years and the age at first calving would be 5 to 7 years. Because camels can live up to 40 years, it is possible to produce a number of calves similar as are possible for cow (Musa and Merkt, 1990).

Puberty in males occurs at 6 years of age and good service ability is maintained until 18 to 20 years (Novoa, 1970 and Wilson, 1984). The female camel

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is considered to be a seasonal breeder with a marked peak in sexual activity (Wilson, 1984). Factors that affect the beginning of the breeding season, its duration and intensity of sexual activity include: local climatic condition, nutrition and management. It may be pointed out that, the male camels are sexually active for a few months each year, the so called rutting. The time of rutting season differs from region to region (Yagil, 1985).

In the Libyan dromedary the breeding season start in October (El Tamour) and terminates in March (El Rabia), (Zaid *et al.,* 1991) .

Novoa (1970) showed that sexual activity in camelids appeared to be acyclic; females did not have estrus cycles comparable to those of spontaneous ovulators. Chen *et al.* (1980) indicated that female bacterian camels exhibited follicular cycles, the follicles developing and regressing one by one. It took 19.10 ± 4.25 days from the start of development of follicle (~ 0.5 cm in diameter) to begin its regression. One mature or developing follicle was usually present in an ovary. When not allowed to mate, the camel manifested prolonged period of estrus however; if mating occurred, ovulation would take place in 30-48 h later. Shalash and Nawito (1964), Shalash, (1980) suggested that copulation, mechanical or electrical stimulation of the cervix and other afferent stimuli would be necessary for ovulation in the dromedary. San Martin *et al.* (1968) reported that ovulation in alpaca was induced by coitus, and that follicles ovulated 26 h after coital stimulation or 24 h after intravenous injection of hcG. Fernandez-Baca *et al.* (1970) indicated that mounting accompanied by intermission were necessary to provide adequate stimulation for LH release and subsequent ovulation in alpaca. Musa and Abusineina (1978) reported that ovulation in the dromedary camel was not spontaneous and required coitus stimulation, and that manual stimulation of the cervix did not induce ovulation. Chen *et al.* (1983) reported that mounting and stimulation of the cervix did not elicit ovulation in the bacterian camel however, vaginal insemination did induce ovulation, but the numbers of animals were very small. Chen *et al.* (1985) reported that semen-induced ovulation in the bactrian camel. Agarwal and Rai (1995) reported that camel is an induced ovulators and needs mating stimulus for ovulation.

The present study was therefore undertaken to investigate the ovulation-inducing effect of semen in the one-humped Arabian camels .

Materials and Methods

Animals and Methods

Fifty breeding camels, 8-14 years of age, free from any detectable genital abnormalities and 6 high fertile male camels, 5-10 years of age, were kept in separate areas. The range was good and the camels were grazed or browsed freely all the year round were given supplementary food with 2 kg grain every evening in the winter months. The average body weight of female camels was about 450 kg and that the males was about 580 kg .

From the beginning of the breeding season (started from October and terminated in March) development of follicles was followed daily by rectal palpation. When the follicles had reached a diameter of $\geq$ 12 m (Skidmor *et al.,* 1996), the females were treated with materials deposited intravaginally or by intramuscular injection of hormones. The ovaries were checked for ovulation by rectal palpation at 24, 36, 48 h after treatment.

Intravaginal Administration

A rubber inseminating tube of the type used for horse AI, was inserted gently and as deeply as possible into the vagina. The materials to be tested were injected through the tube by means of syringe .

Whole Semen

Semen of male camels was collected by means of artificial vagina as used for cattle. The semen was used immediately or stored at 0 to -10^{o}C for different lengths of time. The semen was thawed and warmed to 37^{o}C before use. The insemination volume was 0.5 to 7.0 ml. Bull, goat semen samples (2-3 ml) stored in the refrigerator (0 to -2^{o}C) was also tested.

Seminal Plasma

After collection, the semen was centrifuged (500 g), the supernatant was examined microscopically and when sperm count was < 10000 / ml, the seminal plasma was used on a volume of 3 ml (Chen *et al.,* 1985).

Washed Spermatozoa of High Concentration

After centrifugation of semen and removal of the supernatant, saline (9 g NaCl / 1) was added to the sediment and the suspention was recentrifuged. The procedure was repeated 3 times and the final pellet was examined. Washed spermatozoa were used at a concentration $4\text{-}7\times 10^{8}$ ml and an insemination volume of 3 ml (Chen *et al.,* 1985).

Accessory Sex Gland Secretions

Male 6 was vasectomized, collection of semen started 6 days after operation and was repeated every 2 days until for a period of 18 days (Chen *et. al.,* 1985).

Skim Milk

As control, skim milk from a cow was deposited into the vagina in a volume of 6 ml.

Natural Mating

Male camels were allowed to copulate and 4-10 min after the end of coitus, the duration of which was about 3 min, semen was flushed out of vagina with saline.

Exogenous Hormones

When ovulation did not occur in response to intravaginal treatment (except for the control) hormones were injected i.m. to determine whether the materials were ineffective or the follicle were unable to ovulate. The hormones used were LH (Wuhan Biochem Pharmaceutical Co., Hankow, China), 300 i.u in 4 ml saline: hcG (Tong-Feng Pharmaceutical Co., Beijing), 1000-2000 i.u. in 4 ml saline and LHRH analogue (Biochemical Institute – Shanghai), 250-500 μg in 2-4 ml saline.

Results

Ovulation-Inducing Effect of Components of Camel Semen

Whole semen: Eight females from ten inseminated ovulated (80%). The least amount of semen required for inducing ovulation was about 1.0 ml. All females inseminated with 1.0 ml semen or less (0.1-0.2 ml semen was left in the inseminating tube) ovulated. One semen sample stored at about $-10^{o}C$ for two months was effective in inducing ovulation. The ovulation time was similar to that after natural service, with 6 (60%) females ovulated after 36 hr and 3 (30%) having ovulated by 48 hr. While only one female (10%) did not ovulate. There was no differences in the effect on ovulation when the semen samples were fresh and contained live spermatozoa (9/10 ovulating) or had been frozen at $-10^{o}C$ for several days and contained dead spermatozoa (8/10 ovulating).

Seminal plasma: Among 10 females inseminated 8 ovulate.

Washed spermatozoa: None of 10 females inseminated with high concentration washed spermatozoa ovulated.

Accessory sex gland secretion: All females (10) inseminated (including 4 natural services by the vasectomized male), ovulated.

Control substance: None of the 10 females tested with skim milk ovulated.

Natural service: Among five females given natural service followed by flushing of vagina, four did not ovulate.

Effect of bull and goat semen: Among five females inseminated with bull semen, 2 had ovulated after 36 hr and 2 had ovulated after 48 h. Five females inseminated with goat semen did not ovulate.

Ovulation-inducing effect of semen of individual male camels in this part of the present study 6 male camels were used and the effect of their semen on ovulation is summarized in Table 1. Camel 3 appeared different from the others (fewer females ovulated in response to its semen). Cystic follicle were detected in the ovaries of 2 of the females treated with semen of this male, and also 4 females that had not ovulated in response to male 3 did ovulate in response to hcG or LHRH injection, indicating that the follicles were able to ovulate .

TABLE 1. Ovulation inducing effect of individual male camel.

Male	Insemination		Mating	
	No. of ♀ tested	No. of ovulation	No. of ♀ tested	No. of ovulation
1	3	3	1	1
2	14	13	6	6
3	15	9	5	3
4	11	8	3	3
5	4	3	2	2
6	3	3	–	–

Reaction of individual female camel to semen: Out of fifty female camels investigated, 5 showed abnormal ovulatory response. One female suffered from chronic cervicies, and another had cystic follicles after insemination with semen of fertile male camels in two successive seasons. The other 3 females did not ovulate in response to insemination, but did ovulate after injection of the hcG; other female camels reacted to semen of the same male and ovulated.

Ovulation-inducing effect of some reproductive hormones: The results of intramuscular injection of hormones are summarized in Table 2. The interval between injection and ovulation in all cases was 36 h.

TABLE 2. Ovulation-inducing effect of reproductive hormones.

Hormone	Dose	No. of female tested	No. of ovulation
LH	300 i.u.	5	5
LHRH	250 µg	4	4
LHRH	500 µg	5	4
hcG	1000 i.u.	2	2
hcG	1500 i.u.	3	2
hcG	2000 i.u.	3	3

Discussion

Results indicated that ovulation in Arabian one-humped camels is not spontaneous and is induced by seminal plasma. Spermatozoa were not effective in inducing ovulation. This conclusion agrees with those obtained by Agarwal and Rai (1995) and Chen *et al.* (1985), who reported that, insemination of seminal plasma can cause ovulation indicating the presence of some ovulation inducing factor in it. Bull semen also seemed to contain the ovulation inducing factors in our study however, goat semen did not. The nature of the ovulation inducing factor was found similar to GnRH (Agarwal and Rai, 1995), The relation of ovulation with reproductive hormones was described by previous authors, who found that the preovulatory peak of LH and the postovulatory peak of progesterone seem to be important indicators of ovulation .

Ovulation can be induced by luteinising hormone (LH), human chrionic gonadotrophin (hcG) and gonadotrophin releasing hormone (GnRH) (Musa *et al.,* 1993). However, the nature of the inducing factor and the mechanism of stimulation of LH release after its absorption remains to be clarified. The vagina or the uterus may be the place of absorption, since intrauterine insemination of females also led to ovulation. Absorption may be very rapid because 1 of 5 females ovulated after mating though the semen was flushed from the vagina 4-10 min later.

In the present study ovulation occurred in 23/31 (74.19%) camels after insemination (Chen *et al.,* 1985 reported 41/47 = 87%) although in the previous work (Chen *et al.,* 1980) reported that, ovulation took place in all of 26 females mated naturally. The mating behavior might therefore have some augmentative effect on the semen-induced ovulation. There are also variations in the response of individual females and the ability of particular males to induce ovulation (Chen *et al.,* 1985).

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التبـويض يستحث ببـلازمـا السائـل المنـوي في الجمال العربية وحيدة السنام

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القـــاهـرة - مصـــر

المستخلص . لتحديد العوامل التي تسبب حدوث التبويض في الجمال العربية ذات السنام الواحد استخدام في هذه الدراسة ٥٠ أنثى و ٦ ذكور في موسم التلقيح . وبعد التلقيح بعينات من السائل المنوي في المهبل ، تم فحص التبويض عن طريق الجس المستقيمي . ولقد أظهرت النتائج أن التبويض في إناث الجمال (النوق) يستحث ببلازما السائل المنوي ، وليس بالحيوانات المنوية . وأظهرت النتائج أن نسبة حدوث التبويض بعد التلقيح كانت ٨٠٪ . ولقد اتضح أن معظم الإناث (٦٠٪) حدث لها تبويض بعد ٣٦ ساعة من التلقيح ، وبقية الإناث حدث لها تبويض بعد ٤٨ ساعة . واتضح أن أقل كمية من السائل المنوي يمكن أن تحدث التبويض هي ١ ملل. وأظهرت النتائج أيضًا أن الحقن بهرمونات LH ، LHRH ، hcG يسبب حدوث التبويض حتى في تلك الإناث التي لم يحدث لها تبويض نتيجة حدوث التلقيح .

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Spacing Effects on Relative Growth Rates of Diameter, Height and Biomass Production in *Leucaena leucocephala* (Lam.) de Wit. before and after Pruning

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ABSTRACT. Seedlings of *Leucaena leucocephala* (Lam.) de Wit. were planted in the field at the Agricultural Experiments Station of the College of Agriculture, King Saud University, Riyadh, Saudi Arabia, in October 1995. The trees were planted at spacing of 0.70, 1.40 and 2.10 meter either between rows or between trees within row. The trees were pruned after 18 months of planting. The relative growth rates of both diameter and height increased with increasing the distance between trees but decreased with age. Pruning increased the effects of both diameter and height growth on total above-ground biomass; with a larger contribution of diameter particularly in both medium and wide spacing regimes.

Introduction

Stem growth is a function of the growth of both height and diameter. The growth status of the seedlings, therefore, may be expressed in terms of total height and current height growth increment (Jobindon, 1994). Tree volume is also a function of the square of diameter (Van den Beldt, 1982). Thus, exploring the variability in early diameter and height growth rates is important, when interpreting development of the stands. Trees of the same age grow in height at roughly the same rate, provided that site conditions are uniform. The growth of diameter is much more variable than that of height, therefore the trees in an even-aged stand are not as uniform in diameter as they are in height. Pruning is used to produce knot-free wood; when commercial lumber is sought of and also to lengthen the branch-free bole of trees. It is possible to plant new stands at a very wide spacing with a small number of trees and employ drastic pruning not only to get rid of branches but also to prevent boles from becoming too tapering. Pruning therefore, has positive effects on growth of trees when is done at the proper time. However, a fast relative growth rate can be achieved through an efficient uptake and/or use of resources such as water, nutrients and light (Norgren, 1996). The growth rate of diameter depends upon the degree of competition, thus its pattern can be controlled to a large degree through spacing (Philip, 1994). Higher stem-wood production in turn can be achieved through a faster rate of total biomass production and/or by allocating a larger proportion of the biomass produced to stem growth (Norgren, 1996).

The present study aims to investigate the effects of spacing on the stem diameter, height and above-ground biomass production of leucaena trees before and after pruning.

Materials and Methods

Plant Material

Seedlings of *Leucaena leucocephala* (Lam.) de Wit. (six month-old) were planted in the field at King Saud University Experiments Station near Riyadh, Saudi Arabia, in October 1995.

Site Characteristics

The location where leucaena seedlings were planted is 24º6′N, altitude; 46º5′E, attitude; 650 m above sea level, with average temperatures ranging between 0ºC in winter and 37ºC in summer and 50 mm annual rainfall. The soil is sandy loam with average 61, 23 and 15 % of sand, silt and clay, respectively (Aref, 1987).

Experimental Design and Treatments

The leucaena seedlings were planted in the field using a randomized complete block design with three blocks; each had three experimental plots. The seedlings were planted at spacing either of 0.70 or 1.40 or 2.10 meter (between rows) and between trees (within row) as treatments. Each treatment had 36 seedlings distributed into three experimental plots. The seedlings were irrigated once a week. Stem diameter at 30 cm above soil surface and total tree height all were measured every two months for each tree. After 18 month of the planting time the trees were subjected to low pruning, where two to three of low branches were removed. Meanwhile two randomly chosen trees from each plot (excluding those in edge rows) were felled. The above-ground parts (TAGDWT) of the felled trees were divided into leaves and stems and their dry weights were determined. The relative growth rates (RGRs) of stem diameter and height were quantified every six months through four sequential intervals; twice before pruning, and twice after pruning using, the following equations (Šesták *et al.,* 1971 and Hunt, 1978):

$$RGR_D = \log_e D_2 - \log_e D_1 \ / \ t_2 - t_1 \text{ and } RGR_H = \log_e H_2 - \log_e H_1 \ / \ t_2 - t_1$$

Where RGR_D and RGR_H are relative growth rates of diameter and height,

Log_e is the natural logarithm.

D_1 and H_1 are diameter and height at the beginning of an interval, and

D_2 and H_2 are diameter and height at the end of this interval, respectively.

Statistical Analysis

The obtained data were statistically analyzed through analysis of variance, using a randomized complete block design through SAS computer programme.

Results

The statistical analysis of the obtained data revealed that spacing had significant effects upon the growth of *Leucaena leucocephala* trees. The relative growth rates (*RGRs*) of both diameter and height increased significantly with increasing the distance between trees ($P < 0.0001$) and ($P < 0.001$), respectively (Fig. 1, a&b). On the other hand, the *RGRs* of both diameter and height decreased steadily with time ($P < 0.0001$) and ($P < 0.0001$), respectively, but the reductions were not similar for the different spacing regimes. For instance, by the second interval, just before pruning, there were marked reductions in the *RGR* of diameter accounted for by 61, 60 and 64% in the close, medium and wide spacing, respectively ($P < 0.0001$) (Fig. 1, a&b). However, the magnitude of reductions was less pronounced at the third interval (44, 38 and 21% of the values in the second interval). Thereafter, there were 36% and 42% reduction in *RGR* of diameter in the close and wide spacing, respectively whereas no change was found in that in the medium spacing. The *RGR* of stem height decreased significantly from interval to the next. After pruning (at the third interval), the reductions were 57, 67 and 76% in the close, medium and wide spacing, respectively. However, the *RGRs* of height did not differ between the spacing regimes from the second interval and onward. By the last interval there was a slight increase for the *RGR* of stem height in the wide spacing.

Regression analysis revealed that the growth of both diameter and height had differently affected the above-ground dry weight of leucaena trees before and after pruning (Table 1).

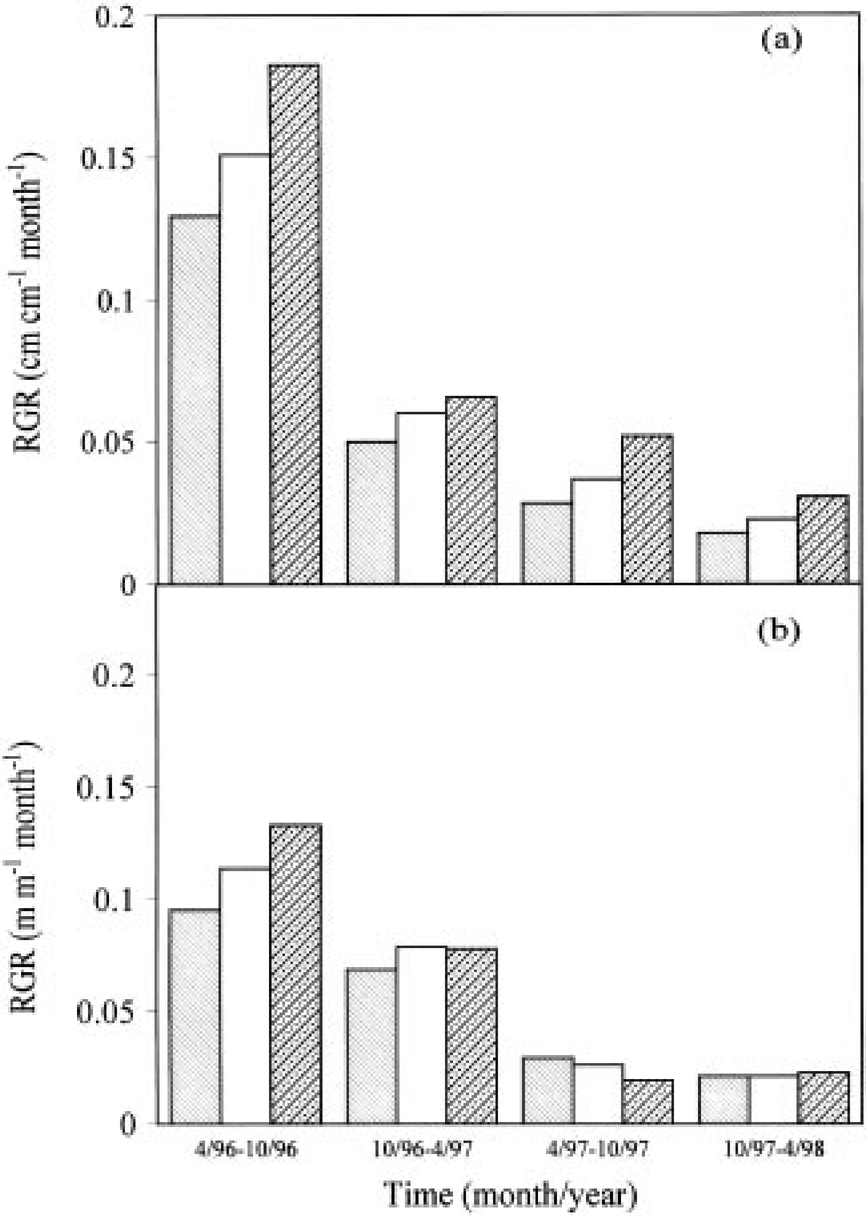

FIG. 1. Relative growth rate of diameter (a) and height (b) of *Leucaena leucocyphala* as affected by three spacing regimes namely ▨ 0.70, □ 1.40 and ▨ 2.10 m.

TABLE 1. Analysis of variance tables for total above-ground dry weight of *Leucaena leucocephala* trees as affected by spacing regimes and growth of both height and diameter before and after pruning.

1 – Before pruning

(a) Height

Close spacing (0.70 m)

Variable	D. F.	Parameter estimated	Probability level	R^2
Intercept	1	– 81.260	0.0097	
Height	1	26.751	0.0035	0.905

(b) Diameter

Close spacing (0.70 m)

Variable	D. F.	Parameter estimated	Probability level	R^2
Intercept	1	– 17.449	0.0629	
Diameter	1	1247.176	0.0028	0.915

(2) After pruning

(a) Height

Close spacing (0.70 m)

Variable	D. F.	Parameter estimated	Probability level	R^2
Intercept	1	– 76.961	0.0001	
Height	1	37.792	0.0001	0.998

Medium spacing (1.40 m)

Variable	D. F.	Parameter estimated	Probability level	R^2
Intercept	1	– 49.675	0.0079	
Height	1	15.564	0.0013	0.941

(b) Diameter

Close spacing (0.70 m)

Variable	D. F.	Parameter estimated	Probability level	R^2
Intercept	1	– 122.913	0.2299	
Diameter	1	3247.103	0.0966	0.539

Medium spacing (1.40 m)

Variable	D. F.	Parameter estimated	Probability level	R^2
Intercept	1	– 31.793	0.4290	
Diameter	1	1035.049	0.1582	0.429

The increase in total above-ground dry weight of trees in the close spacing before pruning was due to the increase in the growth of both diameter and height (*TAGDWT* = – 17.45 + 1247.18 *D*, R^2 = 0.915 and *TAGDWT* = – 81.26 + 26.75 *H*, R^2 = 0.905, respectively) (Fig. 2a and Fig. 3a). After pruning the increase in the growth of height contributed to increasing total above-ground dry weight of the tree more than the growth of diameter, particularly in the close and medium spacing regimes (Fig. 2b and Fig. 3b). These relationships were as the following: *TAGDWT* = – 76.96 + 37.79 *H*, R^2 = 0.998, *TAGDWT* = – 122.91 + 3247.10 *D*, R^2 = 0.54, *TAGDWT* = – 49.67 + 15.56 *H*, R^2 = 0.941 and *TAGDWT* = – 31.79 + 1035.05 *D*, R^2 = 0.43, respectively. The effects of height growth upon total above-ground dry weight of leucaena trees increased after pruning than before pruning in all spacing regimes (Fig. 3, a&b).

