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Full Length Research Paper

Development of Drying System for Dew Harvesting: A New Approach to Collect Water Supplement for Grazing Plants in Arid Regions

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Passive dew harvesting and rainwater collection requires very small financial investment, hence has the potential to exploit a free and clean source of water in rural areas. The increase of livestock production in Saudi Arabia has resulted in a parallel increase in demand for grazing plants and hence greater exploitation of ground water for irrigation. The current trends in water conservation policies, necessitates finding alternate sources of water to provide minimum grazing requirements. Dew condensation on greenhouse dryer cladding and assorted other surfaces was frequently noticed. Accordingly, this study was performed to measure the quantity of condensation in arid regions. Dew was measured by using (I) glass of flat plate solar collector, (II) tempered glass of photovoltaic (PV) and (III) double sloped (25°) acrylic plexiglas of greenhouse dryer. The total amount of dew was measured during the years 2013/2014in Alahsa, Saudi Arabia. The condensate dew drops were collected naturally (before scraping) and by scraping once and twice. Dew began to condense mostly between 12:00 am and 6:30 am and its intensity reaches its peak at about 45 min before sunrise. The collected dew and rain water were applied to *Atriplexhalimus* species for two years. Dry matter, forage yield and survival percentage were recorded. The cumulative dew yield on double-sloped test roof varied with wind speed and direction. Results indicated that wiping twice gave more dew yield compared to one wiping or collection by gravity. Dew and rain pH were neutral (close to 7) and the total mineralization was appropriate. The ions concentration is as per standard of World Health Organization for potable water. The highest average survival percent of *Atriplexhalimus* was 98.8% in winter but decreased as time progressed. It was 99.9% in the first year. *Atriplexhalimus* produced average forage yield of 2350 and 4120 kg/ha for first and second year, respectively. Using existing drying system for dew and rain harvesting could provide a potable water source for arid region.

Keywords: PV module, flat plate solar collector, greenhouse, drying system, dew collection, water vapor, rain water harvesting, irrigation, *Atriplexhalimus* species.

INTRODUCTION

Shortage of drinking water is chronic, severe, and wide-spread in the regions of Northern Africa, Middle East, and Central and Southern Asia. The problem of providing arid areas with fresh water can be solved by transportation of water from other locations; desalination of saline water (ground and underground); and extraction of water from atmospheric air [Hamed, 2000].

Transportation of water through these regions is usually very expensive, and desalination depends on the presence of saline water resources, which are usually rare in arid regions. Atmospheric air is a huge and renewable reservoir of water. This endless source of water is available everywhere on the earth surface [Hamed et al., 2011].

Dew water is widely used by plants and small animals where, in arid and semiarid environment, it provides the necessary amount of water for life to exist and even develop [Steinberger et al., 1989]

Dew is the moisture (water vapour) which condenses from the atmosphere on plants, soil, or other surfaces near the ground. Dew point is the temperature at which a parcel of air becomes saturated when cooled at constant pressure and constant water-vapor content. The dew forms primarily during the early morning hours when the temperature approaches its minimum diurnal value. It often forms in the early evening also, and in such cases probably continues to accumulate slowly throughout the night. However, the rate of formation must decrease owing to the fact that the layer of air closest to the ground becomes saturated.

The dew formation depends on the following conditions:i) A radiating surface, well insulated from the heat supply of the soil, on which vapor may condense; ii) A clear, still atmosphere with low specific humidity in all but the surface layers, to permit sufficient effective terrestrial radiation to cool the surface; and iii) high relative humidity in surface air layers, or an adjacent source of moisture such as a lake, river…etc. [Taylor, 2014 and Żaneta et al. 2008].

The dew will be heaviest on surfaces which are the best radiators, that is, dark and opaque surfaces such as green grass. For the same reason, dew will be heaviest when the wind is light or absent because the lack of mixing allows the temperature inversion near the ground to be maintained and to intensify.

Several experiments were carried out to observe dew of daily or seasonal changeable amount [Muselli et al, 2009,Zangvil, 1996]. The rate of dew accumulation and total deposition present interesting research questions [Jacobs et al., 1999, Jacobs et al., 2000]. In some studies, dewfall was estimated by direct weighing method measuring the increment of the collector at the beginning and finality time of condensation [Adrie et al., 1999]. However, collectors of different material lead to different results even other parameters are quite similar [Li, 2002].

Specific devices are used to study corresponding type of ecosystem on measuring dewfall, for the formation of dew largely depends on the surroundings, temperature, light, relative humidity, etc. Collectors such as Micro-lysimeter[Adrie et al., 2002], Plywood and synthetic velvet[Giora, 1999] were used in arid and semi-arid ecosystem. Plastic sheet and polyethylene plate were applied as collector in tropical rain forest[Liu et al., 2001a, Liu et al., 2001b] and urban ecosystem[Ye et al., 2007], respectively.

A major limitation in assessing the ecological and environmental role of dew is the extreme difficulty of collecting accurate measurements. In the majority of cases, dew is an important moisture input and plays a significant ecological function in most desert ecosystems [Jacobs et al., 2002].

Information regarding the chemical composition of dew is not often interpreted with meteorological data. Very limited studies have been done on dew chemistry worldwide [Beysens et al., 2006, Jiries , 2001 and Muselli et al., 2002].

In a special case, not only dew collectors had to be determined in arid and semi-arid, forest or urban ecosystem, but also the models which were able to calculate dewfall on collector varies were deduced [Gandhidasan and Abualhamayel, 2005, Adrie et al., 2008]. Therefore, there are no internationally standard methods or devices for dew observation. Each type of ecosystem should select its proper collector [Baixing and Yingying, 2010].

The maximum dew yield that can be expected is of order 0.7 l/m^2 as limited by available cooling energy (25-100 W/m^2) with respect to the latent heat of condensation (2.5 kJ/g). Systematic investigation of yield radiative materials with hydrophilic properties for drop recovery and adapted condensing architecture was performed with respect to local meteorological parameters as wind speed, wind direction, relative humidity, …etc. [Beysens et al., 2003 and Muselli et al., 2002]. For a plane condensing structure the best tilt angle with horizontal has been found to be 30° [Beysens et al., 2003].The roof must have a steepness of at least 20°. Some of the existing buildings-especially their roofs- present opportunity to produce dew water without any financial investment, except a small amount for the collection gear. The advantage for the user is that water would be produced right on their own roof top.

It is estimated that about 216,000 ha of agricultural lands in Saudi Arabia are currently cultivated with forage crops, producing nearly 326,000 tons per year (Ministry of Agriculture and Water, 2002).

Atriplex species is a shrub with a C4 photosynthetic pathway (Ben Hassine et al, 2008) which makes it competitive in growth and biomass production under limited water supply (Ozturk et al, 1981).

To ensure the success of transplantation of Atriplex shrubs especially in the establishment year, a supplemental irrigation after plantation is recommended, so that the seedlings develop deep roots in the first season which improves survivability and yield. For this reason, seedlings are planted accompanied with water harvesting techniques such as contour furrows so that water is retained on the land near the roots of the shrub. After studying the effect of water stress on biomass production, it was found that the production of Atriplex shrubs substantially increased to 2000 kg.ha-1 by applying additional irrigation water using water harvesting techniques compared to 400 kg/ha with no irrigation (Abu-Zanat et al., 2004).

Surveying the grazing plants indicated that, the *A. halimus* specie is native to Saudi Arabia (Chaudhary, 1999) and has high to fairly good nutritive values (Towhidi, 2007; Haddi et al., 2009).

To ensure success of establishment of forage shrubs, water harvesting techniques can be used to collect rain water in areas close to the shrubs. Conservation and development of water resources are important ways to reduce human impact on water resources and environment. Water harvesting is a promising method for development of water resources especially in the arid environment where much pressure is exerted on the ground water (Ahmed et al., 2007).

The objective of this study was to determine to what extent the use of already existing drying system can provide a substantial amount of dew/rain water that naturally formed on rooftops as a source of potable water. If the amount is found to be considerable, then it can be developed and enhanced further from readily available material. The possibility of cultivating of *A. halimus* plant under different levels of supplementary irrigation will also be evaluated.

