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Fog water collection and reforestation at mountain locations in a western Mediterranean basin region

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Abstract

An inland mountainous location in the east part of the Iberian Peninsula was selected for reforestation studies based on the fog water collection potential prevailing in the area and the high level of land degradation resulting from recurrent forest fires in the past. Prior to the beginning of reforestation and during the whole length of the campaign, a survey study of fog yields and fog-carrying wind directions was conducted by means of an instrument ensemble that consisted of a passive cylindrical fog water collector, a rain gauge, a wind direction and velocity sensor and a temperature and humidity probe. Once wind directions involved in most of the fog water collection were determined, a low-cost 18-m^2 flat-panel collector made of UV-resistant HD-polyethylene monofilament mesh was also deployed and oriented to attain maximum efficiency. Comparison between fog water collections rates in both cylindrical and large flat-panel collectors allowed the finding of a simple methodology that uses wind information to transform one variable into the other. Bulk fog-water catches were then estimated at other locations in the Valencia region for which cylindrical collector fog-water data exist. At the reforestation site, a total of 620 1-year-old seedlings of *Pinus pinaster* and *Quercus ilex* were planted in an area of about 2500 m^2. Water from the 18-m^2 flat panel collector was stored in high-capacity tanks and small timely water pulses localized deep in the planting holes were conducted during the first summer period by means of an irrigation network. Results indicate that survival rates and seedling performance of the two species planted improved with the use of small timely waterings and additional treatments with composted biosolid.

1. Introduction

The experimental site selected for the reforestation study (Mount Los Machos in Figure 1) is located in the interior of the Valencia region, western Mediterranean basin. The annual pluviometric regime ranges from 400 to 600 mm corresponding to a dry Mediterranean climate [4]. The region meets most of the geographical conditions for fog occurrence and collection potential as compiled in [5]. Previous studies using the mountain network of cylindrical collectors shown in Figure 1 have quantified fog water collection as a function of wind behavior at each of the specific stations [6], [2], [1]. The good potential shown by most of these locations brings to consider collected fog water as a new resource in restoration activities of remote areas where land degradation may be severe.

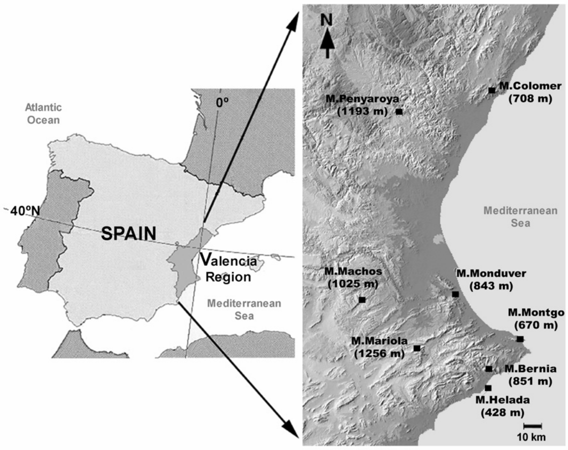

Figure 1: Map location for the restoration site at Mount Los Machos and rest of mountain stations using cylindrical collectors.

2. Methodology

The experimental site at Mount Los Machos could be divided into two parts: a fog-water collection and storing area and the reforestation plot itself, the former being 40 m above the latter. This difference in elevation alone resulted in a water pressure of about 4 atm at the end of each irrigation line. Site preparation and seedling planting took place from December 2006 to January 2007. The study uses data that extend into the whole year 2007.

At the top part of the experimental site, a cylindrical fog-water collector, an 18-m^2 flat-panel collector and three 1000-l water tanks were arranged for fog-water volume measuring, harvesting and storing. The cylindrical collector was part of an instrument ensemble holding other additional environmental sensors, being a rain gauge and a wind direction and velocity sensor the most remarkable. This cylindrical collector acts as a passive device and is handmade constructed using a pair of discs strung with nylon line to attain omnidirectional collection efficiency [2]. Additionally, an upper 60-cm diameter plastic tray carries out the function of a protective cover to avoid major rain interference [3]. The collected fog water volume per unit area (l/m^2) is calculated by dividing the collected volume by the effective collection surface of the collector (base diameter times height).

The 18-m^2 flat-panel collector was also built using low-cost materials with final dimensions of 6.4 m in width and 2.8 m in length. Fog droplets are captured on the panel mesh, and, as they become bigger, they flow downwards under gravity. Water accumulates into a tilted gutter that connects through a hose with three interconnected 1000-l tanks to store water. Water flow produced by the flat panel was measured using a level pressure sensor that was permanently maintained at the bottom of one of the tanks. According to previous data taken by the cylindrical collector, the flat panel was deployed at a fixed orientation of 55º from North in order to attain maximum efficiency during fog harvesting.

