

Water status of hydrophobic leaves improved by the impact of artificial dew deposition on leaf energy balance

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Abstract

Uptake of water from the surface of the leaves instead of the roots has been observed in many different species and many different ecosystems. This phenomenon, called foliar uptake, is common when rainfall is scarce and non-meteoric water (like dew or fog) is the only source of water. However, many species across the world have very water repellent leaves and none of the past studies have tried to differentiate between the uptake of deposited water droplets and the impact of those droplets on the energy balance of the leaf. We conducted three experiments on the highly hydrophobic *Colocasia esculenta* leaves that allowed us to investigate the impact of non-meteoric water deposition on the energy balance of the leaves, while ruling out any direct water uptake. We present evidence that the effect of the droplets on the energy intake of the leaves impacts its water balance. We conclude by presenting three possible mechanisms through which water droplets impact the leaf energy balance.

1 I. Introduction

2 Because it occurs consistently in all environments, non-meteoric water is an important source of water
3 for many plants. But because it only provides small amounts of water, it is often overlooked in large
4 scale models past the ecosystem level. Plants from many different environments have long been known
5 to be using fog [Stanton and Horn, 2013, Eller et al., 2013, Berry and Smith, 2014] or dew [Andrade, 2003,
6 Clus et al., 2008, Lakatos et al., 2012] through foliar uptake. The literature suggesting the importance of this
7 mechanism is growing and includes a wide range of plant species and areas.

8 So far, most studies have been focusing on determining circumstances in which plants use foliar uptake
9 as a source of water. Vegetation in dry and fog prone areas like coastlands [Burgess and Dawson, 2004,
10 Stanton and Horn, 2013] or mountain hillsides [Berry et al., 2014] is adapted to using fog as its main source
11 of water. Similarly, dew water has been shown to be a major source of water on islands where fresh water is
12 scarce [Clus et al., 2008] or by species that have physical features allowing them to collect dew water, like
13 epiphytic bromeliads [Andrade, 2003] or lichens [Lakatos et al., 2012]. Both grow on other plants, often
14 without any access to soil water. All those case studies focus on very specific plants, particular either by their
15 morphology or the ecosystem they grow in.

16 But many species actually have very water-repellent leaves [Neinhuis and Barthlott, 1997] and leaves that
17 are often exposed to dew tend to be more hydrophobic [Aryal and Neuner, 2009]. Those hydrophobic species
18 are most likely not adapted to uptake water from their leaves. For most plants, non-meteoric water deposition
19 is a source of nuisance as it may freeze and cause damages to the leaf in cold environments, or stagnate and
20 cause rotting and pathogen infection in warm environments [Evans et al., 1992]. However, not all of them are
21 as water repellent as water lilies and micro-droplets of water will indeed form on the surface of even very
22 hydrophobic leaves. The interaction of those droplets on the leaf energy balance has not yet been studied,
23 despite its potentially very large impact. Indeed, dew or fog formation impacts large areas at once and small
24 changes in the energy balance of each single leaf could therefore have large a large impact at the ecosystem
25 level.

26 **Leaf energy balance** Because they are unable to move to the shade, leaves are very vulnerable to sun
27 radiations, and leaves can often be warmer than the surrounding air. Leaf temperature will in turn affect
28 saturation vapor pressure, isotope fractionation, respiration, photosynthesis and many other functions. Because
29 their boundary layer is thinner, smaller leaves tend to be at a temperature closer to the ambient air. This
30 is the reason why, on a single tree, sun leaves are usually smaller than shade ones. To stay cool, leaves
31 usually use a combination of re-radiation (transfer of energy to the surroundings), convection (heat loss as
32 cool air moves over a surface) and evaporative cooling (evaporation of water inside the leaf into water vapor,
33 which is an exothermic process) [Vogel, 2012]. During a drought, leaves have to preserve water to maintain
34 turgor pressure, which competes with evaporative cooling. In this case, leaves are left with re-radiation and
35 convection to cool themselves down, which is not enough to maintain a low temperature. If the duration of
36 the drought extends for too long, this can lead to plant mortality.

37 By depositing a layer of small water droplets on the surface of the leaves, non-meteoric water can

provide the plants with a pool of water that will supplement the scarce leaf water and provide a form of externalized evaporative cooling. Moreover, the presence of the droplets will both increase the albedo of the leaves, allowing it to reflect more energy [Pinter, 1986], and increase surface roughness which will increase the leaf boundary layer, therefore decreasing the vapor pressure deficit (VPD) and lowering the evaporative demand. By affecting the leaf energy cycle, the deposition of non-meteoric water droplets is therefore directly affecting the water status of the leaf. Depending on the location and climate, dew deposition can take from 1.5 [Abteu and Melesse, 2012] to 6 hours [Monteith, 1957] after sunrise to completely evaporate from the surface of the leaves. Dew and fog can also form in the late afternoon before sunset [Wilson et al., 1999, Kabela et al., 2009]. Although neither dew nor fog is usually present at the hottest hour of the day, they can effectively shorten the duration of the water-stressed part of the day. This will significantly help the plant maintain its water status over an extended period of drought [Madeira et al., 2002, Proctor, 2012].

In this study, we present three experiments that focus on the effects of water droplets deposition at the surface of *Colocasia esculenta* leaves. This specie is native from South East Asian tropical forests but has been cultivated across the world as taro for many centuries. With a contact angle of 164° [Neinhuis and Barthlott, 1997], *Colocasia esculenta* is considered to have highly water-repellent leaves. Its leaves can reach a size of up to 50 cm in length and 40 cm in width, allowing for high-resolution mapping of the leaf water properties. Using isotopically labelled water as well as traditional plant physiology techniques, we confirm that the *Colocasia esculenta* leaves do not uptake water from the surface of the leaves. We also show that water droplets deposition decreases leaf transpiration and increases water potential. We conclude by presenting three mechanisms that explain the influence of water deposition on water-repellent leaves and that could have large impacts on plant water and carbon cycles.