MATERIALS AND METHODS

Experimental site

The research was conducted at the Research Station, College of Agricultural and Food Sciences, King Faisal University, Al Ahsa(Latitude: 25°18'N, Longitude: 49° 29' E), Saudi Arabia. The elevation is about 179m above sea level. The climate of Al Ahsais arid mostly characterized by hot and dry summer with cool and slightly wet winter and limited renewable water resources. The Kingdom of Saudi Arabia lies entirely within arid and semi-arid dry land, with an annual rainfall ranging from 0 to 100 mm/annum.Natural water resources in Saudi Arabia, like in other arid countries, are limited. There is also a lot of pressure on these resources due to alarming rates of increase in demand for irrigation water.

The soil is sandy loam and slightly alkaline (pH= 8.2, ECe = 2.1Mohs. cm^{-1}). The total amount of rainfall during the year (2013/2014) of the experiment was 68.3 mm.

MATERIALS

Application of solar energy for extraction of water from atmospheric air in the climatic zones of Saudi Arabia is interesting. Currently, this work only considers atmospheric water vapor processing (AWVP) approaches using cooled surface to condense water. The collection of dew water is a simple and sustainable technology to obtain fresh water for afforestation, gardening, and as a source of drinking water for human and animal consumption.

In this research an existing solar photovoltaic powered drying system was developed in order to harvest the dew water. In this case, the drying system had two advantages. The first advantage is the possibility of drying products during day time, while the second one is the harvesting of dew water during night, in addition to harvesting of rain water. The drying system is not the main subject of this investigation, but will focus and discuss the dew water as well as rain water harvesting.

The drying system consists of PV module, flat plate solar collector and even span type greenhouse (drying chamber). Three different materials were used as dew water collectors.

The even-span is the standard type and full-size structure. The two roof slopes are of equal pitch and width. The two sloping surfaces were erected on a triangular shape as shown in Figure 1. The ridge (drying chamber) was oriented north-south. The roofing and walls of the greenhouse dryer were made of commercially available transparent Plexiglas sheets 2mm thick and IR emissivity of 0.86 at wavelength 2-5.6µ. Roof slope is about 25°, left half-slope (1.3 m^2 .i.e. 0.65 m width × 2.00 m length) towards west, while right half-slope with the dimensions towards east. Separate provision gutter and collection vessel were installed on each side. The gutter is fixed on upper side of the wall and under the roof of the greenhouse at an angle of 15° sloping away from the prevailing wind. The gutters were used to run off the dew condensation and rainfall water. There is a thermal curtain installed under the

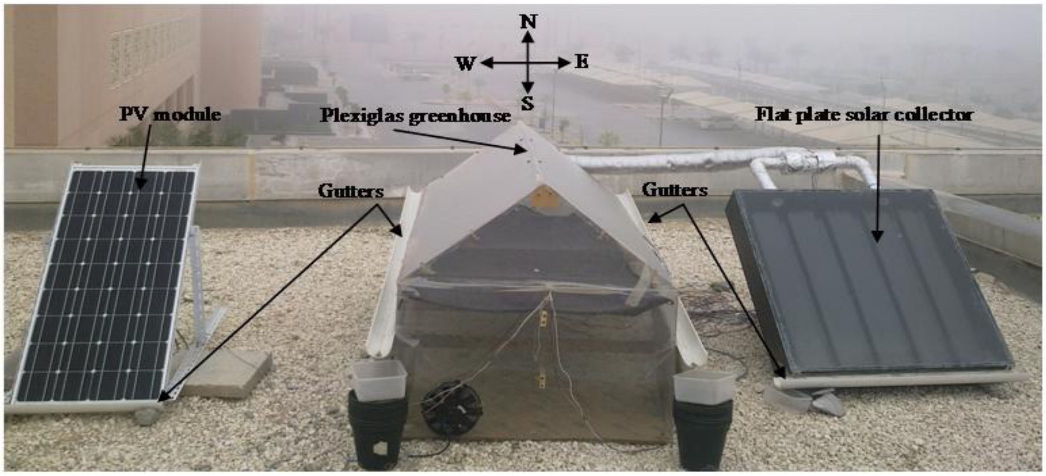

Figure 1: Dew collection off of a greenhouse dryer roof, solar collector surface and PV module surface

roof and above the product net which covered the entire area of greenhouse (i.e. 1 m width × 2 m length).

The flat plate solar collector was connected to the greenhouse dryer to provide an auxiliary heat for drying air. The collector is rectangular in shape with size of 1.0 m length ×1.0 m width × 0.20 m height. It is equipped with absorber plate made of galvanized corrugated sheet having size of 1.0 m length ×1.0 m width × 0.0015 m thickness. The absorber plate is painted with matt black paint and insulated from back side with 10 cm wood shavings. The top of the collector is made of one layer colorless glass sheet of 4 mm thickness × 1.00 m long × 1.00 m wideness and IR emissivity of 0.90 at wavelength 8-14 µ. A gap of about 10 cm between the glass cover and the absorber plate forms the air passage. The collector is supported by a stand for obtaining the desired optimum tilt angle of 25° and oriented towards south. There is a gutter installed at the lower end of the solar collector for run off the dew condensation and rainfall water to a collection vessel.

The PV module of ASEM type (100 W) is used to operate the fan of drying system. The PV size is 1.20 m length × 0.54 m width × 0.03 m thickness, which mounted on a stand for obtaining the desired optimum tilt angle of 25° and oriented due south. The emissivity from the front glass surface is given as 0.91 [Notton et al, 2005] while the value for the back surface of the PV panel is 0.85 [Morgan et al., 2002]. There is a gutter installed at the lower end of the solar module for run off the dew condensation and rainfall water to collection vessel.

METHODOLOGY

Air temperature and relative humidity, wind speed, solar radiation …etc. were obtained from Meteorological station at Research Station of King Faisal University, Al-Ahsa.

After condensing number of dew droplets, they combine to form larger droplets, run down the collector into gutters and eventually into the container where it measured.

Droplets remaining on the collection surface were transferred to the collector using a polyethylene scraper. The dew samples were collected early in the morning. Before the expected appearance of dew, the collection surface was flushed with deionized water and subsequently dried. The dew samples were collected only on rainless nights to eliminate the influence of precipitation as shown in Figures. 2, 3 and 4.

Samples were collected during or immediately after deposition. They were stored at low temperature without preservatives because the analysis was performed either directly on-site, or immediately after in the laboratory. Samples were analyzed for pH, volume, and conductivity. Selected anions and cations were quantified.

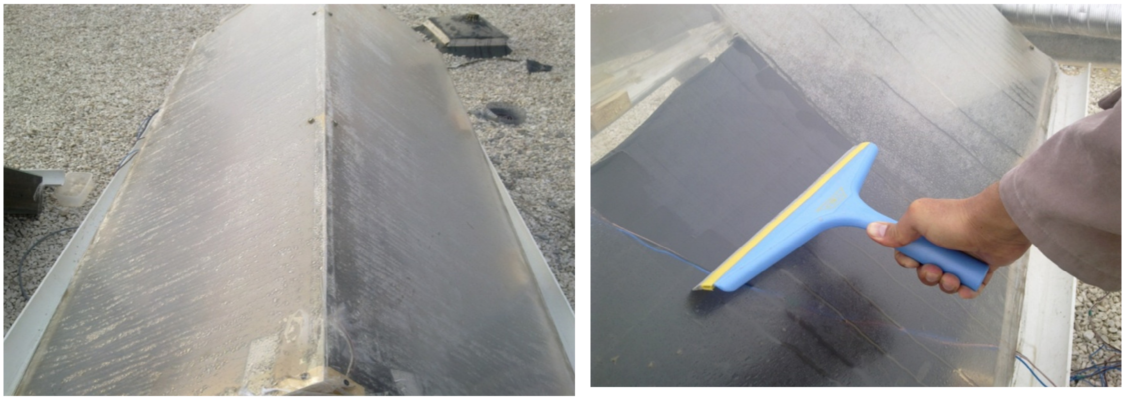

Figure 2: Dew condensation on the greenhouse roof (left) and scraping dew (right).

