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The importance of horizontal precipitation for growth of juvenile stages of Dragon tree on Canary Island

DIPLOMA THESIS

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Title: **The importance of horizontal precipitation for growth of juvenile stages of Dragon tree on Canary Island**

Abstract: *Dracaena draco* is native to subtropical arid area of Macaronesia. Horizontal precipitation is an important component of water balance in such arid and semiarid areas. Morphological, anatomical and physiological adaptations to drought stress and demonstrated ability to absorb condensed water on the leaves into the stem tissues were discovered at *D. draco*. The aim of performed measurements was to quantify the importance of horizontal precipitation as an additional source of moisture during the critical period of juvenile stages of *D. draco* in Anaga (Tenerife). Measuring sets based on lysimeters measured the weight changes of seedlings placed in flowerpots hanging on the weights. The results of measurement proved that the seedlings can partly replace loss of water from evaporation by the water uptake from the atmosphere. Water uptake from the atmosphere took place mainly at night and the water output by transpiration predominated during the day. Horizontal precipitation replaced the evaporation by 6–10 % in the first period measured from October and did not replace the evaporation in the second period of measurements that started in January.

Key words: Canary Island, cloud forest, *Dracaena draco*, horizontal precipitation, Tenerife

Autor: Bc. Klára Lengálová

Název: **Význam horizontálních srážek pro růst juvenilních jedinců dračinců na Kanárských ostrovech**

Abstrakt: *Draceana draco* se nachází v subtropické aridní oblasti Makaronésie. Horizontální srážky jsou v aridních a semiaridních oblastech nezanedbatelnou složkou vodní bilance. U *D. draco* byly zjištěny morfologické, anatomické a fyziologické adaptace na stres suchem a prokázána schopnost absorbovat vodu kondenzovanou na listech do pletiv v kmeni. Cílem měření, v oblasti Anaga (Tenerife), bylo kvantifikovat vliv horizontálních srážek jako dodatečného zdroje vláhy v kritickém období juvenilní fáze vývoje u *D. draco*. Měřící sady na bázi lyzimetru zachycovaly změny váhy sazenic umístěných v květináči zavěšeném na váhách. Výsledky měření prokázaly, že sazenice dokáží ztráty vody výparem částečně nahradit příjmem vody z atmosféry. Příjem vody z atmosféry probíhal především v noci a výdej vody transpirací převažoval ve dne, horizontální srážka nahrazovala výpar o 6–10 % v první periodě měřené od října, v druhé periodě měřené od ledna už horizontální srážka výpar nenahradila.

Klíčová slova: *Dracaena draco*, horizontální srážky, Kanárské ostrovy, mlžný les, Tenerife

CONTENT

1. INTRODUCTION

Cloud forests provide very precious ecosystem services. Tree species in this ecosystem define the structure of forests and contribute to their resilience, trees also provide a wide range of products to the local inhabitants. However, cloud forests are botanically extremely rich and face to a threat to its existence as well as other tropical forests. Exceptional ecology and their location is predisposed to fragmentation of biotopes and mainly to climate change (Bubb et al. 2004).

Cloud forest is a unique ecosystem with two important aspects–hydrological and biological. From the biological point of view, the cloud forest has a great value because of high biodiversity with a significant number of endemic species (Bruijnzeel & Hamilton 2000; Hamilton 1995). From the hydrological point of view, the cloud forest is characterized by high proportion of horizontal precipitation in mode of water ecosystem (Hamilton 1995). The fog creates an exceptional microclimate (Hildebrandt & Eltahir 2006) and influences energy, light and temperature regime of the ecosystem and is the importer of a potentially large amount of water that is collected in the tree crowns (Hildebrandt & Eltahir 2008; Mulligan 2010). Cloud forests have the attention for their source of fresh water. The unique ability to capture the rainfall and horizontal precipitation is used by local communities.

Cloud forests are usually located in areas where the water is not limiting factor for the plants growth. However, the precipitation amount is low in cloud forests of arid and semiarid zone, so horizontal precipitation is very important source of water. The amount of captured horizontal precipitation is dependent on vegetation structure and therefore the negative interventions to the ecosystem lead to the reduction in the amount of above–ground biomass and captured horizontal precipitation.

Dracaena draco growing on Canary Islands has lot of morphological, anatomical and physiological adaptions for the capture of precipitation. Typical is the crown in shape of umbrella which is adapted to intercept humidity from horizontal precipitation (mist and dew). This endemic species is a species in which it has been proved the absorption ability of water condensed on the leaves into the vascular system of the trunk. The quantification of the amount of captured horizontal precipitation by *Dracaena draco* seedlings creates a projection of horizontal precipitation as an additional source of moisture in critical phases of development in juvenile stage.

2. AIMS AND OBJECTIVES

The diploma thesis is focused on *Dracaena draco* seedling and its ability to capture horizontal precipitation as an additional source of water and explain the importance of horizontal precipitation for seedlings in critical phase of their development. The aim of the work is to design and develop methods (both, for measurements and for data assessment) able to evaluate the importance of captured horizontal precipitation by *Dracaena draco* in natural conditions. The experimental hypothesis was based on the ability of *Dracaena* seedlings to capture a sufficient amount of horizontal precipitation necessary for their survival in the conditions of Tenerife cloud forest. Presented methodology has a wide scope of utilization and will be usable outside the European temperate forest biome.

3. LITERATURE REVIEW

3.1. Water balance of forest ecosystem

3.1.1. Water in the atmosphere and hydrological cycle

In the Earth's atmosphere, the water is presented in three states – liquid, solid and invisible vapour (FWR 2005). The water in atmosphere is necessary for the landscape sphere and for the life on the Earth (Vysoudil 2013).

The water cycle or hydrologic cycle is the continuous movement of water (Pagano & Sorooshian 2002) accompanied by changes of water states in the geosphere composed of: lithosphere, hydrosphere and atmosphere (Penka 1985). The cycle can be divided into six stages: evaporation, transport, condensation, precipitation, groundwater and run off (FWR 2005).

The process is initiated by the solar radiation. Water is transferred from the surface to the atmosphere through evaporation (FWR 2005). In the atmosphere, the water vapour is getting cold and condenses within clouds and precipitates in the forms of rain, snow, sleet, or hail back to the Earth's surface (Pagano & Sorooshian 2002). Water in the form of precipitation mainly falls back on the open water surface or is intercepted by vegetation (Gustard 2008). If precipitation do not fall to open water surface, water infiltrates into the ground surface and leak into deeper zones to become a part of groundwater storage or become mixed with saline groundwater in coastal zones (Pagano & Sorooshian 2002).

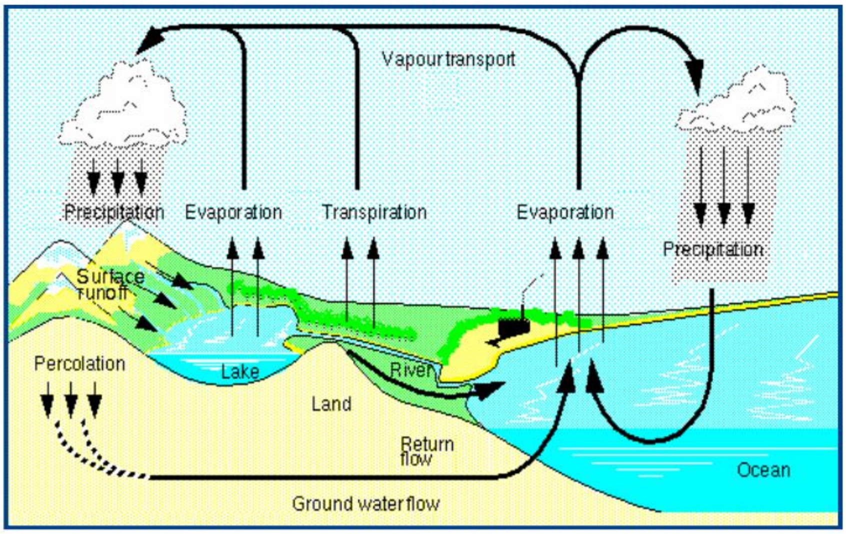


Fig. 1 The stages of hydrological cycle (FWR 2005)

3.1.2. Evaporation

The important component of hydrological cycle is evaporation when the water is transferred from the surface to the atmosphere, this is a process by which water changes from a liquid to a gas (FWR 2005). The amount and intensity of evaporation depend on aridity, temperature and wind speed. More evaporation is from the oceans than from the land (Bharatdwaj 2006). The evaporation is distinguished by the evaporating surface (Žalud 2015):

- evaporation – evaporation from inanimate surfaces: water surface, ice, snow, soil (physical vapor). Apart from the meteorological characteristics there are also important characteristics of the soil especially soil hydro limits values (field water capacity, full water capacity, wilting point, number of hygroscopicity).
- transpiration – water evaporation from the plant, where the water was a part of plant cells (physiological vapor). The evaporation is mainly through the stomata, 5–10 % is evaporated by cuticle.
- interception – water evaporation from the plant, where the water was not a part of plant cells. The surface of the plant has an area capacity at what the precipitation may evaporate. The capacity of cover is dependent on the size parameter LAI (Leaf Area Index), which is a dimensionless number expressing the total leaf area (m^2) per 1 m^2 of the Earth surface. It is a non-productive evaporation (loss of water from the ecosystem without its use).

The combination of these processes is summarized as evapotranspiration. Changes in evaporation are important for evaluating the development of vegetation.

3.1.2.1. Evapotranspiration

Evapotranspiration is the total water lost from a cropped (or irrigated) land on the grounds of evaporation from the soil and transpiration by the plants or used by the plants in growing up of plant tissue (Raghunath 2006). The evapotranspiration rate is expressed in millimetres (mm) per unit time. The rate represents the amount of water lost from a cropped surface in units of water depth (Allen et al. 1998). Evaporation is not easy to measure. The most widely used method of estimating is based on lysimeter experiments, field experimental plots and installation of sunken tanks (Raghunath 2006).

3.1.3. Air humidity

Water vapour content in the air is termed as humidity (Penka 1985) and is expressed as the amount of vapour contained in the air at given temperature (Starý 2005). The absolute humidity is expressed in grams of water per cubic meter of air [g*m $^{-3}$], it is marked with e and is expressed as a water vapour pressure in kPa (Starý 2005). However, for humidity expression is commonly used relative humidity. Relative humidity has a great climatic significance because the possibility precipitation depends on it. Also, the amount of evaporation depends on relative humidity. It decreases with high relative humidity and increases with low relative humidity (Bharatdwaj 2006).

According to Ramis et al. (2005), relative humidity (h) is expressed in percentage and is defined as proportion between the vapour pressure e and the saturation vapour pressure *es (t)* at the corresponding temperature. The formula is:

$$h = 100\frac{e}{es(t)}$$

The saturation deficit (d) express the ratio between maximum pressure (tension) of water vapour at a given temperature and the actual tension of water vapour, is measured in kPa. The formula is (Vysoudil 2013):

$$d = E - e$$

Dew point is the temperature where condensation begins (°C). At this temperature vapours are saturated and begin to condense this means that if the temperature decrease below the dew point, water vapour condenses (Vysoudil 2013), water droplets (or ice crystals) in the air are collected and create a cloud (Starý 2005; Vysoudil 2013). If the relive humidity is lower than 100 %, then the dew point temperature is lower than the actual temperature (Vysoudil 2013).

3.1.4. Condensation and desublimation

Condensation is the change of physical state of matter from gas phase into liquid phase and desublimation is a process in which water vapour changes state from gas phase to solid phase (Moravec 1994). In both processes releases latent energy, whereas at desublimation the amount of released energy is higher (Žalud 2015).