II. Methods

II.1 The added value of stable isotopes

Stable isotopes of water hold great potential for resolving transpiration and evaporation fluxes across multiple scales [Griffis et al., 2010, Rothfuss et al., 2012, Wang et al., 2013]. The process of evaporation is accompanied by a high degree of isotopic fractionation that leads to evaporated water with an isotopic composition depleted in the heavy isotopologues $H_2^{18}O$ and $HD^{16}O$, where D symbolizes deuterium. This is due to the difference in vapor pressure of the different isotopologues [Farquhar et al., 2006]. Isotopic compositions are commonly expressed in terms of the relative ratios

$$\delta_i = \left(\frac{R_i}{R_{r_i}} - 1 \right) \times 10^3$$

of isotope ratios [Mook, 2006], where δ_i is expressed in ‰ and the index i stands for ^{18}O or D. $R_{^{18}O} = [H_2^{18}O] / [H_2^{16}O]$ and $R_D = [HDO] / [H_2O]$ are the isotope ratios, while the R_{r_i} are the ratios of the corresponding standard. For water, the reference is the Vienna Standard Mean Ocean Water (VSMOW). Deuterium excess (d-excess)

is a widely used measure of how evaporated a pool of water (ocean, lake, leaf) is and is defined as:

$$\text{d-excess} = \delta\text{D} - 8 \times \delta^{18}\text{O}.$$

The average d-excess for precipitation is 10. Lower d-excess values generally indicate that the pool undergone some evaporation [Brooks et al., 2014]. Stable isotopes are also very efficient in helping identify different water sources in plants [Ehleringer and Dawson, 1992]. Kinetic isotope effects associated with the difference in diffusivity of the different isotopologues of water can lead to different isotopic composition [Farquhar et al., 2006]. Simple mixing models allow one to separate the composition and the fluxes coming from different sources. For this reason, stable isotopes are great natural labels that can be used to track pathways of water within plants without harming them.

II.2 Experiment 1a: Effects of dew deposition on *Colocasia esculenta* water isotopes in natural conditions

This first experiment examines leaf scale spatial and temporal patterns of water isotopes induced by the presence or the absence of dew under drought condition. Six bulbs of *Colocasia esculenta* were planted in separate pots. All pots were placed outside and received full sun for four weeks. During this time, all plants were heavily watered with tap water to allow plant growth. Once the six plants reached maturity, watering stopped and the plants were moved to a shaded area to remove any sun exposition difference between the plants. The area was very protected and temperature was usually lower than outside of it. Similarly, relative humidity was usually slightly higher. Three of the six pots were left to dry and did not receive any water for the rest of the experiment. The upper surface of the leaves of the other three pots were misted with isotopically enriched water ($\delta^{18}\text{O} = 8.85 \text{ ‰}$, $\delta\text{D} = 737.64 \text{ ‰}$) every two days using a spray bottle. All of the extra water would run off the leaves, leaving them covered in submillimeter size droplets, which is a realistic size for dew deposition drops [Defraeye et al., 2013]. The misting simulated dew and occurred as early as possible in the morning. In order to avoid contact between the misted water and the soil in the pots, the surface of all pots was covered in wrapping plastic. Six leaves were collected between the beginning of the drought/dew treatments and the end of the experiments, three weeks later. The sampling and the analysis are described in Section II.5.

II.3 Experiment 1b: Effects of water droplets deposition on *Colocasia esculenta* leaf water isotope under high water stress conditions

This second experiment was designed to artificially increase the contrast between the drought and misted treatments from Experiment 1a. The plants from this former experiment were moved into the laboratory and well-watered for multiple weeks to offset any effects from the first experiment. Two leaves of similar size and of the same *Colocasia esculenta* plant were cut at the junction of the petiole and the rachis and left to dry 80 cm under a blue light (Eiko 1960 EBW, 500 W, 10500 lumens, color temperature of 4800 K). One leaf was misted with isotopically labelled water ($\delta^{18}\text{O} = 8.85 \text{ ‰}$, $\delta\text{D} = 737.64 \text{ ‰}$) every half-hour. The other leaf was left to dry without any intervention. After four hours, samples were collected from both leaves

as described in Section II.5.

II.4 Experiment 2: Effects of dew deposition on *Colocasia esculenta* leaf water potential under high water stress conditions

In this final experiment, we focused on the effect of water droplets deposition on leaf water potential under high water stressed conditions. One leaf was cut at the junction of the petiole and the rachis and left to dry. Three different water stress conditions were tested here: natural drying, high heat drying and high heat & mist. In the high heat case, the leaf was placed 80 cm under a blue light (Eiko 1960 EBW, 500 W, 10500 lumens, color temperature of 4800 K) and left to dry for up to 10 hours. In the high heat & mist case, the leaf was also misted with ultra pure water every hour using a spray bottle. Again, surplus water was allowed to runoff, leaving the leaf covered in submillimeter size water droplets. Leaf disks of 1 inch diameter were collected every hour. The surface of each leaf disk was wetted with ultra pure water, immediately sanded with ultra-fine sandpaper (3M, 600 grit sandpaper), and the water potential analyzed on a WP4C (Decagon Devices Inc.).

