An ecohydrological and soils study in a montane cloud forest in the National Park of Garajonay, La Gomera (Canary Islands, Spain)

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Chapter VIII

SUMMARY
AND
RECOMMENDATIONS
FOR FUTURE RESEARCH

VIII SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

VIII.1 BACKGROUND, SETTING AND RESEARCH OBJECTIVES

Laurisilva vegetation is a laurel-dominated subtropical forest formation of great scientific value which was widespread in the southern Mediterranean region during the Tertiary era. Today it survives in the Macaronesian Region (composed of the Cape Verde islands, the Canary islands, Madeira and the Azores between 15° and 41°N latitudes), on mountains where humid conditions are guaranteed throughout the year. The Canaries are situated close to the West African coast and experience a lack of precipitation during five months (from May to September). The survival of the *laurisilva* vegetation so close to the Sahara desert can be explained by the particular climatic setting of the Canary Islands. The combination of being located on the south-eastern edge of the Azores anticyclone, coastlines being washed by cold Atlantic currents, and the occurrence of north-easterly trade winds allows the formation of a subsidence thermal inversion that translates into a stratocumulus deck on the windward sides of several of the islands that is locally known as the 'sea of clouds'. Although the cloud belt exhibits a seasonal change in elevation (lower in summer, higher in winter), it mitigates dry atmospheric conditions where and when it occurs in two ways: not only do the trees catch moisture from the fog brought in by the trade winds but also evaporative losses are much reduced. Although all seven Canary Islands must have been covered to some extent by *laurisilva* forests, some islands such as Lanzarote lost all their forests as a direct consequence of past human activities. The most extensive contiguous area of *laurisilva* is found in central La Gomera. In 1981, the Spanish authorities declared the forests in the Garajonay area a National Park in order to better protect and conserve these unique forests and in 1986 it became a UNESCO World Heritage Site. The Park is important not only for its special biodiversity but also for the water resources of La Gomera. Underneath this relatively wet mountainous area the main water storages of the island are found in the form of volcanic aquifers. Laurel forests differ in floristic composition and structure with elevation and different forest types may occur within close proximity of each other, e.g. stunted ridge-top forests on exposed ridges and mountain summits, slope forests of intermediate stature, and tall-broad-leaved valley-bottom forests. Comparatively little is known of the ecohydrological behaviour of each of these forests but given their different degrees of exposure to the trade winds and the fog that these carry, it is expected that their respective contributions to soil- and groundwater recharge will be different.

Arguably, the hydrometeorological situation is the most complex on the exposed and windy ridges. Here, the rain can be expected to come in under variable angles (depending on wind speeds, rainfall intensity and raindrop size) whereas in addition as yet unknown amounts of wind-driven fog will be captured by the vegetation. It was hypothesized that at the more sheltered valley-bottom locations fog will be much less important in terms of frequency of occurrence and as an input of water whereas deviations in rainfall angles from the vertical would also be expected to be (much) smaller. As such, emphasis in the present work was placed on evaluating the water budget of a ridge-top forest, Here, at 1270 m in the 44 ha Jelima headwater catchment in Central La Gomera, measurements were made of rainfall and (potential) fog water inputs using passive fog screens placed above the canopy, as well as of throughfall, tree transpiration (sap flow gauges) and soil water content. In addition, rainfall, fog and throughfall were also determined at a slope forest site (1220 m) and at two valley-bottom sites (1170 and 1140 m) within the catchment.

The following sections summarize the main findings of the current research, starting with a characterization of the degree of water repellence of the volcanic soils and ways to quantify this (Chapter III). This is followed by the quantification of rainfall, fog and throughfall in the wind- and fog-exposed ridge-top forest site (Chapter IV) and at the other, more sheltered locations (Chapter V). Chapter V also discusses the results of an application of the analytical model of rainfall interception to predict canopy interception under conditions of rain-only, fog-only, and mixed precipitation events. In Chapter VI the soil water uptake of the ridge-top vegetation is examined whereas in Chapter VII the influence of key climatic variables (radiation, temperature, vapour pressure deficit) and soil water content on surface conductance behaviour in the two dominant species of this forest (*Myrica faya* and *Erica arborea*) are quantified. Apart from listing the main findings per Chapter in corresponding sections, various recommendations for further research are offered. The latter are presented in a different format within each section to facilitate distinction between results and recommendations.