Condensation and desublimation do not take place only in the upper atmosphere in the form of clouds, but also in the lower atmosphere and on the Earth's surface (Žalud 2015), where due to condensation of water vapour are created particles directly on the Earth's surface. Condensations are divided according to different criteria. Penka (1985) divides the precipitation according to the state on 1) liquid: rain, drizzle, pelting rain and 2) solid: hoarfrost hail, hailstorm. Vysoudil (2013) distinguishes precipitation by origin on 1) falling – precipitation from clouds (vertical) and sedimented (horizontal). There are other divisions for example by the occurrence or causes. Žalud (2015) divides condensates according to the place where they occur. Condensates formed on the Earth's surface and lower atmosphere are horizontal precipitation.

3.1.4.1. Condensates on the Earth's surface

Žalud (2015) states that condensation and desublimation on the Earth's surface is in progress on any active surface whose temperature is equal or lower than the dew point, and in this group, there are (Žalud 2015; Raghunath 2006; Vysoudil 2013):

- dew – Moisture condensed from the atmosphere in small drops on the cool surfaces. It arises in connection with radiation cooling, in this process the surface temperature, where the water condensates, decreases under the dew point. Plants are able to use the dew during the dry season to overcome the deficit of water. This is significant in tropical arid areas at lower altitudes. It also has a significant phytopathological meaning when moistening the leaves helps to develop some fungal diseases.
- frozen dew – frozen dew droplets
- frost – a feathery deposit of ice formed in humid air conditions on the ground or on the surface of exhibited objects by dew or water vapour that has frozen glaze ice.
- glaze – freezing of drizzle or rain when they come in contact with cold objects
- black ice – occurs when the snow melts and then again freezes

3.1.4.2. Condensates in the lower layers of atmosphere

In the ground layer of atmosphere there are accumulated condensates that are known as fog or haze, and are the only two processes that occur in this layer. The difference between these two processes is only in intensity (Žalud 2015). Raghunath 2006 also adds a mist that is very thin fog.

3.1.4.3. Fog

Cermak et al. (2009) define the fog as a condition with a visibility of less than 1000 m at ground level, caused by a dispersion of small water droplets in the air. Droplets have size from about 0,005 to 0,05 mm (Žalud 215) and the speed of fall is so low that, even in very light winds, the droplets travel almost horizontally. Fog has an ecological importance as a water source in coastal deserts and tropical cloud forests (Cermak et al. 2009). Fog arises in the presence of condensation particles when the air is saturated with water vapour, r = 100 % (Novák 2004). However, Croft (2003) describes that relative humidity for condensation do not necessarily to be 100 % but may be as low as 80–90 %. Fog may form in place, be transported from one area to another, and may form in minutes or over an hour, depending local conditions. This author also states that fog is often called as ‘a cloud on the ground’ that consists of visible hydrometeors. Based on visibility, Vysoudil (2013) divides fog into 4 levels of intensity:

- light fog – range of vision 500–1000 m
- moderate fog – range of vision 200–500 m
- dense fog – range of vision 50–200 m
- very dense fog – range of vision less than 50 m

Other division is according to Žalud (2015) based on type of formation:

- fog from cooling
    - radiation fog – linked to the radiation cooling (expenditure of energy by longwave radiation from the Earth's surface) and therefore accompany radiation temperature inversion. Usually they are only in the morning and after the sunrise they disappear.
    - advection fog – creates when the moist air passes over a cool surface by advection (wind) and is cooled. Often it lasts a day or longer.
- fog from evaporation – forms by the evaporation of warmer water level above which the air is cooler. The fog rises above the land in autumn and winter when water in lakes and rivers is still warmer than the surrounding air. There occur also in the arctic seas and at edges of glaciers.

- orographic (rising) fog – air masses pass over a mountain. The fog can be seen as a cloud around the mountain summit.
- frontal fog – creates by mixing two volumes of air with different temperature and high relative humidity at atmospheric fronts.

3.1.5. Precipitation

Precipitation is the primary mechanism for transporting water from the atmosphere to the Earth's surface (FWR 2005). When the air is getting colder the saturation of water vapour increases. When the temperature falls below the dew point temperature, part of water vapour condenses around condensation particles (particles of dust, smoke, pollen, or even molecules of gases). In this way water droplets and snowflakes are arisen and they form clouds or fog. Under this condition they get larger and fall as precipitation (Starý 2005). Atmospheric precipitation may be classified according to the various criteria. Žalud (2015) describes the division based on the place of occurrence on vertical precipitation and horizontal precipitation (see above in chapter about condensation).

Vertical precipitation begins to fall from the clouds at the time when its weight overcomes the upward force which is given by force of convection flows (Žalud 2015). Rainfall does not occur unless the cloud droplets become so large due to coalescence that the air becomes unable to hold them (Bharatdwaj 2006). For an objective evaluation of rainfall activity, it is measured the amount, intensity (i. e. quantity of rainfall over a period) and duration. Precipitation is measured in millimetres, whereas 1 mm corresponds to 1 litre of water per 1 m^2 of areas, in case of snow, 1 mm corresponds to about 1 cm of powder. For quantification is used a rain gauge (Skřehot 2004).

Žalud (2015) explains two mechanisms whose result is increasing the weight of the particles and thereby increasing the gravitational force.

- coalescence – it is with water droplets when they shrink and collect each other. This type is more often in tropical areas where even at high altitudes, the temperature is above zero. The droplets size is various; its diameter is from 0,5–8 mm but usually it is about 1–3 mm.
- diffuse transfer – more often in moderate areas. It is a very effective way of increase particles especially in mixed clouds.

Vysoudil (2013) describes that amount of annual precipitation differs regionally. It is influenced by latitude but also by local geography. Best known influence to amount of annual precipitation is the vertical segmentation of relief. Elevations in natural environment force the air flow rise along the windward slopes. This results in the adiabatic cooling, which leads to the clouds formation. By contrast, the leeward side of the mountains can cause a rain shadow. The second basic cause of the differences in the amount of precipitation in the vertical orientation is the orientation of slopes. Southern slopes are more radiated which leads to significant warming in upper layer of the atmosphere and thus to formation of convection.

3.1.6. Run off and infiltration

Basic input component of the run off process is the atmospheric precipitation. Rainfall may fall on an impermeable surface, which leads to its accumulation and subsequent evaporation (Chmelová & Frajer 2014), other portion of rainfall infiltrates into the ground and the rest run off along the Earth's surface (Raghunath 2006). The total run off is divided into surface and underground, and is influenced by soil and geological conditions, vegetation cover and soil management in forestry and agriculture (Starý 2005).

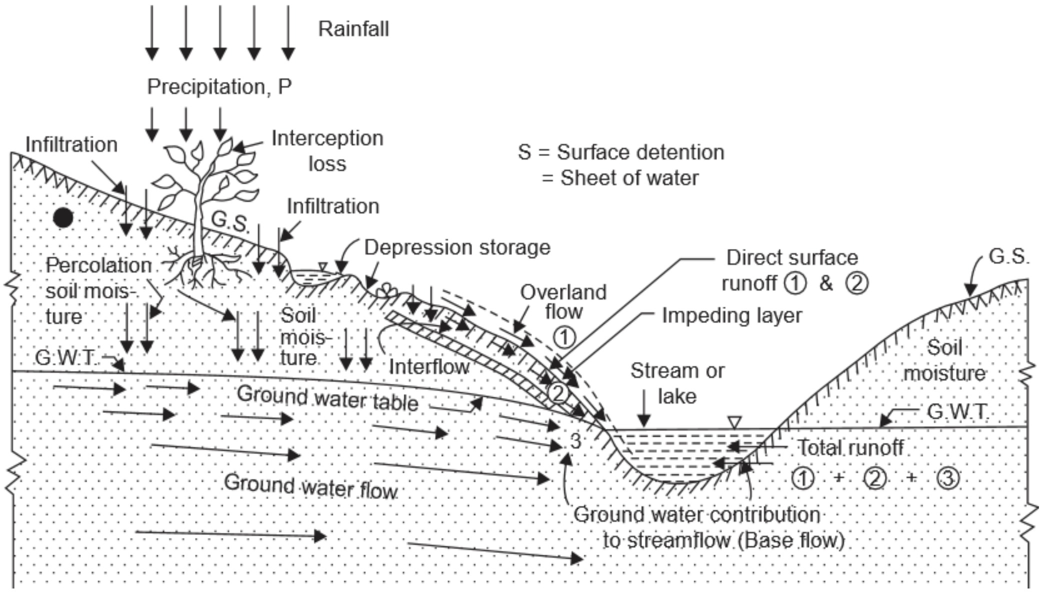


Fig. 2 Disposal of rain water (Raghunath 2006)

Different surfaces can capture different amounts of water and absorb water at different degrees. When the surface becomes less permeable, an increasing amount of water can cause a greater potential for flooding (FWR 2005).

Water that infiltrates into the ground surface can leak into deeper zones to become a part of groundwater storage to eventually appear again as stream or become mixed with saline groundwater in coastal areas (Pagano & Sorooshian 2002).

3.2. Cloud forest

From the biological and hydrological point of view, cloud forest is unique and important ecosystem (Bruijnzeel et al. 2010) that is marked by periods of persistent annual or seasonal cloud immersion (Hildebrandt & Eltahir 2008). It exists lot of definition, classification and descriptions of cloud forests, they are not stabilized and they often overlap or contradict each other. For the purpose of this work, it was selected often used Grubb's definition: "Cloud forests are forests affected by frequent and/or persistent ground-level cloud" (Grubb 1977). Tropical cloud forest includes forests in humid tropical areas, which are surrounded by foggy clouds in direct contact with the mountain slopes, besides the presence of rainfall, there is a high proportion of horizontal precipitation (Hamilton 1995). Persistent fog creates an exceptional microclimate (Hildebrandt & Eltahir 2006) and its presence as an importer potentially large quantities of water which is intercepted by vegetation (Hildebrandt & Eltahir 2008; Mulligan, 2010) significantly affects the hydrological and soil properties of forest (Stadtmüller 1987), but also power, light and temperature regime of ecosystem.

Cloud forest has certain characteristics. Bubb et al. (2004) states that the term tropical montane cloud forest must meet two conditions: average annual rainfall is from 500 to 6 000 mm and forests are located at an altitude from 500 m. Bubb et al. (2004) also states that there is significant diversity in the occurrence of cloud forests depending on the altitude. Their occurrence in inland is between 2 000 and 3 000 meters a. s. l., while in coastal and island mountain areas the cloud forests begin to occur already at 500 m a. s. l. Averages are areas in the range up to 350 km from the coast with altitude of 1 700 m with the average temperature 14 to 18 °C and an average annual precipitation of 2 000–2 600 mm (Eltahir 2011).

