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Research

Optics of sunlit water drops on leaves: conditions under which sunburn is possible

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Summary

- It is a widespread belief that plants must not be watered in the midday sunshine, because water drops adhering to leaves can cause leaf burn as a result of the intense focused sunlight. The problem of light focusing by water drops on plants has never been thoroughly investigated.
- Here, we conducted both computational and experimental studies of this phyto-optical phenomenon in order to clarify the specific environmental conditions under which sunlit water drops can cause leaf burn.
- We found that a spheroid drop at solar elevation angle $\theta \approx 23°$, corresponding to early morning or late afternoon, produces a maximum intensity of focused sunlight on the leaf outside the drop's imprint. Our experiments demonstrated that sunlit glass spheres placed on horizontal smooth *Acer platanoides* (maple) leaves can cause serious leaf burn on sunny summer days.
- By contrast, sunlit water drops, ranging from spheroid to flat lens-shaped, on horizontal hairless leaves of *Ginkgo biloba* and *Acer platanoides* did not cause burn damage. However, we showed that highly refractive spheroid water drops held 'in focus' by hydrophobic wax hairs on leaves of *Salvinia natans* (floating fern) can indeed cause sunburn because of the extremely high light intensity in the focal regions, and the loss of water cooling as a result of the lack of intimate contact between drops and the leaf tissue.

Introduction

It is a widely held belief in horticulture that plants must not be watered in the midday sunshine. The most frequent explanation for this is that in direct sunshine water drops adhered to plants can scorch the leaves as a result of the intense light focused on to the leaf tissue. Seventy-eight per cent of the relevant topical websites surveyed by us (Supporting Information, Table S1) answered the question 'Do sunlit water drops burn leaves?' in the affirmative. This attests to the fact that laymen and professionals alike commonly believe water drops on plants after rain or watering can cause leaf burn in sunshine. (We add that morning dew on plants can also persist into the daylight hours and might thus cause leaf burn.) This is a long-standing environmental optical problem, the solution of which is not trivial at all.

An analogous issue is whether or not human skin covered by water drops can be damaged by focused sunlight during sunbathing. Eighty-nine per cent of the surveyed dermatological and cosmetics websites (Table S2) answered the question 'Can sunlit water drops burn the human skin?' in the affirmative. Similarly, in the forestry literature the prevailing opinion is that forest fires can be sparked by intense sunlight focused by water drops on dried-out vegetation (Table S3).

The closest atmospheric optics problem is the refraction of sunlight by falling raindrops, which produces a rainbow. Although the literature of rainbow optics is extensive (Descartes, 1637; Airy, 1838; Nussenzweig, 1977; Können & de Boer, 1979; Lee, 1998), these studies were all limited to the spherical or semi-spherical shapes of falling water drops.

The problem of light focusing by water drops adhered to plants has never been thoroughly investigated, either theoretically or experimentally. In order to fill this gap and determine the specific conditions under which sunlit water drops can cause leaf burn, we conducted both experimental and computational studies. First, we exposed horizontal