II.5 Sampling and processing methods for the isotopic analysis

For the water isotope analysis, each analyzed leaf was sampled in 12 to 25 different locations depending on the size of the leaf. All the sampling points were located on the same half of the leaf and consisted in four holes (6 mm diameter) punched next to each other forming a square. Each hole was punched as quickly as possible to avoid evaporation, which would influence the isotopic composition of the neighboring holes. Each leaf disk was then secured in an aluminum foil and inserted in a sealed vial. The entire leaf was sampled in one go and as fast as possible. The prepared vials were then stored in the fridge until being analyzed. The leaf samples were analyzed using an Induction Module (IM) combined to a Cavity Ring Down Spectrometer (CRDS) L2103-i from Picarro Inc. (Sunnyvale, CA, USA). The IM was set on the "normal leaf" setting: the leaf disks did not appear carbonized and after being dried in the oven at 60°C for 48 hours, they show no decline in weight, proving that this setting dried the leaf samples completely. The IM was equipped with a micro-combustion module (MCM). The MCM has been proven to efficiently reduce the interferences due to the presence of organics in water samples extracted from plants (Kate Dennis, private communication). The entire sampling and IM analysis process lasted from 1.5 to 2 days depending on the size of the leaf.

IM-CRDS analysis sequence The analysis sequence was based on [van Geldern and Barth, 2012]. Following their notation, Table 1 presents the sequence of standards and samples. Six empty vials were run at the beginning of each run. The average water vapor content, $\delta^{18}\text{O}$ and δD for the six vials was measured and introduced in a mixing model that allowed us to retrieve the true isotopic composition of the samples. Reference water samples were run using the paper filter provided with the instrument and the same piece of filter paper was reused for all the injections of a single reference water. We found that 3 μL of reference water were necessary to reproduce the amount of water contained by one punch hole of *Colocasia esculenta*. The data was corrected for drift, memory effect and correction back to the VSMOW scale. The central vein and the half of the leaf that had not been sampled for IM-CRDS analysis were placed in a vial and the water

131 extracted using cryogenic vacuum distillation. The water was then analyzed both by Isotope Ratio Infrared
132 Spectrometry (IRIS) and Isotope Ratio Mass Spectrometry (IRMS) for comparison with the IM-CRDS.

133 **IRIS and IRMS analysis** Ten samples were sent to the Center for Stable Isotope Biogeochemistry at the
134 University of California in Berkeley for IRMS analysis. For the IRMS method, δD was obtained by chromium
135 combustion using an H/Device (labelled as HDEV; Thermo Finnigan, Bremen). Microliters of water were
136 injected in the HDEV and reduced to H_2 gas. The ratio of D/H was then measured on a Thermo Delta Plus
137 mass spectrometer. For the $\delta^{18}O$ analysis, water for both standards and samples were pipetted into glass vials
138 and quickly sealed. The vials were then purged with 0.2% CO_2 in Helium and allowed to equilibrate at room
139 temperature for at least 48 hours. The ^{18}O in the CO_2 was then analyzed by continuous flow using a Thermo
140 Gas Bench II interfaced to a Thermo Delta Plus XL mass spectrometer. In this H_2O - CO_2 equilibration method,
141 the dissolved components (organic and/or inorganic) do not affect the values of $\delta^{18}O$. For the IRIS analysis,
142 1.8 μL of water were injected into a vaporizer and the vapor pushed through a MCM. The concentrations of
143 $H_2^{18}O$ and $HD^{16}O$ were measured on a water isotope analyzer (L2103-i) from Picarro Inc. (Sunnyvale, CA,
144 USA).

145 The ten samples analyzed both by IRMS and IRIS were used to calculate the offset between both analysis
146 methods. All the samples that had been run exclusively by IRIS or IM-CRDS were then corrected for this
147 offset. The IM-CRDS method has not been widely used yet and protocols and precision analysis are still
148 absent from the scientific literature. In order to justify the values obtained using the IM-CRDS, we compared
149 the values obtained from the extracted water of the half-leaf analyzed by IRIS to the average leaf water
150 composition obtained using a nearest neighbor interpolation on the half-leaf analyzed by IM-CRDS. For the
151 seven leaves analyzed by IM-CRDS, the average difference between those two methods was 2.6‰ in $\delta^{18}O$
152 and 3.4‰ in δD . These values are higher than the average difference we observed between two halves of
153 the same *Colocasia esculenta* leaf, both extracted by cryogenic vacuum distillation and analyzed by IRIS
154 (0.3‰ in $\delta^{18}O$ and 1.9‰ in δD). The observed error is therefore not attributable to the analysis on IM-CRDS
155 and IRMS being conducted on each half of the same leaf. Further testing is clearly necessary before using
156 the IM-CRDS technique as an absolute method. However, our goal here is to compare strongly enriched
157 waters and the order of the differences presented in the next section are up to two orders of magnitude bigger
158 than the error observed for the IM-CRDS. We therefore believe that the IM-CRDS is an appropriate method
159 here, as it allowed us to quickly process many small samples, therefore increasing the spatial and temporal
160 resolution of our analysis.