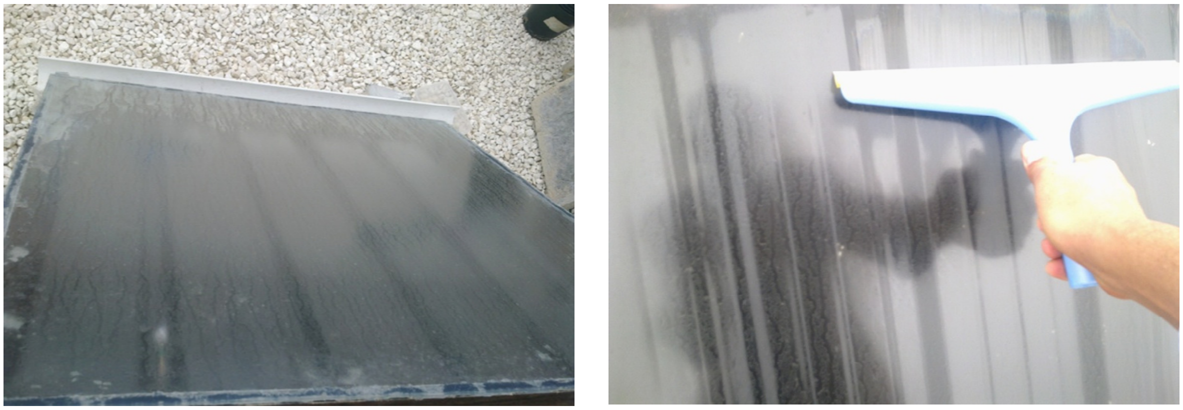

Figure 3: Dew condensation on the solar collector surface (left) and scraping dew (right).

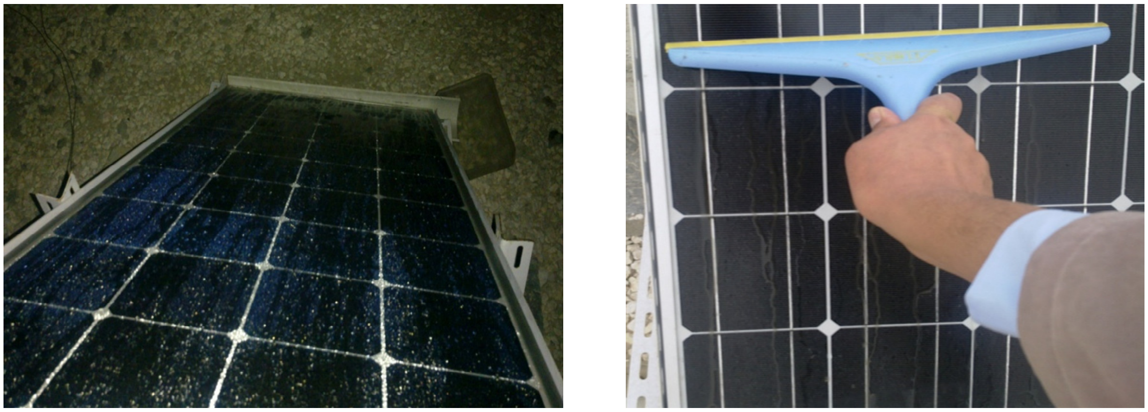

Figure 4: Dew condensation on the PV module surface (left) and scraping dew (right).

Proposition of use dew and rain water for grazing

In many dry coastal areas of the world, horticultural and agricultural crops are grown without irrigation, making full use of dew formation. Only plants which are shallow rooted could make use of dew because the moisture penetrates only a thin layer of soil and evaporates quickly when the sun begins to warm the surface.

Grass or desert shrub characterizes a very large geographic area where the annual rainfall is small. Such

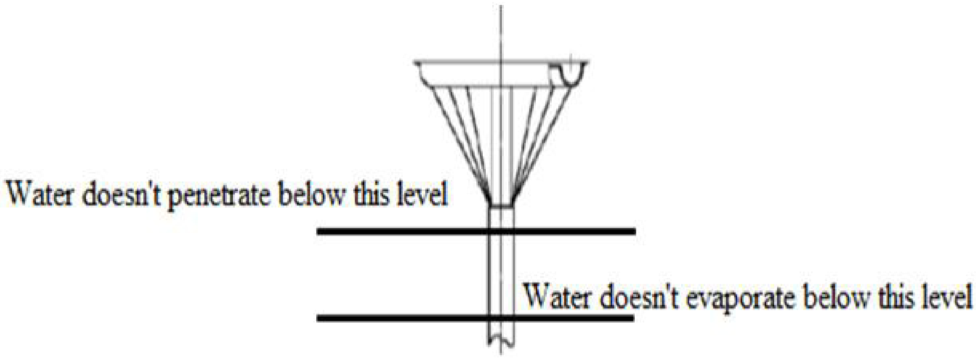

Figure 5: Deep root irrigation funnel

areas are, by their meteorological setting, characterized by a large number of days of no rainfall, and most of the annual rainfall occurs in relatively few days. Dew is formed in the arid environment when there is a big temperature difference between days and nights. But this precious moisture evaporates during the day before it reaches the roots of thirsty plants. It is reasonable to suppose, then, that in such an ecologic setting any factor which doubles the frequency of moisture availability, even though the moisture amounts be small, must materially affect the growing conditions of plants. It is suggested, therefore, that the occurrence of dew is a factor of importance in sustaining the plant associations in grasslands. If there was a way to transport that water directly to the roots before it evaporates, many plants would thrive in an otherwise barren landscape.

A plastic funnel conical in shape with 25 cm diameter and 40 to 60 cm central extension tube (3/4 inch diameter) was used. The proposed deep root irrigation funnel that transfers water droplets from the surface to below the evaporation level is shown in Figure 5. The central tube of the funnel was extended to the expected roots or deep below the surface where it can't evaporate. The funnel was manufactured from recycled plastic while the extension of the central tube was made of metal. The whole cone was assembled as one piece with no moving parts. The collected dew and rain water were kept in separate tanks and used for irrigation according to the schedule mentioned below. Meanwhile the new collected amounts of dew and rain water were added to their tanks to supplement the consumption.

Seeds of *Atriplexhalimus* were collected from wild populations in the Northern region of Saudi Arabia and sown in a greenhouse. Seedlings of uniform size were transplanted to the field at the age of 8 months, in two rows, 1 m apart in all directions. Seedlings were irrigated with pre-harvested water equivalent to 20 mm every two-weeks and continued for 15 months to attain plant establishment.

Supplementary irrigation treatments were used as follow:

1) Non irrigation treatment (rain-fed only)
2) yearlong irrigation with collected rain water (480 mm) at surface
3) yearlong irrigation with collected dew water (480 mm) at surface
4) yearlong irrigation with collected rain water (480 mm) at root zone
5) yearlong irrigation with collected dew water (480 mm) at root zone
6) irrigation during fall and summer with collected rain water (240 mm) at surface
7) irrigation during fall and summer with collected dew water (240 mm) at surface
8) irrigation during fall and summer with collected rain water (240 mm) at root zone
9) irrigation during fall and summer with collected dew water (240 mm) at root zone
10) irrigation during summer only with collected rain water (120 mm) at surface
11) irrigation during summer only with collected dew water (120 mm) at surface
12) irrigation during summer only with collected rain water (120 mm) at root zone
13) irrigation during summer only with collected dew water (120 mm) at root zone

Three months later, the current-year growth of leaves and twigs of all plants was cut manually using scissors, but no growth measurements were taken. All harvested twigs and leaves were more than or equal to 5mm. Average leaf/stem ratio of 0.75 was determined (Data not included).

