American-Eurasian J. Agric. & Environ. Sci., 3 (6): 906-916, 2008
ISSN 1818-6769

Solar Storage Wall and Soil Mulching Effect on Squash Production Inside Polyethylene Greenhouse under the Climate of Egypt

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Abstract: Investigations were carried out to overcome the drop in the greenhouse air-temperature within the cold nights of winter season. Two different available and cheap materials of adobe and red brick were used as an auxiliary solar passive wall. The greenhouse which was comprised adobe solar storage wall (ASSW) and that used red brick (RBSSW) were compared with a control trial greenhouse without storage walls. At the meantime, the control trial greenhouse was compared with an open field trial. Soil covers were applied to study the effect of mulching beside the solar wall presence on squash crop growth. This crop selected because it belongs to cucurbitaceae family, which is sensitive to low temperature, during the coldest night of winter. Horse bean straw of 5cm thick, black plastic mulch of 0.1mm thick were compared with the uncovered soil. It was found that, the greenhouse which had interior storage walls achieved faster and intensive seed germination ratio, plant growth, number of flowers, dry weight and total crop yield, as compared with the control greenhouse.

Key words: Solar passive heat storage walls · Polyethylene and straw mulching covers

INTRODUCTION

The suitable growing conditions for the vegetable crops inside the greenhouse should be controlled. Air temperature inside the plastic covered-greenhouses is affected by the outside weather conditions i.e., incident solar radiation, ambient air temperature and relative humidity and wind speed [1].

The prototype of a solar storage wall was constructed in 1974 in the French Pyrenees [2]. McDaniels [3]described passive solar approach uses a large, massive wall for thermal storage. The design principle is a south facing vertical concrete wall, which is painted black and covered with a sheet of glass.

The thermal storage was found enhancing the natural convection inside the greenhouse, resulting in a continuous heat removal from the thermal wall by greenhouse air at night times [4, 5].

Hassanain and Hokam [6]found that, the greenhouse with the passive wall gave higher greenhouse air temperature as compared with that without walls for the same greenhouse.

The main function of the wall is its ability to store solar energy during the daylight and emit this energy at night. During the daylight the wall is considered as an endothermic body and during the night then the room air temperature drops, the wall body is considered as an exothermic body [7].

The performance of the wall is affected by many factors such as: wall thickness and media used for heat storage [8]. The optimum structural thickness of the solar passive heated dwelling building were found as 37 cm for brick and 35-40 cm for law concrete walls, 40-45 cm for high concrete walls according to Fang and Li [9].

Singh and Tiwari [10] found that a significant effect of the thermal storage (north) wall and the ground air collector occurred on the plant and room air temperatures.

For asymmetric greenhouse, a non transparent, high reflecting wall was more profitable than a transparent wall, whereas there was no difference for symmetric greenhouses [11, 12].

Soil covers and mulching: Candido and Miccolis [13] reported that mulching affect the soil temperature, reducing evaporative humidity, good weed control, earliness effects on yield with better qualitative-quantitative trait

Mulch helps to achieve higher soil temperatures as compared with the uncovered ridges [14]. Soil temperatures influences many factors such as seed

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germination, plant growth, nutrient availability, insect populations and pesticide degradation [15].

Organic mulches: Organic material such as trees leaves, straw, crop residue and peat moss were used as soil mulches. Organic mulch achieves advantages such as reduces the soil water losses, eliminates the high temperature during the hottest summer time, keeping soil warm during winter season, reduce the soil corrosion by heavy rains and reduce the weeds growth. Peat moss of 2-5 cm thick of crop residue are added to the plant rows and around the plants [16]. Straw mulch reduces water evaporation and temperature surface soil, increase soil organic content and improves soil quality [17].

Straw mulch was used to grow organic potato seeds showed a reduction of virus attack on the crops [18]. Straw mulch is effective in improving soil physical conditions if it was used as organic amendment to the soil surface in tropical environments including protection of the topsoil [19].

