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Radiation regime and temperature conditions in the canopy of the succulent shrub *Euphorbia balsamifera*

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RESUMEN: El arbusto suculento *Euphorbia balsamifera* con un dosel individual semiesférico, en forma de sombrilla, tiene un microclima propio y en alguna extensión desacoplado del de las condiciones mesoclimáticas ambientales. Se caracteriza por un sobrecalentamiento interno durante la mañana y primeras horas de la tarde, combinado con un mayor deficit de saturación del aire y una inversión de estas condiciones durante las últimas horas de la tarde y primeras de la mañana. Este microclima parece ser el resultado de un régimen de radiación especifico y de una drástica reducción de la velocidad del viento. El alto valor del albedo de la brillante y glauca superficie del arbusto se encuentra en el rango de los arbustos enanos alpinos y puede interpretarse como una estrategia para disminuir en su interior la insolación, la transpiración y evaporación del suelo, frente a un ambiente semidesertico exterior.
Palabras clave: *Euphorbia balsamifera*, microclima, radiación, morfología, dosel semiesférico, ambiente semiárido, Islas Canarias,

ABSTRACT: The succulent *Euphorbia balsamifera* shrub with an individual hemispherical, umbrella-like canopy forms a distinct microclimate, which is - to some extend - decoupled from the ambient mesoclimatic conditions. It is characterized through an overwarming of the shrub interior during morning and early afternoon combined with a higher air saturation deficit and a conversion of these conditions between late afternoon and early morning. This microclimate seems to be the result of a specific radiation regime and a drastically reduced wind speed. The high albedo values of the bright glauceous shrub surface lie in the range of alpine dwarf shrubs and could be explained as a strategy to decrease insolation, transpiration loss, and soil evaporation inside facing a semi-desert environment outside.
Key words: *Euphorbia balsamifera*, microclimate, radiation, morphology, hemispherical canopy, semi-arid environment, Canary Islands

INTRODUCTION

The succulent spurges with terminal leaf rosettes (genus *Euphorbia* sect. Tithymalus) are an integrate part of the paleotropical arid zone, extending from the Canary Islands to the Near East (fig. 1A). These spurge shrubs express their leaves after the precipitation of an annual regular rain season, delivered in the western populations by the Mediterranean climate influence and in the eastern ones by the monsoon. *Euphorbia balsamifera* is a remnant of a Tertiary or even older drought-adapted vegetation type in northern Africa in suitable habitats (AXELROD & RAVEN, 1978; VERDCOURT, 1969). Morphologically, this species differs from the others out of the Tithymalus group through the hemispherical shape of the bush adpressed to the substratum. All other species express an umbrella-type morphology. It separates in the western subspecies *balsamifera* growing from Portugal-Morocco to the Canary Islands and the mountains of western Africa and an eastern one, ssp. *adenensis*, on the mountains of NE Africa and Arabia (BALLY, 1965). Regarding the representative study area of our experiments, the species grows on the Canary Islands in a belt nearest to the sea (RIVAS-MARTÍNEZ et al., 1993, fig. 1C), whereas all other populations are situated in mountain ranges or semi-desert locations.

On the Canary Islands the species has the potential to endure a physiological dryness near the coasts, influenced by high osmotic potentials in soils caused by the sea-foam. *Euphorbia balsamifera* is the dominate species, accompanied by the shrubs of *E. canariensis, E. obtusifolia* ssp. *regis-jubae, Plocama pendula* and *Campylanthus salsoloides*. The community has been described as a phytosociological subclassification of the succulent shrub belt of its own (*Periploco-Euphorbietum canariensis* subass. *euphorbietosum balsamiferae* RIVAS-MARTÍNEZ et al., 1993). In the *E. balsamifera* belt near to the sea all other species depends on the occurence of the dominating species as a nurse plant in seed germination and growth, growing in the hemispherical canopy or near related to it (MIES in prep.). The environmenatlly essential morphology of this species led to a variety of ecological questions.