The form and appearance of tropical cloud forests differ according to the conditions in which they are exposed, i. e. weather conditions, humidity, altitude or soil type. Bruijnzeel & Hamilton (2000) divide the tropical montane cloud forest by changes in vegetation, including its composition and changes in height main vegetation floor (Fig. 3), with increasing altitude to:

- lower montane cloud forest
- upper montane cloud forest
- subalpine cloud forest

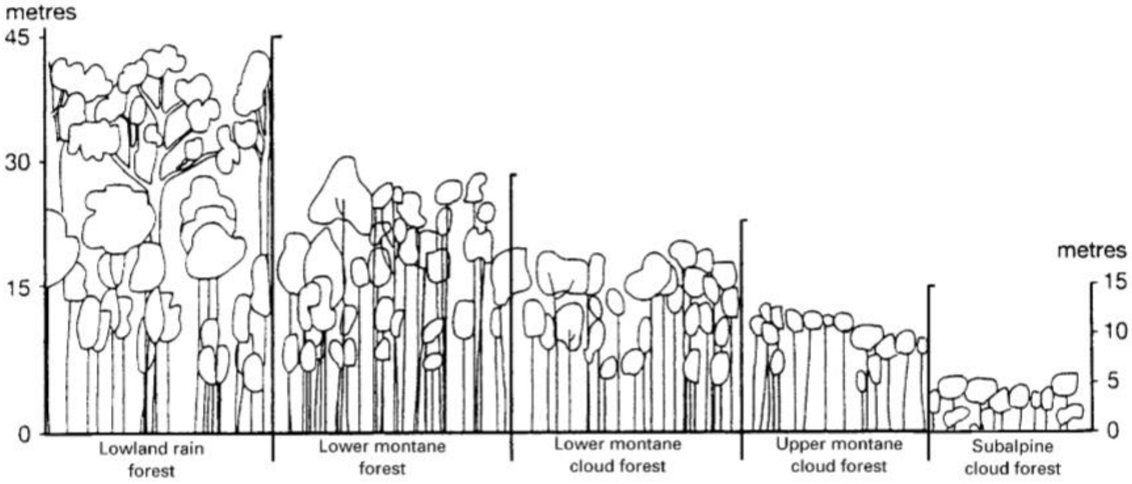


Fig. 3 Generalized altitudinal forest formation series in the humid tropics (Bruijnzeel & Hamilton 2000)

Cloud forest has a high biodiversity with a significant number of endemic species (Bruijnzeel & Hamilton 2000; Hamilton 1995). One of the characteristics of the cloud forest is a rich variety of ferns, mosses, orchids (Bubb et al. 2004) and other epiphytes growing on the tree trunks and branches that make the typical appearance of cloud forests. Oliveira et al. (2014) describes that there is an increase in epiphyte cover and decrease in tree height and canopy segmentation in high-altitude and cloud forests at lower altitudes are closer structurally to lowland tropical forests.

A substantial proportion of the fog that is intercepted by tree crowns may be hold by the foliage and subsequently evaporated back to the atmosphere, or potentially be absorbed by leaves (Eller et al. 2013). Even though that most cloud forests are located in moist regions, some of them have been identified in water limited areas where the horizontal precipitation is an important source of plant available water. In semiarid region where the average annual rainfall is only 100–250 mm, the additional water that the forest collects for itself can be considered distinct and plays an important role in forest survival (Hildebrandt & Eltahir 2008).

There is a direct connection between the amount of forest and water ecosystems and the formation of steppe or desert climate. In areas with plenitude of forests and water surface, the atmosphere is saturated with water vapour and there is enough rainfall, in areas with a lack of forests and water surfaces (especially inland) it comes about to climate change (Penka 1985).

Due to dependence of horizontal precipitation on specific atmospheric conditions, cloud forests already have been considered particularly threatened because of anthropogenic processes that change cloud prevalence (Hildebrandt & Eltahir 2006).

3.2.1. Tropical arid areas and cloud forests

Most evergreen cloud forests are located in humid tropical areas with high annual rainfall, when the role of horizontal precipitation is reduced and is not essential for plant survival (Hildebrandt & Eltahir 2006). However, forests have been identified even in an environment where the water becomes a limiting factor for plant growth (Hutley et al. 1997). In arid and semiarid regions, the amount of horizontal precipitation is major source of water for plant survival. Bruijnzeel et al. (2010a) presents their results in the interception simulation based on developed numerical models of hydrological processes within the cloud forests that state 5 % interception in humid areas but more than 75 % in areas with low rainfall. In humid tropical areas, the combination of the vertical and horizontal precipitation exceeds the rate of water loss in the process of evapotranspiration and the excess water runoff into streams and rivers. This excess is relatively small in arid areas. Water from the horizontal precipitation helps plants with balance the evapotranspiration deficit (Žalud 2015).

Into the category of cloud forests in arid and semiarid areas are also included the laurel forests (called laurisilva or monteverde). The forests of this type are found in Macaronesia, i.e. the Canary Islands, the Azores, Cape Verde and Madeira (García-Santos et al. 2004).

Fig. 4 Laurel forest in Anaga, Tenerife (Author)

Fig. 5 Cloud forest in Anaga, Tenerife (Author)

Laurel forest is classified depending on conditions of water availability into three subtypes (Guimarães & Olmeda 2008): dry laurisilva with precipitation less than 500 mm and higher temperatures, located on southern slopes with occasional influence of the cloud belt; humid laurisilva located on the windward slopes with the influence of the cloud belt, there is lower radiation that results in lower temperatures and precipitation is between 500 and 1 200 mm (Brown & Mies (2012) add that estimated amount of additional fog precipitation intercepted by the trees is 300 mm); hyper-humid laurisilva with precipitation higher than 1 200 mm and is found only in Madeira and Azores.

Marzol et al. (2011) and García-Santos et al. (2004) monitored climate conditions by a meteorological station that was able to measure relative humidity, air temperature, global solar radiation, wind speed, rainfall and intercepted fog water. Research of Marzol et al. (2011) demonstrated that the average of total water collected (rain + fog) in Anaga mountains is around 10 litres/m^2 per day, however there are monthly variations. Table 1 shows the quantity of water collected by the screens on meteorological station: F_1 is the monthly mean of total water collected, F_2 the monthly mean of fog water after eliminating the water of days with rain, F_3 the monthly mean of fog water after eliminating hours with rain. The highest amount of collected fog is recorded in July and August.

Tab 1. Monthly mean amounts of water collected in Anaga (Marzol et al. 2011)

	F1	F2	F3
January	189	35	140
February	207	72	146
March	260	102	194
April	282	162	256
May	288	228	264
June	393	339	388
July	727	694	725
August	641	569	626
September	187	153	179
October	235	113	201
November	174	43	99
December	222	32	141
Mean	**3803**	**2541**	**3361**

3.2.2. European forests

Horizontal precipitation is not created only in cloud forests of tropical areas but is formed also in temperate mountain forests of Europe. This is proved in work of de Jong et al. (2005) who compared evapotranspiration and condensation in the Giant

Mountains and the Alps. The Giant Mountains that form the natural boundary between Poland and the Czech Republic have 240 fog days per year and average relative humidity can frequently overcome 80 % as a result of condensing cloud masses (Dore et al. 1999). The Giant Mountains belong to one of the most fog-dominated regimes of all European mountains. Second study area is in the Alps in Switzerland that is under the influence of low pressure system and occasionally is replaced by alpine föhn wind. Daily condensation in the Giant Mountains is between 3 and 10 times higher than in the Switzerland because of the fog influence. The values depend strongly on plant type, valley shape and climatic influences (de Jong et al. 2005).

3.3. Macaronesian region

Macaronesia is a biogeographical region that comprises the archipelagos of the Azores, Madeira, the Savage Islands, the Canary Islands and Cape Verde and the name was originated by the botanist Philip Barker Webb (Cropper 2013; Sjögren 2000). Canary Islands covering an area of 7 242 km^2 are the largest of the archipelagos and the richest and most diverse islands in the Macaronesian region (Sundseth 2009). The Macaronesian islands are of volcanic origin and are located in the Atlantic Ocean. The distance between the northern and southernmost points at the Azores and Cape Verde is about 2 500 km (Cropper 2013). The main formation of Macaronesian region took place during the Tertiary period when Eurasia and America were situated closer together, however some parts may be even older (Sjögren 2000).

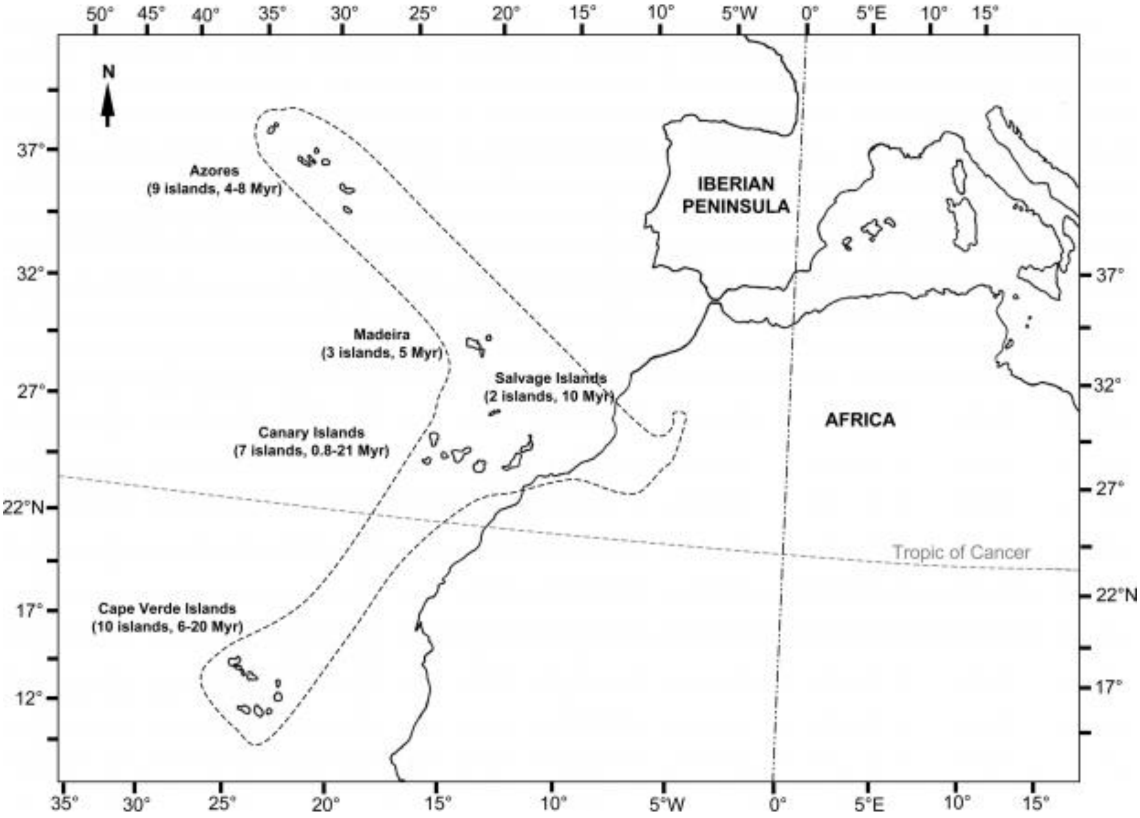


Fig. 6 Map of the Macaronesian region (César-Javier Palacois 2013)

Cropper (2013) describes that the temperature increases and precipitation decreases towards the equator. Precipitation is strongly influenced by orographic rainfall and mostly falls on the windward side of these islands, usually to the north or northeast facing slope due to the persistence of the prevailing trade winds. In the subtropical islands of Madeira and the Canary Islands dominates a typical

Mediterranean climate with low seasonal variation in temperatures and generally dry conditions (precipitation is concentrated in November and December and the amount is seldom more than 250 mm). By contrast, the Azores are climatologically different from Madeira and the Canary Islands with higher precipitation and humidity (EEA 2002).