Plastic mulches: The plastic mulch effect on the microclimate of plastic greenhouse cultivated by cucumber were studied by Salman *et al.* [20]. The black and clear mulches were used in an unheated plastic greenhouse on sandy soil and compared with the soil left bare (control). Soil temperature was found higher under the clear polyethylene mulch and lowest for bare soil. In cucumber, vegetative growth e.g. plants height, leaves number and its surface area was increased by both types of mulch, as compared with controls. The total cucumber yield was increased by mulching for clear polyethylene and black polyethylene as compared with bare soil.

Cebula [21] found that, mulching also favorably affected the marketable quality of the fruits and the earliness. Hu *et al* [22]found that, mulch prevents soil water evaporation and thus helps retain soil moisture. Polythene and straw mulch treatments increased the pod and stover yields of groundnut significantly over chemical and unmulched treatments in both the seasons.

Four surface covering materials of 5 cm thick rice straw, a silver plastic film, a black plastic film and a clear plastic film were compared with bare ground as a control by Awal and Ikeda [23]. They found that, The enhancement of cumulative emergence by increasing soil temperature was reflected in the rate of seedling emergence. The rate of seedling emergence significantly increased with increasing soil temperature and the emergence rates were positive linear functions of the soil temperatures the temperature increased rapidly in soil covered by clear film.

The plastic cover affected the plant growth by decreasing days from planting to emergence and the maturity of many vegetable crops including tomato and cucumber. Also, it increased the total yield and the marketable yield over no plastic mulch [24].

Perez-Diaz *et al.* [25] found that, dark mulches (black, red and gray) had higher soil warming ability than light colored mulches. Tomato plants root zone temperature under colored mulches significantly influenced the plants growth greater than those of the un-mulched soil.

The plastic mulch over trickle irrigation systems was used to save water for strawberry culture, control weeds with less use of herbicides, enhances earliness fruit, keep it clean and increase the fruit size and yield [26]. Ramakrishna *et al.* [27] found that, the polyethylene mulch increased the soil temperature. Groundnut plants in polyethylene and straw-mulched plots were generally tall, vigorous and reached early flowering.

In previous work, effect of the storage wall presence on the soil depth temperature, interior air temperature comparing with the outside air temperature and the solar storage wall efficiency were addressed. In this paper: Effect of the solar storage walls beside the soil mulch on the different plant stages for squash production are investigated.

MATERIALS AND METHODS

Experimental Set-up: Experiments were carried out at the Experimental Farm, Faculty of Agriculture Suez Canal University, Ismailia, Egypt (latitude of 30.62°, longitude 32.27° and 5m above sea level) through the period from 28th November 2004 till April 2005 in order to investigate the effect of using solar storage wall as a passive energy system beside the soil cover on the squash production inside the polyethelene green house. A transparent polyethylene sheet of 0.2 mm thick was used as greenhouse covering sheet. Three identical gable uneven-span plastic greenhouses were constructed of galvanized pipes (25.4 mm diameter). The plane dimensions of each greenhouse were 4 m long and 3 m wide (area of $12m^2$); The northern greenhouse side was 2 m high as shown in Figure (1), while the southern side is 1.1m high. The gable roof has two different rafters, the southern rafter was tilted at 47° with rafter of 2.2 m and the northern rafter tilted at 30° with rafter length of 1.73 m.

The southern rafter was tilted at 47° to maximize the solar radiation flux incident. This tilt angle represented the average optimum tilt angle at noon for fixed surface (stationary non-tracking). It was computated from the following equation [28].

β_0 (at noon) = latitude angle (φ) - declination angle (δ) (1)

The greenhouses were orientated toward the East-West direction, where the southern longitudinal direction faced into the sun rays [29]. The greenhouse door was located in the Eastern side due, to the wind direction blowing from the western direction within the experimental duration time (November to March). Two greenhouses were including solar storage wall (SSW) for auxiliary heating. Meanwhile, the third greenhouse was used as a control trial without solar storage.

A double door was constructed to avoid the air draft, the first door open on a reverse direction to the second one. Advantage of double door is reducing heat losses during reading of data.

