Collection of Fog Water for the Restoration of Degraded Forest Areas in a Western Mediterranean Basin Region. Preliminary results

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ABSTRACT

A mountainous location has been identified for reforestation using the fog water collection potential that exists in the area. The forest area has been burnt several times and its self-recovery has been determined difficult. Thus, this study attempts to use the fog water collected by means of two large flat panels, several water storage tanks and a micro-irrigation network to increase the survival rate of reforestation seedlings. The experimental set-up is discussed and some preliminary results are given in terms of a wind analysis of the fog instrument ensemble data.

1. INTRODUCTION

A previous study (Estrela *et al*., 2004) showed the good potential for fog water collection at certain mountainous locations in the Valencia region of Spain. Annual rates of fog water yield can be significant, and summer rates can also be important if they are compared to the usually null precipitation occurring during this season. A new, easily available water resource would be desirable for the restoration of forest vegetation that has been degraded by the long-term effects of fire. In some areas, native forest vegetation cannot recover by itself. Furthermore, only a small percentage of seedlings in a new reforestation manages to survive after the dry season. The need for some input of water during the dry season is evident. Only two properly-administered waterings during the first and second year after planting would be sufficient for the survival of the seedlings.

To develop this study we selected a location in the interior of the Valencia region, Mt. Los Machos, which fitted our criteria. This site combined the appropriate orographic conditions, the probability of fog presence as indicated by local residents, and local support. Figure 1 shows the geographical location of the study area.

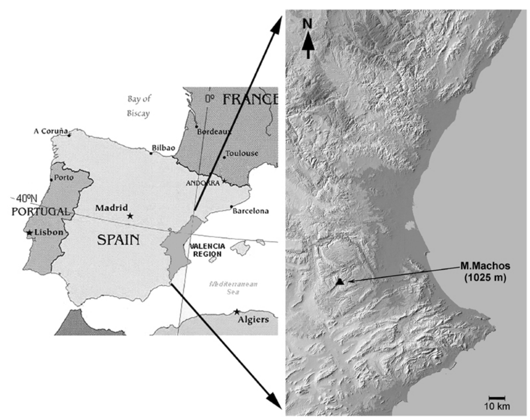

Figure 1. Geographical situation of the experimental site.

2. METHODOLOGY

The experimental site can be perfectly divided into a fog catchment site with all the accoutrements necessary for collecting and storing water and a reforestation plot where the collected water is managed for irrigation.

2.1 Reforestation experiment

The pilot plot is an inland mountainous location, covering a nearly flat area of 2500 m^2. It is situated on a hillside with SE to NE exposition at 971 m a.s.l. and 60 km inland from the nearest coastline. Vegetation is dominated mainly by germinating shrubs such as *Ulex parviflorus*, *Cistus albidus* and *Rosmarinus officinalis*, although *Juniperus oxycedrus*, *Juniperus phoenicea*, *Pinus halepensis* and *Pinus pinaster* are present in scattered patches. The effects of forest fires, and especially of the fire that burnt around 32000 ha to ashes in the summer of 1979, are clearly visible on the plot location. As a result, large and continuous extensions of highly flammable shrubs have emerged and few isolated woodland patches are left (Baeza *et al*., 2007). The presence of small pine individuals among the shrubs is low and it may be due to seeds spreading from the woodland patches.

As the reforestation experiment was to be conservative, only two native species, *Pinus pinaster* and *Quercus ilex*, have been introduced. These two species are perfectly integrated into both the climatic and soil conditions. In particular, *Pinus pinaster* has a high capacity for rapid colonization and is representative of this region. *Quercus ilex* is a local species of high ecological value due to its capacity to resprout after fire (Pausas *et al*., 2004) and to develop into mature-stage forests. Nevertheless, natural forest recovery has been impeded by recurrent fires that have led to the large extensions of shrubs that are typical in the successive stages of degradation. Results will be widely extrapolated to other areas of similar characteristics in the Valencian Community.