In this article, the morphology is discussed in relation to high insolation in a semi-desert environment. The function of the specific plant morphology of *E. balsamifera* is examined in relation to the radiation regime. The species may represent here a model for studying wind, specific thermal conditions outside and inside the canopy as microclimatic gradients, and the energy economics under the conditions of high solar radiation and potential drought stress. The detailed analysis of the energy and water balance of an *Euphorbia balsamifera* shrub would be the general part of a further publication. Out of the same Canarian vegetation type, the evaporation, temperature courses and the transpiration of *Plocama pendula* (GESSNER,1985) and *Euphorbia canariensis* has been investigated (LÜPNITZ & LADWIG, 1992) before.

The radiation environment has been intensively studied within homogeneous, agricultural monicultures (SZEICZ, 1974), alpine dwarf shrubs (CERNUSCA, 1976a,b), coniferous and deciduous forests (TAJCHMANN, 1972; RAUNER, 1976; BALDOCCHI et al., 1984) of the temperate and boreal zone, mediterranean shrublands (CALDWELL et al., 1986), tropical and temperate rain forests (ALLEN, 1972; SHUTTLEWORTH et al.,1984, 1985), whereas general data are lacking for the succulent vegetation of subtropical dry zones.

MATERIAL AND METHODS

The site of the measurement is situated on a relatively young dark lava field at the Malpaís de Güímar on the SE coast of Tenerife Island (28°18'30"N, 16°22'00"W, Canary Islands, Spain). A shrub of *Euphorbia balsamifera* has been chosen 300 m from the sea-shore, at 60 m a.s.l., and in SSE exposition (fig. 1B&C). It covers a ground area of approximately 12 m^2 with mean canopy heights between 1.0 and 1.1 m. The chosen shrub nearly has an ideal position to the axis of sun exposure, regarding that sunset occurs behind a mountain range in the west in the late afternoon. The climate (fig. 1D) of the study area is classified as warm and semiarid, with moderately hot summers and mild winters resulted in an annual mean temperature of 19.5°C. The annual precipitation averages 181 mm in a 18 year term with rainfall in winter and severe drought periods in summer (see RIVAS-MARTÍNEZ et al., 1993; HUETZ DE LEMPS, 1969) . Relative air humidity (RH) keeps in the range of 40 - 70% blown by the maritimic NE trade-winds, whereas low humidity at 10 - 20% is only occuring in occasional situations by Saharan winds from the East.