VIII.2 SOIL WATER REPELLENCE

The loss of soil wettability and the temporal or permanent resistance of the soil to be wetted again are known as soil hydrophobicity or soil water repellence. In general, water repellence may be caused by drying of the soil or by coating of the soil particles with organic compounds. The latter may derive from decomposition products, fungal hyphae or sub-products of the metabolic activity of micro-organisms. The importance of detecting occurrence and degree of soil water repellence in the field relates to its effect on soil hydraulic properties and therefore on the rate of water infiltration and the behaviour of flow through the soil matrix.

Water repellence is typically observed in dry soils, particularly those of a volcanic or peaty nature.

This study investigated (i) whether the volcanic soils (Leptosols and Andosols in the FAO classification) of the Jelima catchment were potentially water repellent; and (ii) the influence of soil water content on degree of water repellence. Based on the results of two commonly used types of laboratory tests for repellence (the water drop penetration time (WDPT) test and the molarity of ethanol droplet (MED) test) and subjecting a large number of field samples of surface soils (n = 140) to a stepwise drying from saturated to oven-dry conditions, a simple model was developed to predict the persistence and degree of water repellence as a function of soil water content.

The ***presently obtained results*** showed that:

- All sampled surface soils (<0.23 m depth) exhibited water repellence upon air-drying.
- Soils developing water repellence were non-allophanic in nature (i.e. they had high Al_p/Al_o ratios), high organic matter content (8-70%), and moderately low pH (ca. 5), whereas samples with lower Al_p/Al_o ratios (<8%), and lower organic matter content were non-water-repellent.
- Organic matter content in itself did not explain the observed differences in degree and persistency of repellency.
- No clear relationships were found between water repellency occurrence and topographic position within the catchment (valley bottom, slope or ridge top) or associated vegetation type (laurel-dominated forest, transitional slope forest and mixed tree-heath/beech forest, respectively).
- The development of hydrophobicity strongly depended on soil water content.
- Soils started to become water repellent close to field capacity and maximum persistence was reached around wilting point.
- Repellence varied non-monotonically with decreasing soil water content and the patterns could be reproduced using simple equations.
- The MED method is to be preferred with strongly hydrophobic soils because it gave less variable results at maximum repellence levels.
- A better characterization of soil water repellence is obtained if the WDPT or MED test is repeated at different soil water contents, particularly at field capacity and permanent wilting point.

The following ***recommendations for further research*** are offered:

1. Although soil organic matter content itself did not explain observed differences in degree and persistence of soil water repellence, further work characterizing the type of organic matter (humus) and compounds therein (e.g. resins, waxes) may reveal specific influences on topsoil water repellence.

2. The behaviour of hydrophobicity strongly depended on soil water content and was reproduced by simple regression equations. However, because the water repellence tests were applied to disturbed soil samples in the laboratory further work should validate the derived equations under field conditions.

3. Further work should assess the role of soil water repellence in the generation of overland flow on the steep slopes of the study catchment.

4. It is important to study the temporal variability of soil water repellence throughout the year (e.g. as a function of soil water content) as this allows an assessment of soil erosion risks.

VIII.3 RAINFALL, FOG AND THROUGHFALL DYNAMICS OF A RIDGE-TOP CLOUD FOREST

The ridges of the Jelima catchment at ca. 1270 m altitude contain a good example of the kind of mixed tree heath-beech cloud forest (*fayal-brezal*) that is typically found on exposed ridge and summit locations in the Garajonay area and elsewhere in the Canaries. This section summarizes the methods and results obtained with respect to rainfall and fog water inputs and their transformation to throughfall at this wind- and fog-ridden site.