Plot preparation involved clearing the preexisting vegetation to avoid plant competition during the establishment of the reintroduced species. Waste from the clearing was crushed in situ and scattered as mulch. Use of this technique in other experiments has proved effective in reducing the potential fire risk by controlling the germination of certain highly flammable species of shrubs, like *Ulex parviflorus* (Baeza *et al*., 2005). On the other hand, individual large shrubs of sprouting species, like *Juniperus oxycedrus* and *Juniperus phoenicea*, and of the pine species, *Pinus halepensis* and *Pinus pinaster*, were left intact during the clearing process.

Soil conditioning involved digging holes with a backhoe; this yielded an average density of 2500 plants per hectare. Plantation was made by alternating the two reintroduced species. Each planting hole features a small basin to improve rainfall collection and storage as well as a group of three stones at the stem base to prevent excessive moisture evaporation, heating in summer, freezing in winter, and/or the appearance of weeds. Moreover, each plant is covered with an individual plastic protector that avoids damage from herbivore or rodents. The plot perimeter has been fenced using cattle mesh since shepherding is typical in the area.

The aim of the plantation experiment was to determine the minimum amount of water needed by the introduced species to survive their first summer and possibly their second one as well. Any technique for supplying water to newly planted tress should also take into account plant survival after the irrigation phase, so that the ability of the species to adapt to the new conditions is not compromised. Thus, three levels of irrigation were to be tested: none, medium and high, and these would be implemented twice a year, at the beginning of spring and summer, always in accord with the climatic conditions. Sampling soil moisture, photosynthetic activity and water potential would indicate the precise moment for irrigation. A particular irrigation technique, called micro-irrigation, was selected for this implementation; it involves traditional dripping but at a depth of 20-30 cm below the soil surface. The micro-irrigation technique favors deep rooting in both species and avoids both the excessive evaporation and the weed appearance that take place with surface irrigation.

Soil treatment techniques that use organic residues, biosolids and muds from wastewater treatment plants, were also employed when planting the seedlings. In Mediterranean climates, the addition of biosolids in the planting holes has proven to improve the individual tree growth notably during the first years although it can also generate an increase in salinity and therefore negative effects (Fuentes *et al*., 2007). Implementing the micro-irrigation technique can avoid these problems by reducing salinity effects and improving plant growth.

2.2 **Fog water catchment set-up**

Fog water was collected at an elevated site above the reforestation plot. Located over a SW-to-NE valley, the site is on a cliff that drops about 40 m to the reforestation plot and then another 300 m to the valley floor. This site is higher than the surrounding area and meets most of the conditions for fog collection potential. As a first step, a fog instrument ensemble (Estrela *et al*., 2004), consisting basically of a passive cylindrical fog water collector, a rain gauge, a wind direction and velocity sensor and a temperature and humidity probe, was deployed at the fog catchment site. This ensemble uses a handmade cylindrical fog collector which is based on the ASRC (Atmospheric Science Research Center, State University of New York) string collector and yields omnidirectional collection efficiency (Falconer and Falconer, 1980). The instrument ensemble must be left in the area to register the environmental conditions present at fog collection in order to obtain information for subsequent activities. The most advisable orientation for the flat panels can be derived from the interpretation of wind statistics in relation to fog occurrence (Estrela *et al*., 2007).

Two large flat panels were built to be installed on the fog water catchment site (Figure 2). Each panel is kept erect by 2 anchored steel poles of 5 m in length. The mesh chosen was a UV-resistant Raschel woven netting in HD polyethylene monofilament acquired at an agricultural materials store. A double layer of mesh reinforced with plastic-coated galvanized wire was used to build the net. Final panel dimensions are 6.4 m in width and 2.8 m in length, resulting in a collection surface of 18 m^2 for each panel. The fog water caught by the net runs into a tilted gutter that has a hole at one of its ends. Other hardware elements such as eye nuts, support cables, shackles, snaps, pulleys, braces and winches were purchased at local stores. Their arrangement when supporting the net was tested with a prototype following several models found in Marzol (2005) and Heerden (2004).

Figure 2. Flat panel prototype being tested at CEAM headquarters.