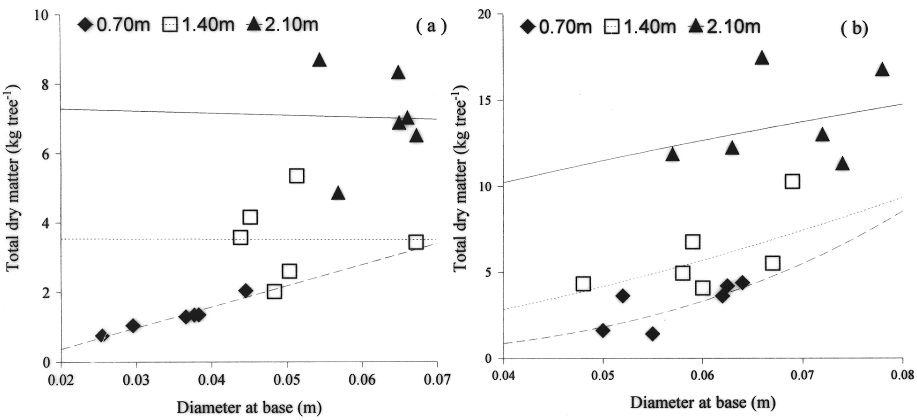

FIG. 2. Relationship between diameter and total dry matter of *Leucaena leucocyphala* as affected by three spacing regimes namely 0.70, 1.40 and 2.10 m (a) before and (b) after pruning.

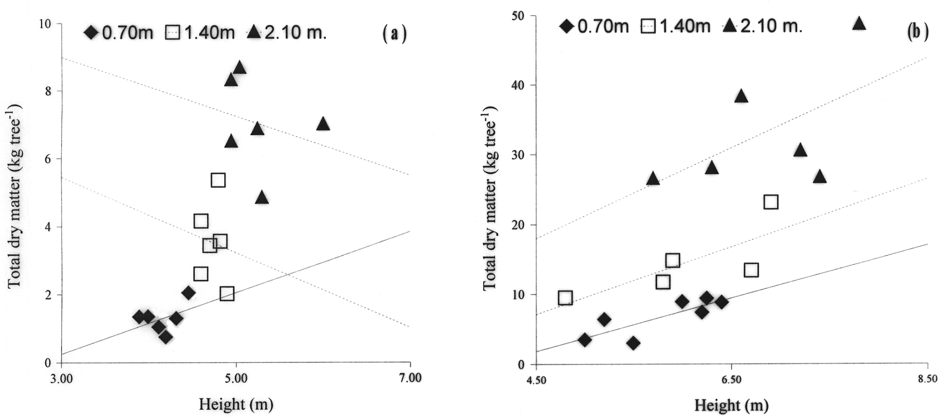

FIG. 3. Relationship between height and total dry matter of *Leucaena leucocyphala* as affected by three spacing regimes namely 0.70, 1.40 and 2.10 m (a) before and (b) after pruning.

Discussion

Increasing stem diameter and height of leucaena trees with increasing the distance between trees is simply a result of exploiting same available below-ground resources (water and nutrient) by less number of trees (Aref *et al.,* 1999). Increasing spacing would also increase biomass of branches, leaves and main roots of trees (Hongtong, 1990). As stem growth is a function of both height and diameter growth thus, exploring the variability in early diameter and height growth rates is important when interpreting development of stand. In the present study relative growth rates of both stem diameter and height of leucaena trees increased in the wide spacing than in both medium and close spacing regimes. This result concurs with that of Nilsson (1994). Increasing growth rate of diameter with increasing the spacing was also reported by Saatawut & Tularak (1986), Orlic (1987), Vacharangkura (1988) and Effendi & Bachtiar (1991). Pruaksakorn (1993) and Jaeghagen (1997), on the other hand, reported increasing height growth rates of trees in wide spacing.

Decreasing relative growth rate of both diameter and height with time in the present study resulted from growing leucaena trees over almost two years. Seedlings seldom grow at an exponential rate over a period of several years (Brand *et al.,* 1987 and Britt *et al.,* 1991, *c.f.* Norgren, 1996), while growth is often exponential during early stage (Hunt, 1978).

The variation in reduction magnitude between diameter and height relative growth rates from interval to the next was a result of the different nature of the growth of both diameter and height. It is common for trees to cease height growth temporarily in late summer (Kramer & Kozlowski, 1960; Zimmermann & Brown, 1971 and Perry, 1971, *c.f.* Salisbury & Ross, 1978). On the other hand, growth of stem diameter (due to expansion of cells produced by the vascular cambium) continues at a decreasing rate, until after height growth stops (Salisbury & Ross, 1978). Increased rate of growth in diameter results in a concurrent increase in the rate of anticlinal division of cambial initials required to produce the needed circumferential expansion (Panshin & de Zeeuw, 1980). The rate of height growth is often almost constant from the time when the trees are well established, and about to close canopy to the time when height is nearing its maximum (Philip, 1994). In the present study, height growth was much less affected by spacing than was the growth of diameter. Variation in the response of relative growth rates of both diameter and height to the change in spacing regimes has been reported by Taurins (1997) who found that stand density has a greater impact on the growth of diameter than on the height of trees. Xie *et al.* (1995) also mentioned that height growth responded to planting density earlier than the growth of diameter, but the later becomes more affected as tree grew. Contradictory, Jones & Bray (1983) found the closest spacing increased height growth of *Acacia falcataria* considerably, but had little influence on the growth of diameter. In the present study the effects of spacing upon height growth rate lasted for a year after planting (by the end of the first interval) whereas continued until the end of the third interval in diameter growth rate. Similar results were obtained for different tree species (*e .g.,* Saatawut & Tularak, 1986, for *Eucalyptus camaldulesis* and Orlic, 1987 for *Picea abies*).

The effect of pruning was more pronounced upon diameter than height growth rate. After pruning the growth rate of diameter decreased by less than before pruning, particularly for the trees in the wide spacing. This may reflect the positive effect of pruning upon the growth of diameter. Green pruning of the crown tends to promote growth in the lower part of the stem, similar to the effects of thinning (Philip, 1994). The height growth rate also decreased after pruning but not as much as that of diameter. This finding is in agreement with that of Narayan *et al.* (1983), who found that the pruning promotes the growth of the main stem of leucaena trees. Trajanovski *et al.* (1989) stated that vegetative growth increment was larger with more sever pruning and *vice versa.* The results of the present investigation showed that above-ground dry weight of leucaena trees was affected before pruning by both diameter and height growth; in particular for the trees in the close spacing regime. However, after pruning the increase in total above-ground dry weight of the trees in all spacing regimes was affected more by height growth.

Conclusion

As the growth of tree stem is a function of both diameter and height growth, thus investigating their relative growth rate as an early test of tree growth seems to be a good tool by which the prospective production of a stand can be predicted. Initial spacing between trees affected the growth of leucaena trees through both diameter and height growth rates. They increased with increasing spacing; with larger effects upon that of diameter on the wider spacing. Pruning after 18 months of planting improved the growth of leucaena trees through decreasing the loss in both diameter and height growth rates with time.

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تأثير مسافات الزراعة على معدل النمو النسبي للقطر وارتفاع الأشجار و إنتاج الكتلة الحيوية قبل وبعد التقليم في أشجار الليوسينا *Leucaena leucocephala* (Lam.) de Wit.

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المستخلص. في أكتـــــوبـــر ١٩٩٥ زرعـــــت شتـــــــلات (*Leucaena leucocephala* (Lam.) de Wit.) في محطة التجارب التابعة لكلية الزراعة بجامعة الملك سعود في الرياض ، على مسافات ٠,٧٠ أو ١,٤٠ أو ٢,١٠ متراً ، بين صفوف الأشجار أو بين الأشجار داخل الصفوف . أجريت عملية تقليم للأشجار بعد سنتين من الزراعة ، كما أسقطت في نفس الوقت شجرتان من كل وحدة تجريبية ، وتم تقسيم كل منها إلى ساق وأفرع وأوراق من أجل تقدير الوزن الجاف لمكونات الكتلة الحيوية للشجرة فوق سطح الأرض . أوضحت النتائج أن معدل النمو النسبي لكل من قطر الشجرة وارتفاعها قد ازداد مع زيادة المسافات بين الأشجار ، ولكنه انخفض مع تقدمها في العمر . كما وجد أن تأثير كل من نمو قطر الشجرة وارتفاعها في الكتلة الحيوية للشجرة فوق سطح الأرض قبل التقليم متساو تحت مختلف أنظمة مسافات الزراعة المستخدمة. أما بعد التقليم فقد كان معظم التأثير في الكتلة الحيوية للشجرة فوق سطح الأرض راجعًا إلى النمو في ارتفاع الشجرة ، وبصفة خاصة تحت نظامي المسافات ١,٤٠ و ٢,١٠ متراً .

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Symptoms of Infestation on Fruits of Ushar Plant *Calotropis procera* (Ait) Ait. by the Cucurbit Fruit Fly *Dacus longistylus* (Wiedemann) (Diptera:Tephritidae) Western Saudi Arabia

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Abstract. This preliminary study was conducted during the years 1996-1997 on the fruits of the desert shrub producing the milky-latex Oshar plant *Calotropis procera* (AIT) Ait, which is widely grown in the western region of Saudi Arabia. Lab and field studies showed that the cucurbit fruit fly *Dacus longistylus* (Wiedemann) (Diptera: Tephritidae) is a serious pests with regard to the fruits of this desert plant. Ovipositing females lay their eggs in groups (8-10 egg masses) inside the fruit. Upon hatching immature larvae feed voraciously on the fibrous and pulp contents of the infested fruit. It has three larval instars and after the third moult the third larval instar make an exit hole on the fruit skin through which it stays for 48 h outside, then enter in the pupal stage most probably in the ground under dried fallen leaves. In severe stages of infestation the fruits change color to whitish gray with subsequent shrivel in size, reduction in weight. Microbial infestation ultimately lead to fruit deterioration.

Introduction

The perennial evergreen milkweed desert shrub *Calotropis procera* (Ait) Ait, which belongs to the widely distributed host plant family Asclepiadaceae is considered an important component of the desert ecosystem especially in low-lying pockets and enclaves, where some underground water might be available. This hardy plant is well known in all deserts and arid lands all over the world and considered as a food source and refuge for a wide number of resident and migrating arthropod pests (AbuThuraya, 1982). Due to its ubiquitous widespread distribution, surviving over a broad range of altitudes it becomes an important entity of the desert fabric (Migahid ,1990; Al Wadi & Abulgaith, 1996 and Al-Ghamdi *et al.,* 1997).

This desert shrub has medicinal and some economic importance since it is traditionally used in folk medicine. Recently based on empirical bioassays, in certain occasions it is as a medicinal plant (Vasileva, 1969; Grag, 1979; Siddiqui *et al.,* 1984 and Masood *et al.,* 1984). It has been documented that the plant juice (milky latex) of both genera of the Asclepiadaceae, *Asclepias* and *Calotropis* contain poisonous and fatal ingredients for most vertabrates and invertebrates (Al-Fifi, 1990). This may be due to the toxic chemical components including usharin, calatropin, ushardin, voruscharin, glycosides calactin, calotoxin, and calotropagenin (Singh and Rastogi, 1970; Seiber *et al.,* 1982; Fredman, 1983 and Danish, 1989).

Based on the contemporary accumulated information, this arid land desert shrub is considered as an important food source creating valuable ecological niche for a myriad number of variegated hexapod (insect, pests, parasitoids and predators) and araneida (Euw *et al.,* 1967; Isman, 1977; Morse, 1985; Faragalla & Taher, 1989; Al-Ghamdi, 1996; Al-Ghamdi *et al.,* 1997).

Although the latex of *Calotropis* plants is toxic to many wildlife but many insects are able to withstand feed and survive on *calotropis* including the plain tiger butterfly *Danus chrysippus, D. plexippus,* local grasshopper *poekilocerus bufonius* Klug, bumble bees, *Bombus terricola, B. vagans.* Furthermore, it accumulate poisons from this plant in their bodies hence used as a deterrent against their natural enemies (Euw *et al.,* 1967; Reichstein *et al.,* 1968; Brower *et al.,* 1972; Isman, 1977; Duffey, 1980; Blum, 1981 and Huheey, 1984). With consideration to all the poisonous chemicals present in the latex of *Calotropis* some studies have shown the possibility of using these extracts as insecticides (Sharma, 1983; Calvin, 1986 and Hinman, 1986). Furthermore, Sharma (1983) was able to achieve good results when using this extracts against *Rhizopertha dominica.*

The cucurbit fruit fly *Dacus cilatus* (Diptera: Tephritidae) is very prevalent insect pest in western Saudi Arabia. It has been reported that, it has about 125 host plants and considered a serious pest on all members of the family cucurbitaceae including squash (*Cucumis pepo* L.) water melons (*Citrllus vulgaris* Schrad.) cucumber (*Cucumis sativus* L.) Sweet melon (*Cucumis melo* var. *aegyptiacus* Naud.) snake cucumber (*Cucumis melo* var. *elongatus* Naud.) pumpkin or winter squash (*Cucurbita maxima* Duchesme) cantaloupe (*Cucumis melo* var. *cantalupensis* Naud.). These annual crops are grown continuously in all vegetable fields and together in citrus and date-palm groves (Al-Fifi, 1990 and Jamal, 1994). Thus *calotropis* due to its evergreen nature and widespread presence represents a valuable alternative host plants for these damaging pests especially those of high cost cash crops. Therefore any future strategy for pest management programs for these fruit flies seriously consider the ecology and arthropod fauna that extent locally on this wild shrub plant. However, *Dacus longistylus* (Wiedemann) was first recorded by Al-Ghamdi *et al.* (1997) on *Calotropis,* currently there is no evidence of its economic importance in the literature review in Saudi Arabia.

This study was conducted with the objectives of documenting the life cycle and symptoms of infestation of *Calotropis* by the cucurbit fruit-fly *D. longistylus* in western Saudi Arabia where no data were present at this stage.

Materials and Methods

This study was conducted during October 1996 to October 1997, where two localities having different latitudes were selected and both representing western region of Saudi Arabia: Jeddah Locality 30 m above sea level (a.s.l.), within King Abdulaiz University campus, behind the University Equestrian club and the second locality is Wadi Al-Hif, (80 km east of Jeddah 155m (a.s.l.) (Fig. 1). Heights of both localities were measured by the altimeter-barometer and the area of each sampling universe was approximately 1500 m^2 (50 m × 30 m). Both chosen sites contain rich shrub cover of *Calotropis,* from which weekly samples were made and brought to the laboratory. The tools of collection included a big pair of scissors used to cut the *Calotropis* fruits with absolute precautions that no drops from the plant latex fall on the face. Four, medium to large, fruits from each plant were carefully recovered and secured individually in a plastic sack. Sacks containing fruits were then brought to the laboratory for incubation at 25 ± 2ºC. All pertinent data were recorded including locality, collector, date of collection. During incubation utmost considerations, were made to change old sacks with new one every two days, as a precaution to keep the vitality and survivalability of the fruits and to discourage any microbial, bacterial and or fungal growth.

The statistical method used included the mean of the length of the adults (male and female) and also the standard deviation conducted in order to estimate the length variation (Snedecor & Cochran, 1974).

Results and Discussion

The field inventory showed that a diverse rich fauna of arthropds (Insecta and Archaneida) were thriving on this evergreen shrub throughout the year especially during spring and summer seasons. Data collected showed that *D. longistylus* was one of the dominant insects throughout the year in both locations under investigation.

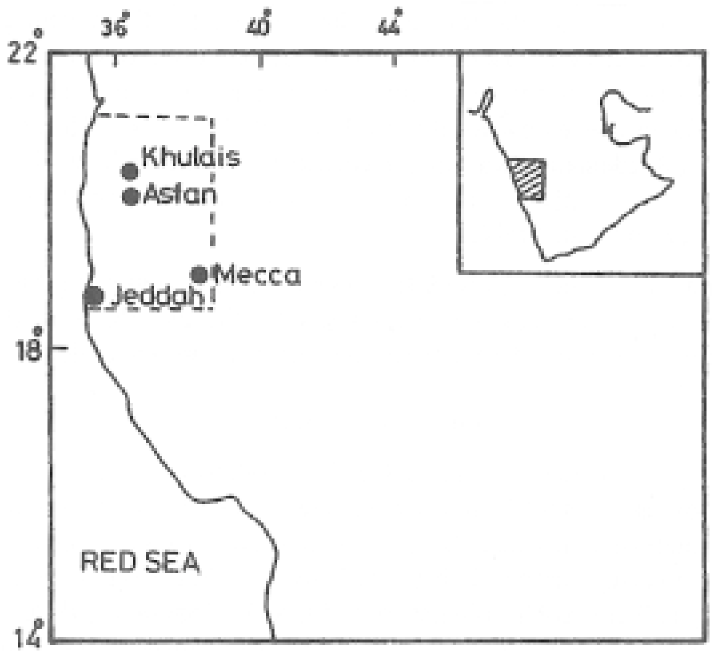

FIG. 1. Map of the midwestern region of Saudi Arabia showing the geographical location of study area.

Insect Description

The size of the adult stage was little less than the size of adult house fly. The body length of the males varies between 0.71-0.78 cm for the males, and between 1.18 cm - 1.33 cm for the females (Table 1). Both had the slight tint of gray color with a yellow spot on top of the thorax together with a longitudinal yellowish line on the upper part of the stomach on both sides of body (Fig. 2). The larvae had whitish yellow color, wormy in shape, with no thoracic or abdominal legs having an overall slender shape. The head was slim and appears like a black spot and abdomen was tapering to an acute end, but still wider than the anterior part of body. The length of a mature larva was approximately 11 mm (Fig. 2).

TABLE 1. Average lengths of male, female, and ovipositor of *D. longistylus* recovered from two localities, Western Saudi Arabia during 1996-1997.

Body length	No. samples	Range mm	Mean ($\bar{x}$)	Std. deviation (SD)
Male	10	0.71 - 0.78	0.756	0.01955
Female	10	1.18 - 1.33	0.762	0.0175
Ovipositor	10	0.43 - 0.53	0.473	0.03433

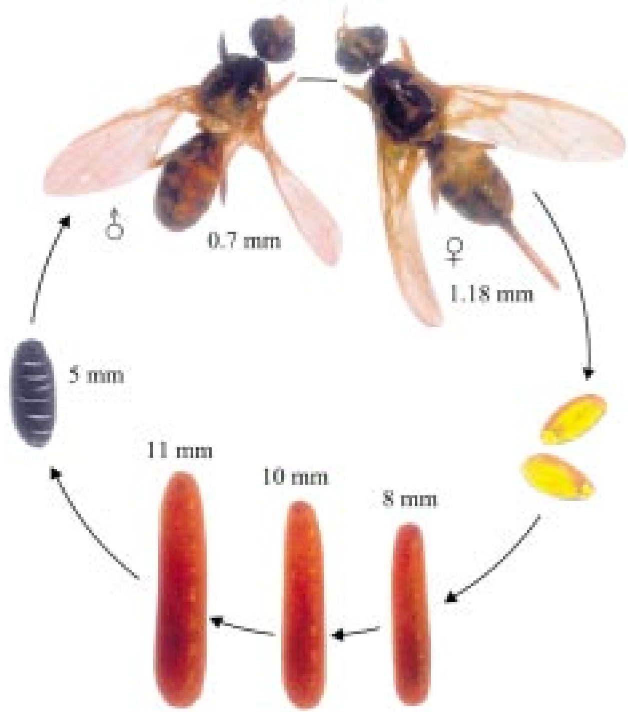

FIG. 2. The life cycle of the cucurbit fruit fly *D. longistylus*.

Life Cycle

During oviposition the gravid female will locate a suitable *Calotropis* fruit and deposit the eggs by its sharp ovipositor (which varies in length between 0.43-0.53 cm) just below the thin, soft epidermal layer of the fruit (Fig. 2 & Table 1). Critical laboratory observations showed that the female secretes a viscous material on the openings made during egg laying on the infected fruits. Recovered data showed that each female lays an average of 40-130 eggs in groups of 8-10 egg masses. Our results were in line with what was reported earlier by Kawar *et al.* (1994) that these types of fruit flies lay approximately 50-150 egg masses in groups of 8-12 eggs at a time within the infested fruits. Upon hatching small tiny larvae will move within the premises (especially under the epidermal layer) causing meandering tunnels (Fig. 3) feeding on the fiberous contents of the mature fruits. The length of the first larval instar may reach about 8 mm (Fig. 2). After the first larval moulting, the second instar larvae will move towards the inside of the fruit pulp causing new deep tunnels, while feeding and leaving waste and ecdysial skins inside the infested fruit (Fig. 4 & 5), however the length of the second larval instar reaches approximately 9 mm (Fig. 2). The next moulting (second to third larval instar) occurred within the fruit. From this investigation we noticed that this fruit fly has only three larval instars and the

FIG. 3. Symptoms of infestation on the internal epidermal layer and the fibrous tissue of the ushar fruit, by the 1st instars of the cucurbit fruit fly.