161 III. Results

162 **Effects of dew deposition in natural conditions** The results of Experiments 1a are presented Figure 1 as
163 maps of the analyzed half leaves. The maps were obtained using an inverse distance interpolation in Matlab®
164 and show the evolution of the d-excess of leaves from the drought and misted treatments collected at 0, 12
165 (dew), 14 (drought) and 21 (dew and drought) days from the beginning of the experiment. All the maps of
166 $\delta^{18}O$ and δD (not presented here) show the expected progressive enrichment of leaf water when moving
167 away from the main stem towards the rims of the leaf [Cernusak and Kahmen, 2013]. This enrichment is

168 due to the progressive evaporation of the leaf water as it moves away from the source water that enters the
 169 leaf through the petiole. The lighter isotopologues are evaporated first, leaving the heavier ones in the leaf
 170 [Farquhar et al., 2006]. This translates into a decrease in d-excess from the center of the leaf towards to
 171 the edges. Those results reinforced our confidence in the IM-CRDS method. The average composition of
 172 each leaf is summarized in Table 2. Comparing same day results for both treatments, we see that the dew
 173 treated plants systematically exhibit higher d-excess values than the drought treated ones. The lower d-excess
 174 values are associated with higher transpiration rate. On the other hand, the misted leaves had a lower rate of
 175 transpiration, which led to higher values of d-excess.

176 Leaves collected from both treatments on day 12 or 14 present results that disagree with the trends formed
 177 by the results of day 0 and 21. In the drought treatment case, d-excess is generally decreasing between
 178 day 0 and day 21, showing increased evaporation. However, the drought treatment leaf collected on day 14
 179 shows values of d-excess higher than expected, signaling a low evaporation rate. In the dew treatment case,
 180 the general trend is reverse and d-excess at the end of the experiment (day 21) is much higher than on day
 181 0. But the dew treated leaf collected on day 12 presents lower values of d-excess than expected from this
 182 general trend. One must recall that the plants were kept outside throughout the experiment and were therefore
 183 subjected to the daily variations of temperature and relative humidity, which both influence the transpiration
 184 rate as well as the isotopic composition. The dew treated leaf collected on day 12 was sampled after a
 185 prolonged period of dry and hot weather that might have enhanced the transpiration despite the artificial dew
 186 treatment. This explains why this leaf presents lower d-excess values than expected. During the experiment,
 187 the plants were kept in a shaded, protected area below a building where the temperature is often lower and the
 188 relative humidity higher than outside of the shelter. During the four days preceding the collection of the first
 189 drought treated leaf (day 14), the air temperature came within 1°C from the dew point temperature every night
 190 (see Figure 2). Because of the locally lower temperature and higher relative humidity under the sheltered area,
 191 natural dew probably formed at the surface of the leaves. Indeed, natural dew formation was observed on the
 192 leaves multiple times. Moreover, a series a small rain events happened on the day preceding the collection,
 193 which would have greatly affected the transpiration rate and the resulting isotopic composition of the the leaf.

194 **Effects of dew deposition in high water stress conditions** Similar maps were produced for Experiment
 195 1b (Figure 3). In this case, the heat lamp artificially increased the transpiration rate in both the drought
 196 and the misted leaves, leading to highly enriched $\delta^{18}\text{O}$ and δD values and very low d-excess values for
 197 both treatments. However, the d-excess in the drought case is a lot more negative (reaching values down to
 198 $\sim -800\text{‰}$) than for the dew treated leaves (reaching values down to $\sim -300\text{‰}$). This experiment was merely an
 199 extreme version of Experiment 1a, with the objective of accentuating the contrast between the two treatments.
 200 While the high heat treatment led to a strong drying of some areas of the leaf, in particular those far away from
 201 the central vein, the large differences observed between the drought and the misted treatments do confirm the
 202 results of Experiment 1a.

203 **Effects of dew deposition on leaf water potential** Experiment 2 was design to look at the temporal
 204 evolution of water potential in artificially drying leaves (see Figure 4). Strong differences in drying pattern

are shown for the misted or drought leaves. In both the natural drying and the high heat & mist cases, the leaf water potential experiences a slow decline, which is best approximated by a linear function. However, the high heat treated leaves experience a faster decline and are best approximated by a parabola. Without the results of Experiments 1 and 2, that confirmed the leaves high hydrophobicity, this results could easily be mistaken for a foliar uptake process.

Large differences in water potential patterns were also observed as a function of leaf size for the high heat treatment: smaller leaves had a stronger decline in water potential than big leaves did. This difference disappears when the leaf is misted. In order to verify that this leaf size difference was not related to a difference in water repartition within the leaf (on a short time scale, evaporation occurs mainly in the lamina), eight *Colocasia esculenta* leaves of length ranging from 14 to 64 cm were weighted, their veins and lamina (inter-vein tissues) separated and re-weighted before being oven-dried for 48 hours and weighted on last time. On average, veins accounted for 39% and the lamina for 41% of the total leaf water. This values are uncorrelated with leaf size (Figure 5), showing that the size dependent change in water potential in the high heat treatment is due to the process of the drying itself, and not due to pre-existing differences in water distribution.

IV. Discussion

Dew and fog have been shown to have a direct impact on plants water status through direct uptake of water from the leaves or needles [Stanton and Horn, 2013, Eller et al., 2013, Clus et al., 2008, Lakatos et al., 2012, Berry et al., 2014, Berry and Smith, 2014]. As mentioned before, *Colocasia esculenta* is native to tropical wetlands and posses highly hydrophobic leaves [Neinhuis and Barthlott, 1997] that allow the plant to prevent the development of fungus. This is confirmed by Experiments 1a and 1b in which the misted leaves all exhibit lower isotopic enrichment in ^{18}O and D than the drought treated leaves. This is the sign that non of the highly enriched sprayed water is being uptaken by the leaves, even in artificially dry and hot conditions. However, despite the leaf's hydrophobicity and the absence of foliar uptake, submillimeter size droplets of water do stay attached to the surface of the leaf and allow it to decrease its transpiration rate and maintain its water potential. The water balance of the leaf is therefore influenced by the change in energy balance associated with the water droplets deposited at the surface. The influence of these water droplets is triple.