The assessment of the “true” water inputs to sites in mountainous areas subject to strong wind is surrounded with uncertainty and results are highly dependent on the methods of collection and the exact location of the site. Rainfall and fog were measured above the canopy between February 2003 and January 2005. Rainfall was measured with a conventional recording rain gauge and fog with a quarter-sized standard fog collector (0.5 x 0.5 m) with a fixed orientation facing the dominant wind direction (NE). The degree of underestimation of incoming rainfall due to wind losses around the gauge was approximated using the approach of Yang et al. (1998). Moreover, under windy conditions rainfall tends to impact against the canopy at an angle. In the case of steep topography, the combined interaction between canopy / slope angle and aspect on the one hand, and the angle and direction of the rain on the other hand, will cause the rainfall intensity as measured by a gauge to differ from that hitting the canopy. The method advanced by Sharon (1980) was used to correct for these effects. Similarly, fixed-screen fog collectors may underestimate fog incidence because for wind directions deviating from the normal (90 degrees) direction the “true” surface area of collection of the fog collector will be reduced. Therefore, the effective surface of fog collection was calculated using trigonometry as a function of wind direction, something which has not been done in previous fog studies in the Canaries. A fog trapping efficiency of 60% was used for this type of wire mesh based on previous measurements by others. Applying the latter value to the corrected fog catch gave the potential fog incidence. Finally, it is well known that major uncertainties are also associated with the measurement of throughfall in species-rich forests. Many studies have tried to reduce the standard deviation of mean throughfall by installing a large number of small gauges that are usually checked manually. Given the remoteness of the study site and the need to have matching records of rainfall, fog occurrence and throughfall it was decided to risk a relatively large error in estimated throughfall and use two automatic throughfall gauges per site. These gauges had a collecting surface of 0.2 m^2 each, giving a total sampling area of 0.4 m^2 per plot (equivalent to 40 standard gauges of 0.01 m^2 each).

The ***presently obtained results*** showed that:

- Rainfall had a strong seasonal character: the rainiest period occurred in autumn and winter whereas rainfall was insignificant during the five-month period between May and September.
- Interannual variability was high, with (uncorrected) annual rainfall in the first year (670 mm) being close to the estimated long-term average of 660 mm but being as much as 1185 mm in the second year.
- Rainfall intensities were generally low, with 50% of the days with rain receiving ≤2 mm and 38% <1 mm. Daily totals in excess of 20 mm occurred on 13% of the rain days.
- Underestimation of measured annual rainfall due to wind losses and slope effects on these exposed ridge locations may reach up to 39% of uncorrected rainfall; 20% was due to wind losses around the gauge and 19% related to slope and rain angle effects in the respective years.
- Fog inputs after correcting for variations in wind direction (F_c) were ca. 882 and 834 mm during the first and second year, respectively. Corrections due to changes in deviation from the dominant wind direction were substantial (+63% on average).
- Relative amounts of throughfall (*Tf*) differed between precipitation type: (i) for events with rain-only, *Tf* was on average 85% of wind- and slope-corrected precipitation inputs; (ii) on days with fog-only, *Tf* constituted a very small proportion (3.0%) of potential fog incidence, suggesting that the fog trapping efficiency of the forest canopy was much smaller than that of the fog screens used; (iii) on days with mixed precipitation (rainfall and fog), average *Tf* was 108% of wind- and slope-corrected precipitation, suggesting fog to be an important contributor under these conditions although the precise mechanism involved

remains unclear. Perhaps a larger proportion of the fog may find its way to the forest floor once the canopy (including bryophytes) is first saturated by rainfall.

- Despite the small absolute amounts of fog water inputs to the ecosystem, fog was the main input of water in the dry summer and acted effectively as a supplementary input besides rainfall during spring, winter and autumn by reducing evaporation (see below), and by increasing the amount of throughfall during mixed events.