FIG. 4. Deterioration of ushar fruit from accumulation of waste and ecdysial skins of the 1st larval instars.

FIG. 5. Waste and accumulation of ecdysial skins of 1st larval instars inside the oshar fruit pulp.

pupal stage occurred outside the infested fruit (Fig. 2). Hence at the end of the third larval instar and before entering the pupal stage, these larvae make pores on the crumpled (still fresh) fruit skin and fall to pupate in the ground reaching a length of 5 to 7 mm (Fig. 2). The pupal stage extend 10-15 days at lab temperature 26 ± 1ºC, whereas each larval instar may take 4-6 days.

Symptoms on Fruit Infestation

Due to the voracious feeding of the immature instars heavy infestation to the fruits was encountered due to their movement, feeding on the fibrous part of the fruits, collection of waste and ecdysial skins within the fruits which lead to the growth of fungal, and bacterial microorganisms that evidently lead to the overall deterioration of the infested fruit. Field observations showed that infested fruits induce the appearance of crumpled wrinkled outside epidermal skin of fruits with a subsequent change to a yellow in color. In case of heavy larval infestation, the fruit color changes to yellowish gray. The infested fruit shrivelled in size with noticeable reduction in weight (Fig. 6). During inspection of infested fruits and after making a longitudinal cut quite a number of different larval instars were observed moving between the fibrous region and the fruit pulp (Fig. 7).

FIG. 6. Outside symptoms of infestation by the cucurbit fruit fly on oshar fruit including wrinkled skin and grayish color.

FIG. 7. Movement of the cucurbit fly larvae between fibrous and pulp layers of the fruit.

Recently the status of this dangerous pest *D. longistylus* was elevated because it is being described as an economic pest due to its wide dispersal in the western region. Its severe infestation of economic cash crops that belong to members of family Cucurbitacae, which is widely cultivated in all valleys and groves especially in commercial vegetable production schemes, caused havocs and entails applying different control measures (Arafat, 1974; Dabbour, 1982 and Talhouq, 1984). These crops include different important cash crops for all farmers in the western region. *Calotropis* is considered as a refuge and an alternate host for this dangerous pest, from where continued invasion of vegetable farms would take place. Therefore and based on this lab and field investigations it is noticed that the curcurbit fruit worm (fly) was the main pest able to make the utmost use of the mature fruits of *Calotropis* and sustain itself within the fruit set as a utopia suitable enough for its reproduction and survival.

With the current increase of the Saudi Arabian Government policies in financing farmers for crop production and with the understanding of the infestation of the vegetable cash crops by these fruit flies, any future pest management programs that might be adopted should consider further ecological studies on *Calotropis* fauna in order to tailor rational logistic pest management strategies for controlling this fruit flies. Caution must be exercised on keeping its migration from *Calotropis* to the main field of horticultural crops, which might inflict severe infestation.

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أعراض الإصابة على ثمار نبات العشار *Catotropis procera* (Ait) Ait. بواسطة ذبابة ثمار القرعيات *Dacus longistylus* (Wiedmann) (Diptera:Tephritidae) في غرب المملكة العربية السعودية

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المستخلص. أجريت هذه الدراسة المبدئية خلال عامي ١٩٩٦ ، ١٩٩٧، وذلك للتعرف على أهم الآفات الرئيسية التي تصيب المحتوى الداخلي لثمار نبات العشار *Calotropis procera* بالمنطقة الغربية من المملكة العربية السعودية . فمن الدراسات الحقلية والمعملية تبين لنا أن هناك آفة رئيسة واحدة هي حشرة ذبابة القرعيات (Diptera: Tephritidae) *Dacus longistylus* . إناث هذه الآفة تقوم بوضع بيضها في مجاميع (٨-١٠ كتل بيض) داخل ثمار العشار ، وبعد الفقس تقوم اليرقات بالتغذية على المحتوى الليفي واللبي للثمرة ، حيث تمر يرقاتها بثلاث انسلاخات . يخترق الطور اليرقي الثالث الثمرة إلى الخارج ، ويمكث ٤٨ ساعة بخارجها ، ومن ثم يدخل في طور العذراء ، والذي غالبا ما يكون في التربة أو تحت الأوراق المتساقطة من نبات العشار . يظهر لون بني فاتح في الإصابات المتقدمة لثمرة العشار بذبابة القرعيات مع ضمور الثمرة وانخفاض في وزنها ، مما يؤدي إلى تلفها.

Environment

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Soil Gel-Conditioner: I. Selection of Appropriate Concentration and Treated Upper Layer Depth for Sandy Soil under Sprinkler Infiltration

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ABSTRACT. Two experiments were carried out to select the appropriate concentrations of Aquasorb gel-conditioner suitable for sprinkler infiltration, without causing surface sealing and the resulted water ponding. The first one was conducted on sandy soil columns treated uniformly with Aquasorb at four concentrations (*C*): 0.0, 0.3, 0.6 and 0.9% (on dry weight basis) under ponded infiltration. The purpose of this experiment was to test the absorbing and retention power of the conditioner especially at high concentration (0.9%). The second experiment was carried out using sandy soil columns treated uniformly with the high concentrations of Aquasorb, namely 0.6 and 0.9% under different sprinkler water application rates (*R*).

The ponded infiltration experiment revealed that Aquasorb conditioner possesses a high superabsorbing and retention power for water especially at high concentration (0.9%). While the sprinkler infiltration experiment revealed that the concentration of Aquasorb was the main dominant variable affecting surface sealing rather than the kinetic energy at the soil surface. Thus it was suggested that the maximum Aquasorb concentration to be used is 0.6% conjugated with 20 cm depth as a maximum treated upper layer depth for sprinkler infiltration.

Introduction

Most of the agricultural soils of Saudi Arabia are sandy in texture, and low in fertility status (Bashour *et al.,* 1983). Low specific surface area, low water-holding capacity, and high infiltration rate, causing inefficient water use, especially, in arid and semiarid regions characterize Sandy soils. On the other hand, the low water infiltration resulting in runoff, erosion, plant injury, and inefficient water use cause a significant problem.

Most of the recent studies concentrated on the effect of soil conditioners, especially, gel-conditioners were carried out under ponded water infiltration (hydrostatics pressure on soil surface) (Al-Darby *et al.,* 1992 and El-Shafei *et al.,* 1994). This case normally does not occur during the irrigation of sandy soils in the arid regions. The irrigation water is usually applied with rates less than the ponded water infiltration rate by the means of sprinkler irrigation or trickle irrigation. However, the studies using gel-conditioner with sprinkler irrigation are still very limited.

The reduction in the soil infiltration rate is caused mainly by seal formation at soil surfaces exposed to the beating action of rain and sprinkler drops (Aarstad & Miller, 1973 and McLntyre, 1958). The addition of cationic polysaccharides and anionic polyacrylamides (PAM) to water, that was applied using a rainfall simulator in the laboratory to soils with low ESP, increased the infiltration rate as compared to the control (Ben-Hur & Letey, 1989; Ben-Hur *et al.,* 1989; Helalia & Letey, 1988 and Helalia *et al.,* 1988). Ben-Hur & Letey, (1989) and Ben-Hur *et al.* (1989) found that low concentrations (10 g m^{-3}) of derivatized polysaccharide guar and polycrylamides (PAM) in water significantly increased the infiltration rate of soils under sprinkler irrigation.

Ben-Hur *et al.* (1990) found that, under rainfall simulator conditions, the addition of a cationic polysaccharide to the applied water decreased seal formation, and increased soil loss and the sediment concentration in the runoff. Levy *et al.* (1992) studied the effects of two polymers (PAM and PSD) during consecutive simulated sprinkler irrigation. They found that for the optimal treatments, infiltration parameters (final infiltration rate and cumulative infiltration) were generally higher in the PAM than in the PSD. The soil losses in all the PAM treatments were significantly lower than those in the PSD treatments, and both polymers stabilized soil aggregates. However, the PAM also cemented aggregates and increased their resistance to erosion. This was because of its longer molecule and limited adsorption.

Shainberg *et al.* (1992) studied the effect of raindrops impact energy, exchangeable sodium percentage (ESP), electrolyte concentration in the applied water, and the addition of non-anionic polyacrylamide (PAM) on aggregate stability and on seal formation for three cultivated soils. They found that: (1) Aggregate slaking took place much faster than seal formation; only 9 mm of rain were needed to disintegrate the aggregates compared with > 40 mm of rain needed for seal formation. (2) Soil ESP enhanced aggregates breakdown at the upper ESP range, whereas the effect of ESP on seal formation was at the lower ESP range. (3) Electrolyte concentration in the applied water had no effect on aggregate disintegration, but affected the rate and final infiltration rate of the seals formed. (4) Adding PAM to the soil improved aggregate stability and increased the permeability of the seal. (5) Aggregate breakdown was suggested as the first step in seal-formation, to be followed by surface compaction and clay dispersion. Le Souder *et al.* (1991) reported that the conditioner (Aluminum polymers) reduced both the breakdowns by slaking and by raindrop impact. The conditioner under rainfall limits the microcraking due to partial slaking, which occurs during the wetting phase. Thus, it retarded all the successive crusting process and the formation of the depositional crust. Under irrigation with moving sprinkler irrigation system, Levy *et al.* (1991) suggested that, reducing runoff was essential for obtaining higher yields. Also they found that the PAM was an effective soil conditioner to attain this target. Smith *et al.* (1990) suggested that adding PAM at a rate of 20 kg ha^{-1} to the surface of a soil irrigated with overhead sprinklers using irrigation water (EC > 0.1 Sm^{-1}) will markedly reduced seal formation and thus improve soil and water management. Terry and Nelson (1986) reported that the method of irrigation significantly affected surface soil bulk density, penetrometer resistance, and infiltration rate in conditioned soils. The flood irrigation caused the disintegration of surface soil aggregates and the development of a surface crust, so the deleterious of the flood irrigation were overcome by irrigating the soil with sprinklers or by treating soil with PAM flood-irrigation.

However, the specific objective of this paper was to determine the best combination of Aquasorb soil gel-conditioner concentration and treated upper layer depth of sandy soil under sprinkler infiltration.

Materials and Methods

The sandy soil (Typic Toripsamments) used in this study was sampled (0-30 cm depth) from the College Experimental and Research Farm at Dierab (Latitude 24º25′N, Longitude 46º34′E), Saudi Arabia. The soil was air dried and passed through a 2 mm sieve, and the initial air dry water content was determined (0.25% wt.). Selected soil properties were determined by standard procedures (Klute *et al.,* 1986). The soil contained 5.5, 2.0 and 92.5% of clay, silt and sand, respectively. It contained very low organic matter = 0.07%, high $CaCO_3$ = 25%, low EC_e = 0.7 dS m^{-1}, pH = 7.39, SAR = 0.71 (saturated extract). The water used had an EC = 0.45 dS m^{-1} and SAR = 0.90.

The gel-conditioner (Aquasorb[1]) used in this study was cross-linked sodium polyacrylate synthetic polymers manufactured in a form of dry white grains

[1]The trade name of the gel-conditioner was included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by King Saud University

with diameter ≤ 1 mm, particle density = 1.1 g cm^{-3}, and bulk density = 0.8 g cm^{-3}. The distilled water was added to the gel-conditioner with ratio 400:1 (on dry weight basis) and the mixture was left for 24 h to equilibrate. The extract of this mixture had pH = 7.9, EC = 0.25 dSm^{-1}, and contained the following soluble cations Na^{+}, K^{+}, and Ca^{++} at amount of 2.8, 0.065 and 0.14 meq/l, respectively. The predetermined amounts of Aquasorb were thoroughly hand-mixed with air-dried soil in all experiments.

Ponded Infiltration Experiment

In this experiment Aquasorb gel-conditioner was uniformly applied to the soil column at four concentrations (*C*): 0, 0.3, 0.6 and 0.9% (on dry weight basis).

The cumulative ponded infiltration as a function of time was determined by means of a flooding apparatus. It was designed to make the collection of accurate infiltration data versus time possible throughout the experiment, and to maintain constant head of water (*h*) above the soil surface by means of bubblier (Mariotte) tube, as shown in Fig. 1.

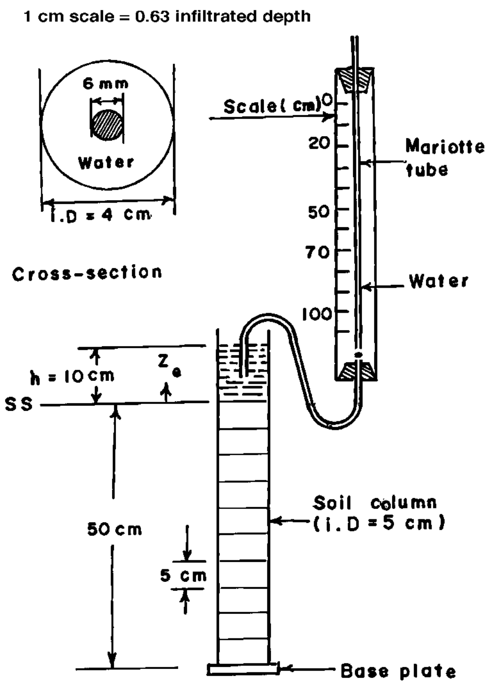

FIG. 1. Schematic diagram of the ponded infiltration experiment. *Ze* is the absolute expansion above the initial soil surfaces (SS).

The soil samples were packed at 1.50 g cm^{-3} bulk density (D_b), to simulate D_b observed in the field, in transparent sectionized lucite cylinder (5 cm i.d., 60 cm long). The treated soil samples were packed by tapping on the bench, each 5-cm increments in the cylinder. For the stability of the soil column during expansion, the column was assembled from the 5-cm sections joined together by grooving and tongue jointing and then covered by white adhesive tape around the circumference. Figure 1 shows schematic diagram of a soil column under ponded infiltration.

Periodic observations were made during ponded infiltration included changes in the position of the soil surface due to expansion, height of the water surface, Mariotte tube reading, and the depth of the visible wetting front. When the wetting front reached approximately 40 cm depth below the initial level of soil surface, infiltration was terminated, then the column was laid horizontally and the sections were separated for determining the water contents gravimetrically and bulk densities along the soil column.

The cumulative ponded infiltration (D) as cm depth of water was corrected for the height of the free water surface on the soil column, which was varying due to surface expansion. Expansion was observed as change in the surface level with respect to the initial surface. From the schematic diagram presented in Fig. 1, it can be inferred that the value of D at any time (t) is equal to

$$D(\text{cm}) = [(S.R.)_t - (S.R.)_o] \times 0.63 + Z_e\ (\text{cm}) \tag{1}$$

where

$(S.R)_t$ = scale reading (cm) at time (t).

$(S.R)_o$ = scale reading (cm) at zero time.

0.63 = correction factor for the scale.

Z_e = absolute value of surface expansion (cm).

Each experimental value was an average of two determinations.

Sprinkler Simulator Experiment

A simple sprinkler simulator (water applicator) was designed to sprinkle the soil surface uniformly at constant water application rate (R).

The simulator was in general similar to that one introduced by El-Shafei *et al.* (1992). It consisted of a water supply reservoir with a constant head siphon (gravity head) supplying water to many capillary tubes (Fig. 2). The water was applied to the surface of each soil column through seven intramedic polyethylene tubes (PE 50) of 0.584 mm i.d. and 0.965 mm o.d. The capillary tubes were held by means of a plastic lid. The maximum falling (travel) distance was 12 cm to minimize the impact (kinetic) energy associated with the falling drops.

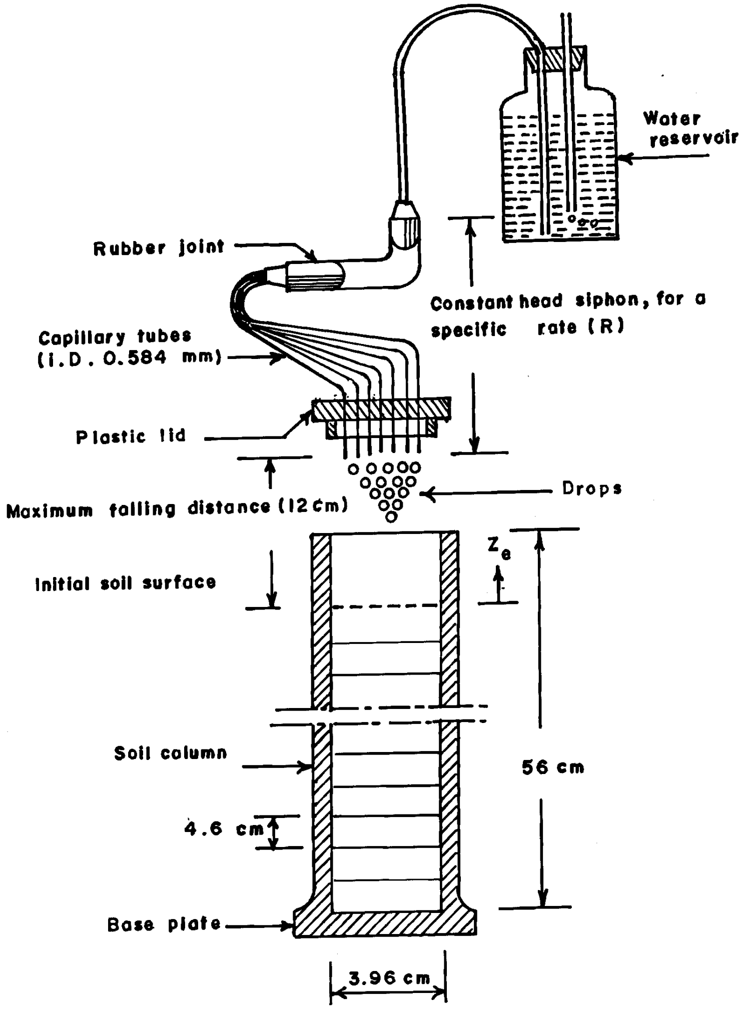

FIG. 2. Schematic diagram of the experimental set up, showing the sectionized soil column under the sprinkler simulator. Z_e is the absolute expansion above the initial soil surface.

The desired application rate (R) was obtained by varying and adjusting the gravity head of the water supply source. The sprinkler simulator was able to supply water at rate (R) ranging from 1 to 25 cm h^{-1}. The falling water drops were assumed to be spherical and the equivalent drop diameter was estimated from the volume of a drop calculated from the mean drop weight of 15 drops.

The Aquasorb concentrations (C) used in this experiment were 0, 0.6, and 0.9% with two water application rates (R): 3.5 and 10.5 cm h^{-1}. The Aquasorb conditioner was uniformly applied to the soil column. The soil samples were packed, by tapping on the bench, in transparent sectionized lucite cylinders by 4.6 cm increments to 1.5 g cm^{-3} bulk density. The lucite cylinder was 56 cm long and 3.96 cm inside diameter. Figure 2 shows schematic diagram of the soil column under the sprinkler simulator.

Kinetic Energy of Falling Drops (K.E) Calculation

By applying the force balance equation for a vertically falling droplet in the air, El-Shafei *et al.* (1993) derived the following equation to determine the water droplet velocity

$$\upsilon = -\frac{r_a h_f}{M} + \sqrt{\frac{r_a^2\, h_f^2}{M^2} + 2\,g\,h_f} \tag{2}$$

in which:

υ = velocity of the falling droplet (cm s^{-1}),

h_f = falling distance (cm),

M = mass of the droplet (g),

g = acceleration due to gravity (980 cm s^{-2}),

r_a = air resistance ($g\ s^{-1}$), which is dependent on droplet diameter (d).

$$r_a = 0.00122\, d^{2.44} \tag{3}$$

where d is in mm.

Then, the kinetic energy of a falling droplet ($K.E_1$) can be determined as

$$K.E_1 \text{ (erg)} = \frac{1}{2} M\upsilon^2 \tag{4}$$

The total kinetic energy of the falling drops ($K.E$) can be estimated as the product of number of drops (N) times the kinetic energy of the falling droplet ($K.E_1$).

$$N = \frac{A_s\ R}{M} \tag{5}$$

in which:

A_s = area of soil surface (cm^2),

R = water application rate (sprinkler intensity), cm h^{-1},

M = mass of the droplet in cm^3 on the basis that ρH_2O equals to 1 g cm^{-3},

N = number of drops per hour per surface area.

The water drops were assumed to be spherical and the equivalent droplet diameter was estimated from the volume of a droplet calculated from mean droplet weight of 15 drops.

The mass of the droplet (M) was 0.0162 g and its equivalent diameter (d) was 3.15 mm. A convenient unit can be achieved if the combination of kinetic energy in joules per square meter per centimeter depth of water times sprinkler intensity (R) in centimeter per hour, which yields a power term with the units of J m^{-2} h^{-1}.