The islands of Macaronesia cover plenty of landscapes ranging from deserts and xerophytic scrubs in arid and rocky areas in the eastern Canary Islands to humid mountain evergreen broadleaf forests and sand dunes in Madeira and the Azores (EEA 2002). Despite covering only 0,2 % of the European Union territory, the Macaronesian region hosts over a quarter of the plant species listed in Annex II of the Habitats Directive (Sundseth 2009). The biodiversity is influenced by forest destruction due to human population growth, agriculture, forestry, fisheries and alien species (BEST).

The number of endemic species depends on the degree of isolation, the topography and age and habitat diversity of the islands (Sjögren 2000). For Macaronesia is estimated a native vascular flora of 3 200 species of which 20 % are endemic. The Canary Islands are the richest with 570 endemics. The island with the significant number of endemic species (320) is Tenerife with the largest numbers of *Aeonium, Sonchus* and *Echium* (Whittaker & Fernández-Palacois 1998). The group of endemic bryophytes in Macaronesia is less known than the vascular plants. There are about 60 species for all Macaronesia and 30 species for each island group (Sjögren 2000).

Characteristic emblem of Macaronesia is laurel forest which is currently found only in few islands in the Atlantic but in past covered large area of mainland Europe (Sundseth 2009). Human activities reduced the coverage from an original 60 % in Madeira to the present about 20 % (15 000 hectares), in Tenerife it is less than 20 %, in Gran Canaria 1 % and in Azores 2 % (EEA 2002). Laurel forests, also called laurisilva (in Spanish monteverde), are humid evergreen forests of the cloud belt of the Macaronesian islands. Tree species form a dense canopy up to 40 m high that does not allow the light penetration (Guimarães & Olmeda 2008) that makes specific microclimate. Most areas are now protected through Natura 2000 (Sundseth 2009). The family *Lauraceae* is important element of laurel forests that are extremely rich in flora and fauna species. Most specific species are *Laurus azorica, Laurus novocanariensis, Apollonias barbujana, Persea indica* and *Ocotea foetens* (Guimarães & Olmeda 2008).

3.3.1. Tenerife

The triangle shaped island Tenerife is situated 28°35´15´´ - 27°59´59´´ N and 16°5´27´´ - 16°55´4´´ W in the Atlantic Ocean off the west coast of Morocco in Africa and is the largest and highest among the seven volcanic island of the Canary archipelago (Del Arco et al. 2005; Li et al. 2015). The island has a surface area of 2 057 km^2 and the highest mountain peak is volcano Pico del Teide reaching 3 178 m a. s. l. that is also the highest peak in Spain where the top is frequently covered by snow (Criado & Paris 2005; Herrera et al. 2001). Tenerife has a subtropical climate with average temperatures varying between 19–25 °C (Li et al. 2015). Tenerife is under the direct influence of the trade wind blowing from the northeast that makes the climate very stable all year (Herrera et al. 2001). The geography characteristic of island (high mountains, strong slopes all over the area) together with prevalent trade winds make very special local climate. The most typical phenomenon is the sea of clouds (Fig. X) which is formed at mid heights when the air mist condenses for the trade winds pressing the air against the hilltops (Pórtoles et al. 2011). The altitudinal limit of the cloud sea is changing during the year, reaching their highest altitude in the winter (Fernández-Palacios 1992). Due to this phenomenon forests are evergreen in an otherwise arid environment (Bruijnzeel & Hamilton 2000). This process creates additional amount of water in the form of horizontal precipitation. Marzol et al. (1997) states that source of water there from fog is four times higher than from the vertical precipitation. Area of sea cloud provides optimal conditions for plant growth, average annual temperature is between 13–15 °C and annual rainfall is higher than 700 mm (Fernández-Palacios 1992).

Fig. 7 Sea cloud, Tenerife (Author)

The combination of the cold ocean currents named the Canaries Current coming from the north as a derivation from the Gulf Stream, trade winds, and the orography makes Canary Islands much wetter than what is usual at this latitude (Herrera et a. 2001). The main environmental differentiation is caused by the existence of a temperature inversion that separates the lower layer of cold humid air from a higher layer of dry cold air at 1 200 m a. s. l. (Fernández-Palacois 1992). Fernández-Palacois 1992 also describes that precipitation decreases towards the coast, reaching its lowest level at the south-eastern and south-western coastal areas less than 200 mm per year.

The volcanic history of Tenerife island can be summarized into 4 cycles (Barrera Morate 2009). Tenerife is characterized by both effusive and explosive eruptions (Li et al. 2015). The oldest parts of the island are the basaltic massifs of Anaga (northeast), Teno (northwest) and some places in Adeje (southwest) where are dominant the materials of the first volcanic cycle in Miocene showing a high degree of erosion. Other parts of Tenerife are covered with diverse basaltic and salic volcanic emissions over the old island core (Del Arco et al. 2005). In the third cycle, the giant Teide stratovolcano together with Pico Viejo were formed and in 2007 they were declared World Heritage by UNESCO (Barrea Morate 2009). Several Teide's eruptions were recorded in the last 500 years, all of them of the effusive type when the lava flows freely without explosive power. Last eruption of explosive type is dated around 1 500 years ago (García et al. 2006). Last volcanic activity was the eruption of the Montaňa Chinyero in 1909 (Kröchert et al. 2008).

Fig. 8 Pico del Teide (Author)

Fig. 9 Ravines on Teide volcano (Author)

Black sand beaches are formed of pebbles or black basaltic shingle, only in the south there are some light beaches formed basically by disintegration of salic materials like trachytic and phonolithic pyroclasts and ash (Del Arco et al. 2005).

3.3.1.1. Vegetation

From a biogeographical point of view, Tenerife is a zone of the Western Canary Province, Canary subregion, Mediterranena region (Del Arco et al. 2005). The diversity of floristic composition of the vegetation in Tenerife is related to different environmental factors (Fernández-Palacois & de Nicolás 1995). Climatic condition play a considerable important role in the distribution of plant species and communities over all spatial scales. Structure of vegetation is also characterized by the amount of soil water that is related not only to annual rainfall but also to soil conditions and topography, which modify water-holding capacity, percolation and evaporation rates of the substrate (Otto et al. 2001).

Vegetation types are not strictly discontinuous along the elevation gradient. Discontinuity of the vegetation in Tenerife is more sharply defined on the windward slope than on the leeward slope (Arévalo et al. 2005). A significant difference between windward and leeward slopes are at the distribution of *Laurus azorica*, *Ilex canariensis* and *Erica arborea*, cloud forest tree species which are restricted to the middle area (500–1 500 m) of the windward slope (Fernández-Palacois & de Nicolás 1995).

The zonal vegetation belts in order of altitude are summarized in figure X

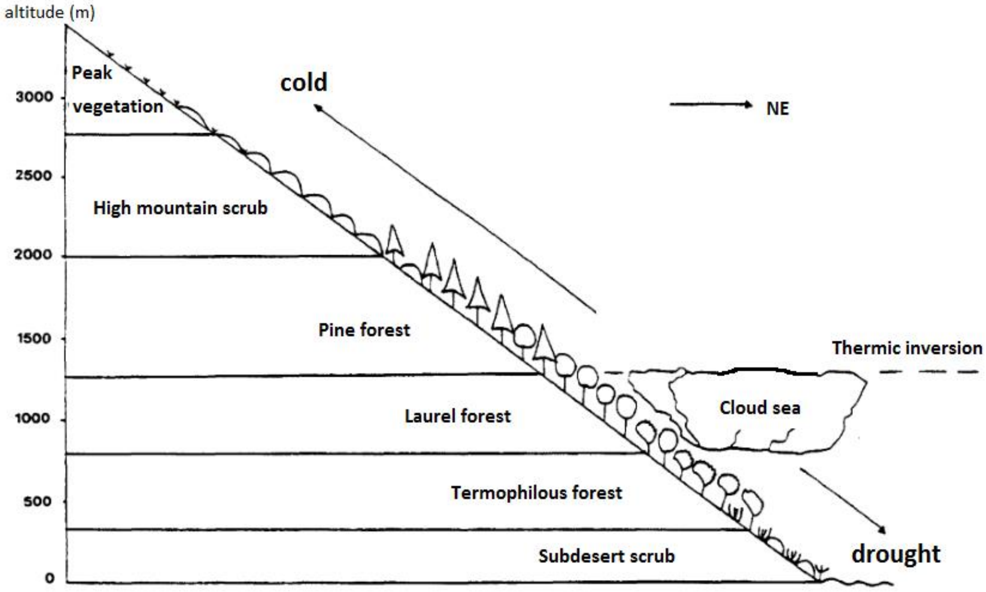


Fig. 10 Vegetation belts on the northeast slope of Tenerife (Fernández-Palacois 1992)

Del Arco et al. (2005) describe 7 climatophilous vegetation series through the zonal vegetation belts:

- *Ceropegio fuscae – Euphorbietum balsamifareae*
- *Periploco laevigatae – Euphorbietum canariensis*
- *Junipero canariensis – Oleetum cerasiformis*
- *Visneo mocanerae – Arbutetum canariensis*
- *Lauro novocanariensis – Perseetum indicae*
- *Sideritido solutae – Pinetum canariensis*
- *Spartocytisetum supranubii*

As it was mentioned above, the endemic flora of the Canary Islands is extremely rich and highly vulnerable to environmental changes (Reyes-Betancort et al. 2008). Well known plant is *Canarina canariensis* (Canary bellflower) that is endemic to Canary Islands and is frequent in laurel forests and forest margins (EEA 2002). Very rare plant is *Stemmacantha cynaroides*, an endemic species in Tenerife that is found only in five locations in an area of 5 km² in Parque national del Teide and a total number of individuals is 151. According to the IUCN, this species belongs to the category Endangered. The main problem affecting the taxon is predation exerted by rabbits and mouflons (Marrero Gómez et al. 2011).

Vegetation of touristic island Tenerife is influenced by human activities; however, the large villages are located mostly near the coast thus human pressure decreases with altitude (Arévalo et al. 2005).

3.4. Genus *Dracaena*

The genus *Dracaena* belongs to the family *Asparagaceae* in the major group *Angiosperms* (The Plant List 2010) and comprises about 40–100 species world-wide, mainly in tropical and subtropical regions of Africa, some species are distributed also in Madagascar, Asia, Socotra, Mediterranean regions, Central America, Cuba, Macaronesia, Northern Australia and Pacific islands (Pei-Luen & Clifford 2010).

The dragon tree group is among the most cited examples of so-called ‘Rand flora’ elements (Denk et al. 2014). In the past, the classification was unclear, Pei-Luen & Clifford (2010) describe that *Dracaena* was placed within in the family *Liliaceae,* then in the family *Agavaceae* and since 2003 *Dracaena* has been classified within the family *Ruscaceae*. However, *Ruscaceae* is combined into the larger family *Asparagaceae* and *Dracaena* was replaced there. Most of *Dracaena* species are shrubs or geophytes that often have the growth habit of tree. There are six arborescent species: *D. cinnabari* Balf. in Socotra, *D. serrulata* Baker in south-western Arabia, *D. ombet* Kotschy & Peyr in eastern Africa, *D. schizantha* Baker, *D. draco* on Macaronesian islands and in Marocco and *D. tamaranae* in Gran Canaria (Adolt & Pavliš 2003). These species are considered to be residues of the Mio–Pliocene Laurasian subtropical forests, however now they are almost extinct because of the climate changes of the late Pliocene that caused the desertification in North Africa (Habrová et al. 2009). The species of *Dracaena* are found in thermo-sclerophyllous plant communities of tropical-subtropical regions which are rather xerophilous, with a rainfall range 200–500 mm and average temperatures of 18–20 °C (Marrero et al. 1998).