First, the droplets increase the albedo of the leaf, allowing more of the radiations to be reflected away from the leaf. The albedo is the reflection coefficient for solar radiations of natural surfaces. Depending on the direction of the incoming solar radiations, water can have an albedo as high as 1 (perfect reflector) whereas typical values for leaves are around 0.2 for visible light. The increase of vegetation albedo due do dew deposition has been observed in the field many times [Pinter, 1986, Zhang et al., 2012]. By reflecting more radiations when there are wet, leaves will then decrease the incoming shortwave radiations and consequently keep their temperature lower. This will in turn reduce the evaporative demand and the leaf transpiration.

Second, part of the on-coming energy will be dissipated through the evaporation of the droplets, which also provides evaporative cooling to the surface of the plant. The energy that is not reflected by the droplets will be used to evaporate them: because of the high heat capacity of water, the evaporation of the droplets

will dissipate energy that will not contribute to the leaf energy budget. Moreover, because evaporation is an exothermic process, the evaporation of the water droplets will result in a cooling of the leaf surface. This will again reduce the evaporative demand and the transpiration.

Finally, the evaporated droplets allow to increase the boundary layer [Defraeye et al., 2013] and locally decrease the VPD, creating a moister environment around the leaf. The evaporation of the droplets will cause the air close to the leaf to have a higher relative humidity than the surrounding air, creating a moist micro-climate around the leaf [Jones, 1992]. This will decrease the difference between the interstitial and the air vapor pressures. This decrease in gradient will therefore reduce the flux of water vapor out of the leaf, namely transpiration. The leaf size dependency of this third mechanism is confirmed by the leaf size dependent behavior observed for the misted case of Experiment 2 (see Figure 4): if only the first two mechanisms were at play, one would not expect a difference between two leaves of different size receiving mist. However, bigger misted leaves will create a larger micro-climate, increasing the length of the boundary layer and therefore decreasing the VPD even further than a small leaf could [Defraeye et al., 2013]. This lower VPD then induces a decrease in transpiration and an increase in leaf water potential, as it is the case in Experiment 2. High water potential values are correlated with high leaf relative water content [Maxwell and Redmann, 1978]. Water potential is also positively correlated with stomatal conductance [Lhomme et al., 1998]: by maintaining a higher water potential, the leaf will be able to open its stomata wider. CO₂ assimilation is in turn linearly correlated to stomatal conductance [Lambers et al., 2008]. As a result, by affecting the leaf energy cycle, dew droplets deposition will allow the leaf to maintain its water status and increase CO₂ assimilation.

Water droplets from rain interception will have a similar effect as non-meteoric water deposition. However in the first case the soil water would also be replenished, making the gain in water obtain by lowering transpiration less necessary than in the case of dew or fog droplets forming during a drought. Many studies have indeed demonstrated that dew or fog deposition had little impact on well watered plants [Andrade, 2003, Eller et al., 2013]. Dew and fog commonly occur all around the world and in a wide range of ecosystems, from drylands [Agam and Berliner, 2006] to tropical forests [Lakatos et al., 2012]. Indeed, regular dew formation has been observed by scatterometer in the upper canopy of the Amazon forest, even during the dry season [Satake and Hanado, 2004, Frolking et al., 2011].

[Frolking et al., 2011] observed a sharp decrease in morning backscatter over the Amazon forest for the summer months of 2005, which they associated with a lack of morning dew formation. This summer was known as a mega-drought for the Amazon forest and led to a high tree mortality [Zeng et al., 2008]. However, the accumulating water deficit anomaly for that year was just as high as that of the year 2002, which did not experience the same tree mortality. The main difference in water resources between the two years appears to be the presence or absence of dew.

The results of our study hint at a large impact of water droplets deposition on hydrophobic leaves in time of drought. The influence of the water droplets on the leaf energy balance will delay the time when leaves will reach their maximum transpiration rate. [Abteu and Melesse, 2012] calculated that dew evaporation from the surface of a leaf takes about 75 min in southern Florida. Many parameters, including leaf size, relative humidity or shading could potentially prolong this time. In the context of climate change and with an increasing number of drought in some tropical forests, and in particular the Amazon forest [Cook et al., 2014],

281 even a small delay in the beginning of the transpiration in the morning could have a huge impact when
282 spanning over the whole dry season and, for example, the entire Amazon forest. While tropical forests are
283 usually carbon neutral, [Gatti et al., 2015] calculated that during the 2010 mega-drought in the Amazon, the
284 basin lost 0.48 PgC.yr^{-1} . This corresponds to about 10% of the amount of anthropogenic carbon released in
285 the atmosphere for that year. Understanding all the aspects of plant functions in topical forests is therefore
286 crucial if we want to better anticipate future climate. Despite its potentially large impact, dew and fog
287 deposition on plants is yet to be include in climate models. Further investigation is now necessary to quantify
288 the transpiration decrease associated with water droplets deposition, as well as the impact on leaf carbon
289 uptake. Combining a process-based model with flux tower and satellite data could help better quantify
290 regional scale carbon uptake.

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Figure Legends

Figure 1: Maps of the spacial distribution of d-excess of five *Colocasia esculenta* leaves collected throughout Experiment 1a. The maps were obtained by inverse distance interpolation of 12 to 25 sampling points analyzed on the Picarro Induction Module. All leaves are about 38 cm long. **Left:** initial leaf collected on day 0. **Top row:** leaves collected on day 14 (center) and 21 (far right) from the drought treatment. **Bottom row:** leaves collected on day 12 (center) and 21 (far right) from the sprayed treatment, where the leaves were sprayed with isotopically enriched water ($\delta^{18}\text{O} = 8.85 \text{ ‰}$, $\delta\text{D} = 737.64 \text{ ‰}$) every two days. The color scheme is the same for all rows and the values are expressed in permil.