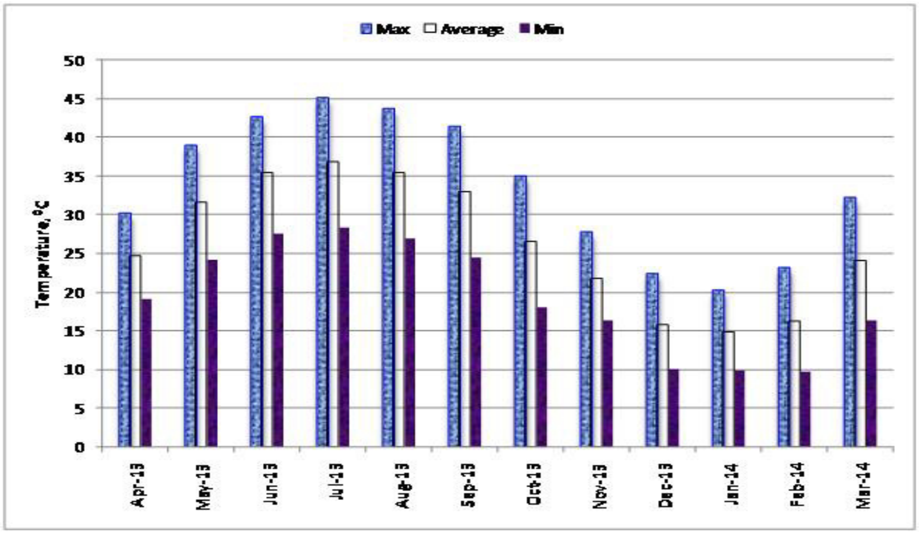

Figure 6: Variation in maximum, average and minimum temperatures versus month of the year for experimental site (April 2013 to March 2014).

Cutting was done every 3 months in order to gather cumulative seasonal dry matter production and continued for the 15 months.

Total fresh weight was determined. Samples of 150 g were taken to determine dry matter content and other subsequent measurements. Persistence was also determined as the percentage of surviving individual plants at each cutting time. Data were subjected to the analysis of variance using SAS statistical package (SAS, 1988).

RESULTS AND DISCUSSIONS

Meteorological data for the experimental site

In order to assess the benefit of dew water collection in addition to rainwater, average monthly weather conditions are recorded. It should be noted that the following weather conditions were taken as monthly average for maximum, average for average, and average for minimum.

Figure 6 shows variation monthly average of maximum, average and minimum ambient temperatures for experimental site during April 2013 to March 2014. The maximum temperature ranged from 20.4°C in January to 45.2 °C in July, while the minimum temperature ranged from 9.7 °C in February to 28.3 °C in July.

Dew yield was strongly correlated with difference between dew point temperature and air temperature. Air temperature represents cooling that must be performed to start condensation. Figure 7 shows variation in monthly average of maximum, average and minimum ambient relative humidity for experimental site during April 2013 to March 2014. The maximum relative humidity ranged from 89.41% in January to 23.6% in June, while the minimum from 6.44% in June to 42.18% in January.

Figure 8 shows monthly average solar radiation of the experimental site for the whole year, where data were taken into account from 8 am to 4 pm. The highest average solar radiation of 769 W/m^2 was recorded in July, while the minimum average of 483 W/m^{2}in January.

Figure 9 shows monthly average wind speed for the experimental site during April 2013 to March 2014. The highest average wind speed of 3.6 m/s was recorded in June, while the minimum average of 1.88 m/s in January. As shown in figure, the lower wind speed during winter season gave the chance for dew water forming.

Figure 10 shows variation in monthly average of maximum, average and minimum dew point temperatures for experimental site during April 2013 to March 2014. The highest dew point temperature ranged from 17.06 °C in August to 4.6°C in June, while the minimum ranged from -2.3 °C in June to 9.1 °C in November.

The total sum of precipitation (rainfall) was 130.28 mm/annum during April 2013 to March 2014. The recorded rainfall ranged from 0 mm to 45.0 mm with average of 0.4 mm during the mentioned period. No rain was recorded during June to October 2013.

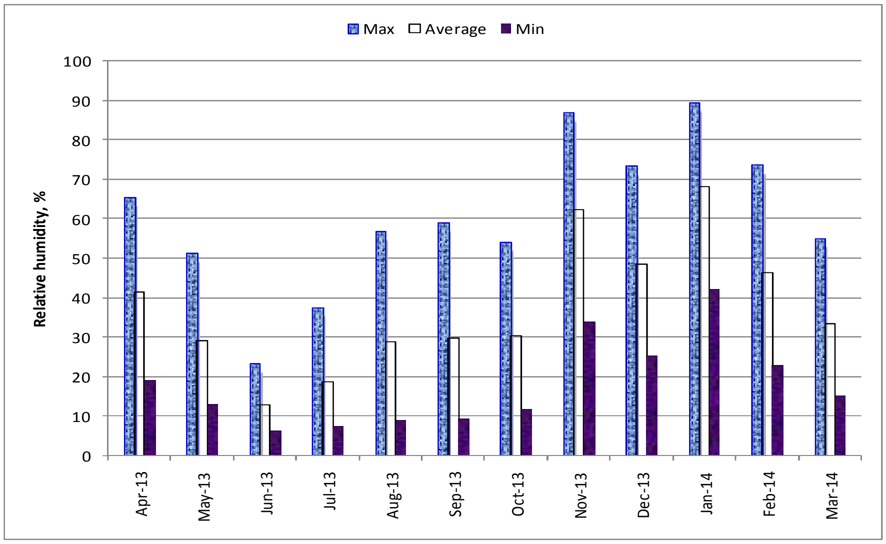

Figure 7: Variation in maximum, average and minimum relative humidity versus month of the year for experimental site (April 2013 to March 2014).

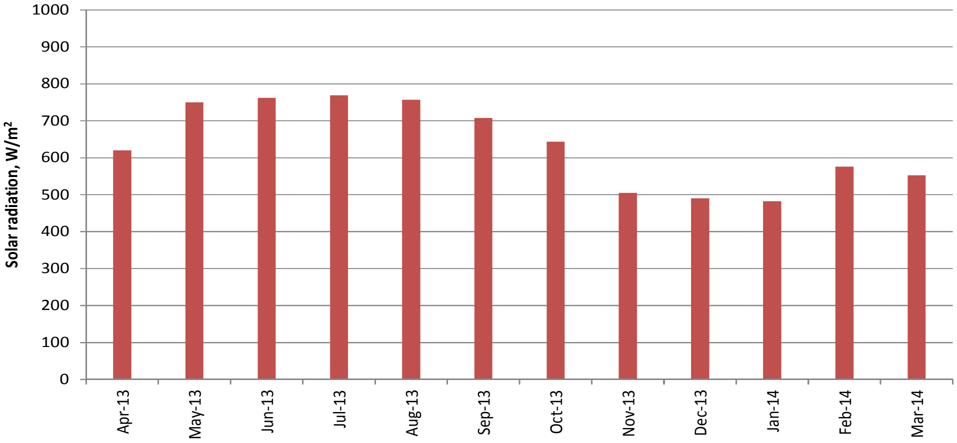

Figure 8: Variation of average insolation versus month of the year for experimental site (April 2013 to March 2014).

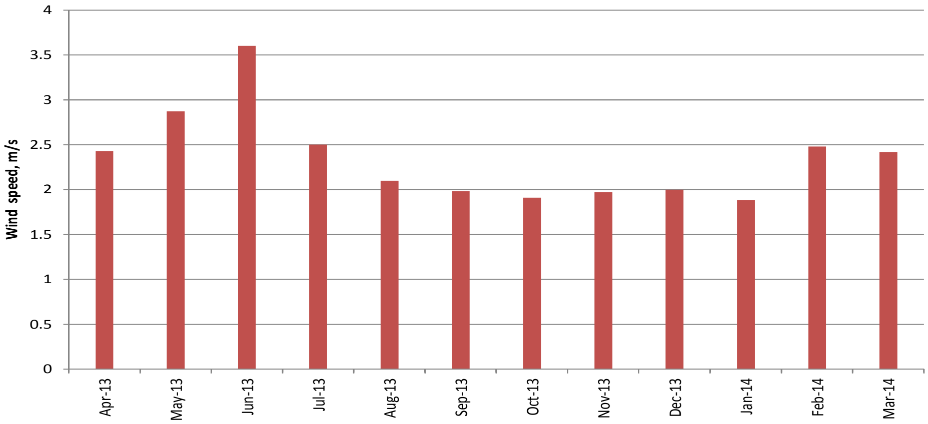

Figure 9: Variation of average wind speed versus month of the year for experimental site (April 2013 to March 2014).