The genus *Dracaena* is special among monocotyledonous plants, because of the secondary thickening of its stems and roots and the tree-like physiognomy of various species. Age estimations of monocotyledonous trees usually cannot be based on tree ring counts, such as those typically used with temperate or boreal species (Adolt et al. 2012). Few analyses focused on age estimation have been published, Symon (1974) and Magdefrau (1975) published growth data from the long– standing direct monitoring of *Dracaena draco* in an artificial environment, but the presented information were only descriptive. Adolt & Pavliš (2004) and Adolt et al. (2012) came up with a method of age determination based on the fact that the growth of a brunches is interrupted by a flowering event, after which one or more new branches are formed. It means that the number of branch segments between a terminal bud and the base of crown (the top of stem) is related to the quantify of flowering events. The age of the crown can be determined by the total duration of the estimated time intervals between all flowering events.

Zelený (2008) writes about the work of Zimmermann & Tomlinson (1970) who described the secondary thickening of dragon trees. The secondary growth in monocotyledonous plants is not common but in the case of dragon trees it is possible thanks to wide belt of meristem in the perimeter of the stem, which produces leptocentric vascular bundles separated by the belts of parenchymatic cells. Vascular bundles have the same characteristics as common monocotyledonous plants, i. e. collateral closed vascular bundles. This creates a special kind of cambium thanks to the activity of secondary thickening meristem (Carlquist 2012).

The dragon trees are typical for their umbrella shape of crown. This crown is adapted to intercept humidity from mist, horizontal precipitation and dew, later falling from the branches. This is also the way to increase soil water potential below the crown. Furthermore, the canopy shadow reduces the soil water evaporation to values lower than someplace else in the environment (Adolt & Pavliš 2003).

Fig. 11 Dracaena draco, Tenerife (Author)

Morphological characteristics are consequences of adaption to drought periods. Features summarize Denk et al. (2014):

- closely packed leaves at brunch apices
- differentiated leaf sheaths
- leaves lacking costae
- flowers with tepals
- free stamens with thickened filaments

Dracaena forests are considered as one of the oldest forest communities on the Earth (Hubálková et al. 2015). At present, *Dracaena* together with *Ficus* belongs to the most grown house plants, especially in Europe (Zelený 2008).

3.4.1. *Dracaena draco*

3.4.1.1. Introduction

Dracaena draco (L.) L. belongs to the group of 'dragon tree group' and occurs in northwest Africa – Madeira, Canary Islands, Cape Verde and southern Morocco, however the wild populations are extremely rare and in Madeira they have become extinct (Nadezhdina et al. 2015). Zelený (2008) describes this species as the largest dendroid *Dracaena* which occurs with single or multiple trunk. The plant can get to an enormous size and reach very old age, "Drago Milenario" of Icod in Tenerife, 20 m high, is said to be about 400 years old (Krawczyszyn & Krawczyszyn 2015) and is considered to be the largest and oldest current Canary Islands dragon tree.

3.4.1.2. Taxonomy

The name *Dracaena* is derived from the Greek word 'drakainia' meaning a female dragon (Gupta et al. 2007). In 1762, Linneaus described this species in his binomial system as *Asparagus draco*, then, in 1767 he changed to *Dracaena draco*, which is the current correct name (Marrero et al. 1998).

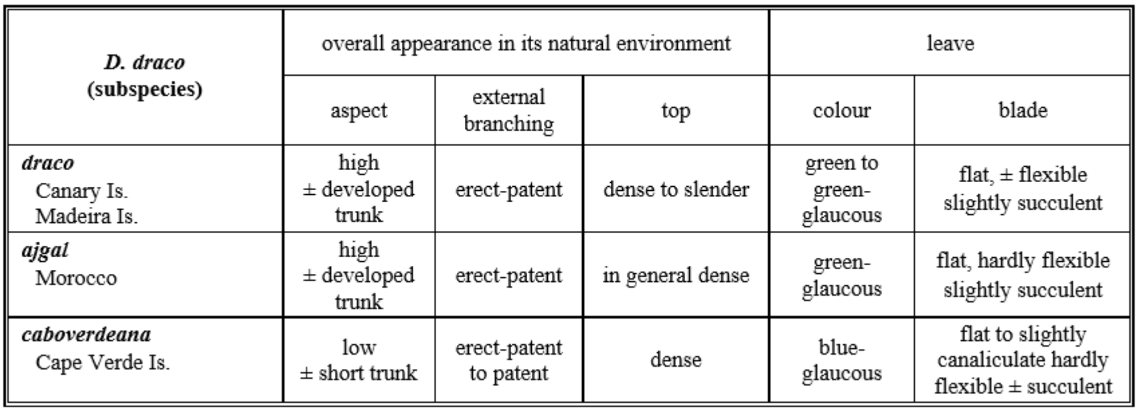
Dracaena draco has subspecies that describe Marrero & A. Pérez (2012) in their work:

- *Dracaena draco* (L.) L. subsp. *caboverdeana*

- *Dracaena draco* (L.) L. subsp. *draco*
- *Dracaena draco* (L.) L. subsp. *ajgal*

Differences among subspecies are seen in table 1.

Tab. 2 Qualitative data of size and leaves of the subspecies (Marrero & A. Pérez 2012)



D. draco **(subspecies)**	overall appearance in its natural environment			leave	
	aspect	external branching	top	colour	blade
draco Canary Is. Madeira Is.	high ± developed trunk	erect-patent	dense to slender	green to green-glaucous	flat, ± flexible slightly succulent
ajgal Morocco	high ± developed trunk	erect-patent	in general dense	green-glaucous	flat, hardly flexible slightly succulent
caboverdeana Cape Verde Is.	low ± short trunk	erect-patent to patent	dense	blue-glaucous	flat to slightly canaliculate hardly flexible ± succulent

3.4.1.3. Natural occurrence and threats

On Tenerife, *Dracaena draco* grows in thermo–sclerophyllous zones between 100 and 600 m. The annual average rainfall of this zone is between 200 and 400mm. On Gran Canaria this species grows in similar areas, but it is scarce. On Cape Verde Islands, *Dracaena draco* is found between 700 and 1000 m (Marrero et al. 1998).

D. draco is registered as vulnerable species on the Canary Islands due to overexploitation of the trees for dragon’s blood in the middle ages and is also cited in IUCN Red List of Threatened Species (Gupta et al. 2007).

3.4.1.4. Habitus

The dragon tree is very variable in the shape. The erect trunk is short, at mature individuals is deeply wrinkled and cracked. In the youth, the trunk is often covered by narrow transverse brownish scars that are traces by the fallen leaves. The plant grows to the height of 21 m and the trunk perimeter can reach 14 m (Maděra et al. 2011). The trunk of *D. draco* holds many sets of branches that grow from the lateral buds (Krawczyszyn & Krawczyszyn 2015). The brunching is sympodial (Symon 1974), lateral brunches swell and gradually exceed the main trunk. On the tips of them there are sword-shaped tough leaves having a narrow whitish margin and greyish waxed coating, growing erectly from the wide base. The length can be over 60 cm with a width about 5 cm, they are glabrous and have greatly dense parallel veins. The tip of young leaves looks like a cape; the oldest leaves are gradually drying and falling off (Zelený 2008).

The inflorescence is always terminal (Mwachala 2005). Flowers are bisexual regular trifoliate and grow on short segmented stalks having shortly tubular intergrown with 6 yellowish-white tips around the upper ovary. The stigma is trilobite. Flowers come into blossom in the night and smell nice, they are probably pollinated by hawk moths. The fruit is fleshy orange sweet berry with three monospermous capsules. The seed germination is hypogeal, i. e. uterus stay in the seed coat underground (Zelený 2008).

Fig. 12 Flowers od *D. draco* (Tim Waters)

Fig. 13 Fruits of *D. draco* (Tim Waters)

According to the research of Krawczyszyn & Krawczyszyn (2015), the dragon tree flowers at ages ranging from 9 to 19 years. Their work is based on a close relationship between the amount of sunlight received by the plant and the age of its first flowering. This characteristic can be also applied on the trunk height. Individuals from full sun start branching closer to the ground and grow shorter than those that grow with less sunlight catching it from overhead.

Krawczyszyn & Krawczyszyn (2014) report about the massive aerial roots in this species. They appear on trees that are injured or under environmental stress and affect growth form and the life cycle of *Dracaena*. The aerial roots emerge from the first set of branches, descend the trunk and grow downwards to ground, the speed of growth is in average 3,3 cm/year.

Fig. 14 Aerial roots of *D. draco* (Author)

3.4.1.5. *Anatomy*

It is known that *Dracaena* species have more complicated vascular system than other monocotyledonous plants due to the secondary vascular thickening of the stem base and roots (Zimmermann & Tomilson 1970). *Dracaena draco* is closely related to the Socotra species *D. cinnabari* (Marrero et al. 1998). The group of species which form the dragon tree group combines specific characteristic of monocots and succulent plant types. Plants with succulent morphology are usually characterised by low flow rates (Nadezhdina et al. 2015). The research of Nadezhdina et al. (2015) focused on morphological, anatomical and physiological features demonstrated the ability of *D. draco* and *D. cinnabari* to absorb the condensed water on the leaves into the stem tissues. The water flows from leaves to the leaf axils and from there it penetrates to the primary parenchyma, then into the secondary part of the stem and is capable to get into the vascular system from parenchyma by osmotic pressure. Both species exhibit properties related to drought tolerance.

Other curious feature is their ability to change the type of photosynthesis. Experimental findings indicate that *Dracaena* is a facultative CAM plant (CAM cycle is used by succulents which must save the water, so they open the stomas in the night). With adequate ensuring of water, the leaves show typical C3 photosynthesis (typically in moderate areas where the photorespiration is not predominated over the photosynthesis), but they gradually change to CAM when they are exposed to increasing levels of drought (Brown & Mies 2012; Yamori et al. 2013).

3.4.1.6. Dragon’s blood

Dragon’s blood is a deep red resin (Wiyono 2010) produced by the dragon trees either naturally or through cuts in trunks and branches. In past, it was highly demanded for its medicinal, industrial, and even magical properties (d et al. 2003). The *D. draco* resin has been used also for artistic purposes and by traditional medicine as haemostatic, antiulcer, antimicrobial, antiviral, wound healing, antitumor, anti-inflammatory and antioxidant (Stefano et al. 2014). The origin of dragon’s blood is supposed to be from Socotra from species *D. cinnabari*. Except for *Dracaena*, dragon’s blood is obtained also from other plant genera: *Croton, Daemonorops, and Pterocarpus* (Gupta et al. 2007). In research of Gupta et al. (2007) about botany and chemistry is proved that *Dracaena draco* is a rich source of cytotoxic steroidal saponins.

4. MATERIAL AND METHODS

4.1. Study area

The Canary Islands are located on the northwest coast of Africa and belong to the subtropical region. The archipelago consists of seven volcanic islands from which Tenerife is the largest with an area of 2 057 km^2 and with the highest point of Spain– Pico del Teide, the volcano measuring 3 718 m (Criado & Paris 2005). The climate is influenced by altitude and exposition to the trade winds blowing from the northeast for almost whole year. The geography characteristic of island (high mountains, strong slopes all over the area) together with prevalent trade winds make very special local climate. The most typical phenomenon is the sea of clouds which is formed at mid heights when the air mist condenses for the trade winds pressing the air against the hilltops (Pórtoles et al. 2011). The temperature inversion separates the lower layer of moist cold air at higher elevations from the dry cold air in the altitude about 1 200 m a. s. l. (Fernández-Palacios 1992) and in the altitude from about 500 to 1 500 m a. s. l. the sea of clouds, “mar de nubes”, is formed (Criado & Paris 2005). The altitudinal limit of the cloud sea is changing during the year, reaching their highest altitude in the winter (Fernández-Palacios 1992).