Water treatments for the two-species seedlings, *Pinus pinaster* and *Quercus ilex*, consisted of natural precipitation as the control (C), one or two water pulses of ca. 4.5 l/hole during the first summer (W1 and W2, respectively), and rainfall exclusion (-W), the latter conducted by means of a plastic sheet being deployed before a rainfall event. During an irrigation pulse, water was injected to 20-25 cm deep by means of microtubing connected to each emitter. In half of the planting holes of each treatment, composted sewage sludge from a local composting facility was applied and mixed in situ with the soil at an application rate of 22 t dry weight per hectarea.

3. Results

3.1 Fog-bearing winds

In Figure 2, the percentage of winds for which any amount of fog collection has occurred is shown in the top windrose, while the percentage of fog water in the total accumulated volume collected at a certain wind direction and velocity is represented in the bottom windrose. A noticeable component peaking between the NE and ENE (55º from North approximately) marks the most efficient direction.

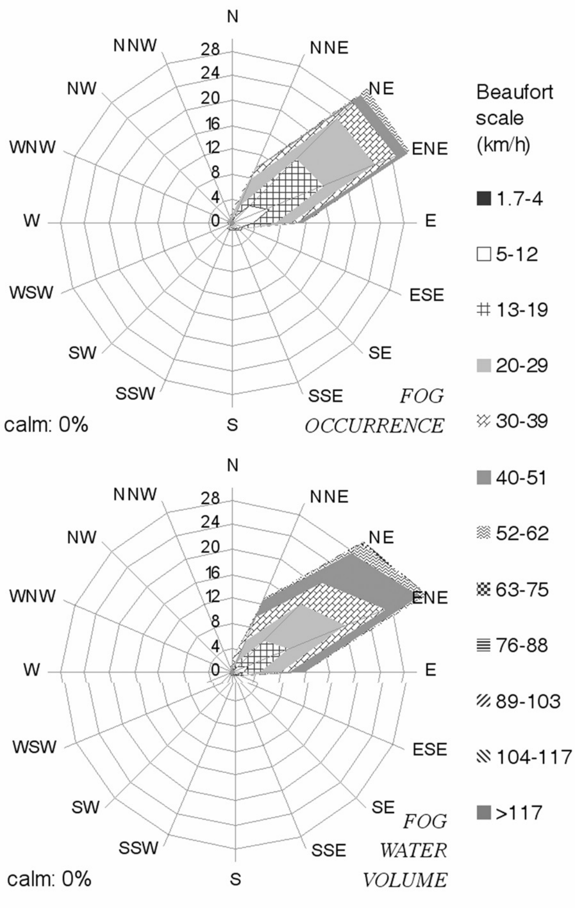

Figure 2: Wind roses that combine data from the cylindrical collector and the wind velocity and direction sensor.

3.2 Omnidirectional fog yields

Monthly fog collection and precipitation rates are obtained as the ratio of water collected volumes to the length in days of available data for each month (Figure 3). The 2007 annual rate given by the cylindrical fog collector, 3.3 $l/m^2/day$, contrasts with the measured rainfall rate, 1.4 $l/m^2/day$. Although fog collection and precipitation are distinct variables, their comparison indicates the site potential for fog water collection in relation to rainfall availability. At this experimental site, collecting fog water seems more profitable and less costly than collecting rain water since fog provides at least twice as much water.

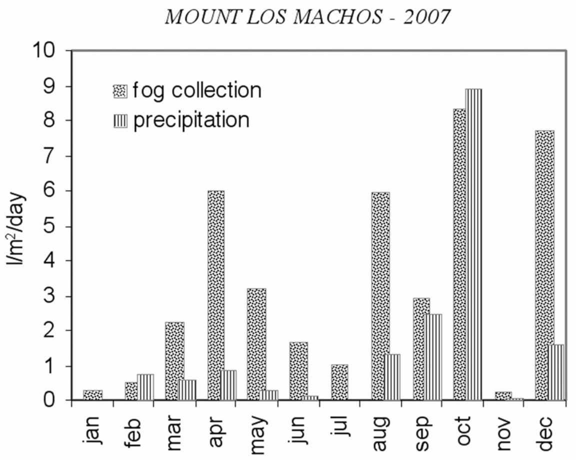

Figure 3: Monthly rates of rainfall and fog collection, given by the cylindrical collector and the rain gauge.

3.3 Seedling survival

After three years from planting, seedling survival was above 60 and 90% in maritime pine and holm oak, respectively, both for the water pulses treatments during the first summer (Figure 4). The three factors included in the analysis: two species, two types of fertilization and four water treatments, resulted in significant differences in seedling survival. Holm oak survival was significantly higher than maritime pine, and survival with compost application was slightly but significantly higher than in unfertilized seedlings. The water exclusion treatment (-W) showed the lowest survival in both species and fertilization treatments. Control seedlings showed intermediate values between the exclusion and the two water pulses treatments in most of the cases. There is a small vanishing tendency of the watering effects as time goes by.