Greenhouses and the open field (that was used as a control trial) were divided into three ridges 3 m long and 0.9 m wide. Each ridge was used as treatment; the soil was covered with black polyethylene (mulch) 0.1 mm thick in the first treatment [24]. The second treatment was uncovered soil and the third treatment the soil was covered with organic material (Horse bean straw) of 5 cm thick.

Solar storage wall: Two storage walls were built from red and adobe bricks. The bricks had the same dimensions of 0.23 m long, 0.12 m wide and 0.06 m thick. The storage wall that was built with red bricks (fire clay bricks), was cemented by a mixture of sand and cement (3: 1). The solar storage walls gross dimensions were 4.0 m long, 2.0 m high and 0.23 m thick this thickness was selected according to equation (12). The solar storage wall (SSW) internal surface was painted with a matt black paint with 0.93 absorptivity [30]. To prevent the heat losses by convection and radiation to the surrounding the external wall surfaces were insulated by 30 mm thick Styrofoam layers. The function of the insulation material was to keep and capture the heat inside the storage wall and to minimize heat losses. Three centimeters Styrofoam insulation l ayer with thermal conductivity of 0.03 $Wm^{-1}{}^{o}C^{-1}$ was used to insulate the northern side of solar storage wall [31].

Environmental conditions for the experimental site: Average weather conditions for the squash stages are given for the different plant stages for the investigation site in the following table. Weather conditions throughout the experiments period were averaged for the experimental site. Average air temperature was 14.2°C, average relative humidity was 67.6 % and the average solar radiation within the daytime was 451.1 Wm^{-2}. Average weather

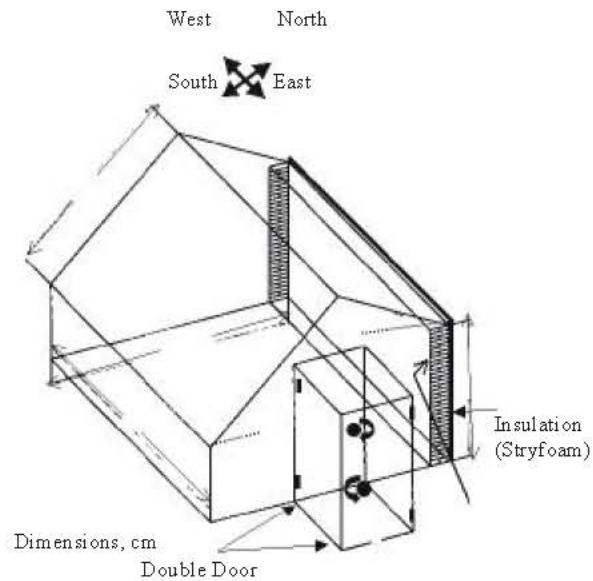

Fig. 1: Schematic diagram for gable uneven-span greenhouse with SSW

conditions are given in Table (2) for the plant stages beginning with the planting date.

Mechanical analysis was conducted on the soil and adobe brick according to the international pipette method [32] to determine the soil structures that is presented in Table (2) side by side with the fraction of the adobe solar storage wall (ASSW). The experimental soil was sandy soil.

Cattle manure of 15 m^3 per feddan (4200m^2) was added during the preparation of root media inside the experimental greenhouses and in open field, this quantity is the recommended for squash, *Cucurbita pepo L.* [33]. Experimental greenhouses and the open field trails plants were irrigated using the farm drip irrigation system. Each treatment consisted of two laterals on two ridge sides. Each lateral included 5 emitters, the emitters were distributed at 0.5 m apart, beside each emitter a hill was found. The treatments include 10 emitters and 10 hills. Nile squash Seeds variety were sown in the soil after irrigation on 28th November 2004 due to the squash crop following to cucurbitaceae family, this family sensitive to the temperature, reduction especially during the coldest night of winter time. Three seeds were drilled in each hill at 0.5 m apart and seedlings were on two sides of ridge then thinned out after 14 days from the planting date, leaving only the strongest one or two plants per hill [33]. Irrigation was applied for the all treatment under greenhouses and open field. The trial soil either indoors under the greenhouses or outdoors