The measurement takes a place in Tenerife, Canary Islands. The area under study is located in Anaga Mountains, 600 meters above sea level, on the windward side of northwest exposition. The experiment was placed in a private garden (geographical coordinates 28 30.234 N 16 22.859 W). In the site is evident the influence of horizontal precipitation in the form of fog and dew. The average annual temperature for the area of “mar de nubes” is 14 °C and average annual rainfall is 700 mm (Fernández-Palacios 1992).

Fig. 15 Location of study area (Google maps)

4.2. Measuring of horizontal precipitation

For measuring of horizontal precipitation there were used three seedlings of *Dracaena draco* 3–5 years old. The seedlings were bought in the ornamental trees nursery in Tenerife and then replanted to the green flowerpots. Into the bottom of the flowerpots were drilled three little holes for rainwater runoff. The flowerpots were filled with the soil from the experimental plot and were hung on automatic hanging weights (Tenzion Compression LoadCell 614C3 50 kg – Visgay Precision Group, USA) and fixed to the iron frames. First, there were dug out holes that were paved with stones for better stability and then the flowerpots were immersed into the holes hanging in the ground level. Data from the hanging weights were recorded into the datalogger MicroLog V3/4.096. In the experimental plot were installed other sensors for measuring of air temperature and air humidity (Minkin THi), global radiation (Minkin RTi) and the rain gauge for vertical precipitation (Pronamic Professional, PRONAMIC ApS – Denmark) with their own dataloggers. All sensors were measuring data in intervals of 3 minutes and stored averages into the dataloggers every 15 minutes. At the beginning and at the end there were taken pictures of each seedling from various sides for create a stereoscopic 3D model to determine the leaf area. The measurement took place in the periods from 10. 10. to 12. 12. 2016 and from 12. 1. to 15. 2. 2017. The weight changes of flowerpots with seedlings in circadian rhythm indicate either the water output by evapotranspiration or water uptake by the atmosphere or vertical precipitation. Horizontal precipitation was identified after the deduction of vertical precipitation.

Fig. 16 Experimental plot of measuring system with seedlings (Author)

Fig. 17 Hanging flowerpot (Author)

Fig. 18 Weight (Author)

Fig. 19 Rain gauge (Author)

Fig. 20 Datalogger (Author)

4.3. Data processing

Primary data from 15 minutes' averages weights of flowerpots with dragon seedlings in the monitored period were corrected regard to the temperature dependence of weights. This dependence was found out by saving the weight with constant load to the clima-box where the temperature was modified gradually. From those corrected data were calculated weight changes of two-time successive data recording. Subsequently, the data from period of precipitation and 3 hours after precipitation in order to avoid the seedling weight loss by water runoff from the flowerpot were deleted. The remaining data were divided into two groups depending on the air humidity. The first part was data corresponding with 100 % humidity and the second part were data corresponding with less than 100 %. However, a suitable condition for water condensation from the atmosphere forming on the leaf surface of dragons are expected also at lower relative humidity and therefore, the data were divided into other two groups that correspond with 97–100 % humidity and less than 97 %. After that it was performed integration of values in periods according to humidity. For this it was used the derivation, mathematical function which doesn't depend on offset. Because of this, increasing and decreasing curves in diagram are continuous. All the above-mentioned operations were realized in the program Mini32 (EMS Brno–Czech Republic).

5. RESULTS

5.1. Weather conditions

The average air temperature, air humidity (Fig. 21) and vertical precipitation (Fig. 22) differ between 2 measuring periods. In period from 10. 10. to 12. 12. 2016 (hereinafter referred to as the first period) the average temperature was 16,5 °C, when the highest value was 28,5 °C and the lowest 9,6 °C. Total amount of precipitation was 169,4 mm that was raining in total 387,5 hours from the entire period (1 500 hours that is equivalent to 26 % of monitored period). From the humidity point of view, 100 % and less than 100 % occur in proportion 35:65 when the 100% humidity predominates mostly in the night until the morning around 10 o'clock and the lowest values are in the afternoon around from 2 to 4 o'clock. In the case of 97–100% and < 97% humidity, the proportion is 47:53. Those values are more balanced.

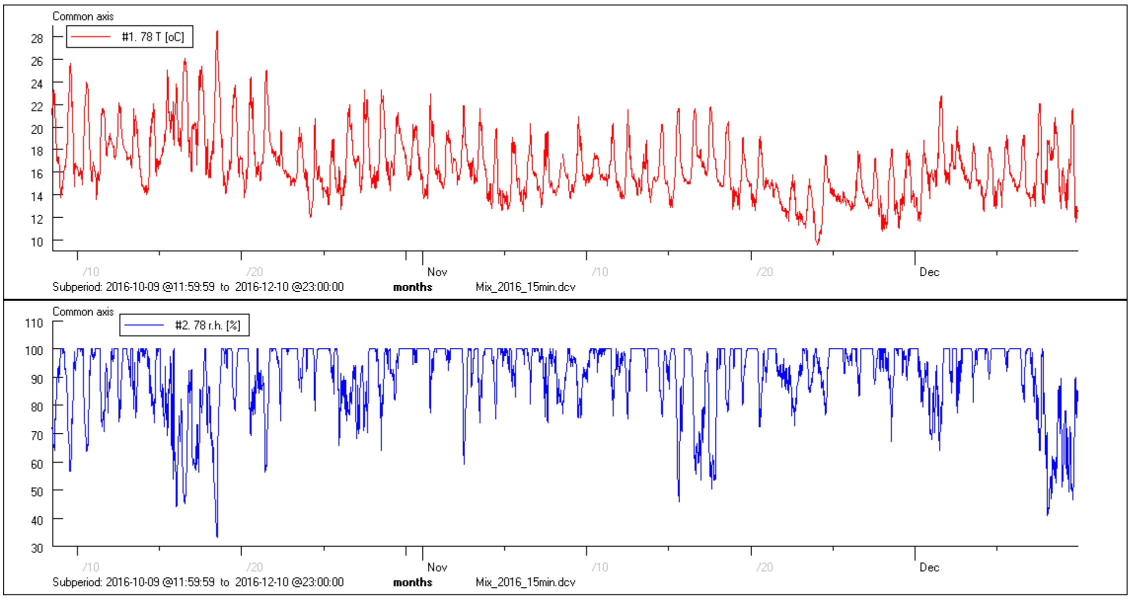


Fig. 21 Diagram of temperature (red, °C) and humidity (blue, %) in the first period

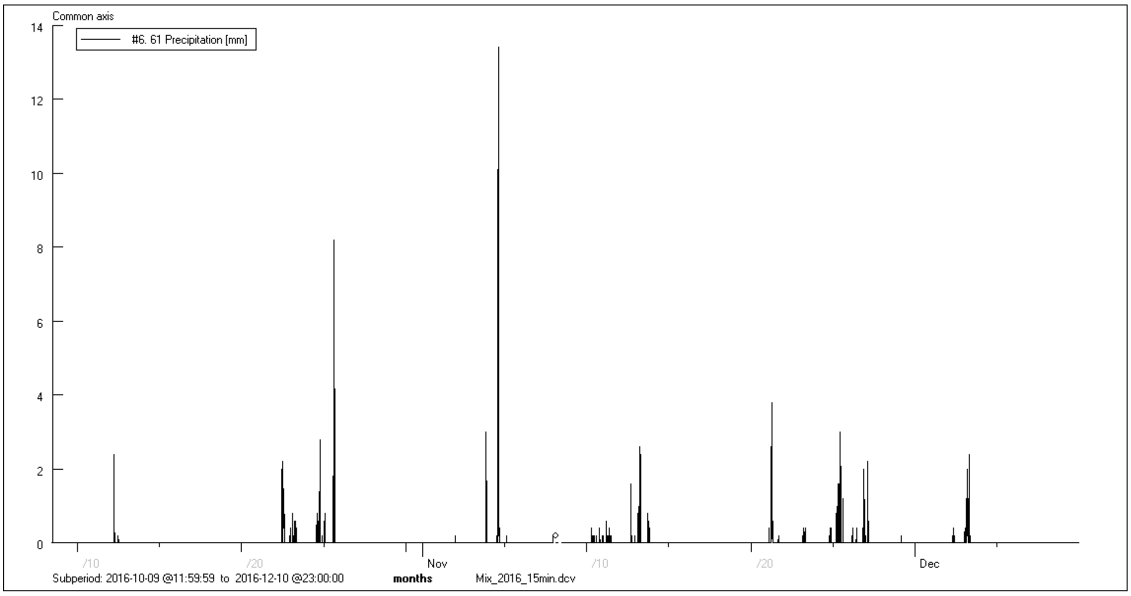


Fig. 22 Diagram of precipitation (mm) in the first period

In period from 12. 1. to 15. 2. 2017 (hereinafter referred to as the second period) the average temperature (Fig. 23) was 12,8 °C, when the highest value was 21,5 °C and the lowest 8 °C. Total amount of precipitation (Fig. 24) was 46,4 mm that was raining in total 19 hours from the entire period (878 hours that is equivalent to 2,2 % of monitored period). From the humidity point of view, 100 % and less than 100 % occur in proportion 27:73, therefore the 100% humidity is not so often as in the first period. In the case of 97–100% and less than 97% humidity, the proportion is 43:57.

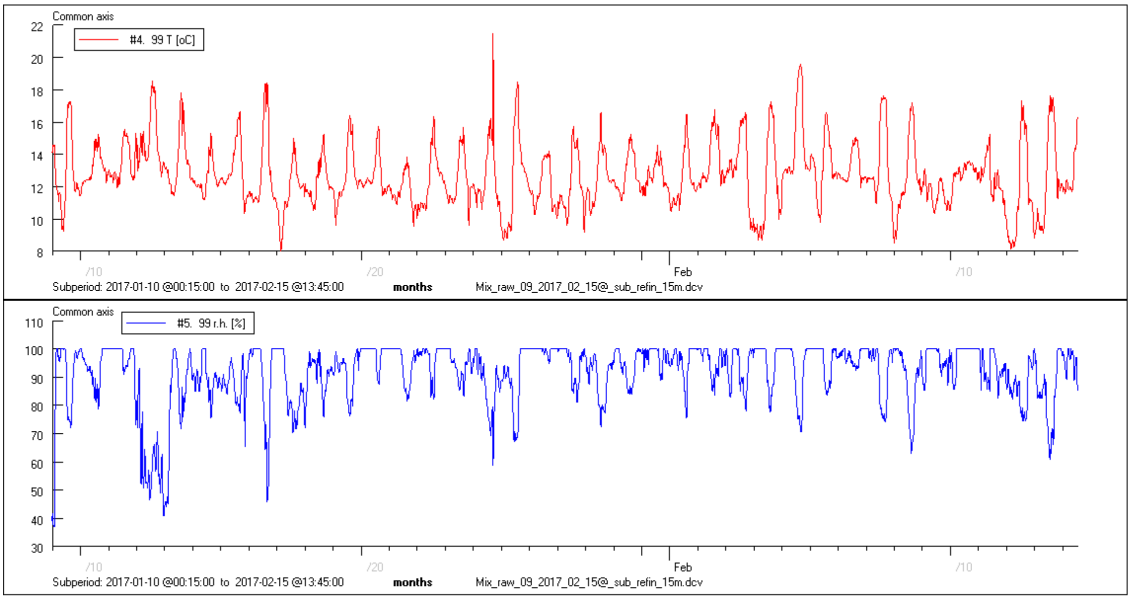


Fig. 23 Diagram of temperature (red, °C) and humidity (blue, %) in the second period