- The overall variability in *Tf* catch for rainfall between the two gauges was high (±30% SD); using eight gauges would decrease the variability to ca. 15%. In the case of events with fog-only, variability in *Tf* catch between the two gauges was even higher (±69%).

The following ***recommendations for further research*** are offered:

1. Existing rainfall and wind records in the uplands of La Gomera and elsewhere may be used to evaluate the degree of potential underestimation in rainfall catch in the past. Future studies in windy mountain areas such as the Garajonay National Park should take into account the under-catch of rainfall due to wind losses around the gauge and slope/rainfall angle effects.

2. To avoid underestimation of fog incidence due to variations in wind direction when using fixed screen collectors it is advisable to use cylindrical fog collectors of well-defined catch efficiency such as the louvered gauge of Juvik and Ekern (1978) or the ASRC string collector (Falconer and Falconer, 1980) unless the screens can be oriented automatically towards the prevailing wind direction.

3. Amounts of fog deposition onto a fog screen are highly sensitive to the trapping efficiency of the wire mesh. The actual mesh efficiency of the type of collector screen used in the Canaries and any changes therein with angle of incidence of the wind-driven drops due to (extreme) variations in wind direction need to be evaluated.

4. No data are available as yet on the liquid water content (LWC) of fog in the Canaries. Measurements of the droplet size spectrum of the fog in relation to visibility would be useful.

5. The large contrast between the very low amounts of throughfall generated by fog-only events and the very high ratios observed during events with mixed precipitation requires further process-based research. Apart from implementing several of the previous recommendations, such work could combine a mass-balance approach for stable isotopes (e.g. 18O) to separate fog and rain water in throughfall e.g. (Dawson, 1998; van Dijk and Bruijnzeel, 2001), measurements of the biomass, water storage capacity, and wetting and drying dynamics of epiphytes and mosses (Hölscher et al., 2004; Köhler et al., 2007; Tobón-Marín et al., 2007), together with improved measurements of (the spatial variability of) throughfall by employing sufficiently replicated sampling.

VIII.4 SPATIAL VARIABILITY OF WATER INPUTS ACROSS THE CATCHMENT AND MODELLING CANOPY INTERCEPTION FOR RAINFALL, FOG, AND MIXED PRECIPITATION

Between 1090 and 1300 m elevation the Jelima catchment is covered by a representative sample of three different subgroups of forest within the subtropical laurel-dominated forest. Tall laurel-dominated forest is found in the sheltered valley bottoms, whereas transition forest of intermediate stature occurs on the slopes, and short-stature mixed tree-heath/beech forest is found on the ridges. Rainfall inputs and fog incidence above the canopy, as well as throughfall were measured using the methods described in the previous section in each of four plots representing the three forest types (two plots were in valley-bottom forest, of which only one was used in the present analysis) from February 2003 to September 2004. In addition, the analytical model of rainfall interception advanced by Gash (1979) and revised by Gash et al. (1995) was applied to predict canopy interception during times of rainfall- only (all plots) and during times of fog-only and mixed precipitation (ridge-top plot only).

The ***presently obtained results*** showed that:

- In the relatively sheltered valley-bottom and slope forests, rain was the main source of water inputs. On the ridge, days with fog or mixed precipitation were much more frequent and potentially contributed as much water as events with rain-only.
- Rainfall corrections for wind losses around the gauge were 6-9% of gross precipitation in the valley and on the slope, compared to 20% on the ridge. Underestimation of rainfall was very modest (2% of P_a^*) for slope/rain angle effects for the slope site because of its orientation towards the west but more pronounced on the windy ridge (14%) and in the valley (7%, possibly due to funnelling).
- Once rainfall was corrected for wind losses and topographic effects, spatial variability between the sites was small (±5.5%).
- Showers at the valley-bottom and slope sites were characterized by low intensities (65% of rain days had ≤2 mm/d), except during the rainiest period (October until January) when convective storms occasionally produced larger amounts (11% of rain days had >20 mm).
- Amounts of wind-corrected fog incidence (F_c) were modest in the valley (27-30 mm/yr) and on the slope (ca. 67-76 mm/yr) but increased exponentially with elevation towards the ridge (834-882 mm/yr), which is explained by the much higher fog frequency and greater wind speeds prevailing on the ridge.
- Absolute amounts of throughfall generated during conditions of fog-only were very small in the valley and on the slope, but also very modest at the ridge top, presumably

because the canopy of the mixed tree heath/beech forest was much less efficient at capturing passing fog than the screen collectors.