The following example will be drawn:

$$K.E_1 = \frac{1}{2} M \upsilon^2 = \text{erg} \times 10^{-7} = \text{J}$$

$$N = \frac{A_s\, R}{M} = \frac{10^4 (\text{cm}^2 \text{m}^{-2}) \times (\text{cm}\ \ h^{-1})}{(\text{cm}^3)} = \text{drops m}^{-2}\ \ \text{h}^{-1} \qquad (5)$$

$$K.E = K.E_1 \times N = \text{J m}^{-2}\text{h}^{-1}$$

Results and Discussion

Ponded Infiltration

The infiltration capacity of untreated sandy soil, where static water head maintained on soil surface, is presented in Fig. 3. The computed power regression equations for the infiltration data depicted in Fig. 3 confirmed the following relationships

$$D = a\ \ t^b \qquad (8)$$

$$I = \frac{dD}{dt} = 60\ a\ b\ t^{(b-1)} \qquad (9)$$

$$I_{av.} = \frac{D}{t} = 60\ a\ t^{(b-1)} \qquad (10)$$

in which

D = cumulative infiltration, cm,

I = instantaneous infiltration rate, cm h^{-1},

$I_{av.}$ = average infiltration rate, cm h^{-1},

t = time, minutes,

a and b = constants depending on soil type.

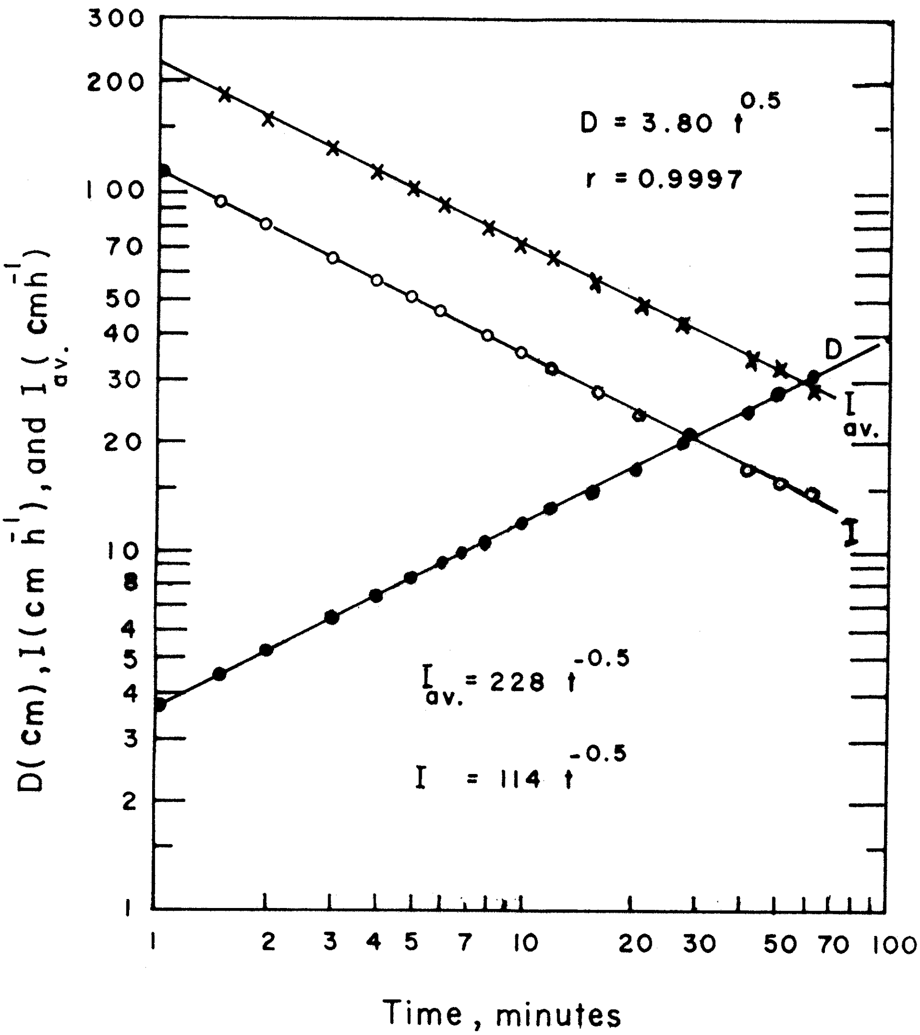

Fig. 3. Infiltration capacity of untreated sandi soil. D = cumulative infiltration, I = instantaneous infiltration rate, and $I_{av.}$ = average infiltration rate.

The results obtained for this sandy soil are in good agreement with Kostiakov (1932) and Baver *et al.* (1972). They stated that for time intervals of a few hours and for uniform materials, the equation of cumulative infiltration is in the form of power type with an exponent (b) close to but not always 0.5. The cumulative infiltration equation for the sandy soil was

$$D = 3.80\, t^{0.50} \tag{11}$$

while the equation of the wetting front advance (L), as could be detected from Fig. 4 was

$$L = 10.80\, t^{0.51} \tag{12}$$

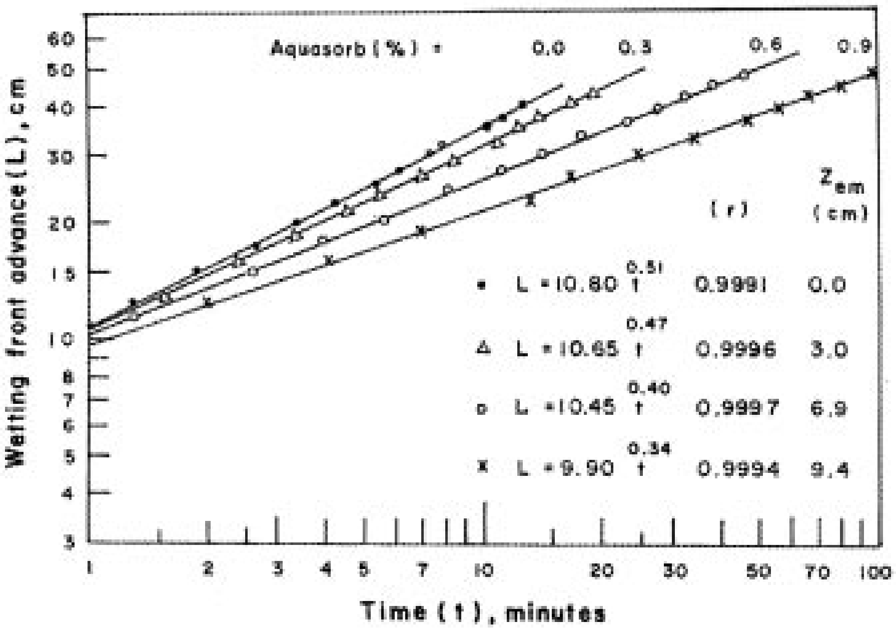

FIG. 4. Advance of wetting front in uniform sandy soil treated with Aquasorb gel-conditioner, under ponded infiltration. The inset equations are the regression of the measured data. Z_{em} is the maximum absolute expansion above the initial soil surface. Each point is an average of two determinations.

It might be interested here to interrelate Equations (11) and (12) as follows

$$L = \frac{D}{\Delta\theta} \tag{13}$$

where $\Delta\theta$ is the water deficit in the transmission zone (Pore space available for infiltration) and equal to $(\theta_T - \theta_i)$.

$$L = \frac{a\ t^{b}}{(\theta_T - \theta_i)} \tag{14}$$

where θ_T is the water content in the transmission zone, and θ_i is the initial water content.

The value of θ_T is approximately 36% while θ_i is equal to 0.375%.

Accordingly, $\frac{a}{(\theta_T - \theta_i)} = \frac{3.80}{(0.36 - 0.00375)} = 10.67$, which is very close to the constant of proportionality (10.80) of Equation (12). The relationship between L and D presented by Equation (13) is in good agreement with El-Shafei and Al-Darby (1991).

It was first intended to investigate the effect of different concentration of Aquasorb gel-conditioner, *viz.,* 0.0, 0.3, 0.6 and 0.9 % on the infiltration characteristics of sandy soil. This range of concentration was chosen on the basis that many researchers have recommended in general a value of neighborhood of 0.6% for different gel-conditioners (*e.g.,* Mustafa, *et al.,* 1988; Mustafa, *et al.,* 1989; Al-Darby *et al.,* 1992 and El-Shafei *et al.,* 1992). They also indicated that a concentration level around 1% would lead to surface sealing.

The following results are dealing with uniform-treated soil columns. It was evident that the wetting front was actually advanced downward and upward with respect to the initial soil surface as a result of soil expansion during infiltration. However, the wetting front advance (L) herein is referring to the vertical distance from the soil surface, regardless of its position, to the wetting front. In other words, at any time during infiltration, the new erected soil surface was always taken as datum line for measuring L as positive value downward.

The results depicted in Fig. 4 illustrate that the advance of wetting front (L) was substantially decreased with increase of Aquasorb concentration (C). The distance to the wetting front (L) as a function of time (t) can be represented by a power-type equation with correlation coefficient (r) > 0.9991.

$$L = A\, t^B \tag{15}$$

Where L is in cm and t is in minutes.

It can be detected from the inset equations depicted in Fig. 4 that both of the constant of proportionality (A) and the exponent (B) were decreasing with increase of C.

For example at $C = 0.0\%$, the values were:

$A = 10.80$ and $B = 0.51$

at $C = 0.9\%$, the values were:

$A = 9.90$ and $B = 0.34$.

However, the cumulative ponded infiltration (D) as a function of time (t) did not follow the same general trend of wetting front advance (L) as can be noticed from Fig. 5. The computed power regression intercept (a) was increasing while the exponent of time (b) was decreasing with increase of C.

For example at $C = 0.0\%$, the values were:

$a = 3.80$ and $b = 0.50$

at $C = 0.9\%$, the values were:

$a = 7.48$ and $b = 0.26$

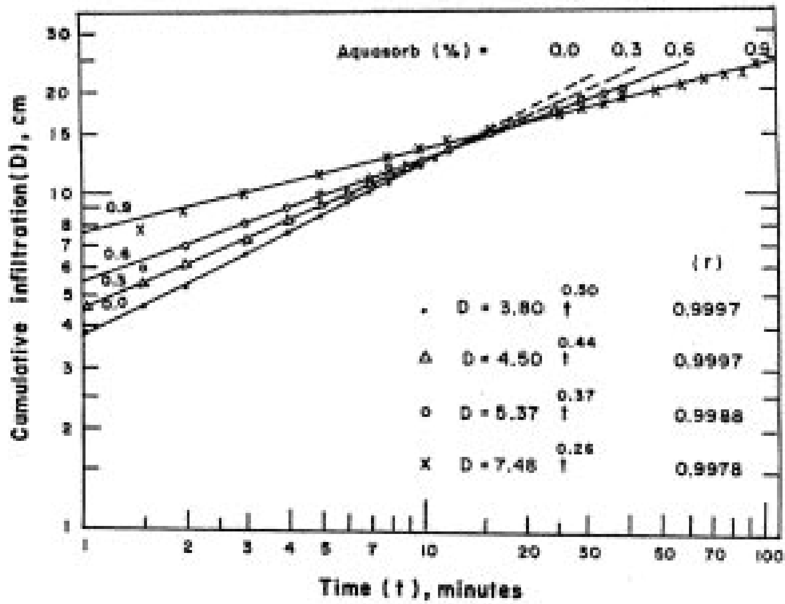

FIG. 5. Cumulative ponded infiltration in uniform sandy soil treated with Aquasorb conditioner. The inset equations are the regression of the measured data. Each point is an average of two determinations.

This means that there was a point of intersection among the different infiltration curves (Fig. 5). The infiltration period can be divided into two main stages. The first stage, which lasted approximately 15 min during which D increased with increase of C, then followed by a second stage characterized with reverse effect. The relationship between D and t can also be presented by a power-type equation with $r \geq 0.9978$.

The previous obtained results indicate that the Aquasorb polymer has high capacity of absorbing water and retaining it at the same time. For example at time (t) = 15 min (point of intersection), the depth of water infiltrated (D) was about 15 cm for all the different concentrations (Fig. 5). The corresponding wetting front advance (L) was 43, 38, 30 and 25 cm for the corresponding C: 0.0, 0.3, 0.6 and 0.9, respectively. It might be mentioned here that most of the surface expansion (> 75%) had been occurred during the first stage of ponded infiltration. The maximum value attained for the absolute expansion (Z_{em}) was 9.4 cm for C = 0.9%.

If the relative expansion (L_r) is calculated as the increase in the height of soil surface divided by the distance to the wetting front (L), one will find that L_r is eventually approached a value of 0.19 for C = 0.9%.

$$L_r = \frac{Z_e}{L} = \frac{Z_e}{Z + Z_e} \tag{16}$$

Where:

Z_e = absolute expansion above the initial soil surface, cm,

Z = depth of wetting front below the initial soil surface, cm,

The volumetric water content (θ) and bulk density (D_b) distribution profiles obtained under ponded infiltration are summarized in Fig. 6. The bulk density of the surface layer was greatly influenced by Aquasorb concentration (C). The higher C, the lowest the resultant D_b at the corresponding depth.

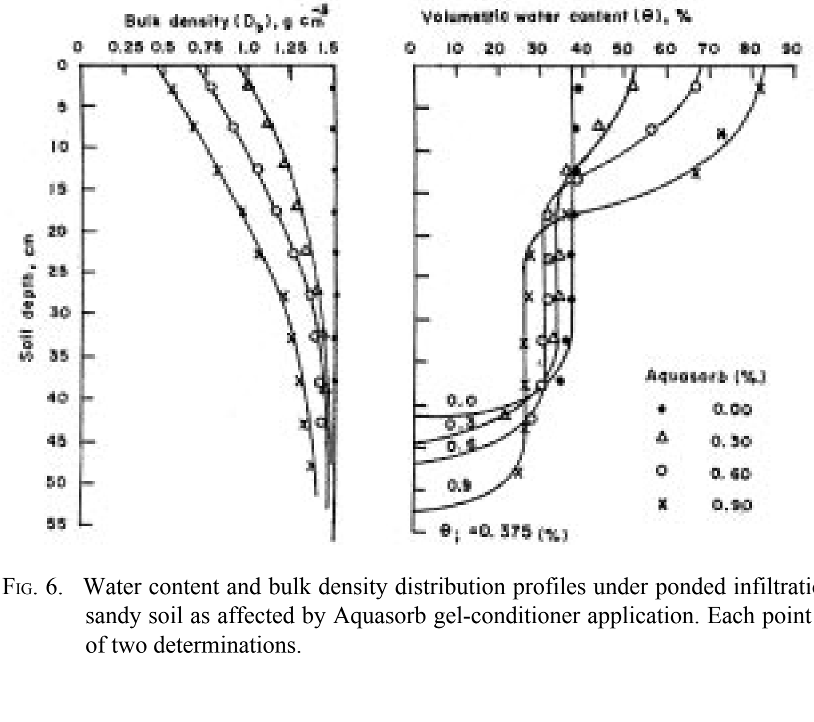

FIG. 6. Water content and bulk density distribution profiles under ponded infiltration in uniform sandy soil as affected by Aquasorb gel-conditioner application. Each point is an average of two determinations.

For example, the values of D_b at the upper layer (5 cm depth) were 1.50, 1.00, 0.76 and 0.52 g cm^{-3} for the corresponding C: 0.0, 0.3, 0.6 and 0.9%, respectively. However at each value of C, D_b was increasing with depth until eventually approached the initial value of $D_b = 1.50$ g cm^{-3}.

The values of bulk density (D_b) were implemented to convert the water content by weight (W) to volumetric water content (θ) for each corresponding depth. It can be noticed from the data depicted in Fig. 6 that a concentration of > 0.3% resulted in θ to be less than W at the upper 5 cm layer.

The water distribution profile (Fig. 6) can be divided into two main zones. The first zone was extended about 20 cm depth below the new erected soil surface and was highly influenced by Aquasorb concentration (C). The higher C, the higher the resultant water content (θ) at the upper 20 cm depth. The second zone was extended from the 20 cm depth to the wetting front and was characterized with reverse effect, *i.e.,* the value of θ which was almost constant decreased with increase of C. This result might be expected since the first zone (20 cm depth) is falling in the first stage of infiltration, which is characterized by high absorption of water.

In the view of the previous results and discussion for ponded infiltration, one may conclude that, the Aquasorb polymer possesses high superabsorbing and retention power for water especially at high concentration (0.9%). Accordingly, it would be wise to carry out preliminary runs using different water application rate (R) under sprinkling with the higher concentrations of Aquasorb to test for surface sealing, and to find out the appropriate and suitable range of Aquasorb concentration for sprinkler infiltration.

Sprinkler-Ponded Infiltration Relationship

Different soil columns treated uniformly with 0.6% and 0.9% Aquasorb concentrations were subjected to low and high sprinkler intensities (R), *viz.,* 3.5 and 10.5 cm h^{-1}. The results depicted in Fig. 7 indicate the occurrence of surface ponding under both application rates for $C = 0.9\%$, even before the wetting front reached 20 cm depth. It can be noticed from Fig. 7 that the surface ponding (water cover) has taken place just when the sprinkler intensity (R) crossed the I-curve and before intersecting the $I_{av.}$- curve. This means that either the kinetic energy of the falling drops ($K.E$) or/and the retention power of Aquasorb have caused the surface sealing.

The energy expenditure by a falling droplet upon reaching the soil surface tends to breakdown or dislodge the surface soil aggregate and causing surface sealing (Richards, 1966; Moldenhauer and Kemper, 1969; and El-Shafei *et al.,* 1993). The term seal is used here to denote a layer of particulate at the soil surface that results in small pores with low water permeability. The values of *K.E* for both sprinkler intensities (*R*) can be obtained by the following calculations using Equations 2 to 5:

$$d = 3.15 \text{ mm}$$

$$r_a = 0.00122\,(3.15)^{2.44} = 0.020 \text{ g } s^{-1}$$

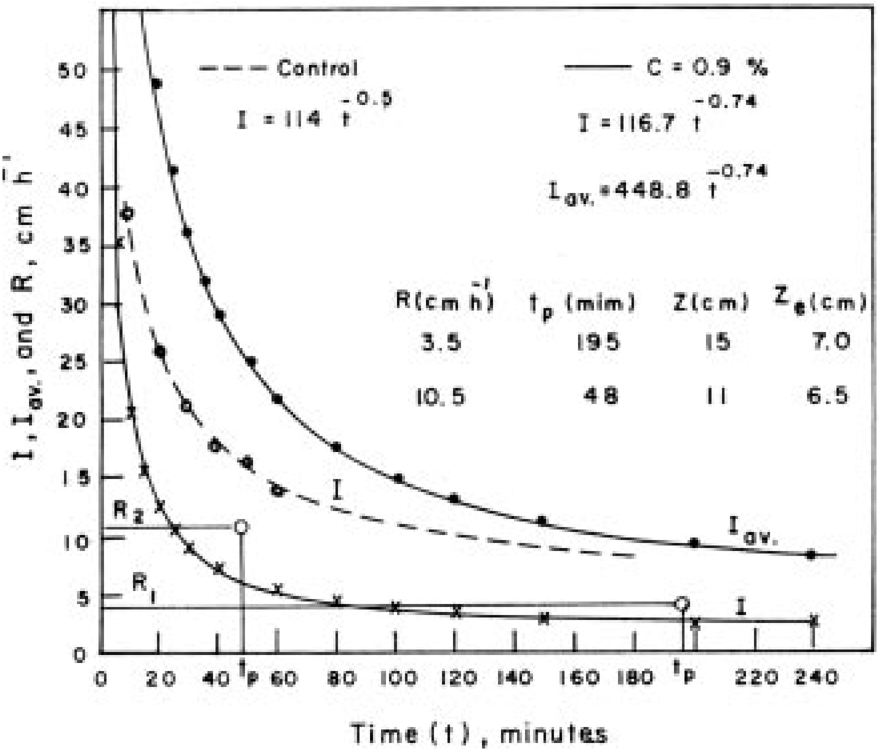

FIG. 7. Sprinkler intensity (*R*) in relation to infiltration capacity of soil treated uniformly with Aquasorb gel-conditioner concentration (*C*) = 0.9%. t_p = time of surface ponding, *Z* = distance to the wetting front below the initial surface, Z_e = absolute expansion above the initial surface, *I* = instantaneous infiltration rate, and I_{av} = average infiltration rate.

Since the falling distance (h_f) was variable due to surface expansion during sprinkling, the maximum falling distance will be used

$$h_f = 12cm$$

$$\upsilon = -\frac{(0.02)\ (12)}{0.0162} + \sqrt{\frac{(0.02)^2(12)^2}{(0.0162)^2} + (2)\ (980)\ (12)}$$

$$\upsilon = -14.82 + \sqrt{219 + 23520}$$

$$\upsilon = -14.82 + 154.08$$

$$\upsilon = 139.26 \ \text{cm} \ s^{-1}$$

$$K.E_1 = \frac{1}{2}(0.0162)\ (139.26)^2$$

$$K.E_1 = 157.1 \ \text{erg} \ = 1.57 \times \ 10^{-5} \ \text{J}$$

For the case of R = 3.5 cm h^{-1}:

$$N = \frac{10^4 \times 3.5}{0.0162} \cong 2.16 \times 10^6 \ \text{drops m}^{-2}\ \text{h}^{-1}$$

then, $K.E \ = \ (1.57 \times 10^{-5}) \ (2.16 \times 10^6)$

$$K.E \ = \ 34 \ \text{J m}^{-2}\ \text{h}^{-1}$$

This value of kinetic energy is considered very low.

For the case of R = 10.5 cm h^{-1}

$$N = \frac{10^4 \times 10.5}{0.0162} \cong 6.48 \times 10^6 \ \text{drops m}^{-2}\ \text{h}^{-1}$$

$$K.E = 102 \ \text{J m}^{-2}\ \text{h}^{-1}$$

which is also considered low (El-Shafei,1988 and El-Shafei *et al.,* 1993).

According to the previous results, it can be concluded that the 0.9% Aquasorb concentration is unsuitable for sprinkler infiltration, and it will cause surface seal resulting in ponding within the range of R used.