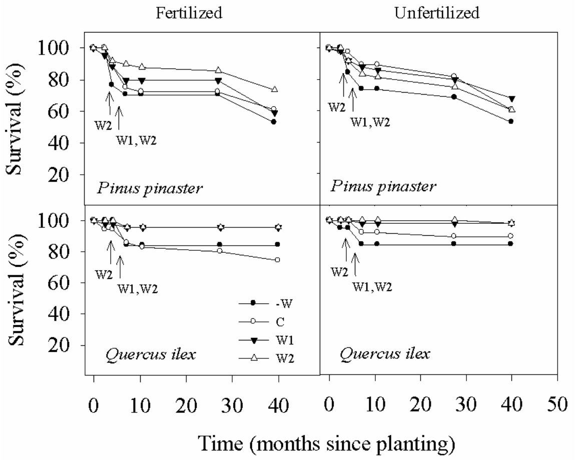

Figure 4: Dynamics of survival in *Pinus pinaster* and *Quercus ilex* seedlings according to different water and fertilization treatments.

3.4 Flat-panel and cylindrical collections

The plot in Figure 5 is obtained when comparing the hourly tank water flows with the cylindrical collector fluxes at the direction of the orientation of the flat panel, as shown by equation 1 [1]. The observed linear tendency proves a 1:1 relation within the limits of the estimation error. It is possible then to predict directional collection rates from omnidirectional data.

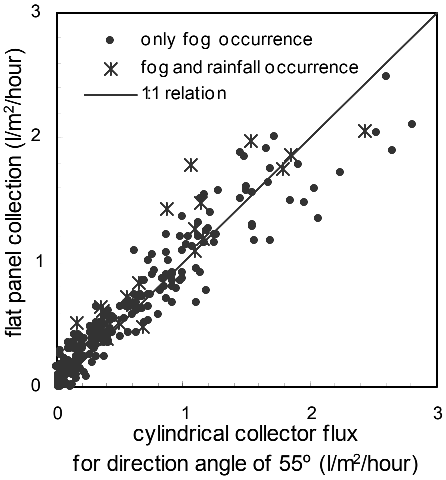

Figure 5: Scatter plot of match-up data from the flat panel and cylindrical collectors.

$$\phi_h = \sum_{1h} f_i \left|\cos(55^o - \theta_i)\right| \qquad (1)$$

where θ_i is the 10-min wind direction, f_i is the cylindrical fog collection in the 10-min period, and ϕ_h is the hourly fog-water flux calculated at the 55º direction, which is the orientation of the flat panel.

3.5 Estimating flat-panel yields

Equation (1) was used to estimate annual rates of fog water collection at different flat-panel hypothetical orientations that could be arranged at each mountain station of our fog collection network (Figure 6). Maximum efficiencies can be achieved at a specific orientation for each station. Some of the stations present little oscillation with respect to orientation.

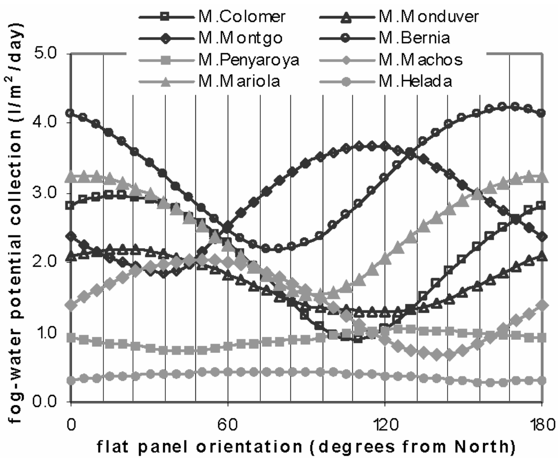

Figure 6: Annual flat-panel fog collection rates estimated by means of equation (1) versus orientation.

Finally, potential fog-water harvesting by an 18-m^2 flat-panel collector for the CEAM network is given in Table 1. The orientation for which maximum efficiency is attained varies with station as well as the ratio of flat-panel over cylindrical collection.

Table 1: Estimated fog water potential by 18-m^2 flat-panel collectors efficiently arranged at each station.

Mountain station	Orientation (º from N)	Fog water collection (l/m^2)	Ratio (flat over cylinder)	18m^2 flat panel collection (m^3)
Colomer	20	1080	0.92	19
Penyaroya	125	379	0.73	7
Monduver	20	801	0.81	14
Machos	50	746	0.91	13
Montgo	115	1343	0.83	24
Mariola	0	1188	0.83	21
Bernia	170	1539	0.82	28
Helada	85	158	0.73	3

6. Summary and Conclusions

The study has stated the use of fog water collection on mountainous locations in the restoration of degraded land in dry Mediterranean climates. In spite of the mild summer conditions during the field campaign, seedling survival was still promoted by small water pulses during the first summer. Ancillary data allowed the conversion of omnidirectional fog-water collection yields into specific directional values, as it is typical of flat-panel collectors.

Acknowledgements

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