Table 1: Average weather conditions for squash plant stages

Stage and Periods	Day length (hr) from Sunrise to Sunset (local time)	Ambient air temperature, °C	Wind speed, ms^{-1}	Solar radiation intensity, Wm^{-2}	Relative humidity, %
Germination (After 12 days)	10:19 (6:36 am till 4:55 pm)	14.8	0.9	496.7	74.0
Vegetation (22 days)	10:16 (6:42 am till 4:58 pm)	13.8	1.1	407.5	71.0
Flowering (13 days)	10:17 (6:44 am till 5:01 pm)	12.5	0.7	327.6	74.9
Fruit (32 days)	10:27 (6:43 am till 5:10 pm)	14.6	1.2	393.3	59.2

Table 2: The experimental soil and the adobe wall structures (ASSW)

	Soil structure %					
Soil	Coarse sand	Fine sand	Total	Silt	Clay	Texture grade
Greenhouse soil	68.93	26.04	95.97	3.81	1.22	Sandy
Adobe brick	27.45	39.55	67.00	12.7	20.3	Sandy clay loam

in the open field trial was kept at 0.5 or (50 %) from the field capacity (*F.C.*) according to Hassanain and Hokam [6] so, the irrigation water was added to maintain the soil at 50 % from its field capacity. The field capacity was determined using the following formula [34]:

$$F.C. = \frac{(M.E.-2.62)}{0.863} \quad (2)$$

Where, *M.E.*, the Moisture Equivalent and it can be approximately calculated from the soil fractions according to [35] as:

$$M.E. = 0.555A + 0.16B + 0.06C \quad (3)$$

Where, "*A*" is the percentage of clay in the soil fraction plus the percentage of the organic matter, "*B*", the percentage of Silt plus the calcium carbonates and "*C*" the sand percentage.

The nitrogen fertilizer in the form of ammonium sulphate (20.5 % N) was directly added to the soil in three equal dozes according to [33], the first one at planting, the second doze was added after 30 days from planting and the third one was added during the plant flowering stage.

Sulpher powder was added according to Hassan [36] to the plant leaves to avoid the fungal growth in three times within the plant growth stage (the second plants stage) as follows:

- First dose was added on the 17th December, 2004 i.e. after 20 days from planting date.
- Second dose was added on the 27th December, 2004 i.e. after 30 days from planting date.
- Third dose was added on the 3rd January, 2005 i.e. after 37 days from the planting date

Methodology

Incident radiation and the greenhouse covering sheet transmitivity determination: Mono Crestline solar cell with dimensions of 75 mm by 75 mm, has voltage of 0.5 volt and current of 800 m Ampere was used to determine the global radiation. The cell was connected to AVO-meter to determine the incident solar radiation. A previously calibration was carried out on the measuring device against Aply Pyranometer. The transmitivity of the greenhouse covering sheet depends upon the incidence angle of the solar radiation and number of covers. Investigations were carried out to determine the transmittance of the greenhouse polyethylene covering sheet used in the investigation. The greenhouse aperture, which faced to Southern direction was divided into cells to determine the covering sheet transmitivity, 300 readings were measured inside and outside the greenhouse for each cell at the same time the covering sheet transmitivity was determine using the following relationship:

$$\tau = \frac{\text{Transmitted radiation inside the greenhouse}}{\text{Incident radiation measured out side the cover material}} \text{x}100 \quad (4)$$

The transmitivity (τ) of the used covering sheet was found 89 % from the incident solar radiation.

Squash (*Cucurbita Pepo L*) seeds vitality: Four indoors replicates were carried out to determine the squash seeds vitality under the lab conditions. Each replicates was

included 10 seeds that were put in flat Petri- dishes. It was wetted by a piece of cotton and left at the lab ambient air of 13.7 °C average temperature. The average seeds vitality after 8 days from the beginning of the vitality trail was as 90 % (averages of 100, 90, 80, 90 and 90% respectively).