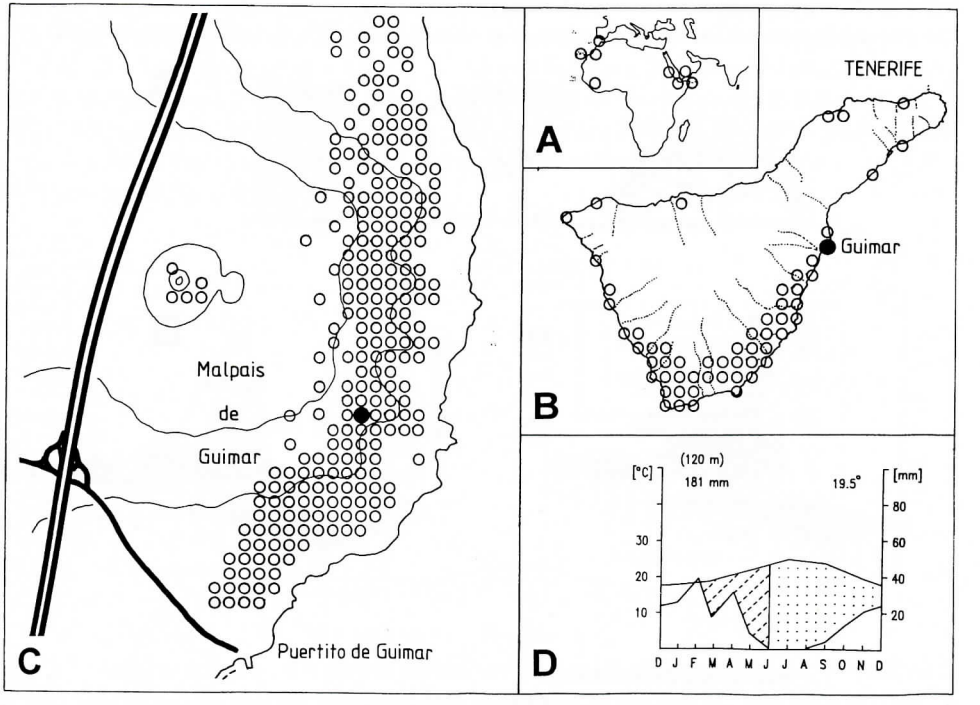

Fig. 1 Distribution of the succulent spurge shrub *Euphorbia balsamifera* in Africa **A**, on Tenerife Island (Canary Islands) **B** and on the Malpais de Güímar **C**. In Africa and the Canaries, the western populations belong to ssp. *balsamifera* and the eastern ones to ssp. *adenensis*. On Tenerife, stands are figured with a domination of this species. **D** The climate diagram from the nearby station Güímar (120 m) shows a semi-arid climate type with the plant available soil water potential in dashed hachures (in the sense of THORNTHWAITE, climate data after RIVAS-MARTÍNEZ et al., 1993)

The leaf area index (LAI, plan area of leaves per unit ground area) of the *Euphorbia balsamifera* shrub was determined by harvesting all the foliage of five representative areas each of 0.25 m^2. Individual leaf areas was measured with a leaf area meter (LI 3100, LICOR) and related to the area covered by the canopy.

Vertical profiles of photosynthetic active radiation (PAR, SKP 210/215, SKYE), global shortwave radiation (GR, TSM-tube solarimeter, DELTA-T and pyranometer 1610, LAMBRECHT), air temperature (thermistor CS/CM-U-V5, GRANT), relative air humidity (HMP 35 TH, VAISALA) and wind speed (three-cup anemometers 14572 and 1442, LAMBRECHT) were determined by measurement of microclimatic parameters at two positions above and three levels (soil level, 40cm, 80cm height) within the spurge shrub (see fig. 2B). Net radiation (NR, net pyranometer 8110, SCHENK) and reflection of PAR / global radiation were measured with inverted sensors mounted in standard distance (1.0 m) above the shrub surface. Leaf, stem and soil surface temperatures were assessed with several fine-wire copper-constantan thermocouples (HERAEUS). Sensor signals were scanned every 30 seconds and mean values were stored every five minutes with two data loggers (Squirrel 1200/1250, GRANT). Micrometeorological studies were performed intensively during five days in May and in December 1994, one day of the measurement period in December was selected for this detailed presentation.

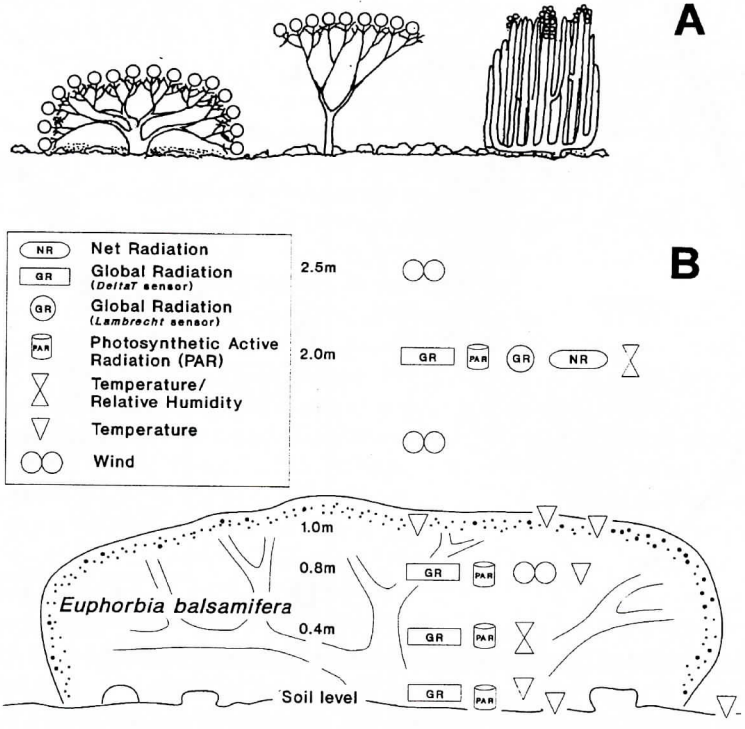

Fig. 2 **A** Morphology of a hemispherical *Euphorbia balsamifera*, an umbrella-shaped *E. obtusifolia* ssp. *regis-jubae* and the candelabrum *E. canariensis* (from left to right). **B** Microclimatic instrumentation above and within the *Euphorbia balsamifera* shrub at Malpais de Güímar (Tenerife)