The same concept of interpretation can be applied on the data depicted in Fig. 8, where C = 0.6%. The lower sprinkler intensity (R_1) of 3.5 cm h^{-1} did not cause surface ponding as R_1 did not cross the I-curve, while the wetting front had advanced 40 cm depth below the initial soil surface. On the other hand, the higher sprinkler intensity (R_2) of 10.5 cm h^{-1} had caused surface ponding when R_2 just exceeded the instantaneous infiltration rate (I) and before intersecting the $I_{av.}$-curve. However, it can be noticed from Fig. 8 that the surface ponding was occurred after the wetting front has been advanced 20 cm depth below the initial surface.

Accordingly, one may infer that maximum Aquasorb concentration to be used is 0.6% conjugated with 20 cm depth as maximum treated upper layer for sprinkler infiltration.

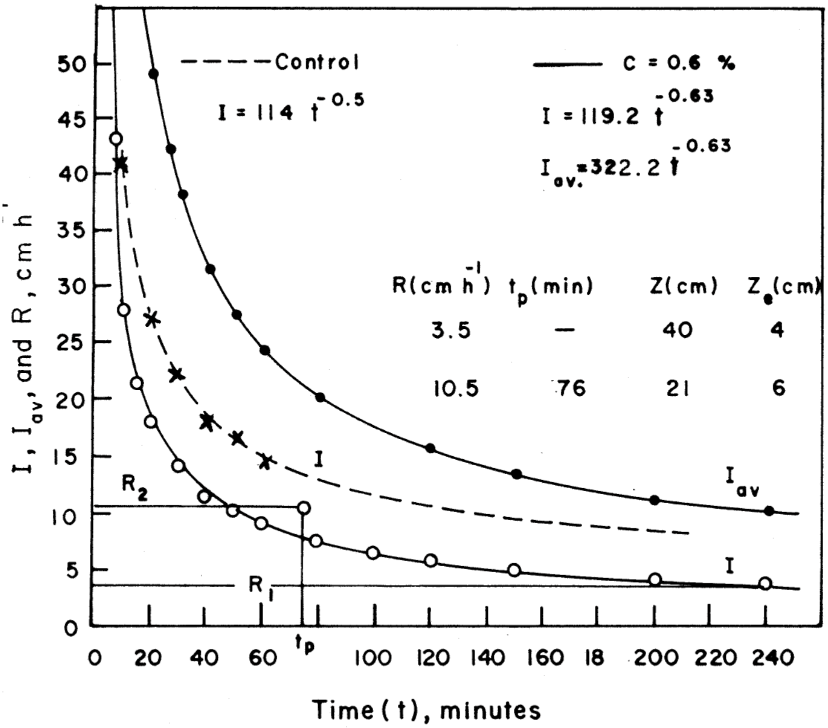

FIG. 8. Sprinkler intensity (R) in relation to infiltration capacity of soil treated uniformly with Aquasorb gel-conditioner concentration (C) = 0.6%. t_p = time of surface ponding, Z = distance to the wetting front below the initial surface, Z_e = absolute expansion above the initial surface, I = instantaneous rate, and I_{av} = average infiltration rate.

The previous results indicate that the concentration of Aquasorb is the main dominant variable affecting surface sealing, rather than the kinetic energy of the falling drops.

It might be mentioned here that a preliminary test was carried out using uniform soil columns of $C = 0.75\%$ and applying the same two sprinkler intensities (R). The results revealed that $R_1 = 3.5$ cm h^{-1} did not cause surface ponding, while $R_2 = 10.5$ cm h^{-1} resulted in surface ponding at time (t_p) = 60 min, when the distance to the wetting front below the initial surface (Z) = 16 cm. This finding again corroborates the previous conclusion that 0.6% is the maximum concentration, which is valid for sprinkler infiltration, within the given range of sprinkler intensity (R).

Conclusions

From this study, the following conclusions can be drawn:

1. The results of ponded infiltration experiment concluded that the Aquasorb gel-conditioner possesses high superabsorbing and retention power for water especially at high concentration (0.9%). These results suggest further study using sprinkler infiltration with different application rates to test for surface sealing in order to select the appropriate range of Aquasorb concentrations.

2. The results of the preliminary experiment using sprinkler infiltration revealed that the 0.9% Aquasorb concentration was unsuitable for sprinkler infiltration, and it will cause surface sealing resulting in water ponding within the used range of water application rates (R). It was also concluded that the maximum Aquasorb concentration to be used is 0.6% conjugated with 20 cm depth as maximum treated upper layer for sprinkler infiltration within the used range of R.

3. The results also revealed that the Aquasorb concentration was the main dominant variable affecting surface sealing, rather than the kinetic energy of the falling drops.

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محسن التربة الجيلاتيني: ١- اختيار التركيز وعمق الطبقة المعاملة المناسبين لتربة رملية تحت التسرب بالرش

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المستخلص. أُجريت تجربتين بغرض اختيار التراكيز المناسبة من المحسن الجلاتيني اكواسوارب الملائمة للتسرب بالرش دون التسبب في تليس للتربة ، ينتج عنه حدوث تراكم للماء فوق سطحها . التجربة الأوليكانت عبارة عن أعمدة تربة رملية معاملة بالأكواسورب بشكل متجانس ، وذلك باستخدام أربعة تراكيز هي: صفر و ٣, ٠ و ٦, ٠ و ٩, ٠٪ (على أساس الوزن الجاف) تحت ظروف التسرب بالغمر ، وذلك لاختبار قدرة هذا المحسن على امتصاص الماء والاحتفاظ به بالذات عند التركيز العالي (٩, ٠٪) . أما التجربة الثانية ، فقد تمت باستخدام أعمدة تربة رملية معاملة بنفس المحسن بشكل متجانس ولكن باستخدام تراكيز عالية من الأكواسورب هي ٦, ٠ و ٩, ٠٪ تحت معدلات رش مختلفة .

أظهرت تجربة التسرب بالغمر أن الأكواسورب يمتلك قدرة عالية جداً على امتصاص الماء والاحتفاظ به في آن واحد خاصة في حالة التركيز العالي (٩, ٠٪) . أما تجربة التسرب بالرش ، فقد أوضحت بأن تركيز الأكواسورب هو العامل المتغير الوحيد والأساسي الذي يؤدي إلى انغلاق سطح التربة بغض النظر عن الطاقة الحركية للماء عند سطح التربة. لهذا فإن هذه الدراسة تقترح بأن أعلى تركيز من الأكواسورب يمكن استخدامه هو ٦, ٠٪ مرتبطًا بعمق ٢٠سم كحد أعلى لعمق الطبقة العلوية المعاملة تحت ظروف التسرب بالرش .

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Soil Gel-Conditioner: II. Effect of Treated Upper Layer Depth on Infiltrability of Sandy Soil under Sprinkler Infiltration

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ABSTRACT. The objective of this study was to investigate the effect of adding Aquasorb gel-conditioner to the upper treated layer on the vertical movement of the water in sandy soil columns (Typic Torripsamments) under sprinkler infiltration.

The Aquasorb gel particles were highly swollen upon water absorption resulted in large surface expansion. The value of the absolute expansion was not influenced by water application rate (*R*), but was linearly increased with increasing concentrations (*C*) and treated soil layer depth (d_t). However, the relative expansion was exponentially diminished with increasing wetting front advance (*L*) and it was dependent on both *C* and d_t, but was not influenced by *R*. The surface expansion occurred gradually during infiltration and most of the expansion (> 70%) had occurred when the wetting front reached 30 cm below the initial soil surface. The rate of wetting front advance (*dL/dt*) reduced by either increasing *C* or *dt* and it increased by decreasing *R*. The resulted bulk density (D_b) distribution profiles was an entity of the Aquasorb conditioner and was not affected by *R* but rather by *C* and d_t. The D_b at the upper 5 and 10 cm depths were significantly reduced by increasing d_t from 5 to 10 cm depth which after no significant differences were evident, whereas, the average D_b at the upper 20 cm depth continued to decrease significantly with increasing d_t. The water distribution profiles were positively influenced by *R, C* and d_t. The average water content (θ) at the upper 5, 10 and 20 cm depths increased exponentially with increasing *R, C* and d_t. However, the average θ at the upper 5, 10 or 20 cm depths were significantly increased by increasing d_t from 5 to 10 cm depth, which after no significant differences were evident.

It can be concluded from this study that the optimum C for a stratified sandy soil profile is 0.4 %, and the optimum d_t is 10 cm, which conjugated with any convenient R under sprinkler (rain) infiltration.

Introduction

Very limited research has been conducted on the influence of soil surface treatment with gel-conditioners (superabsorbents) on water movement under sprinkler infiltration. However, most of the found researches using gel-conditioners were for the purpose of stabilizing soil structure. Blavia *et al.* (1971) and Gabriels *et al.* (1973) have shown that polyvinyl alcohol (PVA) and polyacrylamide (PAM) polymers effectively stabilize surface clods against rainfall energy received between a seeding and a complete vegetative cover.

Among the few researches used gel-conditioners as superabsorbent are El-Shafei *et al.* (1992), El-Shafei *et al.* (1994), and Al-Darby and El-Shafei (1995). El-Shafei *et al.* (1992) suggested to apply Jalma at 0.75% to upper layer (10 cm depth) under medium sprinkler intensity around 2 cm h^{-1}, and wetted depth not more than 20 cm for the benefit of water use efficiency. This is based on rational assessment of two advantages, *i.e,* magnifying the water holding capacity in the upper layer, and diminishing the deep percolation in the lower layer. El-Shafei *et al.* (1994) found that: (1) For vertical infiltration either under ponding or sprinkling, the soil water content can be substantially increased within the first 20 cm depth, where most of the expansion is taken place by adding Acryhope gel-conditioner. (2) Under sprinkler infiltration, cumulative infiltration did not affected by gel-conditioner concentration. (3) The soil expansion as a result of adding Acryhope was taken place more gradually under sprinkler infiltration in comparison with that under ponded infiltration.

Under sprinkler infiltration, Al-Darby and El-Shafei (1995) found that the absolute expansion of soil as a result of high swelling of gel-particles (Acryhope) was not affected by the sprinkler intensity. The bulk density of the upper treated layer was greatly reduced by increasing gel concentration. The rate of wetting front was diminished by either gel-conditioner concentration or sprinkler intensity. The water content at the upper treated layer was magnified as gel-conditioner concentration and sprinkler intensity increased, and the gel-conditioner concentration proved to be the dominant factor influencing water and suction redistribution.

The use of sprinkler infiltration gives a special importance to this research, where the precedent studies in this field were very limited. Thus, this study is designed to investigate the effect of adding Aquasorb as a highly swelling gel-conditioner in the form of dry grains with different concentrations applied to the upper treated layer on the vertical movement of the water in sandy soil under sprinkler (rain) infiltration system.

Materials and Methods

The sandy soil (Typic Toripsamments) used in this study was sampled (0-30 cm depth) from the College Experimental and Research Farm at Dierab (Latitude 24º25′N, Longitude 46 º34′E), Saudi Arabia. The soil was air dried and passed through a 2 mm sieve, and the initial air dry water content was determined (0.25% wt.). Selected soil properties were determined by standard procedures (Klute *et al.,* 1986). The soil contained 5.5, 2.0 and 92.5% of Clay, Silt, and sand, respectively. It contained very low organic matter = 0.07%, high $CaCO_3$ = 25%, low EC_e = 0.7 dS m^{-1}, pH = 7.39, *SAR* = 0.71 (saturated extract). The water used had an *EC* = 0.45 dS m^{-1} and *SAR*= 0.90.

The gel-conditioner (Aquasorb[1]) used in this study was cross-linked sodium polyacrylate synthetic polymers manufactured in a form of dry white grains with diameter ≤ mm, particle density = 1.1 g cm^{-3}, and bulk density = 0.8 g cm^{-3}. The distilled water was added to the gel-conditioner with ratio 400:1 (on dry weight basis) and the mixture was left for 24 h to equilibrate. The extract of this mixture had pH = 7.9, *EC* = 0.25 dSm^{-1}, and contained the following soluble cations Na^+, K^+ and Ca^{++}, at amount of 2.8, 0.065 and 0.14 meq/l, respectively. The predetermined amounts of Aquasorb were thoroughly hand-mixed with air-dried soil in all experiments.

A simple sprinkler simulator (water applicator) was designed to sprinkle the soil surface uniformly at constant water application rate (*R*). Full description and illustration of the simulator were presented in Al-Asfoor *et al.* (2000).

The Aquasorb concentrations (*C*) used in this experiment were 0, 0.2, 0.4 and 0.6% with two water application rates (*R*): 3.5 and 10.5 cm h^{-1} .This range of *C* was chosen according to the finding of Al-Asfoor *et al.* (2000). They used low and high water application rates (*R*) under sprinkling with higher Aquasorb concentrations (*C*) namely 0.6 and 0.9% to test for surface sealing and to find out the appropriate and suitable range of Aquasorb concentrations for sprinkler infiltration. In this experiment, the treated soil with Aquasorb gel-conditioner was added to the top soil layer at four depths (d_t): 5, 10, 15 and 20 cm. The soil samples were packed, by tapping on the bench, in transparent sectionized lucite cylinders by 4.6 cm increments to 1.5 g cm^{-3} bulk density. The lucite cylinder was 56 cm long and 3.96 cm inside diameter.

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[1]The trade name of the gel-conditioner was included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by King Saud University.

The wetting front advance (L) and soil expansion versus time (t) were observed until the wetting front reached to about 40 cm below the initial level of soil surface, where the infiltration was terminated. The column, then, was laid horizontally and the sections were separated for determining the water distribution and bulk density profiles. Each experimental value was replicated three times.

Results and Discussion

Wetting Front Advance

During the sprinkler infiltration, the surface layer was wetted by drops of water applied at a rate (R) sufficient to prevent surface ponding. The gel-particles formed as a result of adding Aquasorb were swollen upon water absorption causing surface expansion of magnitude depending on Aquasorb concentration (C), and the depth of treated upper layer (d_t). Additional drops of water incident on the surface increased surface expansion until maximum swelling was attained under a specific R. At the same time, the surface layer tend to drain down until the next drop of water was incident on the surface. Thus, the wetting front was advanced upward and downward, with respect to the initial soil surface, during infiltration. However, the wetting front advance (L) herein is referring to the vertical distance from the new erected surface to the wetting front. This means that at any time during infiltration the soil surface was always taken as a datum line for measuring L as a positive value downward.

Figure 1 was chosen as an example to show the effect of Aquasorb concentration (C) and water application rate (R) on wetting front advance of sandy soil. The results depicted in Fig. 1 indicate that initially the rate of wetting front advance decreased with increasing C at the corresponding R. For example at R = 3.5 cm h^{-1} and d_t = 10 cm, the time required for the wetting front to advance 40 cm depth were approximately 184, 202 and 230 min for C = 0.2, 0.4 and 0.6%, respectively. Whereas the rate of wetting front increased with increasing water application rate (R) at the corresponding Aquasorb concentration (C). For example at C = 0.6% and d_t = 10 cm , the time (t) required for the wetting front to advance 40 cm depth (L) were approximately 230 and 87 min for R = 3.5 and 10.5 cm h^{-1}, respectively. However, the rate of advance (dL/dt) in the upper treated layer of the stratified profile decreased with increase of Aquasorb concentration (C). It appears that the (dL/dt) started to deviate when the wetting front had just penetrated the interference zone between the upper treated layer and the untreated lower layer. The dL/dt attained a constant value, which was consistently the same of the untreated uniform profile for the corresponding R. This finding is more evidence with R = 3.5 cm h^{-1} compared to R = 10.5 cm h^{-1}. The relationship between L, and t for C = 0.0% can be presented by the following linear equation (r > 0.9996)

$$L = 0.49 + 0.24\,t \qquad \text{for } R = 3.5 \text{ cm h}^{-1} \tag{1}$$
$$L = 0.54 + 0.60\,t \qquad \text{for } R = 10.5 \text{ cm h}^{-1}$$

where L is in cm and t is in min.

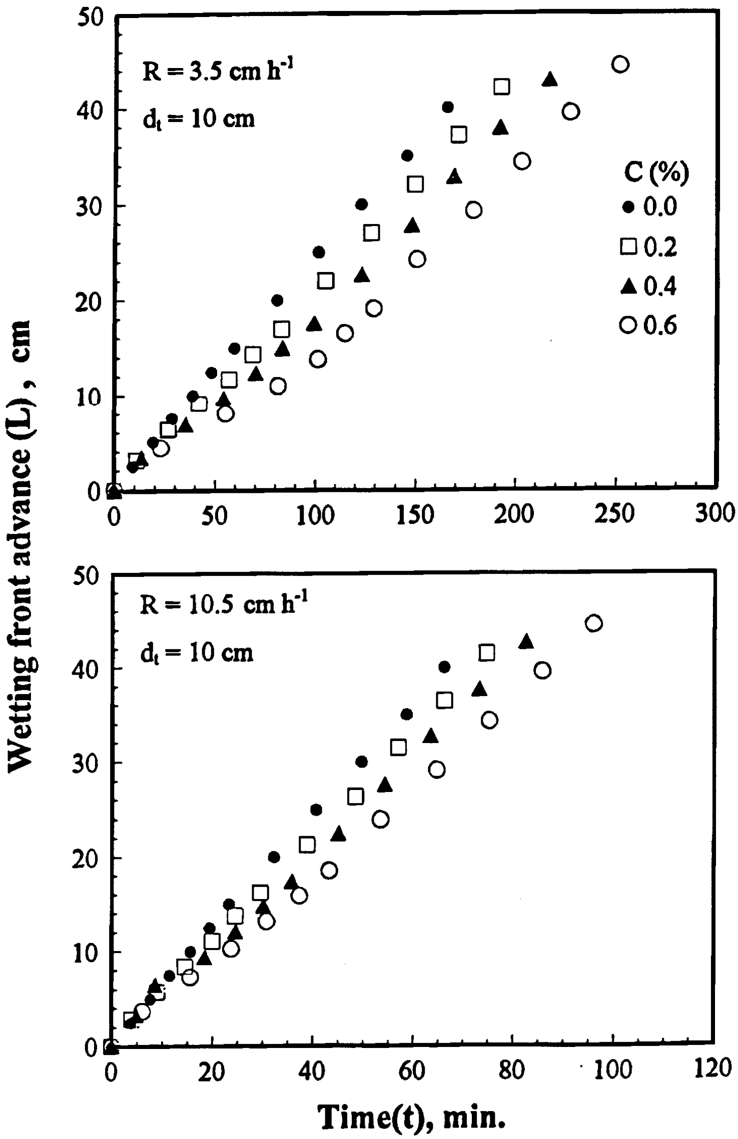

Fig. 1. Wetting front advance as affected by Aquasorb concentration (C) and water applicate rate (R) applied to the upper layer depth (d_t = 10 cm) of sandy soil.

Figures 2 and 3 illustrate the combined effect of the three factors: C, d_t and R on the rate wetting front advance (dL/dt). These two figures indicate that the (dL/dt) decreased with increase of treated upper layer depth (d_t) at the corresponding R and C. For example at $R = 3.5$ cm h^{-1}, and $C = 0.6\%$, the time required for the wetting front to advance 40 cm-depth (L = 40 cm) were approximately 202, 230, 234 and 260 min for d_t = 5, 10, 15 and 20 cm, respectively. The effect of d_t on the dL/dt increases with increasing Aquasorb concentration (C) at the corresponding R, whereas this effect decreases with increasing water application rate (R) at the corresponding C. The results of Forward Stepwise Regression Analysis supported the above findings. It revealed that R had positive effect on (dL/dt), whereas C and dt had negative effect on (dL/dt). Accordingly, the time required for the wetting front to advance 40 cm below the new erected soil surface (t_{40}) in minutes attained during sprinkler infiltration as a function of R, C and dt can be presented by the following exponential equation with $r = 0.9968$.

$$t_{40} = 242.3_e^{-0.13R + 0.52C + 0.008d_t} \tag{2}$$

The above equation is valid for $3.5 \le R \le 10.5$ cm h^{-1}, $0 \le C \le 0.6\%$ and $5 \le d_t \le$ cm.

Expansion

Applying Aquasorb to the upper layer (5,10,15 or 20 cm depth) of sandy soil produced surface expansion as a result of the high swelling of gel-particles under sprinkler infiltration. The results of Forward Stepwise Regression Analysis revealed that R had no significant effect on maximum absolute expansion (Z_{em}), whereas Z_{em} increased linearly with increase of Aquasorb concentration (C) and treated layer depth (d_t) under sprinkler infiltration (Fig. 4). Al-Darby and El-Shafei (1995) working with different gel-conditioner showed no significant effect of R on Z_{em} and a linear increase with increasing C. Since the absolute expansion of untreated sandy soil is zero, thus the resulted linear functions are forced to go through zero. Accordingly, the Z_{em} attained during sprinkler infiltration as a function of C and d_t can be presented by the following multiple regression equation with $r = 0.9926$.

$$Z_{em} = 6.89\,C + 0.04\,d_t \qquad \text{for } 0 \le C \le 0.6\% \text{ and } 5 \le d_t \le 20 \text{ cm} \tag{3}$$

where Z_{em} and d_t are in cm, and C is in %.