Determination of the Squash crop yield: The effect of microclimatic conditions inside the greenhouses on the four growth stages (i.e. germination, vegetation, flowering and fruit yield was investigated). Plant length was measured every 7 days from 16 days of planting date. Flowering measurement were taken every day through out this stage (from the begging flower appearance). Squash crop yield were collected through the period of fruit stage from 15/1/2005 to 2/3/2005. Fruits were picked at three days intervals staring from day number 49 from planting date. The fruits were picked up at accepted size for the local Egyptian customer average length and diameter of 12.6 and 3.1 cm (average standard deviation of 1.11 and 0.46, respectively) and average weight of 75 grams. The total crop in kg/Feddan was estimated for each treatment.

Wall-thickness determination: The gray soils reflectivity (i.e. the sandy- loam solar wall) is ranged from 0.15 to 0.25 according to Brutsaert [37]. The absorbed radiation will heat up the storage wall by two-dimension unsteady state conduction as well as the soil. The following assumptions were considered for solar wall evaluation as a heat storage and its performance:

- The physical properties of the greenhouse soil layers remains constant for the duration of the study.
- Heat distribution in the soil is symmetrical along the greenhouse.
- The thermal admittance denotes by (U) is a factor that, express the wall ability to absorb and store heat duration one part of a cycle and then release the absorbed heat back through the same surface during the second part of the cycle, it is given as [7]:

$$U = \Delta Q / \Delta T_w \tag{5}$$

Where, (U) is the thermal admittance ($Wm^{-2}\,°C^{-1}$), Q is the stored heat per the unit of wall area (Wm^{-2}) and ΔT_w is the magnitude of the average storage wall temperature (°C) and it's given for thickness wall as:

$$\frac{\Delta Q}{\Delta T_w} = \sqrt{\frac{2\,\pi\,k\,\rho c_p}{t}} \tag{6}$$

Where, k, ρ, c_p are the thermal conductivity of the storage wall-material ($Wm^{-1}{}^{\circ}C^{-1}$), density (kgm^{-3}), specific heat ($Jkg^{-1}{}^{\circ}C^{-1}$) and time (hours), respectively.

There is an optimum wall thickness (L), according to Taha [7], which was denoted by Balcomb [38] as:

$$L = 1.18\sqrt{\frac{tk}{\pi\rho c_p}} \tag{7}$$

From equation (6), solar wall will release its stored heat within time (t) that can be given as:

$$t = \left[(2\pi k\rho c_p)^{0.5}\frac{\Delta T_w}{\Delta Q}\right]^2 \tag{8}$$

$$t = (2\pi k\rho c_p)\left[\frac{\Delta T_w}{\Delta Q}\right]^2 \tag{9}$$

Substituting (t) from equation (9) in equation (7) to find out the optimum thickness for the given wall [6]:-

$$L = 1.18\left[2\pi k\rho c_p\left(\frac{\Delta T_w}{\Delta Q}\right)^2\left(\frac{k}{\pi\rho c_p}\right)\right]^{0.5} \tag{10}$$

$$L = 1.18\left[1.41k\left(\frac{\Delta T_w}{\Delta Q}\right)\right] \tag{11}$$

$$L = 1.67k\left(\frac{\Delta T_w}{\Delta Q}\right) \tag{12}$$

RESULTS AND DISCUSSION

Effect of solar wall and soil covering type on the field germination ratio: Germinated seeds were counted every day through the germination stage (after planting). The variation between different greenhouses with different solar walls and open field are shown in Figure (2) and presented in Table (3). In general, seeds

Table 3: Effect of the soil covering treatments and solar storage wall on the field germination ratio, %

	Open field			Greenhouse without SSW			Greenhouse with ASSW			Greenhouse with RBSSW		
Time from planting date (day)	Uncovered soil	Covered soil with plastic	Covered soil with straw	Uncovered soil	Covered soil with plastic	Covered soil with straw	Uncovered soil	Covered soil with plastic	Covered soil with straw	Uncovered soil	Covered soil with plastic	Covered soil with straw
Field germination ratio, %	23.3	33.3	40.0	60.0	70.0	66.7	70.0	86.7	80.0	70.0	90.0	80.0

germinated inside the greenhouse which had storage walls trials faster and intensively compared with the greenhouse without storage walls and open field trials. This refers to the air and soil temperature increase inside the greenhouses that comprised storage walls compared with that for the greenhouse without storage wall and the outside ambient open field. Also, seeds germinated inside greenhouse without storage wall trial faster and intensively compared with the open field trial. Planting these seeds under the different greenhouses in a comparison with a control trial greenhouse and open field caused a difference in the germinated ratio, as given in Table (3).