Figure ??: **Top panel:** Difference between the air and the dew point temperature over the course of the experiment ($^{\circ}\text{C}$). **Bottom panel:** Rainfall (cm) over the course of the experiment. The blue dashed vertical lines mark the days of collection: the initial leaf was collected on day 0, leaves from the dew treatment were collected on day 12 and 21 and leaves from the drought treatment were collected on day 14 and 21. Red horizontal arrows indicate days when the leaves most likely experienced natural dew deposition because of the local air temperature and relative humidity under the sheltered area. The collection of the first dew treated leaf happened right after a series a small rain events and four nights in a row of temperatures close to the dew point temperature.

Figure 3: Maps of two leaves left to dry under a 500W blue light for four hours. **Top row:** $\delta^{18}\text{O}$, δD and d-excess of the non-sprayed leaf. **Bottom row:** $\delta^{18}\text{O}$, δD and d-excess of the leaf sprayed with isotopically enriched water ($\delta^{18}\text{O} = 8.85 \text{ ‰}$, $\delta\text{D} = 737.64 \text{ ‰}$) every half-hour. The non-sprayed leaf shows higher enrichment and lower d-excess values that are associated with increased transpiration compared to the sprayed leaf.

Figure 4: Five examples of the temporal evolution of leaf water potential of *Colocasia esculenta* leaves. The red diamonds are 38 cm long leaves. All other leaves are 45 cm long (black and blue). On the left, natural drying (black dotted line) and both sizes leaf in the high heat & mist (red dashed and blue solid lines) case are best fitted by a linear relation. On the right, the high heat drying case is best fitted by a parabola for both 38 (red dashed line) and 45 cm (blue solid line) leaves.

Figure 5: Percent water from veins and lamina for eight leaves of *Colocasia esculenta* with lengths ranging from 14 to 64 cm. **Red squares:** % water from the lamina (dashed red line represents the mean value). **Black circles:** % water from the veins (solid black line represents the mean value). On average, veins accounted for 39% and the lamina for 41% of the total water content of the leaves. The repartition of leaf water between the veins and the lamina show no significant correlation with leaf size.

Identifiers		
ID	Type	Injections
Blank 1	Empty vial	1
to		
Blank 6	Empty vial	1
DEST	Drift ref. water	10
HIS	High ref. water	10
ANTA	Low ref. water	10
DEST	Drift ref. water	10
HERA	QC ref. water	4
Sample 1	Sample	4
to		
Sample 10	Sample	4
DEST	Drift ref. water	6
Sample 11	Sample	4
to		
Sample 20	Sample	4
DEST	Drift ref. water	6

Table 1: Typical sequence layout of an IM-CRDS run with four reference waters. Following [van Geldern and Barth, 2012], *HIS* and *ANTA* are the names of the reference waters with high and low delta values, *DEST* and *HERA* are intermediate waters. *DEST* is the drift monitoring reference water whereas *HERA* is treated as a sample for quality control. All reference waters except *HERA* are used for memory correction.

Day	Treatment	$\delta^{18}\text{O}$ (‰)	δD (‰)	d-excess (‰)
0		20.0	24.1	-136.1
14	Drought	13.3	-1.5	-108.0
12	Dew	15.3	20.32	-102.4
21	Drought	23.0	15.1	-169.0
21	Dew	13.4	-2.7	-109.6

Table 2: Average leaf isotopic composition obtained by nearest neighbor interpolation for each of the leaves presented in Figure 1. Comparing leaves collected on the same day, dew treated leaves have a higher d-excess compared to the drought treated plants, signaling that dew treated plants experience lower levels of transpiration over the course of the experiment.