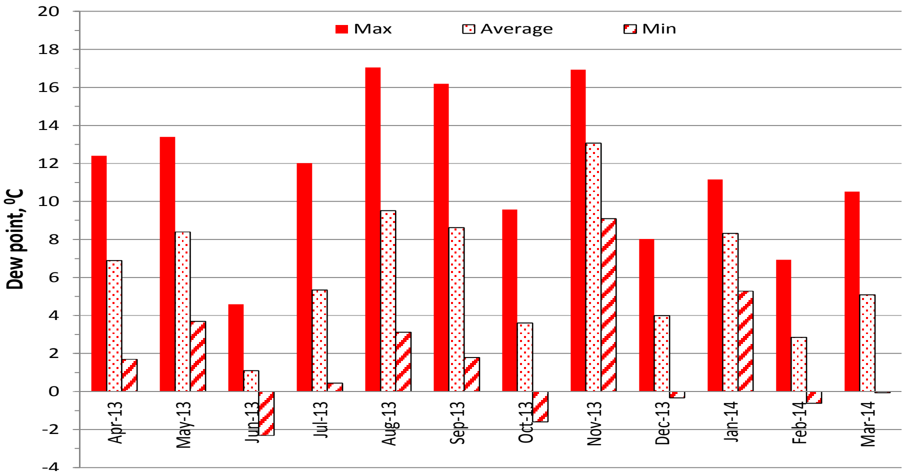

Figure 10: Variation of maximum, average and minimum dew point temperature versus month of the year for experimental site (April 2013 to March 2014).

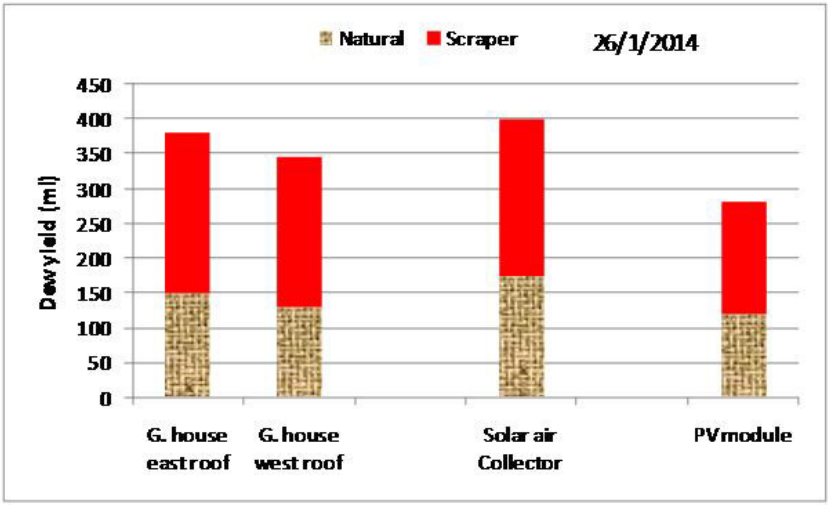

Figure 11: The dew yield over the three condensers in case of natural collection and using scraper once before sunshine.

Dew and rain yields

There are several models available to predict dew water (Jacobs et al., 2008; Nikolayev, et al., 2001), but they all need extra measurements such as condenser surface temperature, long wave radiometer measurements which were not available here. Therefore, the actual dew yield was measured under correlated main atmospheric parameters.

The dew yield data for several nights are shown in Figs. 11 to 13 and presented in Tables 1 to 3. Scraping proved to be an important component for dew collection. The potential of scraping was reported by Muselli et al. (2002).Dew water was recovered in the collection bucket by gravity. In the early morning, the remaining drops on the condensers were systematically wiped once or twice and the volume of collected water compared before and after wiping. Figure 11 shows the collected dew water from the three condensers in case of natural collection and wiping once before sunshine. The total collected dew water was 380, 345, 400 and 280 ml for east greenhouse roof, west greenhouse roof, solar collector surface and PV module surface, respectively. The dew collected by gravity (naturally) was 39.47, 37.68, 43.75 and 42.86% for east greenhouse roof, west greenhouse roof, solar collector surface and PV module surface, respectively. While the dew collected by scraper was 60.53, 62.32, 56.25 and 57.14%, respectively for the same condensers. It should be

Table 1: Variation of ambient conditions in one dew night (26/1/2014).

Hour of day	Ambient temperature, °C	Dew Point, °C	Relative humidity,%	Wind speed, m/s	Wind direction	Rain fall, mm	Remarks
12:00AM	12	10.0	89.1	0	Calm	0	
1:00 AM	11.0	10.0	91.1	0	Calm	0	
2:00 AM	11.0	9.0	92.4	0.8	NW	0	
3:00 AM	11.0	10.0	97.4	1.1	NW	0	
4:00 AM	11.0	10.0	99.1	1.4	NW	0	
5:00 AM	11.0	10.0	100	0	Calm	0	
6:00 AM	10.0	10.0	100	1.9	NW	0	Fog
7:00 AM	10.0	10.0	97	1.5	NW	0	Fog
8:00 AM	12.0	11.0	94	2	NW	0	
Average	**11.0**	**10.0**	**95.6**	**0.97**		0	

NW = North West

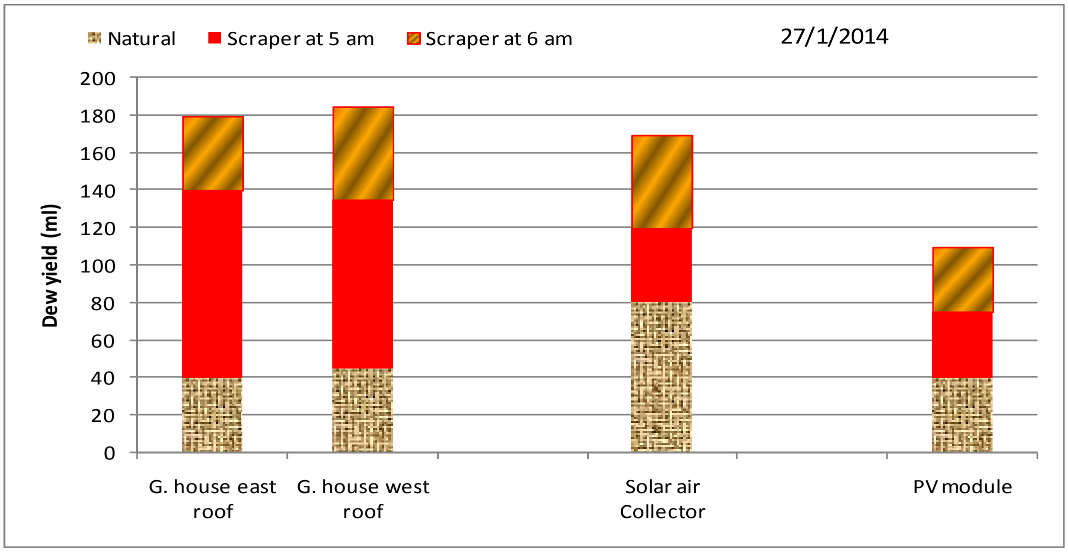

Figure 12: The dew yield over three condensers in case of natural collection and using scraper twice (at 5 and 6 am).

noted that, without wiping, the sun evaporation decreased the yield by the same factor.

As shown in the Figure 11, the dew collected from the greenhouse east roof was more than the west roof and this may be due to the wind direction. Wind brings moisture that enhances dew formation. It also increases the heat exchange with air by convection and turbulence. Meanwhile it prevents or hinders dew formation, and hence is a key parameter. The wind regime is characterized by the North West dominant direction (Table 1), which affected the dew collection. In Al-Hasa, Saudi Arabia the most frequent and strongest winds are from the North or North West. The orientation of the condenser, facing south, is thus appropriate. The average ambient temperature, dew point, relative humidity and wind speed were 11°C, 10°C,95.6% and 0.97 m/s, respectively (Table 1).