RESULTS

The diurnal courses of photosynthetic active radiation (PAR) and netto radiation (NR) were quite similar to those of global radiation (GR), so a linear regression of the radiation components outside the shrub could have been established:

$$NR\ [W/m^2] = 0.81\ GR - 63\ [W/m^2],\ R^2=0.97$$

$$PAR\ [\mu mol\ photons/\ m^2\ s] = 1{,}97\ GR\ [W/m^2],\ R^2=0.98$$

Global radiation (GR) above the shrub showed a typical curve for a bright day with frequent changes of sunny and cloudy periods, with radiation values about 300-500 W/ m^2 between 9:00 and 15:00 hours (solar time) and maximum values around 600-700 W/m^2 at midday (fig. 3A).

At the 0.8m-level within the shrub most GR values lay between 150-200 W/m^2 except shorttime maximum values from 300 to 400 W/m^2 around midday. At the 0.4m-level the maximum radiation values hardly exceeded 200 W/m^2 with base values about 100 W/m^2, whereas the irradiance at soil level lay around 50-60 W/m^2 (fig. 3A).

At the 0.8m-level most PAR values ranged between 200 and 300 µmol photons / m^2 s with rare peaks about 1000 µmol, at the middle of the shrub the normal values of 200 µmol were interrupted by shorttime values between 800 and 900 µmol photons / m^2 s. At soil level the PAR values only increased in sunflecks to values above 100 µmol photons/ m^2 s (fig. 3B).

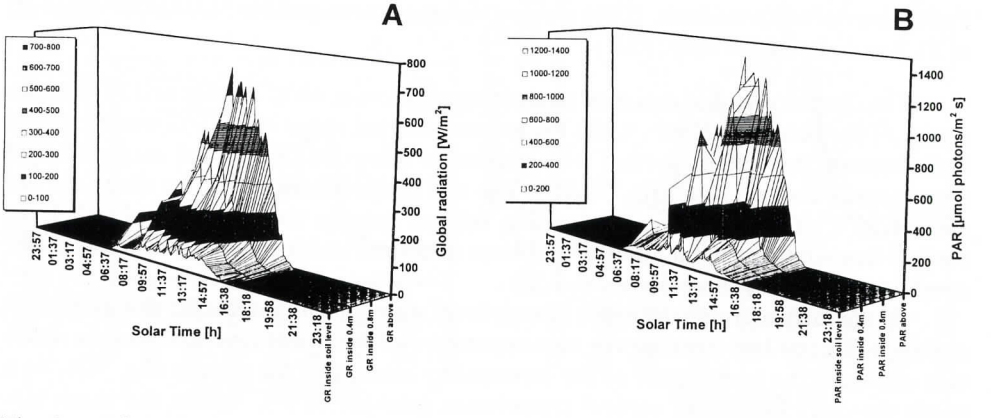

Fig. 3 Diurnal courses of **A** global radiation (GR) and **B** photosynthetic active radiation (PAR) above and within the spurge shrub *Euphorbia balsamifera,* illustrate as vertical profiles (December 1994).

20% of incident global radiation and 13% of PAR were reflected by the shrub canopy. Incident GR was reduced about 56% by the upper 20-30 cm thick layer of foliage and small branches with a leaf area index of 1.13, 25% reached the centre of the shrub and about 11% penetrated to the ground. PAR was attenuated to 43% from the upper shrub layer, 31% reached the 0.4m-level and 13% penetrated to the soil level. (fig. 4).