Squash seeds germination was affected by the soil covering treatments either by a black plastic mulch or straw. It is obvious that, seeds germinated in the covered soil trial (mulch or straw) faster and intensively compared with that of the bare soil under the same greenhouse. This refers to the covering effect which increased the soil temperature above that for the bare soil. The maximum, minimum and ideal soil temperatures for the squash in the germination stage that are as are 38, 21-35 and 35°C, respectively [39]. Table (4) represents maximum and minimum soil temperatures that measured within the experiments in the germination stage.

Plant growth within the vegetation stage: In general, the squash plants under the greenhouses that comprised solar storage wall were faster comparing with the greenhouse with no walls. This due to the storage wall that increased the greenhouse air temperature above that for the control trial one. The variations between the different greenhouses in term of the plant vegetation stage are shown in Table (5). This was side by said with the effect of the soil covering type as the plant length was found highly affected by the soil covering treatments. The maximum, minimum, day and night air temperatures for the squash in the vegetation stage that are recommended by Hassan [39]: are 33-36, 5-8, 19-29 and 12-15°C, respectively. Table (6) represents maximum,minimum, day and night air temperatures for the squash that measured within the vegetation stage. The cultivated plants in the covered soil with black plastic mulch and the horse beans straw of 5 cm thick were higher compared with the other uncovered soil under the same soil and inside the same greenhouse. Maximum plant height at cretin specific time i.e., after 37 days from the planting date was obtained from the greenhouses that comprised solar storage wall. Plants height inside the greenhouse that comprised adobe solar storage wall were found to be 49.3, 62.1 and 69.6 cm for uncovered soil, covered soil with a plastic mulch and straw, respectively. Meanwhile, it was found as 54.9, 68.1 and 65.4cm, respectively inside the greenhouse comprised red brick solar storage wall. Also, average plants length were found as 47.6, 57.9 and 48 cm for uncovered soil, covered soil with a black plastic mulch and covered soil with straw, respectively inside the greenhouse without storage wall (control trial greenhouse). In the open field trials the plant growth were later comparing with that grew inside the greenhouses this, due to the drop in the air temperature during this period of the year. Maximum plant length obtained in the open field was occurred after 72 days from the planting date, it was found as 21.4, 24.3 and 22.4 cm for the uncovered soil, covered soil with plastic mulch and covered soil straw, respectively.

Flowering stage: Cumulative for number of flowers were found for the different treatments inside greenhouse and open field are shown in Figure (3). In general, the flowering stage was found affected by the presence of the solar wall inside greenhouse. Numbers of flowers inside the greenhouse that comprised walls (adobe and red brick) were faster and intensively flowered compared with that were cultivated inside the greenhouse without storage walls. On the other hand, flowering was found affected by covering the soil with