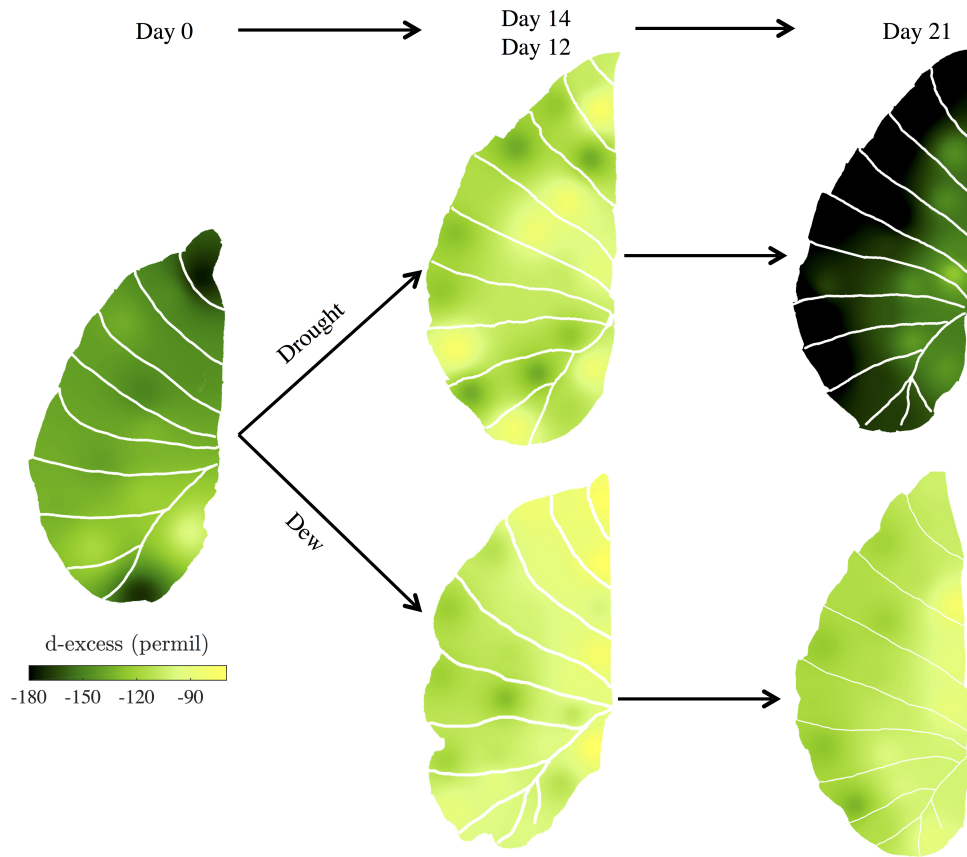


Figure 1: Maps of the spatial distribution of *d*-excess of five *Colocasia esculenta* leaves collected throughout Experiment 1a. The maps were obtained by inverse distance interpolation of 12 to 25 sampling points analyzed on the Picarro Induction Module. All leaves are about 38 cm long. **Left:** initial leaf collected on day 0. **Top row:** leaves collected on day 14 (center) and 21 (far right) from the drought treatment. **Bottom row:** leaves collected on day 12 (center) and 21 (far right) from the sprayed treatment, where the leaves were sprayed with isotopically enriched water ($\delta^{18}\text{O} = 8.85\text{‰}$, $\delta\text{D} = 737.64\text{‰}$) every two days. The color scheme is the same for all rows and the values are expressed in permil.

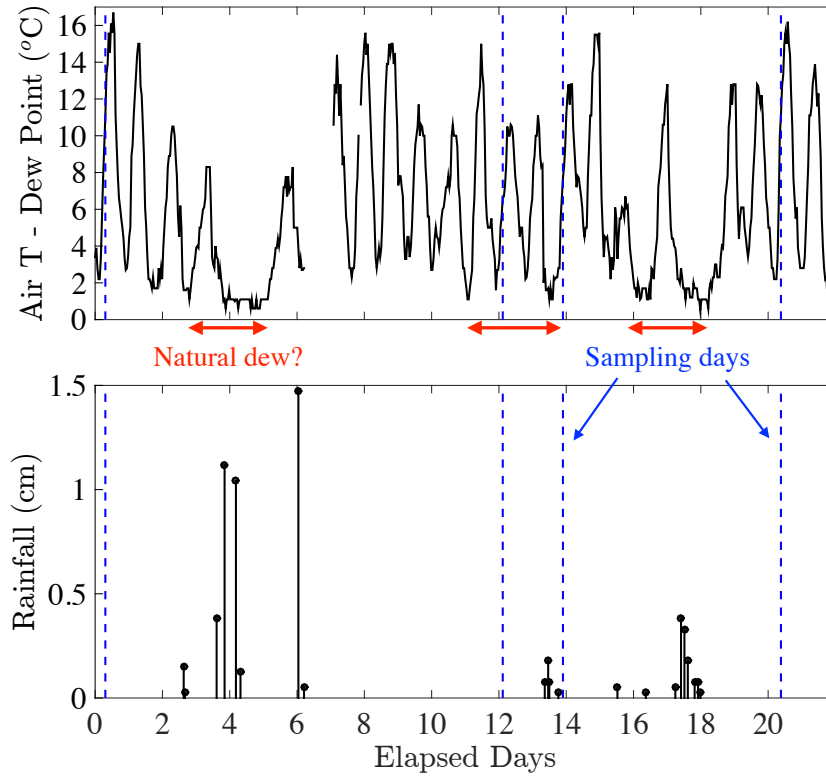


Figure 2: *Top panel:* Difference between the air and the dew point temperature over the course of the experiment (°C). *Bottom panel:* Rainfall (cm) over the course of the experiment. The blue dashed vertical lines mark the days of collection: the initial leaf was collected on day 0, leaves from the dew treatment were collected on day 12 and 21 and leaves from the drought treatment were collected on day 14 and 21. Red horizontal arrows indicate days when the leaves most likely experienced natural dew deposition because of the local air temperature and relative humidity under the sheltered area. The collection of the first dew treated leaf happened right after a series a small rain events and four nights in a row of temperatures close to the dew point temperature.