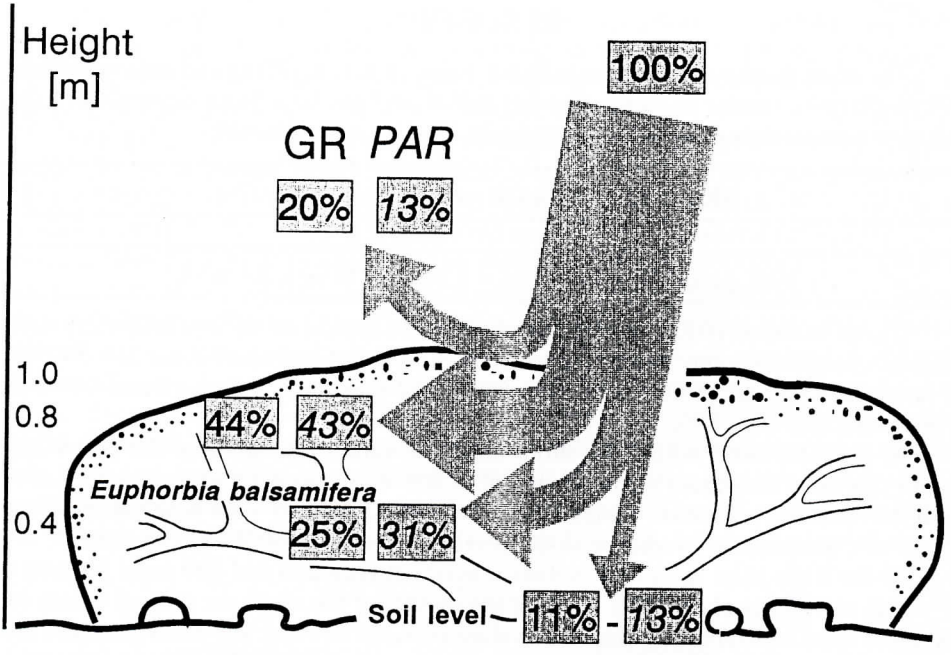

Fig. 4 Partitioning of the incident global radiation (GR) and photosynthetic active radiation (*PAR*) at the different layers within the hemispherical canopy of an individual *Euphorbia balsamifera* shrub, 100% incident radiation correspond to 11.0 MJ/m² day (GR) or 21.7 mol photons/m² day (PAR)

The diurnal range of variation in air temperature was 10°C outside and 12°C in the centre of the succulent shrub, while the greatest diurnal range of 13.3°C was measured close beneath the canopy surface with maximum values of 28.5°C and maximum leaf temperatures around 30°C (fig. 5D&E). The soil temperatures below the shrub did not exceed 25°C (fig. 5E), whereas the lava surface outside was heated to 43°C. Lava surface temperatures about 50-60°C has been measured under summerly macroclimatic conditions (data not shown).

At the early morning the upper canopy level warmed with increasing sun irradiation at first, before at late morning the air temperature of the lower levels within the shrub also exceeded the temperature of the surrounding air outside the canopy (fig. 5D). As a result the daily maximum vertical temperature gradient of 6°C within the shrub was developed already around 8.00 h (solar time).

The warming of the air within the shrub was connected with a higher saturation deficit of 100-200 Pa for almost 5 hours around midday, while during the rest of the day the body of the shrub acted as a water vapour source with lower air saturation deficits (fig. 5B) than outside the canopy, resulted in 6-8% higher air humidity values. The absolute air saturation deficits varied between 0.5-1.5 kPa at night and 1.5 -3 kPa during daytime (fig. 5C), while the relative air humidities ranged between minimum values of 15-20% at afternoon and 60-70% during night.

In the late afternoon the temperatures in the upper canopy became cooler than those in the body of the shrub due to radiative cooling at the canopy-air surface resulted in a net loss of longwave radiation with values between -75 and -80 W/m² (fig. 5A). The insulating effect of the vegetation kept the soil surface cooler during the day and warmer during the night than the shrub surface. The drastic reduction of the wind speed by the upper canopy to a third of the outside air velocity (data not shown) supported the heat storage of the shrub centre during the daytime until the early evening.

