Water storage on compliant plant leaves

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1. INTRODUCTION

Climate change is an important subject that can have serious consequences for future generations. The causes of the latter are multiple but often have the same effect, the imbalance of natural equilibrium put in place by the ecosystem that is the Earth. One of these disruptions amongst so many others is that of the water cycle, which is strongly impacted by plant leaves water retention. Indeed, canopy interception is a process of considerable importance for the hydrological cycle since annual interception losses in forests can amount to more than a quarter of total rainfall (Hörman et al. 1996, Dingman 2002). Therefore, there is an interest in quantifying this amount of water that can be stored according to plant leaf characteristics.

2. PROBLEM STATEMENT

Since any dynamic motion of a leaf leads to vibrations that only could make water slip, the maximum leaf storage capacity is found by considering the problem as static. Moreover, it has been observed that the maximal reachable water storage capacity creating a film of water upon the leaf is lower than the one obtained by loading a leaf with separated droplets. In conclusion, the aim of this study is to find a relationship between leaf storage capacity and leaf compliance by combining an analytical approach with experiments where the leaves are loaded with water droplets quasi-statically.

3. METHODOLOGY

Foremost, the problem will be posed by designing a leaf model that highlights the relevant parameters which are supposed to influence its water storage capacity. Then, according to this model, a dimensional analysis will be performed to identify the dimensionless parameters to be varied throughout the experiments in order to establish the relationship between leaf compliance and water storage capacity. Afterwards, the model will be tested experimentally using a toy model of a leaf made of kapton. Finally, the experimental results will be processed numerically using an image processing algorithm and the value of these parameters will be determined.

3.1 Leaf model

Throughout this study, the leaves will be considered as some rigid bodies that tilt, with respect to the horizontal plane, according to the load to which they are subjected. Thus, this model reduces the study to plant leaves for which the bending is concentrated on the petiole while the leaf blade remains, as an approximation, rigid. Therefore, plant leaves could be modeled by a linear mass attached to a torsion spring as represented in Fig. 1. Furthermore, the study is reduced to a two-dimensional problem, provided that the leaf width is large compared to the capillary length λ_σ so that the droplets should not slip off the sides of the leaf but only from its tip. Finally, the shape of the leaf must not be bowl-like so that it does not store water and a typical tree that possess such leaves is a beech.

3.2 Dimensional analysis

The water storage capacity of a leaf $\mu = V_w/S$ is defined as the volume of water V_w laying on a leaf of surface S. By considering the problem as static, it is supposed to be influenced by:

- ρ: water density ρ;
- σ: water surface tension;
- α_0: dry leaf inclination angle;
- k: stiffness of the petiole;
- g: gravity acceleration;
- R: droplet characteristic length.

By using the Vaschy-Buckingham theorem, one finds

$$\mu = \lambda_\sigma f(\pi_1, \pi_2, Bo),$$

where,

- $\pi_1 = (\rho g k)/\sigma^2$;
- $\lambda_\sigma = \sqrt{\sigma/(\rho g)}$;
- $\pi_2 = \alpha_0$;
- $\mathrm{Bo} = (\rho g R^2)/\sigma$.

Therefore, in order to establish the relationship between the leaf water storage and the leaf compliance, the dimensionless parameter π_1 will be varied while α_0 and Bo are kept constant.

3.3 Experimental approach and setup

The value of π_1 is easily adjustable since the stiffness of the petiole can be tuned with respect to its length. Nevertheless, a change in the stiffness would lead to a change in the dry inclination angle, which is an undesired behavior. Therefore, to overcome this problem, the dry inclination angle will be manually adjusted using a rotating clamp as it is shown in Fig. 2. The experimental setup is relatively simple and can be described as follows:

- The artificial leaves are made of kapton which displays similar characteristics to the one of a leaf while making sure that its quality will not decay over time. Furthermore, the artificial leaf blade are made rigid using a double sided adhesive tape, whereas the petiole is not so that it takes up all the bending.
- The leaf is clamped on a 3D mounted support which itself is placed on top of a balance. In addition to that, its shape has been design to fit perfectly a balance protection so that the mass of the water that slips is not measured.
- The balance weights the leaf at a saving rate defined by the user during the experiments.
- A water dispenser is placed right above the leaf and has a movable nozzle.
- A camera films continuously the leaf in order to capture the evolution of its compliance. The camera point of view is represented in Fig. 3a.

In order to compute the angle of compliance, a linear regression is performed. Indeed, the position of the bottom pixels of the leaf are used as a point cloud. It is important to notice, as it can be seen in Fig. 4, that the size of the droplets that are loaded on the leaf has an influence on the storage capacity. Thus, this size could be varied independently from the stiffness.

4. TIMELINE

The research schedule is represented in Fig. 5. This schedule is realistic since the preliminary experiments were done in a few minutes each.