- Amounts of throughfall produced by rain-only events were 79% in the valley, 83% on the slope, and 85% on the ridge and exhibited an inverse trend with forest LAI. Conversely, during events with mixed precipitation, throughfall exceeded wind-corrected rainfall inputs at all three sites, suggesting that fog may contribute more to throughfall when combined with rainfall than when it occurs alone. The difference is thought to reflect the contrast in the degree of wetting of canopy and bryophytes during conditions of fog-only and mixed events.
- The analytical interception model of Gash was calibrated during days with rain-only. Derived values for canopy storage capacity for the three forests were not significantly different but increased with a greater presence of needle-leaved tree-heath.
- Storms >2 mm were estimated to produce stemflow in the valley and slope forests vs. 3.2 mm in the ridge-top forest.
- Mean rates of wet canopy evaporation $\overline{E_w}$ as derived from rainfall interception measurements at the three sites was 0.28 ± 0.02 mm/h vs. 0.04 mm/h (rainfall-only) to 0.09 mm/h (fog-only) according to the Penman-Monteith equation. This contrast is attributed to the fact that the Penman-Monteith equation does not take into account the potentially large amounts of advected energy that may be brought in from the nearby ocean. The higher $\overline{E_w}$ rate during fog events compared to rainy conditions is due to the higher radiation loads received during times of fog compared to rain.
- The analytical model predicted measured amounts of throughfall associated with rainfall-only events quite well. Furthermore, the calibrated model for days with fog-only indicated that actual amounts of fog stripped by the canopy of the ridge-top forest were 13% (on average) of the potential fog deposition as measured above the canopy (D_{Fc}) whereas for mixed precipitation events optimized actual amounts of captured fog was 20% of D_{Fc} .

The following ***recommendations for further research*** are offered:

1. To complement the current preliminary study of spatial variability of fog inputs in the Jelima catchment additional fog collectors (preferably of the cylindrical type) should be installed to cover slopes of different orientation. The results may be usefully compared with predictions made by the spatially explicit FIESTA_fog delivery model of Mulligan and Burke (2006).

2. Throughfall measurements need to be improved by using a sufficiently replicated number of gauges. The improved data set may be used to re-calibrate the Gash model to better predict net water inputs to the soils of the valley and slope forests where fog incidence was not important (see also the final recommendation of the previous section).

VIII.5 STAND TRANSPIRATION AND CANOPY CONDUCTANCE OF MIXED TREE-HEATH / BEECH FOREST ON THE RIDGE

Next to rainfall and fog water inputs and their conversion to throughfall, measurements were made of transpiration (soil water uptake) and soil water content in the ridge-top forest at 1270 m. Sap flow was measured continuously in seven trees selected from the two most abundant tree species present in the forest, *Myrica faya* and *Erica arborea*, using the heat dissipation technique. Sap flow rates in individual trees were scaled to the stand level using empirical relationships between sap flux and tree diameter at breast height (DBH) per species and information on DBH distribution per species in the plot. Soil water content was measured using Time Domain Reflectometry (TDR) probes down to a depth of 0.3 m. This section summarizes the main results obtained with respect to transpiration and derived estimates of canopy conductance, and the effects of changes in climatic parameters and soil water content on transpiration and conductance.