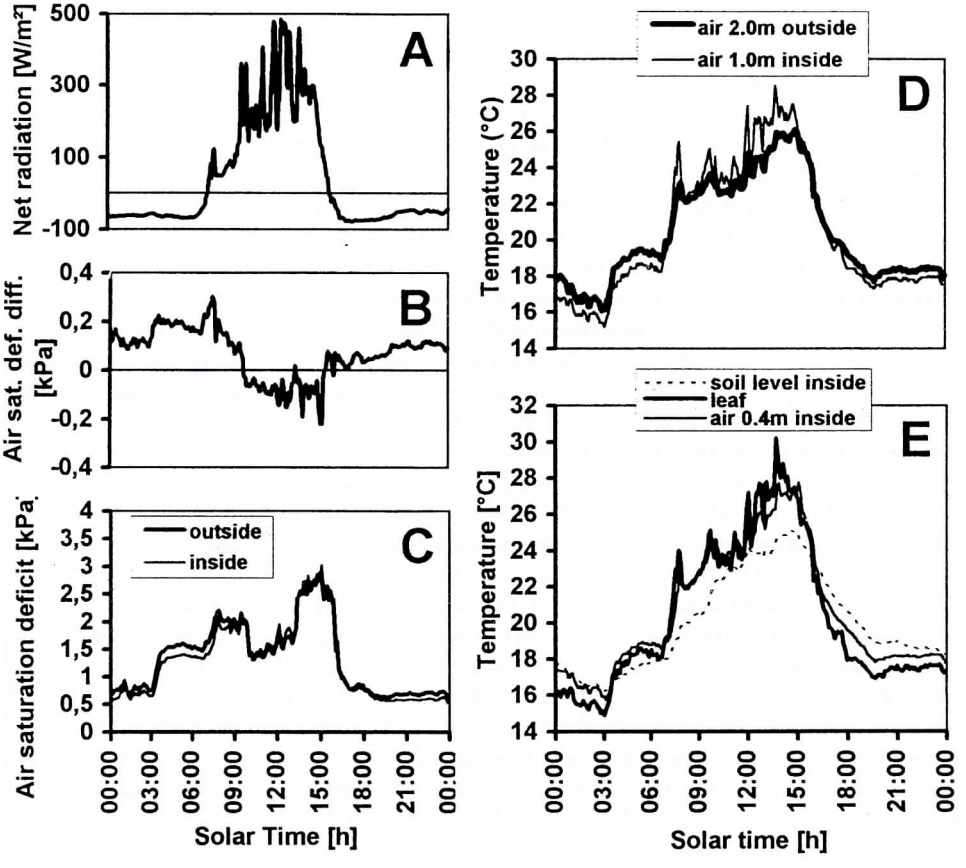

Fig. 5 Diurnal courses of microclimatic elements in and above the hemispherical canopy of *Euphorbia balsamifera* (13. December 1994): **A** Net radiation 1.0m above the shrub canopy. **B** Air saturation deficit difference between outside and inside air humidity conditions. **C** Absolute air saturation deficit outside and within the shrub. **D** Air temperature outside (2.0m) and within the top canopy layer (1.0m). **E** Air temperature (0.4m) within, leaf temperature and soil surface temperature below the shrub

DISCUSSION

The radiation environment within vegetated canopies depends on sun-earth geometry, atmospheric conditions, site-specific factors of vegetation (e.g. canopy architecture, optical properties of the phytoelements) and topography (see Ross, 1981). The shortwave reflection of the *E. balsamifera* shrub ranged between the albedo of meadows (22-25%, EILS, 1972) and forests (10-15%, KIESE, 1972) in the order of magnitude of alpine dwarf shrubs (17-20%, CERNUSCA 1976 a,b) or evergreen scrubs (Maquis, 21%, MONTEITH & UNSWORTH, 1990). PAR reflection lie above the ratios of alpine dwarf shrubs (5-6%, CERNUSCA,1976 a,b). The high reflection coefficients of the *E. balsamifera* shrub can be considered as a strategy of plants under high irradiance exposures, occuring in deserts, sea shores or highlands, to reduce the input of solar energy (GATES, 1980). Otherwise, the energy input result in an increase of leaf temperatures to lethal levels (ELLER & FLACH, 1990). This high reflectivities - especially in the vitally active wavelengths - can be effected by adaptations of individual leaves to moisture stress (e.g. waxy leaf surfaces, leaf hairs, thick leaves), which clearly influence the optical properties of leaves (SINCLAIR & THOMAS, 1970). HEMMERS et al. (1986) and GÜLZ et al. (1988) reported the high quantity of liquid and crystalline wax components with reflective or fluorescing characteristics on the surfaces of Mediterranean spurges.