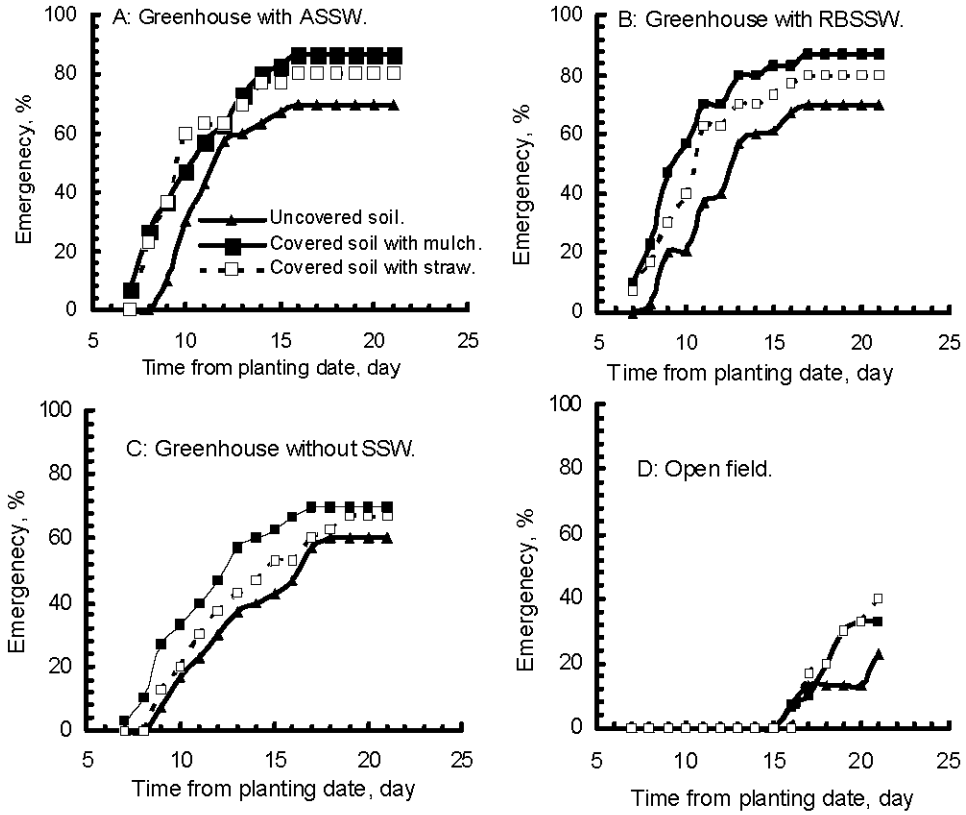

Fig. 2: Effect of the solar storage -wall beside soil covering treatments inside the greenhouses and in the open field on the cumulative germination ratio

Table 4: Averages for the maximum and minimum soil temperatures within the germination stage

Treatment	Maximum, °C	Minimum, °C
Open field	21.5	13.7
Greenhouse without SSW	28.4	18.1
Greenhouse with ASSW	29.5	19.4
Greenhouse with RBSSW	29.9	19.2

Table 5: Effect of storage wall and the soil covering treatments on the height of squash plants

	Plant height(cm)								
	Greenhouse without SSW			Greenhouse with ASSW			Greenhouse with RBSSW		
Day number from planting, (day)	Covered soil with plastic	Uncovered soil	Covered soil with straw	Covered soil with plastic	Uncovered soil	Covered soil with straw	Covered soil with plastic	Uncovered soil	Covered soil with straw
16	12.7	8.6	10.4	14.2	8.8	16.7	15.4	11.2	15.3
23	22.4	16.8	20.1	24.5	19.3	25.7	26.6	20.7	25.6
30	37.8	29.5	31.1	41.7	31.6	45.6	44.8	36.6	41.3
37	57.9	47.6	48	62.1	49.3	69.6	68.1	54.9	65.4