The ***presently obtained results*** may be summarized as follows:

- Sap flow activity in similarly sized trees of *Erica arborea* (narrow-leaved) and *Myrica faya* (broad-leaved) trees were roughly four times higher in *E. arborea*. In addition, fluxes increased markedly with stem diameter in *Erica* but not in *Myrica*.
- Estimated contributions to overall stand transpiration by *E. arborea, M. faya* and *Laurus azorica* were 40%, 48%, and 12%, respectively, compared to relative contributions to stand basal area of 33%, 57% and 10%, respectively.
- Night-time transpiration was observed in both *Erica* and *Myrica*; rates were ca. 5% of daytime transpiration rates.
- In this humid (although rainless in summer) ridge-top forest, transpiration was limited by available radiant energy (governed in turn by fog occurrence) and by stomatal control (mostly during the dry summer months).
- During times of fog, transpiration was reduced by 10-90%.
- Because of reduced transpiration during times of fog, and because of stomatal control during dry periods, annual transpiration losses during the two years of observation were very similar (412 and 420 mm), despite rainfall inputs being almost twice those of the first year.
- Canopy conductance was inversely related to vapour pressure deficit of the atmosphere and increased with radiation at low intensities. However, there was no significant relationship with soil moisture content in the first 0.3 m depth, even though soil moisture reached very low values in summer. It was inferred that roots had access to water present in deeper layers, e.g. through cracks in the rocks below 0.3 m depth.

- Similarly, during the five dry months of the year (May - September), atmospheric water inputs hardly contributed to soil water reserves. Because the reserves in the top 0.3 m were insufficient to satisfy vegetation water demand, the water must have been supplied from the subsoil.
- Gaps in the stand transpiration record may be filled using the Penman-Monteith equation combined with the calibrated Jarvis model for the estimation of canopy conductance. However, the model performed less satisfactorily under very humid atmospheric conditions (>80% of relative humidity) when transpiration values were low and variations in conductance high.
- To fill short gaps in the transpiration record, the performance of the artificial neural network (ANN) approach was superior to the Penman-Monteith/Jarvis approach. Results obtained with the ANN improved as the conditions between the 'training' and 'test' periods were more similar, regardless whether atmospheric conditions were humid or dry.

The following ***recommendations for further research*** are offered:

1. Sap-flow measurements need to include the largest trees within the experimental plot because these dominated overall stand water use. In addition, sensors need to be installed at different depths within the trunks to adequately characterize changes in sap-flow patterns with depth.

2. In order to validate the various assumptions that were made to scale sap-flow measurements made at a single-point to the whole tree, further work should address the exact area of conducting sapwood in the studied trees (particularly for Myrica faya) as well as variations therein between individual trees.

3. Direct measurements of stomatal conductance (and leaf area) are needed for comparison with the indirect estimations of canopy conductance derived in the present study.

4. Transpiration and canopy conductance were not affected by moisture content in the top 0.3 m of the soil. Measurements are needed of the moisture content in deeper layers as well to establish whether transpiration is influenced by soil moisture at all.

VIII.6 WATER BALANCE OF THE RIDGE TOP FOREST OF THE JELIMA CATCHMENT

Regional water budget studies are necessary for the assessment of available water resources and for adjusting La Gomera's water policies in the light of expected climate change (Hay, 2000; Sperling et al., 2004). In this section the results obtained in the respective chapters are combined to solve the simplified water budget equation for the ridge-top forest site in terms of the residual input to soil and groundwater recharge. The simplified annual site water balance, in which soil and understory evaporation were considered negligible, can be stated as:

$$Tf + Sf = OF + E_T + \Delta S + D \qquad \text{VIII.1}$$

where *Tf* is throughfall, *Sf* stemflow, *OF* overland flow, E_T transpiration (soil water uptake), ΔS the change in soil moisture storage, and *D* drainage to deeper layers and the groundwater table, with all values expressed in mm/year. The *OF* term was assumed to be negligible because no overland flow was ever observed in the plot, not even during high rainfall. Furthermore, Höllermann (1981) found minimal surface runoff and erosion during rainstorms of very high intensity (>100 mm/d) under laurel and tree-heath forests. Throughfall, transpiration and change in soil water storage down to 0.30 m depth were measured directly whereas stemflow was estimated using regressions against uncorrected rainfall derived by previous investigators (see Chapter V for details). Because *Tf* data were not available after September 2004, *Tf* totals for the remainder of the second year were estimated using regressions that were derived separately for days with rain-only, fog-only, or mixed precipitation during the first year. The simplified water budgets for the ridge-top forest during the two years are summarized in Table VIII.1 (values of inferred drainage rounded off to the nearest 5 mm).