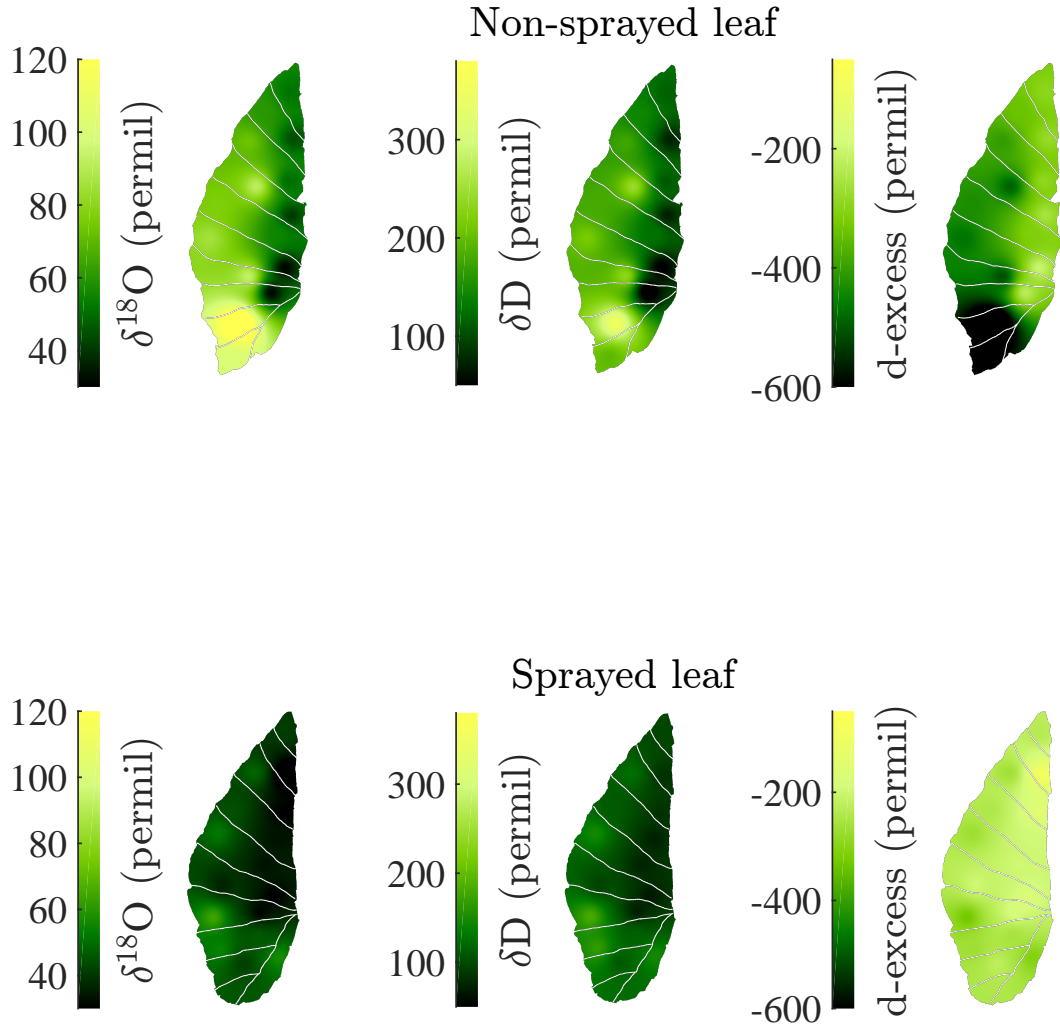


Figure 3: Maps of two leaves left to dry under a 500W blue light for four hours. **Top row:** δ¹⁸O, δD and d-excess of the non-sprayed leaf. **Bottom row:** δ¹⁸O, δD and d-excess of the leaf sprayed with isotopically enriched water (δ¹⁸O = 8.85 ‰, δD = 737.64 ‰) every half-hour. The non-sprayed leaf shows higher enrichment and lower d-excess values that are associated with increased transpiration compared to the sprayed leaf.

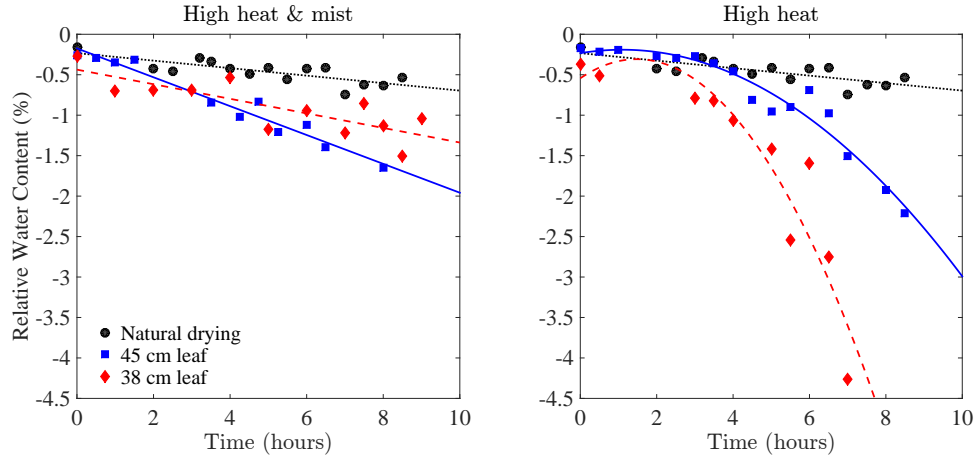


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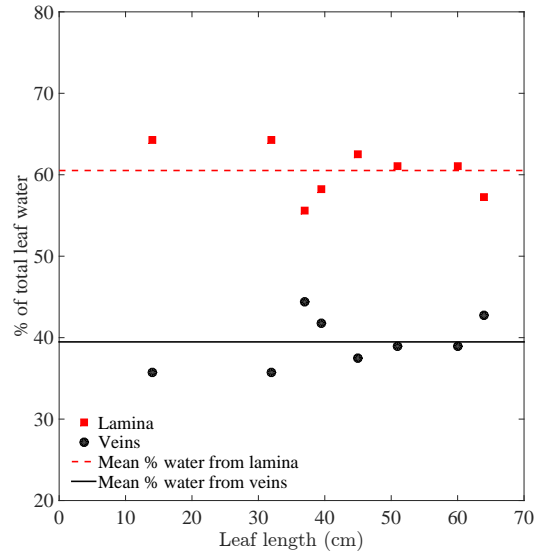


Figure 5: Percent water from veins and lamina for eight leaves of *Colocasia esculenta* with lengths ranging from 14 to 64 cm. **Red squares:** % water from the lamina (dashed red line represents the mean value). **Black circles:** % water from the veins (solid black line represents the mean value). On average, veins accounted for 39% and the lamina for 41% of the total water content of the leaves. The repartition of leaf water between the veins and the lamina show no significant correlation with leaf size.