The gutter fixed to the net bottom and was connected to a PVC pipe that ends in three 1000-litre water tanks. A pipe connection between the tanks keeps the water at the same level, with a maximum storage of 3000 liters per deposit. The main water conduction extends between the water tanks and the reforestation plot. The resulting pressure produced by the difference in elevation is about 4 atm, which is sufficient for irrigation applications. Once on the reforestation plot, the conduction splits and distributes water over an irrigation network that reaches each of the planted seedlings. The three possible irrigation conditions, none, medium and high, can be present in the same row in an alternating way. The seedlings of the two species were also homogeneously distributed. A total number of approximately 900 seedlings were planted over an area of 2500 m^2. Figure 3 shows the irrigation layout implemented on the fog water catchment site and the reforestation plot.

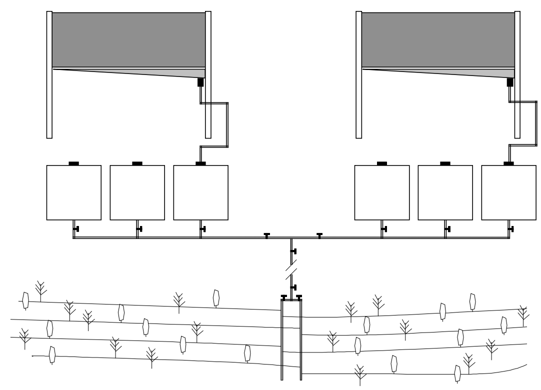

Figure 3. Irrigation system layout

3. **RESULTS**

Results are only preliminary since all the systems/seedlings have been deployed/planted recently, and use of the stored fog water is expected at the beginning of the dry season. By the moment, the only data we have been able to process correspond to the measurements obtained from the fog instrument ensemble. The most valuable information has been produced by the wind data in combination with both fog event occurrence and collected fog water volume. This information has been used to improve the orientation of the flat panels so as to attain maximum efficiency.

Figure 4 shows wind statistics over 6 months for the fog water catchment site according to both a 16-direction wind rose diagram and the Beaufort wind velocity scale. The wind rose at the top is derived from the entire set of wind data, the one at the left-bottom uses only wind data with simultaneous fog occurrence, and the one at the right-bottom gives the percentage of fog water over the total accumulated volume collected at a certain wind direction and velocity. The calculations involved for the right-bottom wind rose follow a similar procedure to those for the left-bottom wind rose, but in the latter each fog collection occurrence is weighed according to the water volume yielded. The general wind rose for all data shows that the most frequent winds are distributed in two components: a dominant one (around the WNW direction) and a very small one (around the NE direction). The other two wind roses, for which the wind data is processed depending on fog occurrence and collection, present only one large component that stretches towards the NE with a 45° width. This implies that on our site, winds carrying fog do not normally agree with the most frequent winds; rather, they generally come from the NE, which coincides with the valley orientation and is the shortest way to the coastline. Aligning the flat fog-collection panels with this in mind will increase productivity and may also lessen the effects of the WNW winds, which are the most frequent and the strongest ones in the area.

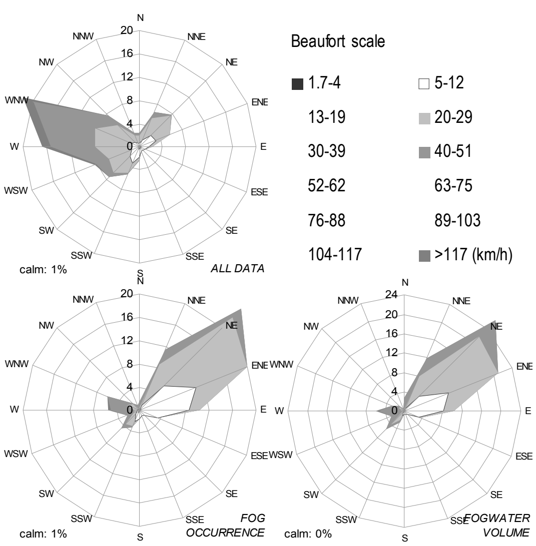

Figure 4. Wind roses for the six-month period

4. ACKNOWLEDGEMENTS

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