Figure 4 illustrates the positive effect of both C and d_t on Z_{em}. It is clear that C was the main variable with greatest effect on Z_{em} for each treated depth, which can be presented by linear equation of the form $Z_{em} = bC$ with $r > 0.9987$

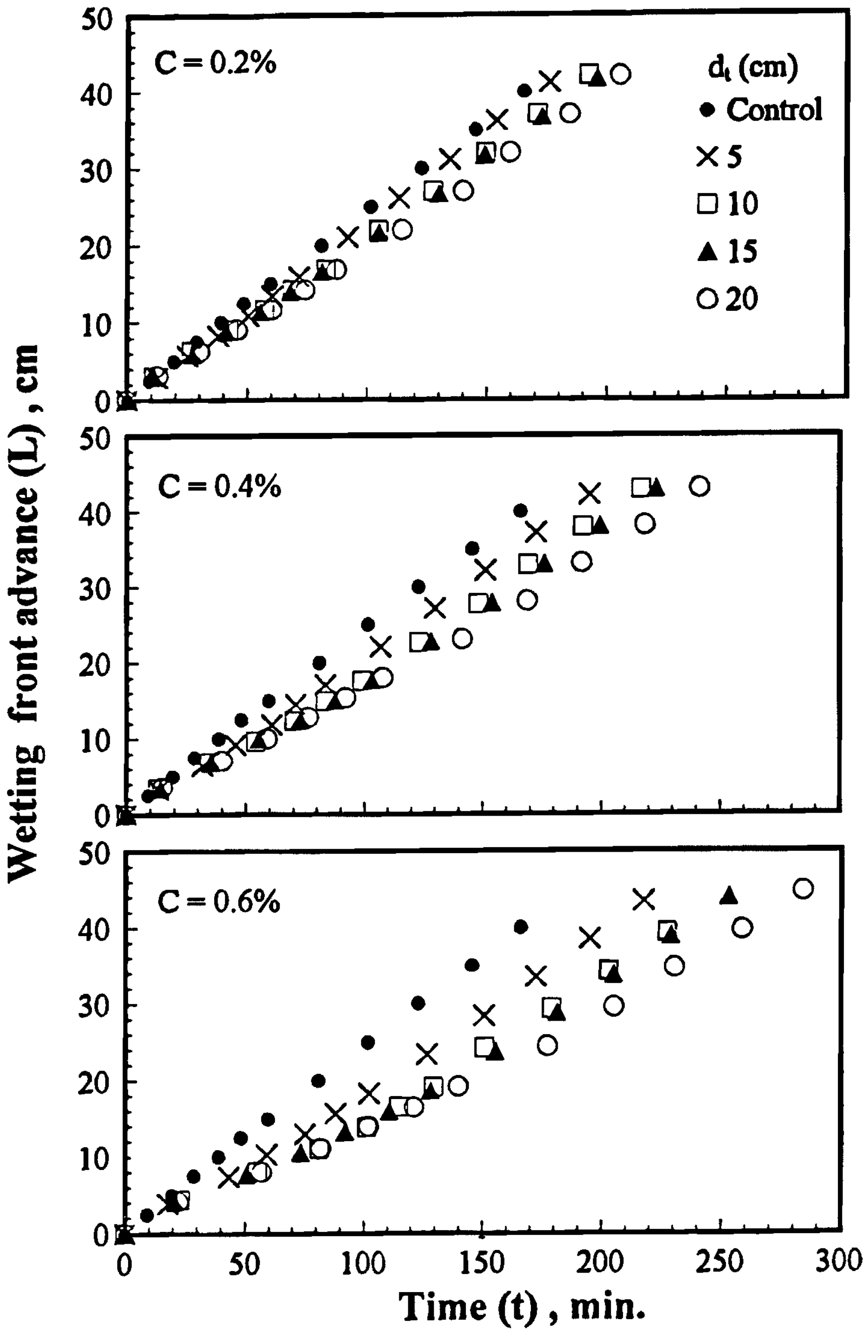

FIG. 2. Wetting front advance as affected by treated layer depth (d_t) and Aquasorb concentration (C) under sprinkler infiltration rate (R = 3.5 cm h^{-1}).

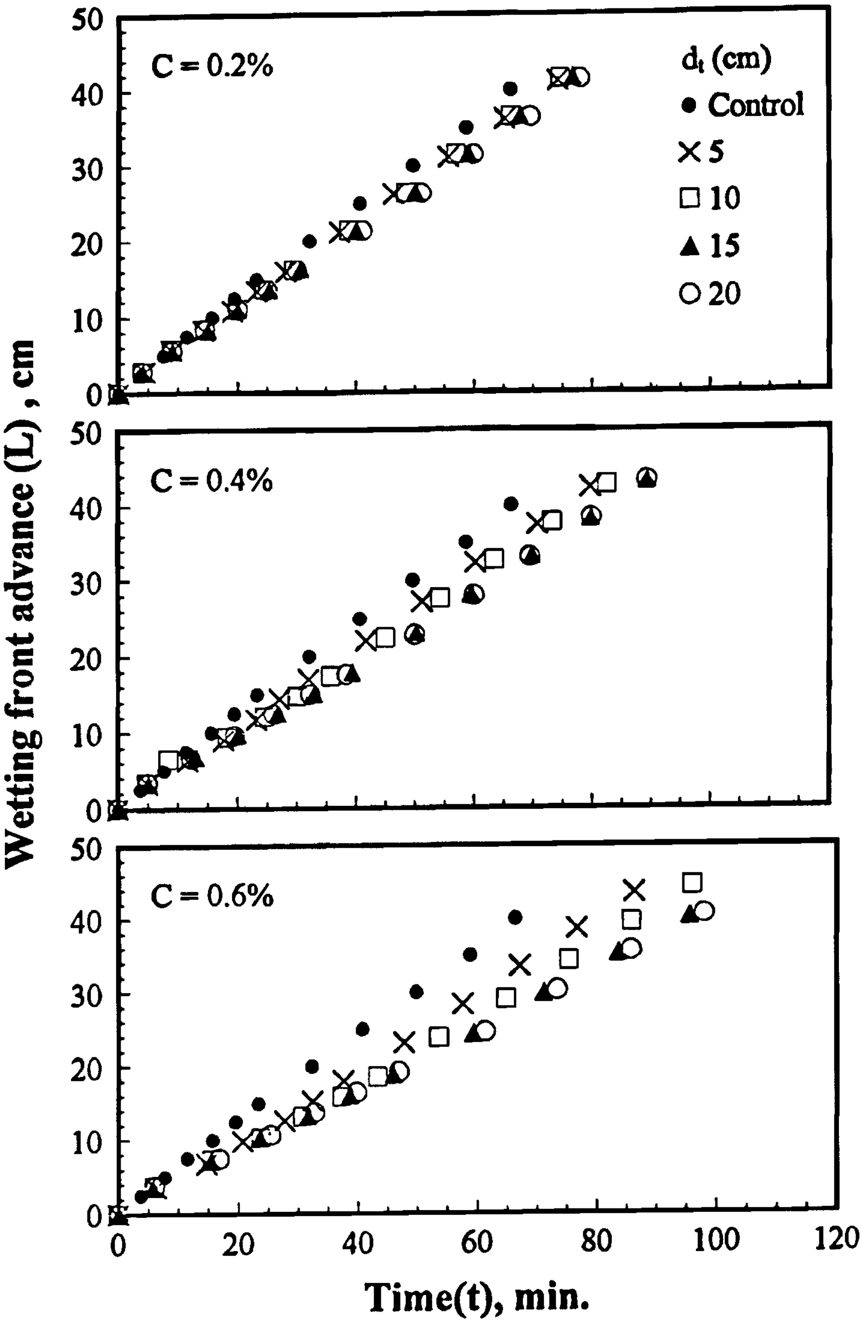

FIG. 3. Wetting front advance as affected by treated layer depth (d_t) and Aquasorb concentration (C) under sprinkler infiltration rate (R = 10.5 cm h^{-1}).

(Fig. 4). For example, the values of Z_{em} at treated depth (d_t) of 5 cm were 1.13, 2.28 and 3.37 cm for C = 0.2, 0.4 and 0.6%, respectively. It is also evident that Z_{em} increased with increasing the depth of the treated upper layer. This can be shown by the fact that the slope of the linear relationship between Z_{em} and C are increasing with increasing d_t. The rates of change (slopes) were 5.86, 7.36, 7.86 and 8.39 for 5, 10, 15 and 20 cm treated layer depth, respectively.

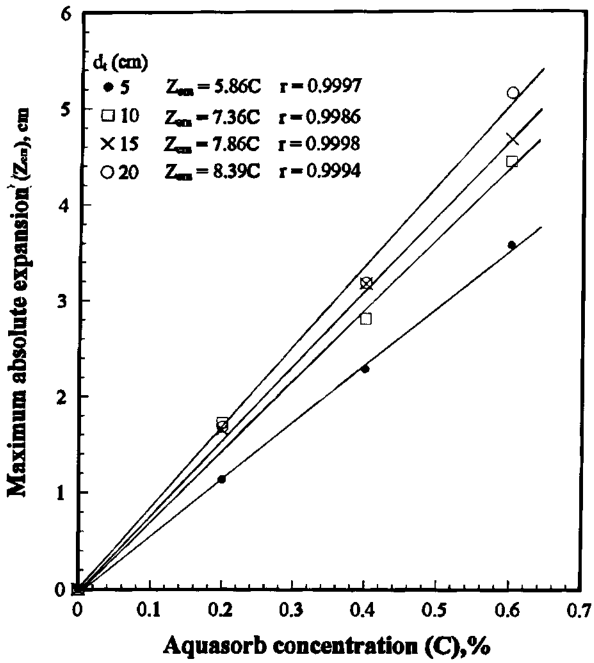

FIG. 4. Maximum absolute expansion (Z_{em}) as affected by Aquasorb concentration (C) and treated layer depth (d_t) regardless of water application rate (R).

The relative expansion (L_r) as introduced by El-Shafei *et al.* (1994) was determined during sprinkler infiltration.

$$L_r = \frac{Z_e}{L} = \frac{Z_e}{Z + Z_e} \tag{4}$$

where Z_e is the absolute expansion above the initial surface (cm) and Z is the depth of wetting front below the initial surface (cm). Similar to the effect on Z_{em}, Forward Stepwise Regression Analysis revealed that R had no significant effect on L_r, whereas L_r was affected significantly with C and d_t. Figure 5 shows the relationships between L_r and L as affected by C and d_t. The L_r was exponentially decreased with increasing L and can be represented by the following general equation

$$Lr = A_e^{-BL} \tag{5}$$

where A and B are constants depending on C and d_t. Table 1 shows the parameters A and B. Note that B (slope) was not affected by either C or d_t, whereas A (the intercept) was affected by C and d_t. The arithmetic average of B is 0.036. The effect of C and d_t on A can be presented as follows ($r = 0.9783$)

$$A = 0.006 + 0.58\ C + 0{,}004\ d_t \tag{6}$$

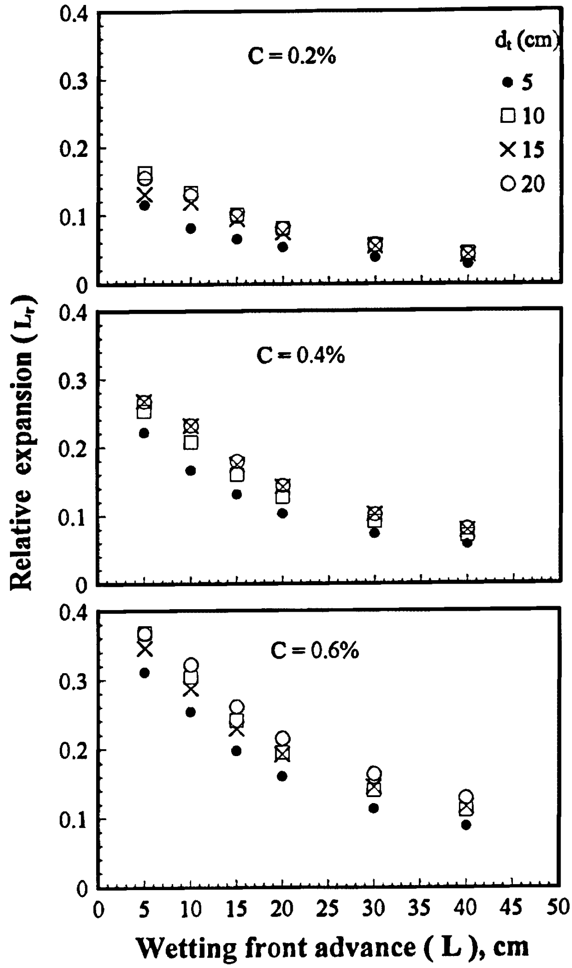

FIG. 5. The relationship between wetting front advance (L) and the relative expansion (L_r) as affected by Aquasorb concentration (C) and treated layer depth (d_t) regardless of water application rate (R).

The following numerical example will be drawn for the case of $C = 0.4\%$, , $d_t =$ 10 cm, and $L = 40$ cm :

Table 1. The parameters A and B of the exponential relationship of L_r versus L ($L_r = A_e^{-BL}$) and their correlation coefficients (r) as affected by Aquasorb concentration (C) and treated layer depth (d_t).

C (%)	d_t (cm)	A	B	r
0.2	5	0.124	0.038	– 0.9881
	10	0.186	0.038	– 0.9922
	15	0.157	0.034	– 0.9948
	20	0.181	0.037	– 0.9951
0.4	5	0.244	0.038	– 0.9883
	10	0.290	0.037	– 0.9924
	15	0.313	0.036	– 0.9934
	20	0.313	0.035	– 0.9930
0.6	5	0.355	0.036	– 0.9928
	10	0.417	0.035	– 0.9924
	15	0.383	0.031	– 0.9917
	20	0.420	0.031	– 0.9950

The computed values by Equations 5 and 6 were A = 0.278 and L_r = 0.069. The computed L_r compared favorably with the observed one (0.071) with a deviation of 3.4%. Generally, the computed L_r compared favorably with the observed values with overall deviation ranged from 2-20%.

Moreover, it should be noted from Fig. 5 that the surface expansion occurred gradually during infiltration, and most of the expansion (> 70%) had occurred when the wetting front reached 30 cm below the initial soil surface.

Bulk Density

The bulk density (D_b) distribution pattern was not greatly influenced by *R,* but was mainly influenced by Aquasorb concentration (C) and the treated layer depth (d_t) as shown in Fig. 6 and 7. This finding was evident from the results of the Forward Stepwise Regression Analysis, which revealed that R had no significant effect on the average bulk densities at the upper 5, 10 and 20 cm depth (D_{b5}, D_{b10} and D_{b20}), whereas D_{b5}, D_{b10} and D_{b20} decreased linearly with increasing Aquasorb concentration (C) and treated layer depth (d_t) under sprinkler infiltration. This result strongly corroborates the finding obtained for soil expansion that the magnitude of R has non-significant effect on expansion under sprinkler infiltration. Al-Darby and El-Shafei (1995) working with different gel-conditioner showed no significant effect of R on D_b. The relationships between the average D_b at the upper 5, 10 and 20 cm depth (D_{b5}, D_{b10} and D_{b20}) and C and d_t can be presented by the following multiple regression equation with $r > 0.9361$.

$$\begin{aligned} D_{b5} &= 1.58 - 1.11C - 0.005d_t \\ D_{b10} &= 1.62 - 0.93C - 0.008d_t \\ D_{b20} &= 1.64 - 0.63C - 0.010d_t \end{aligned} \tag{7}$$

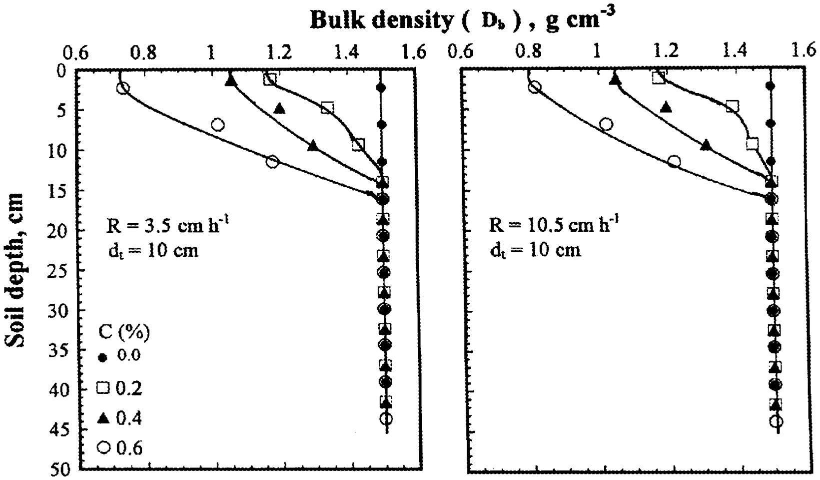

FIG. 6. Bulk density distribution profiles as influenced by water application (R) and Aquasorb concentration (C) applied to the upper layer depth (dt = 10 cm) of sandy soil.

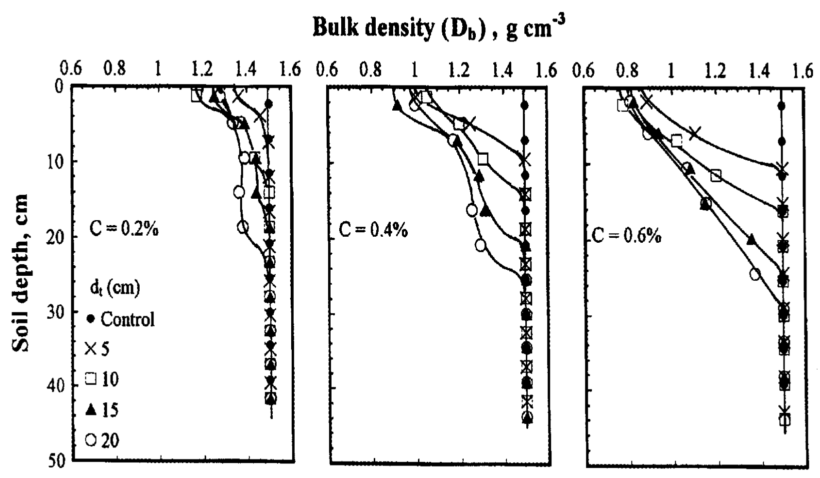

FIG. 7. Bulk density distribution profiles as influenced by Aquasorb concentration (C) and treated layer depth (d_t) regardless of water application rate (R).

Figure 6 was chosen as an example to illustrate the effect of water application (R) and Aquasorb concentration (C) on D_b at treated depth (d_t) =10 cm. It indicates that the higher C, the lowest the resultant D_b, and the non effect of R on D_b at the upper treated surface layer. However, for each value of C, D_b was gradually increasing with depth until eventually approached the initial value of D_b (1.50 g cm^{-3}) for sandy soil. Figure 7 illustrates the effect of different treated upper layer depths (d_t) for each C on D_b regardless of R. Note that the effect of treated layer depth (d_t) was more pronounced as C increased. For example, when d_t increased from 5 to 10 cm depth, the average D_b at the upper 5 cm depth decreased by approximately 6.4 and 16%, for C = 0.2 and 0.6, respectively. The analysis of variance revealed that the average D_b at the upper 5, or 10 cm depth were significantly (P = 0.01) reduced by increasing d_t from 5 to 10 cm depth, which after no significant differences were detected. For example, the average D_b at the upper 5 cm depth were 1.24, 1.17, 1.15 and 1.16 g cm^{-3} and the average D_b at the upper 10 cm depth were 1.33, 1.24, 1.22 and 1.21 g cm^{-3} for d_t = 5, 10, 15 and 20 cm depth, respectively. However, the average D_b at the upper 20 cm continued to decrease significantly (P = 0.01) with increasing d_t. The average D_b at the upper 20 cm depth were 1.41, 1.35, 1.29 and 1.26 g cm^{-3} for d_t = 5, 10, 15 and 20 cm depth, respectively.

Volumetric Water Content

The average water content at the upper treated layer (θ) was greatly increased by all the used factors R, C and d_t as can be deduced from Fig. 8, 9 and 10. The results of Forward Stepwise Regression Analysis revealed that the average water content at the upper 5, 10 and 20 cm depth (θ_5, θ_{10} and θ_{20}) increased exponentially with increasing R and C, and d_t under sprinkler infiltration. Accordingly, the θ_5, θ_{10} and θ_{20} as functions of R, C and d_t can be presented by the following multiple regression equations with $r > 0.9778$

$$\begin{aligned} \theta_5 &= 25.53_e^{0.017R + 1.15C + 0.005d_t} \\ \theta_{10} &= 23.34_e^{0.021R + 1.07C + 0.006d_t} \\ \theta_{20} &= 23.34_e^{0.022R + 0.70C + 0.005d_t} \end{aligned} \tag{8}$$

Figure 8 illustrates the water distribution patterns as affected by Aquasorb concentration (C) under two different sprinkler intensities (R) for chosen treated layer depth (d_t = 10 cm). It appears that the water content was greatly increased by either C or R. For example, at C = 0.6% and d_t = 10 cm, the volumetric water content (θ) at 10 cm soil depth were approximately 39.2 and 42.6% for R = 3.5 and 10.5 cm h^{-1} respectively, and at R = 3.5 cm h^{-1} and d_t = 10 cm, θ at 10 cm

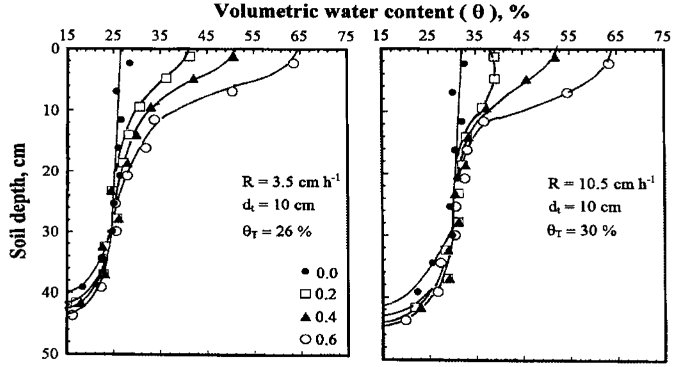

FIG. 8. Volumetric water content distribution profiles as influenced by water application rate (R) and Aquasorb concentration (C) applied to the upper layer depth (d_t = 10 cm) of sandy soil.