Figure 12 shows the collected dew water from the three condensers; natural collection and wiping twice (at 5 am and 6 am) before sunshine. The total collected dew water was 180, 185, 170 and 110 ml for east greenhouse roof, west greenhouse roof, solar collector surface and PV module surface, respectively. In east greenhouse roof, the dew percentage was 22.44, 55.56 and 22.0% for gravity collection, wiping at 5 am and wiping at 6 am, respectively. While in west greenhouse roof, the percentage of dew was 24.28, 48.69 and 27.03% for gravity collection, wiping at 5

Table 2: Variation of ambient conditions in one dew night (27/1/2014).

Hour of day	Ambient temperature, °C	Dew Point, °C	Relative humidity,%	Wind speed, m/s	Wind direction*	Rain fall, mm	Remarks
12:00AM	13	11	92.3	1.5	East	0	
1:00 AM	12	11	94	0	Calm	0	
2:00 AM	12	11	96.5	0	Calm	0	
3:00 AM	12	11	97.3	0	Calm	0	
4:00 AM	12	12	100	1.4	NNE	0	
5:00 AM	13	12	100	1.0	NNE	0	
6:00 AM	13	12	100	0	Calm	0	Heavy fog
7:00 AM	13	13	100	0	Calm	0	Fog
8:00 AM	13	13	94	1.2	NW	0	Fog
Average	**12.6**	**11.8**	**97.1**	**0.57**		0	

*NNE = North- North East NW = North West

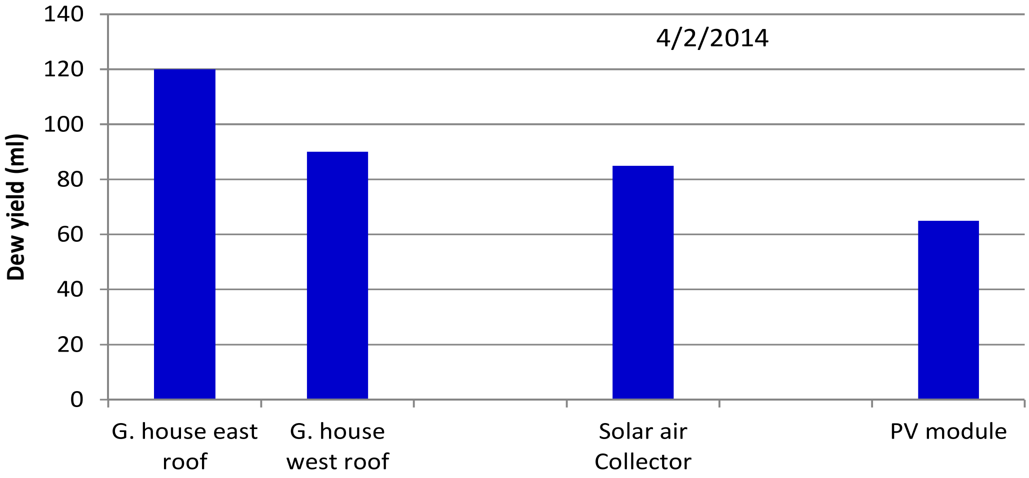

Figure 13: The dew yield over the three condensers on a foggy night using scraper once before sunshine.

am and wiping at 6 am, respectively. The percentage of dew was 47.06, 23.53 and 29.41% for gravity collection, wiping at 5 am and wiping at 6 am, respectively in case of solar collector. While in case of PV module, the percentage of dew was 36.36, 32.0 and 31.64% for gravity collection, wiping at 5 am and wiping at 6 am, respectively.

From Figs. 11 and 12, it is clear that the highest percentage of collected dew by gravity was obtained from solar collector followed by PV module and greenhouse roof. This might be due to the smooth surface of the glass which helped in the dew collection.

Figure 12 shows that, the dew collected from the greenhouse West roof data was more than the East roof data. This might attributed to the wind direction. Table 2 shows that, the wind below mostly from North-East direction during the specific day, which affected the dew collection. The average ambient temperature, dew point, relative humidity and wind speed were 12.6°C, 11.8°C, 97.1% and 0.57 m/s, respectively.

Figure 13 shows the collected dew water from the three condensers in case of wiping once before sunshine in one foggy night. The total dew water was 120, 90, 85 and 65 ml from east greenhouse roof, west greenhouse roof, solar collector surface and PV module surface, respectively. It should be noted that, the dew collected by gravity (naturally) was very little and neglected, while the collected amounts were by wiping in case of the foggy morning. This case emphasize that, without wiping the condensers, the sun evaporation would evaporate the total yield.

Table 3: Variation of ambient conditions in one foggy night (4/2/2014)

Hour of day	Ambient temperature, °C	Dew Point, °C	Relative humidity,%	Wind speed, m/s	Wind direction*	Rain fall, mm	Remarks
12:00AM	17	14	80.5	1.5	North	0	
1:00 AM	17	14	84.7	0	Calm	0	
2:00 AM	16	13	88.4	0	Calm	0	
3:00 AM	15	13	89.6	0	Calm	0	
4:00 AM	15	13	92.5	0	Calm	0	
5:00 AM	15	14	98.1	2.1	NW	0	Mostly Cloudy
6:00 AM	15	13	100	0	Calm	0	Partly Cloudy
7:00 AM	16	15	100	0	Calm	0	Fog
8:00 AM	16	16	100	2.1	NNW	0	Fog
Average	**15.8**	**13.9**	**92.6**	**0.6**		0	

* NNW = North- North West NW = North West

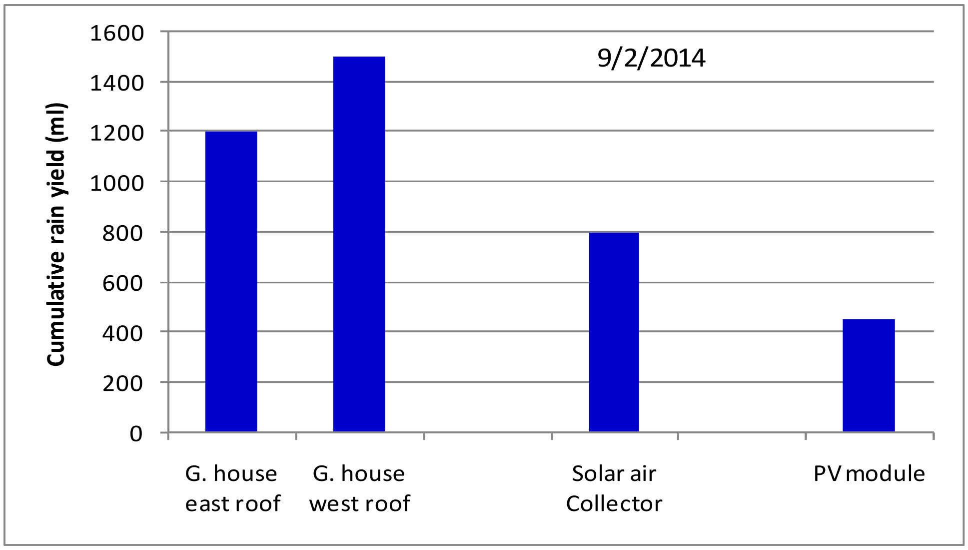

Figure 14: The cumulative rain water yield from different condensers in case of natural collection.

From Figure 9.13, it is clear that the dew collected from the greenhouse east roof was more than the west roof and is attributed to the wind direction. Even though the weather was almost calm, but when wind blew from North West direction (Table 3), it affected the dew collection. The average ambient temperature, dew point, relative humidity and wind speed were 15.8°C, 13.9°C, 92.6% and 0.6 m/s, respectively. High dew yields are found when relative humidity was high, and wind speed was low and less cloud cover. Dew at Al-Ahsa, Saudi Arabia Occur mostly in winter and seldom or not possible in summer. The modest decrease of temperature during the winter months over compensates for the winter minimum of moisture and enhances the possibility of reaching the dew point by radiational cooling at the ground surface. The importance of dew lies not in the total quantity but in the frequency of occurrence.