Table VIII.1 Site water balance (mm/yr) for the mixed tree-heath/beech forest at 1270 m in the Jelima catchment, La Gomera, between February 2003 and January 2005.

	Tf + Sf (rain-only)	*Tf* (fog-only)	*Tf + Sf* (Mixed)	*Tf + Sf* (Total)	E_T	ΔS	*D*
February 2003-January 2004							
Amount of water (mm)	546	22	297	865	412	-50	505
Maximum random absolute error (mm)				±253[1]	±91[2]	±5[3]	190[4]
February 2004- January 2005							
Amount of water (mm)	1242	28	305	1575	420	20	1135
Maximum absolute random error (mm)				±472[1]	±92[2]	±2[3]	±430[4]

([1]) based on ±30% standard deviation in total throughfall (see Chapter IV); [2] based on ±22% standard deviation in total transpiration (see Chapter VI); [3] ±10% (see Chapter VI); [4] Square root of the quadratic error.

Annual net precipitation inputs to the forest floor between February 2003 and January 2004 amounted to 865 ± 178 (S.E.) mm including 19 mm of stemflow (the error of which is unknown but considered small in absolute terms). For a stand-level transpiration value of 412 mm and a change in soil water storage of -50 mm, a residual net recharge to deeper layers (below 0.30 m) of 505 mm was obtained.

The second year (February 2004 - January 2005) was much wetter (wind-corrected rainfall P_a* 1695 mm vs. 900 mm in the first year). Throughfall was 1542 ± 323 (S.E.) and stemflow 33 mm. Taking into account the transpiration of 420 mm and the change in soil water storage (20 mm) implied an estimated net recharge of 1135 mm/yr, i.e. more than double the value derived for the first year. This large inter-annual variability illustrates the importance of long-term monitoring of atmospheric water inputs. Furthermore, cloud-affected ridge-top forest occupied ca. 25% of the catchment area and as such its positive water budget is important for the overall water budget of the catchment. Additional sap-flow work would be needed in the slope and valley-bottom forests to derive the water budget for the catchment as a whole.

The uncertainty associated with the two estimates for recharge is quite large because the residual estimate of a water budget calculation contains the sum of the errors of the respective components. The standard deviation of the mean *Tf* was ±30%; the overall maximum error in stand transpiration was estimated at ±22%, whereas that in soil water storage was taken to be equal to the error in the fitted calibration curve for the TDR probes (10%). The overall error in the estimated drainage was calculated as the square root of the sum of the squared errors of each water balance component: ±38% mm (Table VIII.1).

Finally, Sperling et al. (2004) predicted for the period until the end of 21st century a strengthening of the subsidence of dry, warm air in the Canaries and a lowering of the trade wind inversion, which is expected to constrain the limit of the cloud tops. This, in turn, will increase the diurnal temperature range, vapour pressure deficits and the occurrence of intense radiation, and decrease the frequency of clouds during the dry season. If true, these forecasts imply that the currently experienced humid atmospheric conditions provided by the clouds in the study area during the dry season would be replaced by enhanced evaporative demand of the atmosphere and increased soil water depletion. According to the findings of the present study, stand transpiration of the mixed forest on the ridges during prolonged rainless conditions is controlled by stomatal closure. Nevertheless, a rise in tree water use may be expected due to this expected drying of the atmosphere, with correspondingly negative results for the recharging of soil- and groundwater reserves (on top of the expected 10% reduction in annual rainfall; Sperling et al. (2004)).