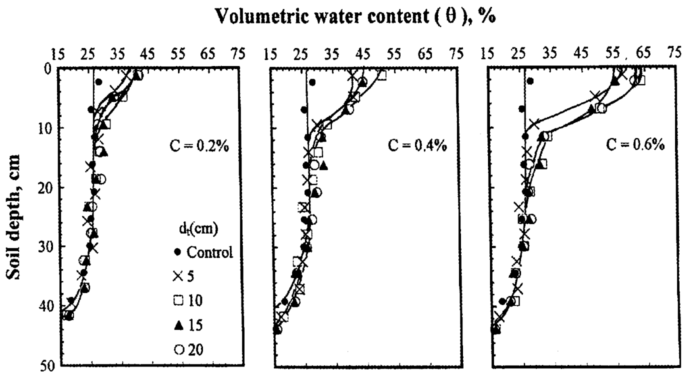

FIG. 9. Volumetric water content distribution profiles as influenced by Aquasorb concentration (C), and treated layer depth (d_t) under sprinkler infiltration rate (R = 3.5 cm h^{-1}).

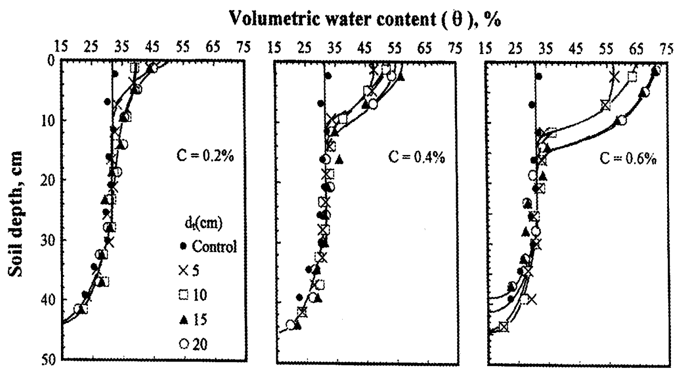

FIG. 10. Volumetric water content distribution profiles as influenced by Aquasorb concentration (C) and treated layer depth (d_t) under sprinkler infiltration rate (R = 10.5 cm h^{-1}).

soil depths were approximately 30.4, 32.6 and 39.2% for C = 0.2, 0.4 and 0.6% respectively. The results depicted in Fig. 8 also indicated that the constant water content (θ_T) in the untreated lower layer was unaffected by the treatment in the upper layer, but rather by sprinkler intensity (R). It appears that if the Aquasorb-treated soil overlies the untreated sandy soil, water content in the lower layer will be consistently the same at corresponding depths in uniform sandy soil under the corresponding R. In other words, there existed a transmission zone with a uniform water content (θ_T), which only depending on R. The values of θ_T were approximately 26 and 30% for R = 3.5 and 10.5 cm h^{-1}, respectively. Figures 9 and 10 show the water distribution patterns as affected by d_t with the corresponding R and C. It should be noted from Fig. 9 and 10 that the addition of Aquasorb conditioner resulted in high θ, however, it appears that was no significant differences between treated layer depths for a particular R and C. The analysis of variance revealed that the average θ at the upper 5, 10 or 20 cm depth were significantly increased (P = 0.01) by increasing d_t from 5 to 10 cm depth, which after no significant differences were detected. For example, the average θ at the upper 5 cm depth were 42.16, 44.91, 45.31 and 46.04%, and the average θ at the upper 10 cm depth were 38.57, 41.47, 42.18 and 42.97%; and the average θ at the upper 20 cm depth were 34.10, 36.31, 37.03 and 37.07% for d_t = 5, 10, 15 and 20 cm depth, respectively.

Conclusion

From this study, the following conclusions can be drawn:

1. Under sprinkler infiltration experiment, the wetting front advance rate (dL/dt) was significantly affected by the rate of the water application (R), the Aquasorb concentration (C), and the treated layer depth (d_t). The dL/dt decreased by increasing both C and d_t, while it increased by increasing R. Thus, the time required for the wetting front to advance to certain depth (say 40 cm) below the new erected soil surface was exponentially related to R, C and d_t.

2. The water application rate (R) had no significant effect on the maximum absolute expansion (Z_{em}), whereas Z_{em} increased linearly with increase of Aquasorb concentration (C) and treated layer depth (d_t) under sprinkler infiltration.

3. Similar to the effect on Z_{em}, R had no significant effect on the relative expansion (L_r), whereas L_r was affected significantly with C and d_t.

4. Under sprinkler infiltration, the results revealed that the surface expansion occurred gradually during infiltration, and most of the expansion (> 70%) occurred when the wetting front reached 30 cm below the initial soil surface.

5. The bulk density (D_b) distribution was not greatly influenced by R, but was mainly influenced by both C and d_t. It was found that R had no significant

effect on the average bulk densities at the upper 5, 10 and 20 cm depth, whereas these bulk densities decreased linearly with increasing C and d_t under sprinkler infiltration. The average D_b at the upper 5 or 10 cm depth were significantly reduced by increasing d_t from 5 to 10 cm depth, which after no significant differences were evident. However, D_b at the upper 20 cm depth continued to decrease significantly with increasing d_t. The effect of d_t on D_b was more pronounced as C increased.

6. The water distribution pattern was greatly influenced by all the used factors R,C and d_t. The average water content (θ) at the upper 5, 10 and 20 cm depth increased exponentially with increasing R, C and d_t under sprinkler infiltration. However, the average θ at the upper 5, 10 or 20 cm depth were significantly increased by increasing d_t from 5 to 10 cm depth which after no significant differences were detected.

7. It was evident that when Aquasorb treated soil layer overlies the untreated sandy soil, water content in the lower layer will be consistently the same at corresponding depths in uniform sandy soil under sprinkler infiltration.

8. From the stand point of water beneficial use, this study suggested to apply Aquasorb conditioner to the soil surface layer to the depth of 10 cm, which after no significant differences on water content and D_b were detected.

9. This study also suggested that the optimum rate of Aquasorb for stratified sandy soils was 0.4%, which conjugated with any convenient R to wet the sandy soils within 30 to 35 cm depth below the initial surface, and without making any surface sealing resulting in water ponding.

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محسن التربة الجيلاتيني: ٢- تأثير عمق الطبقة المعاملة على تسربية التربة الرملية تحت التسرب بالرش

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*و **قسم علوم التربة والمياه ، جامعة الاسكندرية ، الاسكندريـة - مصر*

المستخلص. تهدف هذه الدراسة إلى معرفة تأثير المحسن الجيلاتيني اكواسورب المضاف إلى الطبقة العلوية المعاملة على حركة الماء الرأسية في أعمدة تربة رملية تحت التسرب بالرش. فقد وجد أن حبيبات الأكواسورب الجلاتينية تنتفخ بدرجة عالية بمجرد امتصاص الماء ، مما ينتج عن ذلك تمدد كبير للسطح . لم تتأثر قيمة التمدد المطلق بمعدل الرش (R) ، ولكنها زادت خطيًا بزيادة كل من تركيز المحسن (C) وعمق الطبقة المعاملة (d_t) . وعلى أية حال ، فإن التمدد النسبي ، وهو عبارة عن الزيادة في ارتفاع سطح التربة مقسومًا على تقدم جبهة الابتلال (L) ، قد تناقص أسّيا بزيادة الطول L ، وكان معتمداً على كل من C و d_t ، ولكن لم يتأثر بـ R . وطبقًا لهذا ، فإن تمدد سطح التربة حدث تدريجيا خلال التسرب ، وأن معظم التمدد (أكثر من ٧٠٪) قد حدث عندما وصلت جبهة الابتلال ٣٠سم تحت السطح الابتدائي للتربة . كما وجد أن معدل تقدم جبهة الابتلال (dL / dt) قد انخفضت بزيادة C أو d_t ، ولكنها زادت بزيادة R . إن قطاعات توزيع الكثافة الظاهرية (D_b) الناتجة من إضافة المحسن لم تتأثر بقيمة R ، ولكنها تأثرت معنويًا بكل من C و d_t . حيث انخفض متوسط D_b في الـ ٥ و ١٠سم العلوية معنويًا بزيادة d_t من ٥ إلى ١٠سم ، التي بعدها لم يلاحظ أي اختلافات معنوية . أما قطاعات توزيع الرطوبة، فقد تأثرت إيجابيًا بجميع العوامل الثلاثة المستخدمة R ، و C ، و d_t . حيث زاد أسيًا متوسط المحتوى الرطوبي (θ) للأعماق ٥، و١٠، و ٢٠سم

العلوية ، بزيادة كل من R ، و C ، و d_t . وعلى أية حال ، فإن متوسط θ في الأعـمـاق الـعلوية ٥، و١٠، و٢٠سم قـد زاد مـعنويًا بزيادة d_t من ٥ إلى ١٠سم ، التي بعدها لم يلاحظ أي اختلافات معنوية .

مما سبق يمكن الاستنتاج من هذه الدراسة أن التركيز (C) الأمثل لقطاع تربة رملية طبقية هو ٠,٤٪ ، وأن العـمق الأمثل للطبقة العلوية المعاملة (d_t) هو ١٠سم مرتبطة بأي معدل رش مناسب (R) تحت ظروف التسرب بالرش .

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Vadose and Groundwater Interactive Model to Study the Soil Water Flow in Dry Condition

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ABSTRACT. In order to estimate the efficiency of biological drainage in lowering groundwater levels, a numerical interactive link between the SWATR and FMAQ models is developed. SWATR simulates water flow in the vadose zone, while FMAQ simulates the flow in groundwater. In the vadose zone, one-dimensional vertical flow is assumed, while it is simulated as two-dimensional horizontal flow for the groundwater. The main assumption of this interactive link is that the actual evapotranspiration is considered equal to the negative recharge rate from the groundwater table, which is the only excitation of the groundwater FMAQ model. The effect of meteorological conditions, sink term description of plants and soil properties of vadose and groundwater zones are considered. The water table fluctuation is the main output of the model.

For the climate, soil and plant characteristics considered, and to drain biologically a groundwater table at depth 100 cm below ground surface, the conducted sensitivity analysis shows that best root depth of a plant should be between 90 and 100 cm. For the same water table in a clayey soil, plants of root depth of 60 cm do not need irrigation (under the studied conditions) since they are capable of extracting water from the groundwater for a period of 20 days. For root depth of 90 cm with no precipitation, the overall actual transpiration increases with the increase of temperature or wind speed. No change in overall actual transpiration was noticed until the value of precipitation reaches 5 mm/day. After this value, the trend of increase is exponential although it is very small. The overall transpiration after 28 days decreases in the following order: clay, silt, and finally sand.

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1. Introduction

It has been observed that, in the last two decades, the groundwater level has risen considerably in the agricultural lands due to the increase of water use, the lack of adequate drainage and the presence of the High Dam. For example, the average groundwater level in Siwa Oasis rose from 150 cm below ground surface in 1962 (Parsons, 1962), to 75 cm in 1987, according to the "First Annual Report of the Biological Drainage Project in Siwa Oasis" undertaken by the Desert Research Institute (1989). This rise in water levels has damaging effects on plant growth since it reduces the roots' capability of extracting water even from the vadose or the unsaturated zone.

This shallow groundwater level could affect the evapotranspiration that can be predicted while modeling the flow in the vadose zone, taking water uptake into consideration, which is essentially a one-dimensional vertical flow. To compute the change in groundwater the in-plan two-dimensional horizontal flow in the saturated zone has to be considered. For the complete analysis of the biological drainage problem, which is an interaction between the two above described systems, a three dimensional flow model for the unsaturated-saturated zones would be needed (Neuman, 1973). This may turn to be expensive, time consuming and of quite an elaborate mathematical formulation.

To bypass solving the three-dimensional problem, a numerical interactive link between two existing models is proposed in this research. The models are:

- SWATR (Feddes *et al.,* 1978), which is a one-dimensional vertical model of unsaturated flow that computes the actual evapotranspiration, and
- FMAQ (El-Didy and Contractor, 1986), which is a multi-aquifer model for the flow in the saturated zone, that computes the groundwater level for a given stimulation.

This suggested numerical link permits predicting the actual temporal evapotranspiration and the drop in groundwater level, given the type of plant, soil characteristics, and hydrogeological and meteorological data. The aim of this paper is first, to describe this link procedure, and second, to present the results of a parametric study of the response of the complete model to changes in the above-mentioned data. We begin first by describing briefly the two already existing models SWATR and FMAQ.

The SWATR Model

The numerical model SWATR (Feddes *et al.,* 1978) is a transient one-dimensional finite-difference model for the vadose zone. The model, which has a possibility of simulating water uptake by roots, was developed at the Institute for Land and Water Management Research, Wageningen, the Netherlands, and is programmed in FORTRAN 77.

The basic flow equation of this model (Equation 1) is based on Darcy's law, the continuity equation, and a volumetric sink term, describing the root water uptake. This equation is solved by a finite difference scheme, as proposed by Haverkamp *et al.,* 1978. The derivation of this equation and the main idea of the description of the sink term S and its calculations can be found in Feddes *et al.,* 1978.

$$\frac{\partial_\psi}{\partial_t} = \frac{1}{C(\psi)} \cdot \frac{\partial}{\partial_z}\left[K(\psi)\cdot\left(\frac{\partial\psi}{\partial z}-1\right)\right] - \frac{S(\psi)}{C(\psi)} \tag{1}$$

Where

- ψ Soil water pressure head (negative in the vadose zone), [cm];
- C Differential moisture capacity $d\theta/dh$, with θ being the volumetric soil water content, [cm^{-1}];
- K Hydraulic conductivity of soil, [cm/day];
- S Water uptake by roots (sink term considered positive from the soil to the roots), [day^{-1}]. The integral of this sink term (S), over the rooting depth L_r, gives the actual transpiration, E_{pl}
- z Vertical distance, positive downwards, [cm]; and
- t Time, [days].

$$E_{pl} = \int_{z=0}^{z=L_r} S\,dz \tag{2}$$

and

$$E_{pl} = E - E_s \tag{3}$$

where E is the actual evaporation from soil and transpiration by plants, and E_s is the bare soil actual evaporation.

Two factors control the rate at which water is returned from the soil to the atmosphere by evapotranspiration E (evaporation from soil and transpiration by plants): atmospheric demand and soil-water availability. If soil water at the surface or in the root zone is not limited then, E^*, defined as the potential evapotranspiration, is equal to the potential rate as determined by air temperature, wind speed, relative humidity, solar radiation and other meteorological conditions.

Since in our research only biological drainage is considered, the evaporation from bare soil (E_s) is negligible and the whole area is cultivated with plants.

Therefore, the actual evapotranspiration and the actual transpiration by plants are equal and the two terms could be used interchangeably.

Assumptions

For the formulation of the equation and its solution procedure, the following assumptions are made:

1. One-dimensional vertical flow in the vadose zone,
2. Soil is homogeneous and isotropic,
3. Only desorption curve is considered in $K(\psi)$ and $\psi(\theta)$ (relationships (*i.e.,* no hysteresis),
4. Pneumatic potential is neglected ($\psi_{gas} = 0$):
   – Water flow through very dry soils can be satisfactory described by Darcy's law, considering liquid flow only.
   – Soil evaporation can be calculated as a Darcian flux into the atmosphere, where the soil matric potential head at soil surface ψ is in equilibrium with the humidity of the surrounding atmosphere.
5. Effect of salinity of the soil water on water flow is neglected,
6. Crop is supposed optimally supplied with nutrients, and
7. Flow of water from roots into soil is neglected.

Initial and Boundary Conditions

As initial condition for the SWATR model, one has to prescribe for each nodal point either the water content or the suction. For the boundary conditions, the case is that of a soil profile with a shallow groundwater level fluctuating with time. The processes in the vadose zone are governed both by the meteorological conditions at the soil surface and the conditions in the groundwater zone of the soil. Here one has a mixed type of boundary conditions: Specification of the dependent variable, *e.g.,* the groundwater level where the pressure head is zero at the bottom and specification of the flow through the boundaries at the soil surface, *e.g.,* the precipitation and the actual evapotranspiration as determined by the meteorological conditions and the water availability. The input and output of the SWATR program is summarized in Fig. 1.

The FMAQ Model

The FMAQ model (El-Didy and Contractor, 1986) is a two-dimensional finite element model, which has been developed for the simulation of water flow in a multi-aquifer system consisting of a number of aquifers separated by aquitards. Two-dimensional (x, y) flow is assumed to occur in the aquifers, with one-dimensional vertical flow occurring through the aquitards without any storage effect. The transient groundwater equation for horizontal flow in a single aquifer is expanded to include terms representing its interaction with adjacent aquifers. This equation is solved numerically using the finite element theory and the Galerkin weighted-residual method. The output of this program gives the piezometric head and velocity components at each node in all aquifers.

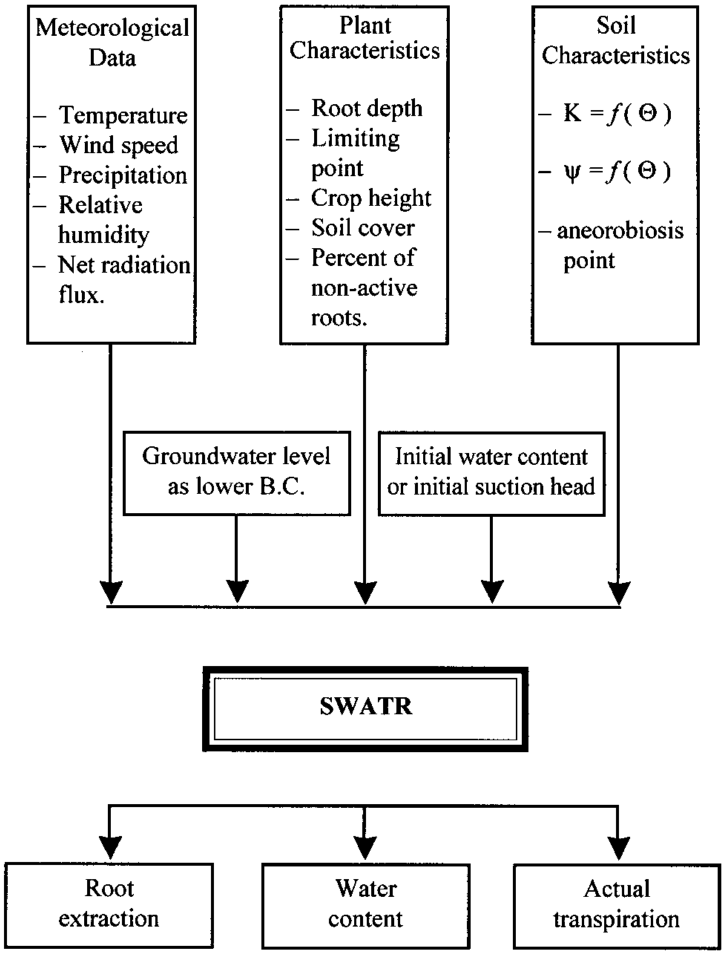

FIG. 1. Input-output description for the SWATR model.

The governing differential Equation (4) for two-dimensional groundwater flow in a non homogeneous, anisotropic, with point and distributed sources or sinks is:

$$\frac{\partial}{\partial x}\left(K_{xx}\cdot B\cdot\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\cdot B\cdot\frac{\partial h}{\partial y}\right)+r_c=S_t\cdot\frac{\partial h}{\partial t} \quad (4)$$

Where:

h = $h(x, y, \mathrm{t})$ = depth-averaged piezometric head, [L];

K_{xx} = $K_{xx}(x, y)$ = aquifer conductivity in the x-direction,[L/T];

K_{yy} = $K_{yy}(x, y)$ = aquifer conductivity in the y-direction,[L/T];

B = $B(x, y)$ = saturated thickness;

r_c = $r_c(x, y, t)$ = distributed flux of water due to evapotranspiration or due to recharge,[L/T] ;

S_t = $S_t(x, y)$ = aquifer storage coefficient,[L^0];

x, y = Cartesian coordinates (principal axes of the hydraulic conductivity/transmissivity tensor), [L];and

t = time,[T].

Assumptions

For this simulation, the following assumptions are made:

1 – Water is considered to be a homogeneous fluid with constant density,
2 – Darcy's law is applicable,
3 – The Depuit approximation is assumed valid; therefore the flow is essentially horizontal in each aquifer,
4 – The aquifer storage is attributable only to specific yield if phreatic, or to storativity, if confined,
5 – The off-diagonal terms of the conductivity tensor, $K_{xy} = K_{yx} = 0$ (x and y are principal axes) for all aquifers, and
6 – The aquitard storage coefficient is neglected, since its effect is generally short lived and the concern is for long term effects.

Initial and Boundary Conditions

For transient flow problems, Equation (4) requires an initial condition, which is the specified piezometric head over the entire domain. Two types of boundary conditions for Equation (4) are considered. The first type requires the piezometric head prescription as

$$h = h_q\,(x, y, t) \tag{5}$$

The second type of boundary condition is prescription of the water flux q_s, across the aquifer boundary.

$$\left(K_x \cdot B\frac{\partial h}{\partial x} \cdot n_{-x} + K_y \cdot B\frac{\partial h}{\partial y} \cdot n_{-y} \right) = q_s(x,y,t) \tag{6}$$

Where n_x and n_y are the x and y components of the unit inward-pointing normal vector n on the boundary. The input and output of the FMAQ program is summarized in Fig. 2.