Figure 14 shows the rain fall water collected to from the three condensers in a rainy night. The data revealed that, the total water was harvested by gravity (naturally) without using the scraper. The total rain water collected was 1200, 1500, 800 and 450 ml for East greenhouse roof, West greenhouse roof, solar collector surface and PV module surface, respectively. It is obvious that the rain collected from the greenhouse West roof was more than the East roof. This might due to the wind direction. As shown in

Table 4: Variation of ambient conditions in one partial rainy night (9/2/2014).

Hour of day	Ambient temperature, °C	Dew Point, °C	Relative humidity,%	Wind speed, m/s	Wind direction*	Rain fall, mm	Remarks
12:00AM	13	10	85.3	5.6	North	0	Mist
1:00 AM	13	10	88.7	3.6	NNW	0.1	Mostly Cloudy
2:00 AM	12	8	89.53	2.6	North	0.4	Mostly Cloudy
3:00 AM	12	7	86.66	4.1	NNW	0.1	Mostly Cloudy
4:00 AM	12	7	77.48	4.1	North	0	Mostly Cloudy
5:00 AM	12	8	72.03	1.5	NW	0	Mostly Cloudy
6:00 AM	12	7	71.96	3.1	NNW	0	Mostly Cloudy
7:00 AM	11	6	70.62	4.1	NNW	0	Mostly Cloudy
8:00 AM	11	5	67.31	5.1	North	0	Mostly Cloudy
Average	**12**	**7.6**	**78.84**	**3.76**			

* NNW = North- North West NW = North West

Table 5: Average dew and rain water quality characteristics

Items	Dew water	Rain water
pH	7.32	6.9
Turbidity, NTU	251	473
Conductivity (EC), µS/cm	725	325
Total dissolved solid, mg/l	225	336
Ca, mg/l	54.2	35.6
K, mg/l	10.3	5.52
Mg, mg/l	17.6	10.68
Cl^-	250.3	149.4
HCO_3^-	1.04	1.42

Table 4, the dominant direction of wind is North West which carry rain in its direction, therefore the west roof harvest rain water more than East roof.

The average ambient temperature, dew point, relative humidity and wind speed were 12.0°C, 7.6°C, 78.84% and 3.76 m/s, respectively. The rain started at 12:20 am and finished at 2:45 am on 9th Feb, 2014. The rainfall intensity varied from 0.1 mm to 0.4 mm during the mentioned period (Table 4).

Dew and rain water quality analysis

Chemically, water vapor in the atmosphere is as clean as the air around it. Naturally occurring dew is a potable source of soft water, generally low on any mineral content.

The results of the analysis of some elements of dew and rain water are presented in Table 5. The mean electrical conductivity (EC) was 725and 325 µS/cm for dew and rain, respectively. The concentration of Cl^- ion and major cations (K^+, $Mg^{2+}$and Ca^{2+}) is analyzed. The concentration of Cl^- ion showed dominance compared to the other elements. The quantity of Cl^- in dew water was maximum (250.3) compared to rain water (149.4). Results indicated that the harvested water is suitable for drinking, irrigation and meet other standard for public consumption.

The dew and rain pH was 7.32 and 6.9, respectively. Dew pH is less acidic than rain because of the short time that dew is exposed to air, thus limiting the adsorption of gaseous CO_2, SOx and NOx.

Table 6: Dry matter, forage yield and survival of the *A. halimus* species in response to different irrigation treatments

	Dry matter (%)	Yield (kg/ha)	Survival (%)
Rain-fed only	42	1130	83.8
Rain water in summer (120 mm) at surface	39	3050	98.6
Dew water in summer (120 mm) at surface	39.3	3170	98.6
Rain water in summer (120 mm) at root	39.6	3640	99.8
Dew water in summer (120 mm) at root	39.7	3720	99.8
Rain water in fall and summer (240 mm) at surface	37.5	2870	99.8
Dew water in fall and summer (240 mm) at surface	37.8	2895	99.8
Rain water in fall and summer (240 mm) at root	38.1	2990	100
Dew water in fall and summer (240 mm) at root	38.3	3005	100
Rain water in year-round (480 mm) at surface	34.4	2630	100
Dew water in year-round (480 mm) at surface	34.7	2710	100
Rain water in year-round (480 mm) at root	35.2	2800	100
Dew water in year-round (480 mm) at root	35.5	2845	100

Effect of irrigation treatments on A. *halimus* productivity

The dry matter, forage yield and survival of the *A. halimus* species in response to different irrigation treatments are presented in Table 6. Analysis of data revealed that there were significant differences observed in forage yield and plant survival among different irrigation treatments.

Averaged over the two years, seasons and supplementary irrigation treatments generally increased forage yield over the non-irrigated treatment.

Results revealed that the highest forage yields (3720 kg/ha) and plant survival (98.9%) were recorded when supplementary irrigation was done at root zoon or below. The supplementary irrigation treatments with dew water were better than rain water but the differences were not significant.

The data in Table 6 revealed that the minimum plant survival (83.8%) and biomass yield (1130 kg/ha) was recorded when only rain water was fed. While the maximum survival (99.8%) and biomass yield (3720 kg/ha) was recorded when dew water was used at root zone in summer. This was followed with rain water of 120 mm at root zone with survival rate of 99.8% and biomass yield of 3640 kg/ha.

Generally, plant survival increased with increasing the amount of supplementary irrigation. Summer irrigation with dew water at root zone accounted for about 62% increase over rain-fed treatment indicating the importance of supplementary irrigation for maintaining a productive stand of shrubs during dry season.

The overall data revealed that the irrigation irrespective of the source and quantity but when applied at the root zones had pronounced effects on survival and biomass production in the present investigations. Than the irrigation when used on the surface. For example, dew water of 480 mm round year gave less biomass of 2710 kg/ha. Similar results were obtained when the crop was applied with year around rain water of 480 mm at surface yielding 2630 kg/ha biomass.

The measured attributes differed significantly among the four growing seasons as shown in Table 7. The highest dry matter percentage was obtained during spring followed by summer, while its lowest value was recorded in fall. Averages of forage yield varied from 395 kg/ha in summer to 1010 kg/ha in fall. Survival percentage decreased as time progressed. It had the highest averages in winter (98.8%) and during the first year (99.9%).

A. *halimus* produced average forage yield of 2350 and 4120 kg/ha for first and second year, respectively. The obtained results are comparable to those reported by Assaeed et al. (2012).

The year and season had a significant effect on both forage yield and plant survival (Table 7). Across seasons and within a year, forage yield was highest in fall and lowest in summer of both years. Across years and within

Table 7: Dry matter, forage yield and survival of the *A. halimus* species in different seasons of the year averaged over different irrigation treatments.

Season/Year	**Dry matter (%)**	**Yield (kg/ha)**	**Survival (%)**
Winter	31.4	840	83.8
Spring	44.9	980	98.6
Summer	42.6	395	98.6
Fall	30.1	1010	99.8
First year	41.5	2350	99.9
Second year	34.1	4120	95.6
Average	37.8	3235	97.95

seasons, the forage yield was higher in the second year than in the first year. Plant survival remained 100% for the first three seasons but decreased thereafter.

Within seasons, spring consistently had the highest dry matter percentage while the lowest value was in fall. These results are comparable to the findings of El-Shatnawi and Turuk (2002) and Assaeed et al. (2012).

As plant survival decreased with time, it was observed that within seasons, winter had the highest survival, while fall had the lowest one. Also over the irrigation treatments, the highest survival percentage was observed when irrigation water was fed to the root zone. Generally, non irrigated treatment had the lowest forage yield. However, forage yield was not consistently parallel to the increase in supplementary irrigation.

Water is the most limiting resource for forage production in arid regions. The present study indicated that supplementary irrigation of A. *halimus* at the root zone increased the forage yield and survival of the plants over the seasons and years.