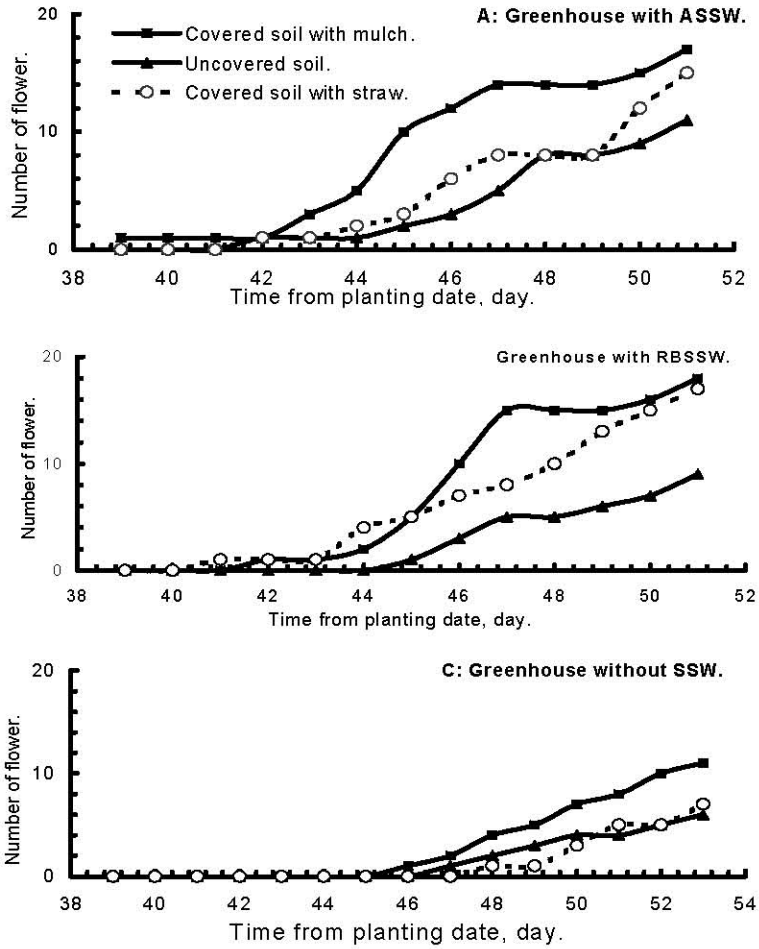

Fig. 3: Cumulative number of flowers as affected by the soil covering treatments and storage walls.

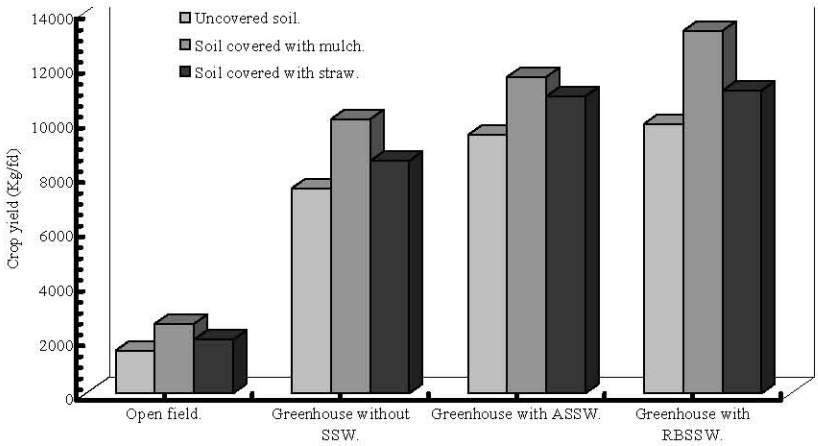

Fig. 4: Total yield of squash crop as affected by the solar storage walls and the soil covering treatments

Table 6: Averages for the maximum and minimum temperatures of air for day and night within the vegetation stage

Air temperature, °C	Open field	Greenhouse without SSW	Greenhouse with ASSW	Greenhouse with RBSSW
Maximum,°C	20.4	32.6	35.6	35.9
Minimum,°C	9.6	9.5	10.6	10.6
Day time,°C	17.1	23.8	26.3	26.5
Night time,°C	10.4	10.4	12.2	12.0

black plastic and straw mulch. It was found that, the number of flowers in the covered soil trial (plastic and straw) were faster and intensively comparing with that were cultivated in the bare soil under the same greenhouse. In the open field trials, flowering stage began later i.e., after 84 day from planting date.

Total yield of squash crop is shown in Figure (4) which reflects how much the squash plants were adapted to the investigated parameters. It was found that, the crop yield was higher for the solar storage wall and the soil covering treatments inside the greenhouse comparing with the open field which are 4920 kg /fedan according to El-Shatoury [33] for the same crop variety and the same soil.

CONCLUSIONS

The study conducted to the following conclusions:

- Seed germination ratio, plants growth and number of flowers inside the greenhouse which has storage walls were faster and intensively, compared with that inside greenhouse without storage wall and open field trial.
- Seeds germination ratio, plants growth, numbers of flowers in the covered soil trial (mulch or straw) were faster and intensively compared with that of the bare soil under the same greenhouse.
- The average total crop yield inside the greenhouses that comprised adobe and red bricks solar storage wall increased by 22.6 and 31.4 % respectively above that obtained form the greenhouse without storage wall.

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