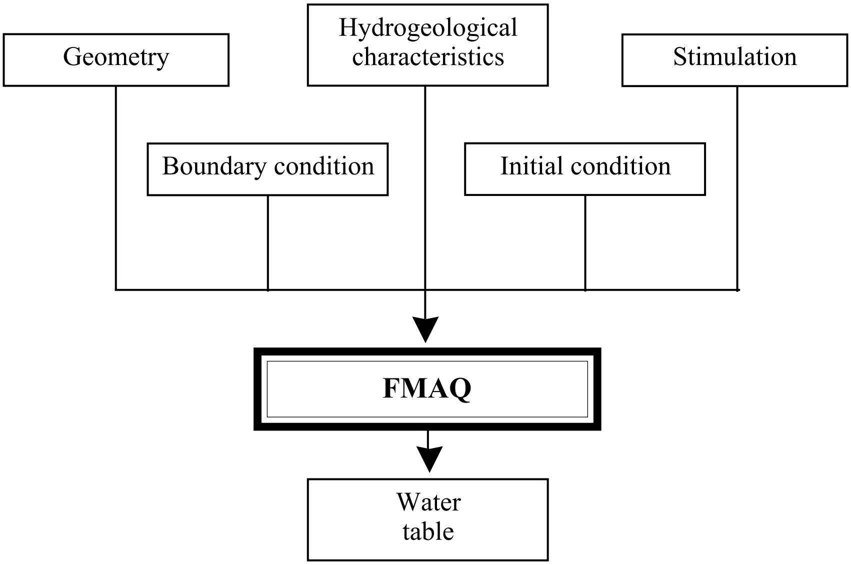

FIG. 2. Input/output description for the FMAQ model.

The Interface between the Two Models

As was previously mentioned, the SWATR program needs as an input the *a-priori* prescribed groundwater level as the lower boundary condition for the unsaturated zone, which prevents the estimation of the drop in water level due to biological drainage. On the other hand, the FMAQ program requires the distributed flux of water r_c as the excitation to compute the new water level. It is assumed that the actual evapotranspiration is equal to this distributed intake from groundwater table. This is true if no change of storage is considered in the vadose zone in each time increment. Therefore, an interaction is needed between the two programs since both depend on each other in a non-linear manner. For this an effective procedure for the transfer of parameters such as the water content in the unsaturated zone, the groundwater level, ... was implemented between the two codes. Thus, to determine the groundwater level drop due to evapotranspiration, the following steps are carried out:

- The study area is discretized into small elements. Cultivated areas (dashed elements) are identified. Actual evapotranspiration will be calculated as negative vertical recharge on each element. For each element, the iteration described in Fig. 3 is carried out for the four corner nodes as presented in Fig. 4.

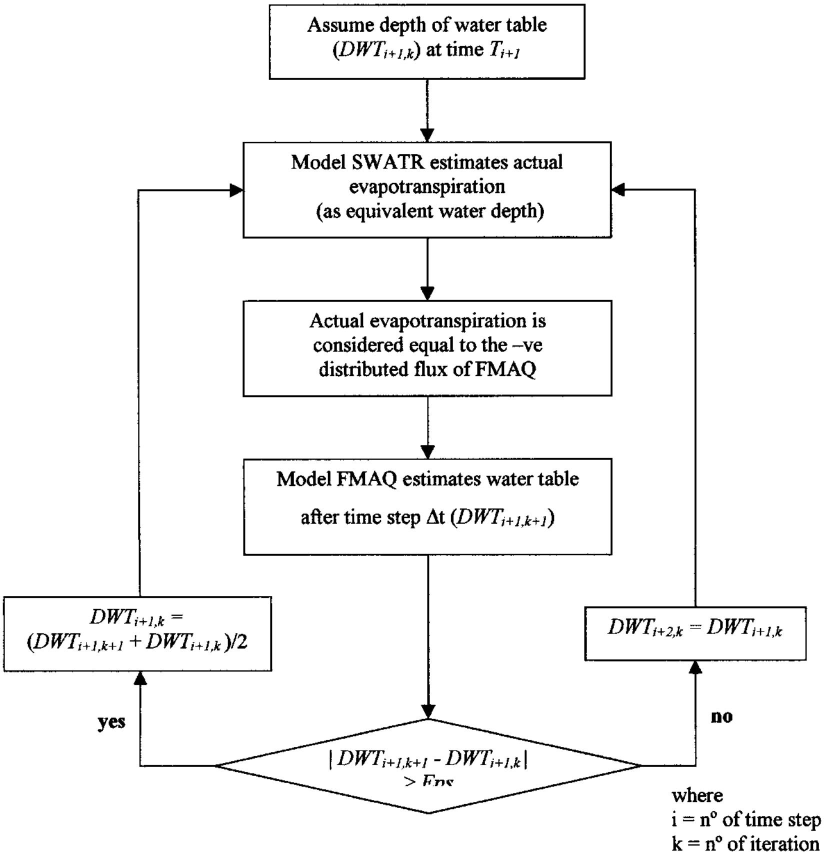

FIG. 3. Flow chart of the suggested numerical interactive link between SWATR and FMAQ.

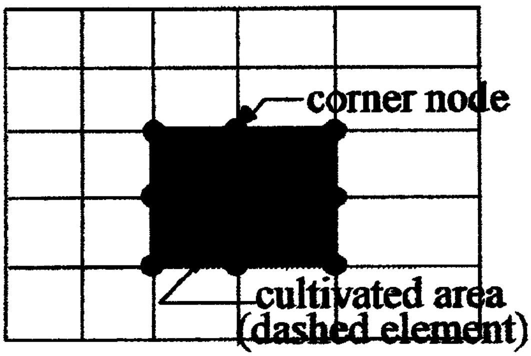

FIG. 4. Area discretization.

- Assume the groundwater level after time increment ΔT for this first iteration to be the original $DWT(i, k)$; *i.e.,* let $DWT(i + 1, k) = DWT(i, k)$, where i is the time step and k is the iteration number.
- Run SWATR once for each corner node of the cultivated (gray) elements (Fig. 4). SWATR is to be run for a time period ΔT with initial depth of groundwater level $DWT(i, k)$ and a final depth equal to $DWT(i + 1, k)$. SWATR's output is the actual evapotranspiration at the nodes in $[LT^{-1}]$ units.
- For each element, the algebraic mean of evapotranspiration at the four corner nodes (in adjacent elements) is the distributed flux of water from the element due to evapotranspiration (negative recharge).
- FMAQ is, then, run for the whole area having the negative recharge of evapotranspiration equal to the negative distributed flux of water, which is the only load on the system with a time increment ΔT and an initial groundwater level depth equal $DWT(i, k)$.
- The output of FMAQ is the new depth of the groundwater level after the time increment and equal to $DWT(i + 1, k + 1)$.
- $DWT(i + 1, k + 1)$ is compared to $DWT(i + 1, k)$.
- If $| DWT(i + 1, k + 1) - DWT(i +1, k) | = \varepsilon$ which determines the acceptable accuracy), then the assumption of $DWT(i + 1, k)$ is correct and $DWT(i + 2, k)$ is calculated similarly. It should be noted that when a new value of DWT is assigned, the following changes are introduced:
  - A new discretization of the vadose zone is made due to the fact that the groundwater level depth is the boundary of this zone.
  - New values of soil moisture content are assigned with a new time step, while soil moisture content values remain unchanged within the same time step.

Capabilities and Limitations of the Proposed Model

The proposed model can handle

- *Various soil types with two-layer soil profile in the vadose zones;*
- *Different types of vegetations,* the user specifies plant characteristics (*e.g.,* root depth, limiting point, crop height, soil cover fraction and non-active percentage);
- *Daily input of meteorological data,* in order to calculate potential evapotranspiration and soil potential evapotranspiration (*e.g.,* temperature, wind speed, precipitation, relative humidity and net radiation flux);
- *Shallow level of groundwater,* described in depth in the previous sections; and
- *Presence of wells, canals and ditches*.

On the other hand, the model can not handle:

1 – *Daily variation in meteorological data,* because the SWATR program offers only the opportunity for *one* 24-hour input of (mean) climatological data.
2 – *Vapor displacement inside soil* ($\psi_{gas\ is\ not\ zero}$): The liquid flow from the soil profile into the atmosphere is calculated with Darcy's Law. Thus, it is not taking into consideration, in the topsoil, of a liquid-vapor interface.
3 – *Osmotic potential gradients:* In saline soils, soil water does not have the same physical properties as in non-saline soils; *e.g.* density, viscosity and surface tension between air and water will be different in saline soil water. This problem is not considered.

Parametric Study of the Proposed Model

The second objective of this paper is to make a parametric study of factors affecting actual evapotranspiration. This sensitivity analysis is applied to evaluate the relative importance of almost all parameters and boundary conditions on the output of the model. In this study, the red cabbage on sticky clay case (as presented by Feddes, 1971) is taken as reference case, and input parameters are varied one at a time. This reference case is described later in detail in the next sections.

Assumptions of Parametric Study

For our numerical experiments, some values and empirical relations are kept the same as in the reference case described in the next section. These are:

1 – Initial Depth of the Groundwater

Since it is not possible to change, in the same time, both the initial depth of the groundwater and other plant and weather conditions, the initial depth of the groundwater was chosen to be at 100 cm below ground surface in all numerical experiments, to take advantage of the capabilities of the suggested numerical link previously described.

2 - Plant Characteristics

Because of lack of data on specific crops and their characteristics, it is assumed that the soil cover is 85% and that the crop height is 42 cm. Both of these factors influence the potential evapotranspiration. The empirical relations governing the potential evapotranspiration were kept constant in all our numerical experiments. These relations are:

- The leaf area index as a function of soil cover (Feddes, 1971);
- The aerodynamic resistance of a crop as a function of crop height (Rijtema, 1965); and

❍ The flux of intercepted precipitation as a function of precipitation rate (Rijtema, 1965).

3 – Properties of the Groundwater Zone

In our numerical experiments, no change was made to the properties of the groundwater zone.

The Reference Case: Red Cabbage on Sticky Clay

The input parameters describing the red cabbage case are as follows:

1 – Plant Characteristics

- Sink term description is shown in Fig. 5.
- Root depth = 90 cm.

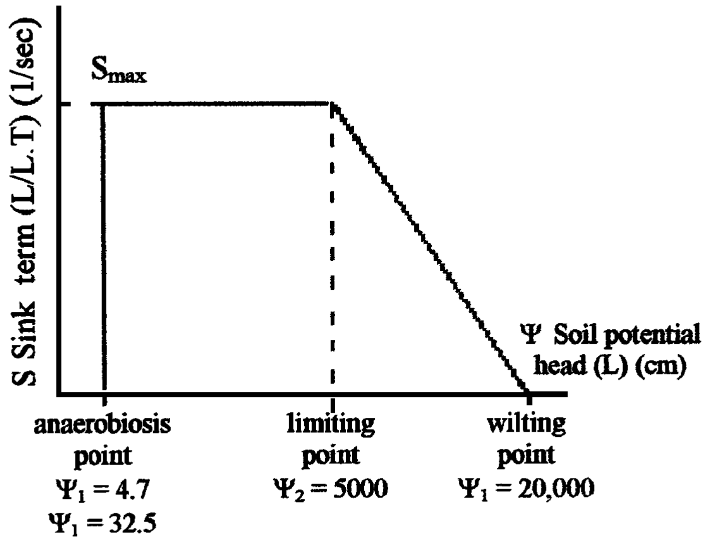

FIG. 5. Sink term description for reference case study (after Feddes *et al.,* 1978).

2 – Meteorological Data

- Tmperature = 25°C
- Wind speed = 3 m/s
- Precipitation rate = 0.0 mm/day

3 – Soil Characteristics

- Upper layer: 42.5 cm of light clay (1.125 gm/cm^3);
- Lower layer: 57.5 cm of dense clay (1.35 gm/cm^3);

- The soil moisture characteristics curve ($\psi = \theta$ relation) was taken from measurements done by Feddes (1971);
- The unsaturated hydraulic conductivity relation for clay is taken as well from the previously mentioned reference; and
- Initial water contents (after Bower, 1988).

Plan of Parametric Study

In the parametric study, the following inputs were changed one at a time with respect to the red cabbage reference case:

- Sink term description,
- Root depth,
- Average daily temperature,
- Precipitation rate at the 4th day of the 7-day time period simulation,
- Wind speed at 2 m from ground surface, and
- Soil type in the vadose zone.

The variation of the actual transpiration against the previous parameters are studied as well as the effect of the variation of each of these parameters on the soil water content and the water uptake by roots.

Conclusions of the Parametric Study

Several conclusions can be drawn out of this parametric study:

1 – Change in anaerobiosis point (ψ_1), for different types of soil, in the upper layer makes no change at all in the system since the range of pressure head ψ is far from the anaerobiosis point in this region, while a small change in anaerobiosis point of the lower layer has the largest effect on cumulative transpiration: the highest cumulative transpiration is obtained at the lowest value of anaerobiosis point = 4.7 cm. Increasing the value of ψ_1 to 40 cm yields to a strong reduction in cumulative transpiration. This is particularly true for the case of shallow groundwater.

2– The effect of changes in limiting point, ψ_2, seems to be of less importance, for root depths of 30, 60, 90 and 120 cm, with groundwater level initially at 100 cm from ground surface.

3 – Changing the wilting point, ψ_3, from 20,000 cm to 15,000 cm yields a bigger decrease in cumulative transpiration. The percentage of decrease is up to 20% in the case of 30 cm root depth. This is particularly true for the case of zero rainfall.

4 – Since it is required to biologically drain a groundwater, that is 100 cm below ground surface, the ideal plant should have a root depth of 90 cm to 100 cm. It is the root depth that gives the maximum transpiration (Fig. 6). It would be also of interest to define the optimum groundwater table that maximizes the transpiration for a fixed root depth, but this will be dealt with in further studies.

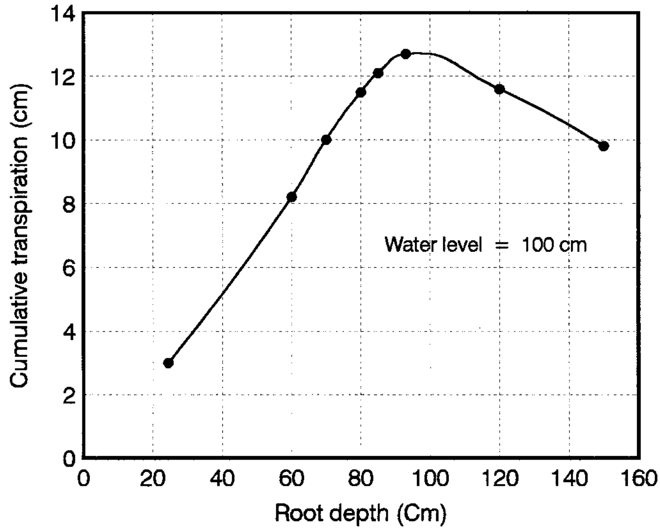

FIG. 6. Overall transpiration after 28 days versus root depths.

5 – For a groundwater level at 100 cm from ground surface in a clayey soil, plants of root depth = 60 cm do not need irrigation, since they are capable of extracting water from the groundwater below for as long as 20 days, even for high temperatures (25°C) or high wind speeds (3m/sec) (Fig. 7). These results could be useful in irrigation scheduling. Nevertheless, it should be remembered that no salt movement was considered in this model.

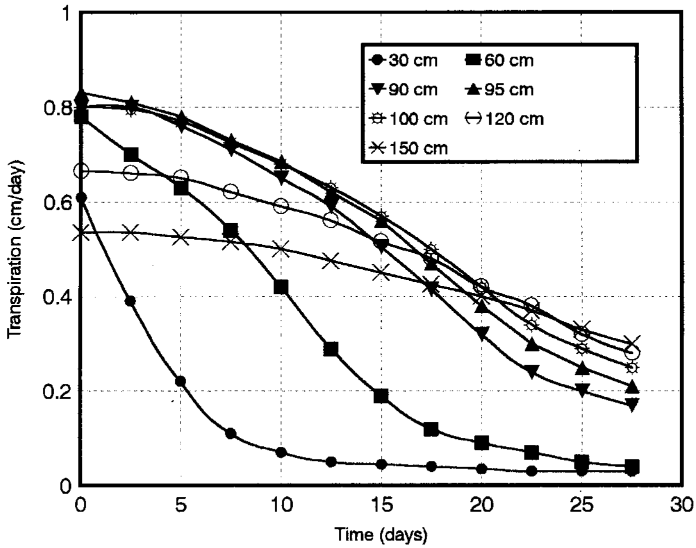

FIG. 7. Transpiration versus time for different root depths.

6 – For root depth of 90 cm and no precipitation condition, the overall actual transpiration increases with the increase of temperature (Fig. 8) or wind speed (Fig. 9.) This increase is not linear and tends to stabilize due to the lack of moisture in the vadose zone.

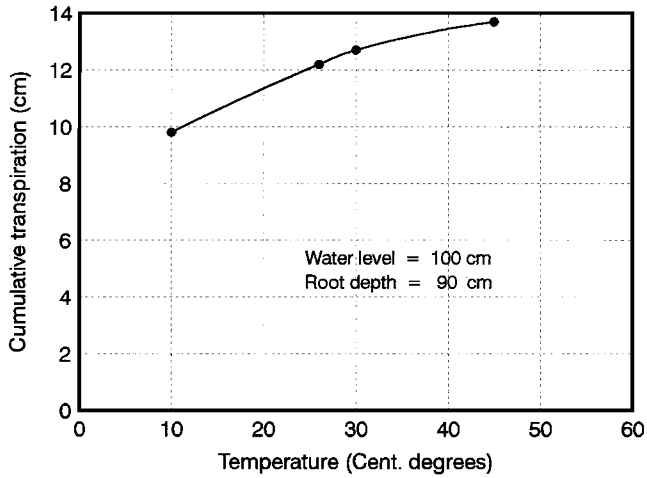

FIG. 8. Overall transpiration after 28 days versus temperature degree.

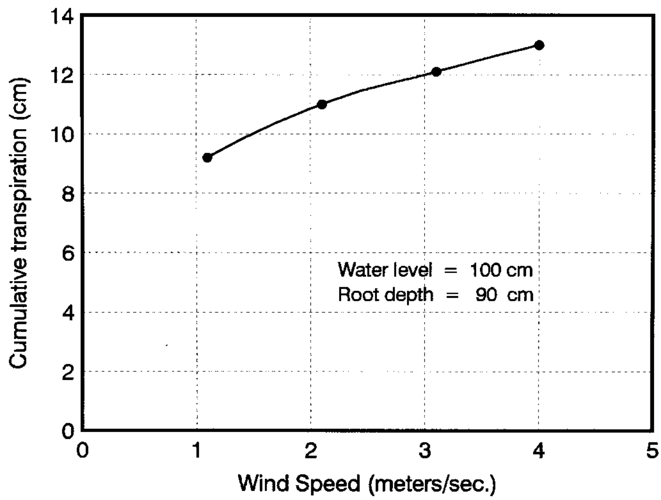

FIG. 9. Overall transpiration after 28 days versus wind speed.

7 – The overall increase in actual transpiration doesn't exceed 0.4%. Thus small values of precipitation have a small effect on water uptake by roots. No change in overall actual transpiration was noticed until the value of pre-

cipitation reaches 5mm/day. After this value, the increase is exponential, although it is very small (Fig. 10).

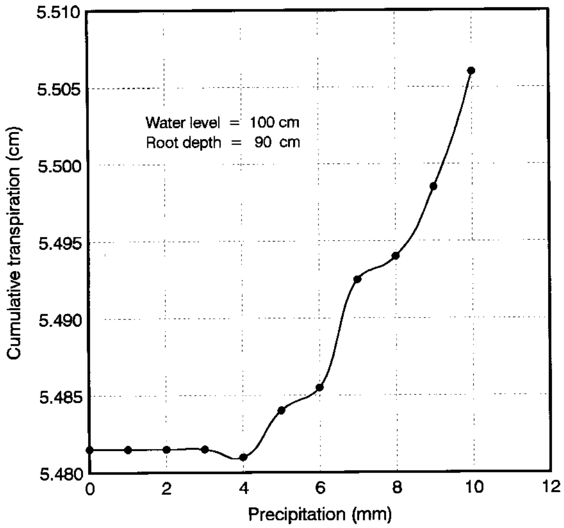

FIG. 10. Overall transpiration versus precipitation.

8 – For what concerns changing the soil type in the parametric studies, overall transpiration after 7 days gives misleading results: It shows that sand gives the second biggest value after clay. This is true only for short time periods, due to high conductivity of sand as was shown (Fig. 11a). From Fig. 11(b), one can notice that overall transpiration after 28 days decreases in the following order: clay, silt, and finally sand.

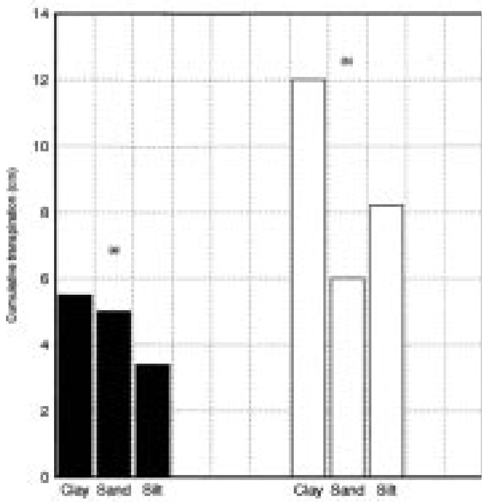

FIG. 11. Overall transpiration for different types of soil: a) After 7 days, b) After 28 days.

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