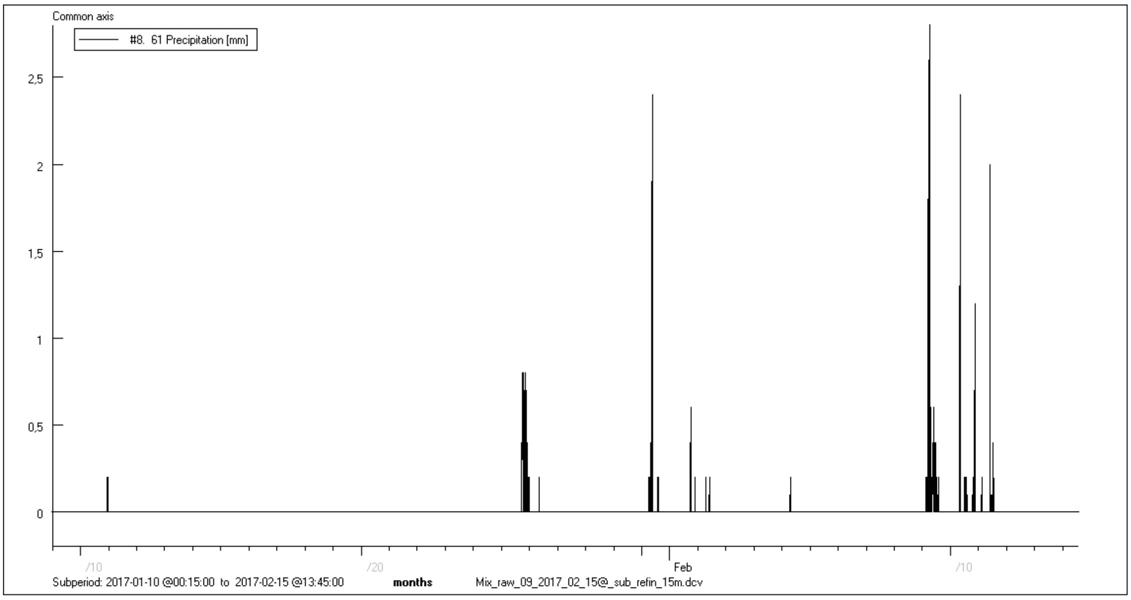


Fig. 24 Diagram of precipitation (mm) in the second period

5.2. Evaluation of seedlings weight changes

The values of changes in the weights of individual seedlings for both monitored periods are shown in table 3. The weight increase of seedlings (their biomass) in the first period reached 0,81 kg (weight 1), 0,65 kg (weight 2) and 0,78 kg (weight 3). In the second period the biomass increase of seedling reached 0,13 kg (weight 1), 0,13 kg (weight 2) and 0,37 kg (weight 3). Because the first period is longer than the second one, the increase was recalculated also per day. Despite this, the biomass increase is still higher in the first period.

Tab. 3 Weight changes of individual seedling in 2 periods

	1st period 10. 10. - 12. 12. 2016			2nd period 12. 1. - 15. 2. 2017		
	weight 1 [kg]	weight 2 [kg]	weight 3 [kg]	weight 1 [kg]	weight 2 [kg]	weight 3 [kg]
Initial value of seedling	4,53	3,47	4,67	5,55	3,96	5,21
Final value of seedling	5,34	4,12	5,45	5,68	4,09	5,58
Total seedlings biomass increment	0,81	0,65	0,78	0,13	0,13	0,37
Mean biomass increment per day	0,0127	0,0102	0,0122	0,0037	0,0037	0,0106

After derivation and integration of corrected data, we gained the sum of the weight changes during the measured periods. The amount of weight increasing in the period between rainfall can be identified with horizontal precipitation or with direct water uptake from the atmosphere by the seedlings and the amount of weight decreasing in periods between rainfall can be identified with evapotranspiration of seedlings.

In the first period when the relative humidity reached 100 %, the sum of weight changes is positive and achieves 0,9 kg (weight 1), 0,6 kg (weight 2) and 0,5 kg (weight 3) (Fig. 25). The sum of seedling weights changes in period with relative air humidity under 100 % are negative and reach -9,3 kg (weight 1), -6,5 kg (weight 2) and -8,5 kg (weight 3) in monitored period (Fig. 25). It means, the evapotranspiration predominates over the weight increase identified by water uptake from atmosphere. There is an importance of period with relative humidity 100 % when horizontal precipitation replaces 6–10 % of what is evaporated during the period with lower humidity.

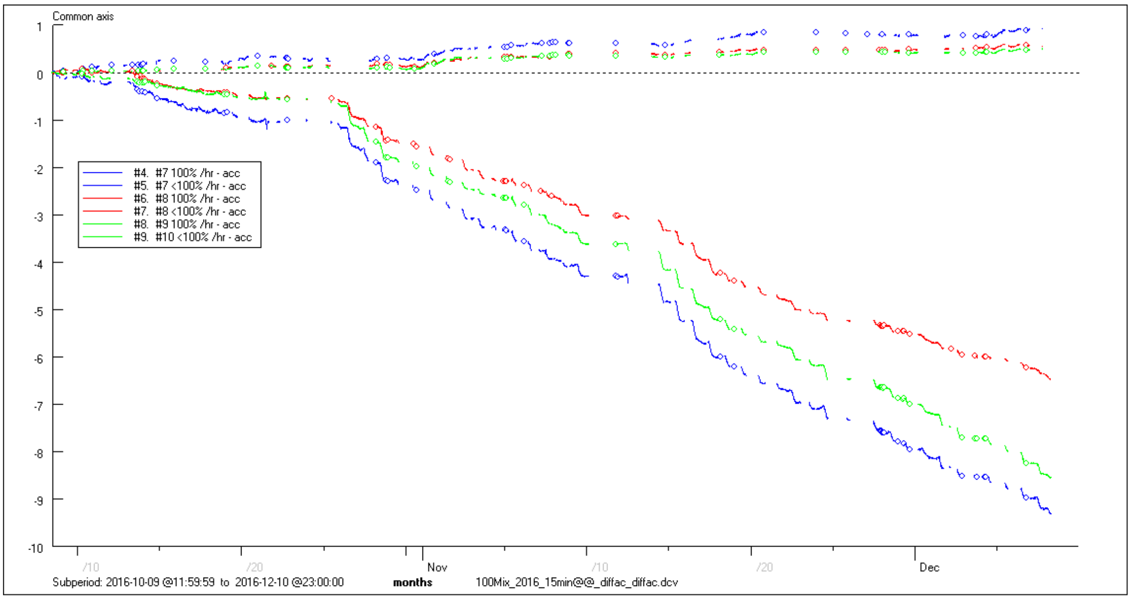


Fig. 25 Diagram of total increasing and decreasing values in the 1st period, 100 % and < 100 % humidity

When the relative humidity reached 97–100 % (Fig. 26), the sum of weight changes is also positive and achieves 1,0 kg (weight 1), 0,5 kg (weight 2) and 0,2 kg (weight 3). The negative values of seedling weights under 97% humidity reached -10,0 kg (weight 1), -5,8 kg (weight 2) and -7,7 kg (weight 3) in monitored period. The evapotranspiration still predominates and the horizontal precipitation replaces 3–10 % of what is evaporated during the period with lower humidity.

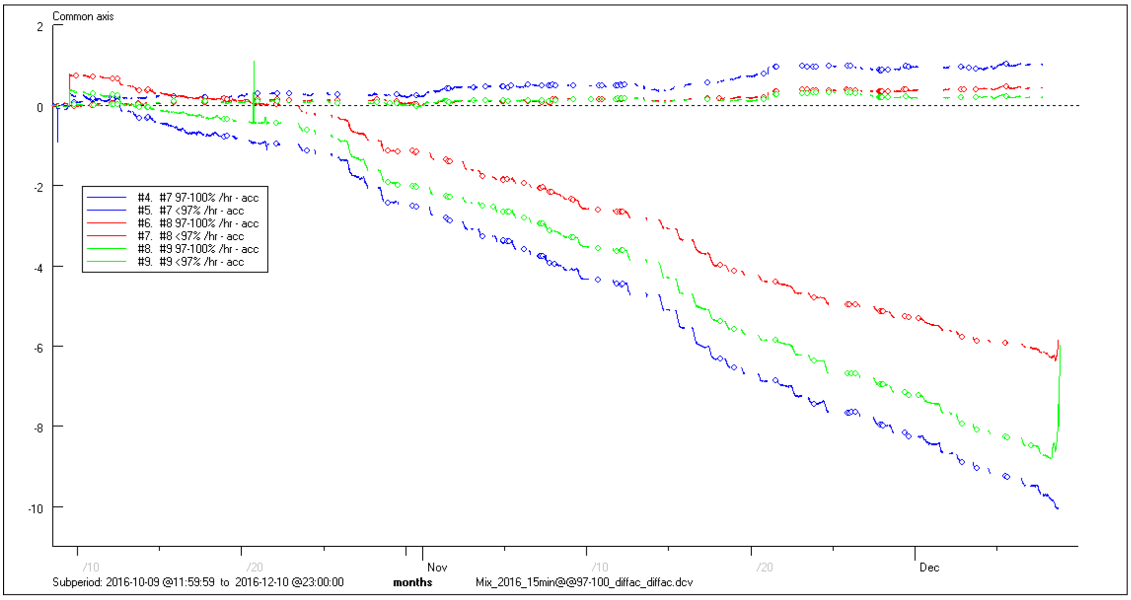


Fig. 26 Diagram of total increasing and decreasing values in the 1st period, 97–100 % and < 97 % humidity

In the second period when the relative humidity reached 100 % (Fig. 27), the sum of weight changes is null or negative and achieves -0,2 kg (weight 1), 0,0 kg (weight 2) and -0,1 kg (weight 3). The values of seedling weights in period with < 100% humidity are still negative and reach -5,7 kg (weight 1), -4,3 kg (weight 2) and -5,1 kg (weight 3) in monitored period. The evapotranspiration predominates and the horizontal precipitation does not replace what is evaporated during the period with lower humidity.