Figures

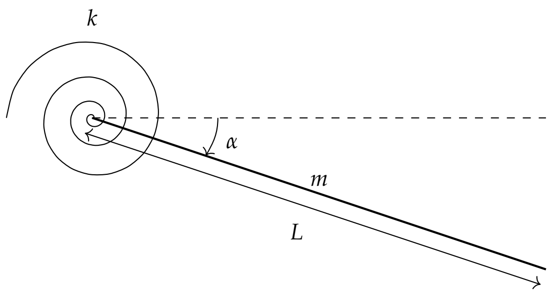


FIGURE 1. Physical model of a plant leaf. The leaf blade of mass m and length L is assumed rigid, with an inclination α. The leaf petiole is modeled with a torsional spring of stiffness k.

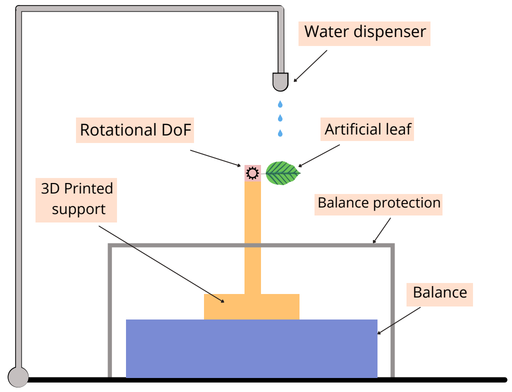
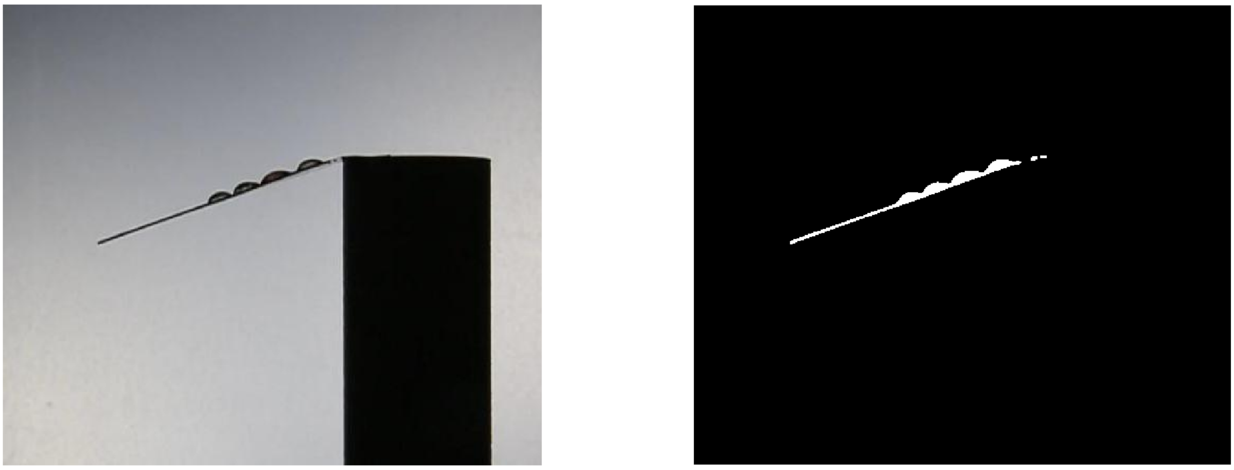


FIGURE 2. Experimental setup.



(a) Raw picture of the leaf

(b) Processed picture of the leaf

FIGURE 3. Image processing applied to the leaf.

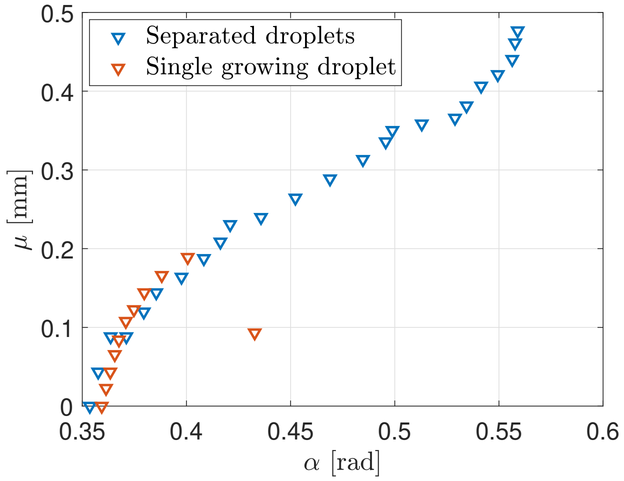


FIGURE 4. Evolution of the water storage capacity μ with respect to the inclination angle α for different droplet sizes. The separated droplets volume has been set as 8 [µL], whereas the single growing droplet slipped when reaching 38 [µL].

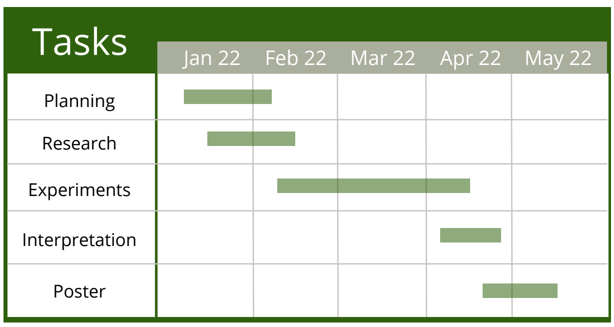


FIGURE 5. Gantt chart

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