CONCLUSION

Water is essential for the environment, for ensuring agriculture growth and hence ensure food security. Dew and rainwater harvesting is a technique to utilize and store precious water that otherwise would go waste. The existing dehydration system was used for dew and rain water harvesting. The effects of different condensers, with and without using scraper on the amount of dew and rain water were studied. Effect of weather conditions on the dew and rain water harvesting was also studied. The highest percentage of collected dew by gravity was for solar collector followed by PV module and greenhouse roof. High dew yields are found when relative humidity is large, and wind speed and cloud cover were low. Naturally occurring dew is a potable source of soft water, where it has low mineral content. The dew and rain pH was 7.32 and 6.9, respectively. The pre-harvested dew and rain water was applied to *A. halimus* species through different irrigation treatments and compared to non irrigation (rain fed only). Significant differences were observed in forage yield and plant survival among different irrigation treatments. The forage yield for first and second year was 2350 and 4120 kg/ha, respectively. Plant survival remained at 100% for the first three seasons but decreased thereafter. Over the irrigation treatments, the highest survival percentage was observed when irrigation water was fed to the root zone. The study revealed that harvesting rain and dew water would be alternative resources of irrigation for forages in the arid areas. However, further work is needed to select a mixture of native species that have high nutritive value and yield over the different seasons of the year in the arid regions.

REFERENCES

Abu-Zanat MW, Ruyle GB, Abdel-Hamid NF (2004). Increasing range production from fodder shrubs in low rainfall areas. *J. of Arid Envts*. 59: 205-216.

Adrie FGJ, Bert GH, Simon MB (1999). Dew deposition and drying in a desert system: a simple simulation model. J Arid Environ. 42: 211–222.

Adrie FGJ, Bert GH, Simon MB (2002). A simple model for potential dewfall in an arid region.Atmos Res. 64:285–295.

Adrie FGJ, Bert GH, Simon MB (2008). Passive dew collection in a grassland area, The Netherlands. Atmos Res. 87:377–385.

Ahmed OCA, Nagasawa R, Hattori K, Chongo D, Perveen MF (2007). Analytical hierarchic process in conjunction with GIS for identification of suitable sites for water harvesting in Oasis areas: Case study of the Oasis zone of Adrar, Northern Mauritania J. Applied Sci., 7: 2911-2917.

Assaeed AM, El-Bana MI, Al-Doss AA and Al-Mohaisen IA (2012). Forage yield and survival of native range species under supplementary irrigation in Central Saudi Arabia. African Journal of Agricultural Research Vol. 7(27), pp. 3933-3938, 17 July.

Baixing YAN, Yingying XU (2010). Method Exploring on Dew Condensation Monitoring in Wetland Ecosystem. Procedia Environmental Sciences, 2 :123–133.

Ben Hassine A, Ghanem ME, Bouzid S, Lutts S (2008). An inland and a coastal population of the Mediterranean xero-halophyte species *Atriplexhalimus* L differ in their ability to accumulate proline and glycinebetaine in reponse to salinity and water stress. *Journal of Experimental Botany*, 59(6): 1315-1326.

Beysens D, Milimouk I, Nikolayev V, Muselli M, Marcillat J (2003).Using radiative cooling to condense atmospheric vapour: A study to improve water yield, Journal of Hydrology 276(1-4), 1-11.

Beysens D, Muselli M, Milimouk I, Ohayon C, Berkowicz SM, Soyeux E, Mileta M, Ortega P (2006). Application of passive radiative cooling for dew condensation. Energy, 31: 1967-1979.

Chaudhary SA (1999). Flora of Saudi Arabia. Ministry of Agriculture and Water, Saudi Arabia 1:692.

El-Shatnawi MJ, Turuk M (2002). Dry matter accumulation and chemical content of saltbush (Atriplexhalimus) grown in Mediterranean desert shrublands. New Zealand J. Agric. Res. 45: 139-144.

Gandhidasan P, Abualhamayel HI (2005). Modeling and testing of a dew collection system. Desalination, 180:47–51.

Giora JK (1999). Altitude dependent dew and fog in the Negev Desert, Israel. Agric Forest Meteorol, 96:1–8.

Haddi ML, Arab H, Yacoub F, Hornick JL, Rollin F, Mehennaoui S (2009). Seasonal changes in chemical composition and in vitro gas production of six plants from Eastern Algerian arid regions. Livest. Res. Rural Dev. 21:1-11.

Hamed AM (2000). Absorption-regeneration cycle for production of water from air-theoretical approach. Renewable Energy, 19(4): 625-635.

HamedAM, Ayman A Aly, El-Shafei BZ (2011). Application of Solar Energy for Recovery of Water from Atmospheric Air in Climatic Zones of Saudi Arabia. Natural Resources, 2: 8-17.

Jacobs AFG, Heusinkveld BG, Berkiwicz SM (1999). Dew deposition and drying in a desert system: a simple simulation model. *J. Arid Environ. 42*: 211-222.

Jacobs AFG, Heusinkveld BG, Berkiwicz SM (2000). Force-restore technique for ground surface temperature and moisture content in dry desert system. *Water Resour. Res. 36*: 1261-1268.

Jacobs AFG, Heusinkveld BG, Berkiwicz SM (2002). A simple model for potential dewfall in an arid region. Atmos. Environ. 64: 285-295.

Jacobs AFG, Heusinkveld BG, Berkowicz SM (2008). Passive dew collection in a grassland area, The Netherlands. Atmospheric Research 87, 377–385.

Jiries A (2001). Chemical composition of dew in Amman, Japan. Atmos. Res. 57: 261-268.

Li XY (2002). Effects of gravel and sand mulches on dew deposition in the semiarid region of China. J Arid Environ. 260:151–160.

Liu WJ, Zeng JM, Wang CM, Li HM, Duan WP (2001a). On the relationship between forests and occult precipitation (dew and fog precipitation). J Natural Resour. 16(6):517–575.

Liu WJ, Zhang KY, Zhang GM, Li HM, Duan WP (2001b).Canopy interceptive effect of dew and fog resources from dry season tropical rainforest in Xishuangbanna. Resour Sci, 23(2):75–80.

Ministry of Agriculture and Water (MAW) (2002). Agriculture statistical book. Department of economics and statistics. Riyadh, Saudi Arabia.

Morgan D, Bazilian D, Kamalanathan H, Prasad DK (2002). Thermographic analysis of a building integrated photovoltaic system. Renewable Energy, 26 (3): 449-461.

Muselli M, Beysens D, Marcillat J, Milimouk I, Nilsson T, Louche A (2002). Dew water collector for potable water in Ajaccio (Corsica island, France). Atmospheric Research 64, 297–312.

Muselli M, Beysens D, Mileta M, Milimouk I (2009). Dew and rain water collection in the Dalmatian coast, Croatia. Atmos Res. 92:455–463.

Nikolayev VN, Beysens D, Muselli M (2001). A computer model for assessing dew/frost surface deposition. Second International Conference on Fog and Fog Collection. St John's, Newfoundland, Canada, pp. 333–336. 15-20/7.

Notton G, Cristofari C, Mattei M, Poggi P (2005). Modelling of a double-glass photovoltaic module using finite differences. Applied Thermal Engineering 25 (2005) 2854-2877.

Ozturk M, Rehder H and Ziegler H (1981).Biomass production of C3- and C4- plant species in pure and mixed culture with different water supply. *Oecologia* (Berl), 50: 73-81.

SAS Inst. (1988). SAS/STAT User's Giude. Release 6.03 ed. SAS Cary. NC p.1027.

Steinberger Y, Loboda I, Garner W (1989). The influence of autumn dewfall on spatial and temporal distribution of nematodes in the desert ecosystem. Journal of Arid Environments 16: 177-183.

Taylor RC (ed.) (2014).*Glossary of Meteorology* (http://amsglossary.allenpress.com/glossary), American Meteorological Society, website visited 25 March 2014.

Towhidi A (2007). Nutritive value of some herbage for dromedary camel in Iran. Pak. J. Biol. Sci. 10:167-170.

Ye YH, Zhou K, Song LY, Jin JH, Peng SL (2007).Dew amounts and its correlations with meteorological factors in urban landscapes of Guangzhou, China.Atmos Res. 86:21–29.

Żaneta P, Marek B, Kamila K, Mieczysław S, Stanisław M, Jacek N (2008). Chemical characterization of dew water collected in different geographic regions of Poland. *Sensors*, 8: 4006-4032.

Zangvil A (1996). Six years of dew observation in the Negev Desert, Israel. J Arid Environ, 32:361–372.