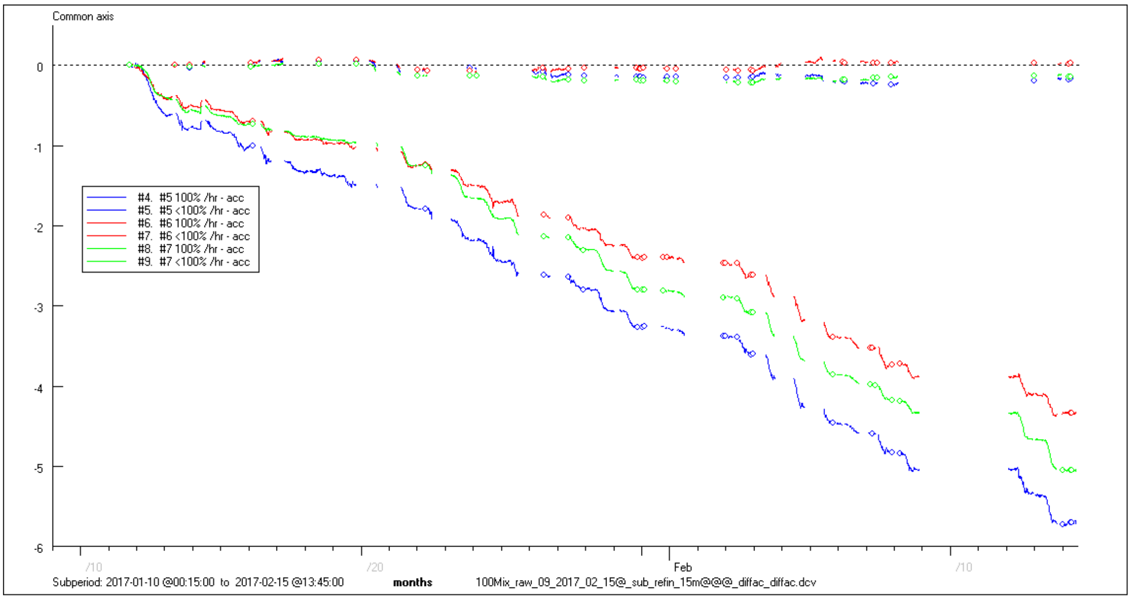


Fig. 27 Diagram of total increasing and decreasing values in the 2nd period, 100 % and < 100 % humidity

When the relative humidity reached 97–100 % (Fig. 28), the sum of weight changes is also negative and achieves -0,7 kg (weight 1), -0,1 kg (weight 2) and -0,5 kg (weight 3). The values of seedling weights in period with < 97% humidity are negative and reach -5,7 kg (weight 1), -4,3 kg (weight 2) and -5,1 kg (weight 3) in monitored period. The evapotranspiration predominates and the horizontal precipitation does not replace what is evaporated during the period with lower humidity.

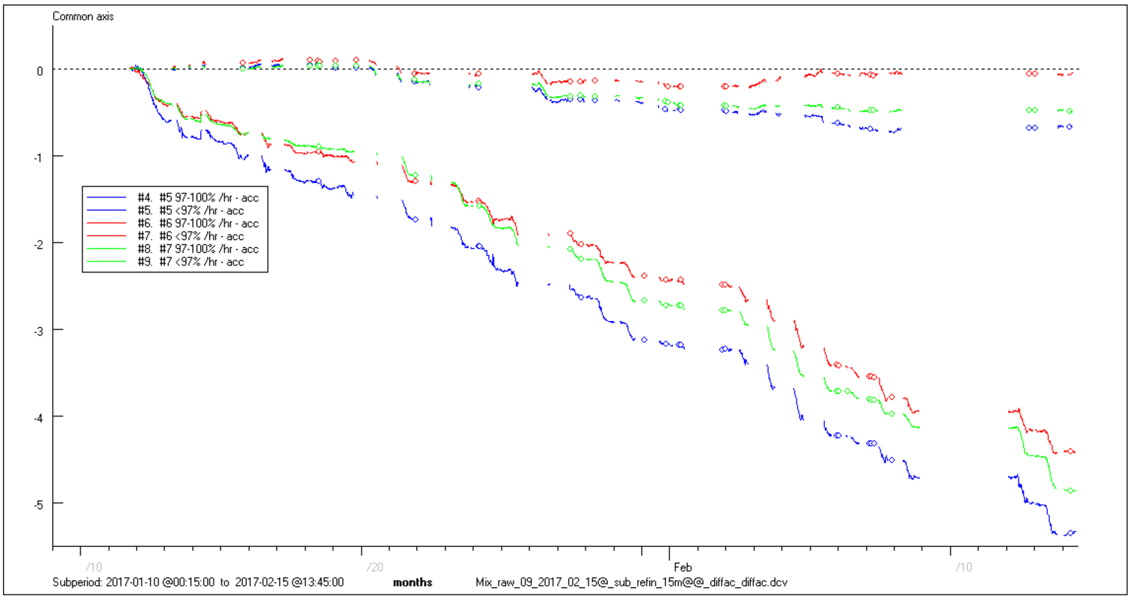


Fig. 28 Diagram of total increasing and decreasing values in the 2nd period, 97–100 % and < 97 % humidity

6. DISCUSSION

In the first period, in the case of humidity division to 100 % and < 100 %, horizontal precipitation replaces 6–10 % of what was evaporated during the period with lower humidity. In division to 97–100 % and < 97 %, horizontal precipitation replaces the evapotranspiration by 3–10 %. In the second period with humidity division on 100 % and < 100 % and 97–100 % and <97 %, horizontal precipitation did not replace the evapotranspiration, sum of weight changes was null or negative in each case.

The results show a distinct decrease in the amount of horizontal precipitation during the winter months which is in compliance with data measured by Marzol et al. (2011). The study period took a place from 2006 to 2010 in Anaga mountains where is located also our measurement. This decrease is caused by the predominance of vertical cloud development and, therefore, there is a reduced presence of stratocumulus cloud formation (Marzol et al. 2011).

Another factor influencing the reduced amount of horizontal precipitation can be the wind speed. Hadaš & Kulhavý (2013) state that the dew formation arises during the windless conditions, respectively at wind speed up to 1 m. s^{-1}. In our measurement, horizontal precipitation in the form of dew is an important type of horizontal precipitation that is formed mainly at night, which corresponds with our results when 100% humidity suitable for condensation predominated mostly in the night until the morning around 10 o’clock.

In the literature, it can be find lot of researches focused on measuring of horizontal precipitation. For example, Hildebrandt & Eltahir (2006) reported 165–246 mm horizontal precipitation for 2004 in Oman seasonal arid cloud forest. Scholte & De Geest (2010) measured the horizontal precipitation with nets on Socotra island in the season of summer monsoon. The presented values were from 0,18 to 10,14 mm per day per m^2 of the net and the measurement lasted from 18 to 80 days. Marzol et al. (2011) measured the horizontal precipitation from 2006 to 2010 in the north-eastern Morocco in Boutmezguida and in Tenerife (Canary Islands) in Anaga mountains. In Morocco, the season with abundant occurrence of fog begins in November and lasts until June, with daily averages of 7,4 to 20,5 mm. In comparison, the main season with fog occurrence on the Canary Islands lasts only from June to August with daily averages of 11,3 to 23,4 mm. The annual averages of horizontal precipitation over the entire period in

Morocco reached from 3 163 to 3 853 mm and the Canary Islands from 2 541 to 3 803 mm.

In contrast to the above–cited authors who measured the horizontal precipitation with nets (Scholte & De Geest 2010; Marzol et al. 2011) and models (Hildebrandt & Eltahir 2006), our method is based on the uptake of horizontal precipitation by the plant in natural conditions and do not determine the exact amount for example in millimetres. The method is able to express the percental proportion of uptake and output.

For the evaluation of the horizontal precipitation importance for seedlings growth would be better to have data from longer period, because results give more specific and clarifying information when the data are continuous. Our research began in April 2016, however after 5 weeks, the datalogger was discharged and the other one could not be installed until the October. This problem repeated in December. In both cases, it was due to the hardware problems in communication between weights and datalogger which caused the datalogger batteries discharging. This error was repaired definitely in December 2016. From this reasons, there are available only data from 2 short periods.

The measured values can be influenced also by the imprecision of the measurement sets (placement of sensors in terrain, influence of humidity to weights) or by exterior effect (strong wind or an animal seated on the flowerpot). Other reason could be imprecise determination of water runoff from the flowerpot after the rainfall period. This problem could be solved by addition of apparatus which would precisely measure the water runoff from the flowerpot.

At the end of the experiment there will be, for the detailed characteristics of the measured object (for all three seedlings), destructively determined the aboveground and underground biomass, biomass of individual leaves, the number, length and area of each leave surface. The measured values of horizontal precipitation during the season will be related to the area of foliage.

7. SUMMARY

The measurement took a place in Tenerife, Canary Islands. The area under study is located in Anaga mountains, 600 meters above sea level, windward side. The location of the area was chosen in consideration of the presence of cloud forests where is very important the source of water in the form of fog and other horizontal precipitation during all year long. Another reason was the occurrence of endemic species *Dracaena draco* which has morphological, anatomical and physiological adaptation to drought stress and is able to absorb the condensed water on the leaves into the stem tissues.

The project was based on 3 measurement sets with seedlings of *D. draco* placed in flowerpots hanging on the weights. Data of weight changes were saved in intervals of 15 minutes into datalogger. The TH sensor, that measures temperature and humidity of the air, and the rain gauge were also installed in the study area.

The results of two measured periods from October to December and from January to February proved that the seedlings can partly replace the loss of water from evapotranspiration by the water uptake from the atmosphere. Water uptake from the atmosphere took place mainly in the night and the water output by transpiration predominated during the day. The research shows that horizontal precipitation replaced the evapotranspiration by 6–10 % in the first period. In the second period, it did not replace the evapotranspiration because of the lower amount of horizontal precipitation caused by local weather conditions. The most expressive are the wind and the predominance of vertical cloud development that causes the reduced presence of stratocumulus cloud formation. Unfortunately, due to failures in the measurement caused by the battery discharging, we have data only from a period in which even Marzol et al. (2011) reported the lowest proportion of horizontal precipitation.

Little is known about the measuring of horizontal precipitation on plant in its natural condition. An important result is that our method for measuring horizontal precipitation of seedlings *in situ* is applicable, but it will require further development in order to better interpret the measured data.

The results open other questions, especially about the way how *D. draco* absorb water from the atmosphere.

8. SUMMARY (CZ)

Měření probíhalo na Tenerife na Kanárských ostrovech. Místo výzkumu se nachází v pohoří Anaga, 600 m n.m., na návětrné straně. Oblast byla vybrána s ohledem na přítomnost mlžných lesů, kde se nachází velice významný zdroj vody v podobě mlhy a dalších horizontálních srážek během celého roku. Dalším důvodem pro vybrání této lokality byl výskyt endemického druhu *Dracaena draco*, který má řadu morfologických, anatomických a fyziologických adaptací k zachycení vody během suchého období. Tento druh je schopný absorbovat vodu kondenzovanou na listech do cévních svazků.

Projekt byl založen na 3 měřících soustavách se sazenicemi *D. draco*, které byly umístěné do květináčů a zavěšené na váhy. Měření probíhalo na principu váhových změn, data byla ukládána každých 15 minut do dataloggeru. V místě měření bylo dále nainstalováno TH čidlo pro měření teploty a vlhkosti vzduchu a srážkoměr.

Výsledky ze dvou měřených period, od října do prosince a od ledna do února, ukázaly, že sazenice dokáží ztráty vody výparem částečně nahradit příjmem vody z atmosféry. Příjem vody z atmosféry probíhal především v noci a výdej vody transpirací převažoval ve dne, horizontální srážka nahrazovala výpar o 6–10 % v první periodě měřené od října, v druhé periodě měřené od ledna už horizontální srážka výpar nenahradila. Důvodem nižšího výskytu horizontálních srážek mohou být zdejší klimatické podmínky. Nejvýraznější z nich se jeví vítr a převládající vertikální mrak, který snižuje výskyt stratocumulus, který tvoří oblaka nízkého patra. Bohužel, díky poruchám v měření, které způsobily vybití baterií, máme data pouze z období, ve kterém i Marzol et al. (2011) uvádí nejnižší podíl horizontálních srážek.

Měření horizontálních srážek přímo na rostlině v jejích přírodních podmínkách je zatím prostudováno velmi málo. Důležitým výsledkem je, že naše metoda měření horizontálních srážek *in situ* na sazenicích je použitelná, ale že bude vyžadovat další vývoj, aby byla naměřená data lépe interpretovatelná.

Výsledky otevírají další otázky, zejména jakým způsobem je *D. draco* schopna přijímat vodu z atmosféry.

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