The global shortwave absorption pattern of the *Euphorbia* shrub corresponds well with the shortwave radiation climate in an open alpine pine-forest (CERNUSCA, 1976c), where almost 60% of the incident GR is absorbed by the upper canopy layer and 28% reaches the lower parts of the stand. The amount of radiation penetrating to the ground exceeds above those reported for alpine dwarf shrubs (1.4-7.6% (PAR), CERNUSCA, 1976a) and forests (4.2% (GR), 2.0% (PAR), ASCHAN et al., 1994; 0.5-2.5% (PAR), KIRA & YODA, 1989) and characterizes the shrub canopy as an open one. The intercepted fraction of incident solar radiation depends on the area of foliage (LAI) and on the spatial distribution of foliage with respect to the direction of radiation. Due to the low LAI of 1.13 and in consideration of the albedos of 20% (GR) and 13% (PAR), approximately 45% (GR) and 51% (PAR) of the remaining radiation is absorbed by the upper canopy layer with the photosynthetic active foliage and the rest of 41% (GR) and 34% (PAR) is intercepted by the succulent stems and branches. The greater PAR attenuation in relation to global shortwave interception is caused by the preferential absorption of PAR from the leaves and has been obtained for several plant communities (e.g. forests, BALDOCCHI, 1984). The interception of radiation by the stems and branches was in the order of magnitude reported by YIM (1969) for some shrub and herb communities.

The air temperatures are kept on a higher level throughout the day like a warm bubble inside of the hemispherical shrub. The location of the maximum air temperatures in the upper canopy layer has been reported also for crops (BROWN & COVEY, 1966), alpine dwarf shrubs (CERNUSCA, 1976a) and forests (BAUMGARTNER, 1956; ELIAS et al., 1989). This overheating of the living tissue and the ambient air is caused by the absorption of radiation and the partitioning of this absorbed energy mainly by sensible and latent heat exchange with the atmosphere. Therefore, the maximum air temperatures within the shrub occurs in a region, where the canopy is increasing in density and the irradiation does not yet decrease too much. During

daytime temperatures decrease both upwards and downwards from this level of maximum heating so that sensible heat is carried up into the air and down into the shrub, whereas at night a thermal conversion occured, which is characterized by increased temperatures upwards and downwards. This temperature minimum is a result of the distinct longwave radiation emission from the shrub canopy and leaded to a sensible heat flux into this active layer from both directions. The convective heat exchange is favoured by the very small leaf size of *E. balsamifera*, which effects a strong coupling of leaf temperatures to ambient air temperatures and avoids a severe overheating of leaf tissue. As a result leaf temperatures do not exceed air temperatures more than 2-3°C. Leaf temperatures around 3°C higher than air temperatures also reported by HÖLLWARTH & KULL (1979) for succulent shrubs near San Isidro (SW of Tenerife). As a further important drought avoidance mechanism, showed by several desert plants, *Euphorbia balsamifera* shed its leaves when confronted with extended dry periods.

In the context of the question of species domination in the vegetation type, the temperature can be regarded as an indicator for a variety of environmental factors selecting and promoting this special type of vegetation. The day temperature bubble indicates a close system of an individual plant, whereas most other vegetation types, so far examined (besides alpine dwarf shrubs), present data from dense interspecific canopies, which express their microclimate in interaction (e.g. laurel forest, ASCHAN et al., 1994). The individual canopy of *E. balsamifera* is not affected by the strong winds acting outside through the specific morphology of this species and the surface covered by the canopy is protected through the symmetrical shade. LÜPNITZ & LADWIG (1992) report the decrease of temperature as a consequence of shade from the inside of an individual shrub of *E. canariansis* from Gran Canaria, not specifying the influence of the affecting winds either. The morphology of *E. obtusifolia* e.g. and most other shrubs out of the area (see GESSNER, 1985 for *Plocama pendula*) are acting different from *E.* balsamifera in having a more or less open umbrella-shaped canopy (fig. 2A), which allows insolation and wind to diminish the chance for root protection, evaporation, and germination of seedlings. The protection of the own roots is essential for a plant species occuring under potential drought stress, if the parts in the substrate are near the surface because of gaining water and nutrition rapidly (shallow root system: NOBEL, 1989). Compared to that species, the morphology of *E. balsamifera* fits better to the highly insolated habitat, reflected even by the *E. balsamifera* vegetation belt closest to the shore halophytes. Interspecific differences in the canopy may reflect the different strategies that different species have to buffer severe drought stress in a fluctuating environment.

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