Humidity and vapour pressure deficit

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***Abstract*—Relative humidity is commonly used to describe atmospheric moisture in controlled plant environments, but it is insufficient on its own for interpreting the strength with which air draws water from leaves. Vapour pressure deficit, or VPD, describes the difference between saturation vapour pressure and actual vapour pressure, thereby integrating temperature and humidity into one indicator of atmospheric drying demand. This paper distinguishes relative humidity from VPD, explains why VPD changes when temperature changes at constant relative humidity, and synthesises evidence concerning VPD and plant water relations. The reviewed evidence supports the interpretation of rising VPD as increasing evaporative demand, with potential consequences for transpiration, stomatal behaviour, photosynthesis, growth and hydraulic risk. However, these consequences vary among species and environmental settings. VPD should consequently be interpreted as a physically meaningful environmental variable, not as a universal crop-control target. The paper concludes that VPD improves interpretation of leaf-atmosphere water exchange, while crop-specific validation remains necessary before environmental ranges are applied to biological decision-making.**

I. Introduction

Atmospheric moisture conditions influence the water demand imposed on plant leaves, yet the variables used to describe those conditions are often treated as interchangeable. Relative humidity expresses the amount of water vapour in air as a proportion of the amount that air could contain at saturation for its present temperature. Vapour pressure deficit, by contrast, expresses the difference between saturation vapour pressure and actual vapour pressure. The distinction is important because VPD represents the remaining vapour-pressure difference associated with evaporation from a moist leaf surface. Relative humidity describes moisture status, whereas VPD provides a more direct description of atmospheric drying demand [1].

Relative humidity alone can therefore be misleading when comparing environments with different temperatures. Saturation vapour pressure changes with temperature, so an unchanged relative humidity percentage does not imply an unchanged difference between saturation and actual vapour pressure. At a different temperature, the same percentage can correspond to a different VPD and hence a different atmospheric pull on water at the leaf surface. VPD is useful because it incorporates this temperature dependence into a single measure, allowing humidity conditions to be interpreted in terms of potential evaporation rather than percentage moisture alone [1].

The significance of VPD does not arise from a claim that it determines every plant outcome. Evidence on rising VPD links increased atmospheric demand with changes in transpiration, stomatal regulation, photosynthesis, growth and hydraulic risk, but also documents substantial variation among plants and ecosystems [1]. This paper examines the physical distinction between relative humidity and VPD, the temperature dependence that makes the distinction necessary, and the evidence connecting VPD with evaporative demand. Its central argument is that VPD is a useful explanatory variable for leaf water demand, but not a universally transferable target.

II. Background and Scope

Plant responses in controlled environments depend on interacting conditions rather than on one atmospheric metric considered in isolation. Evidence concerning light-mediated plant growth shows that environmental and spectral context can modify plant responses, reinforcing the need to interpret individual environmental variables within a wider production setting [2]. This broader context does not directly establish a VPD mechanism, but it clarifies an important analytical limit: neither a relative humidity value nor a VPD value should be treated as a complete account of plant performance. VPD addresses a specific question about atmospheric drying demand, not all environmental causes of variation.

Temperature provides a clear example of why environmental interpretation requires conceptual separation. Research on strawberry nutrient-film systems links temperature with dissolved oxygen limitation, demonstrating that temperature may influence root-zone conditions as well as aerial conditions [3]. This evidence does not establish a relationship between dissolved oxygen and VPD. Instead, it shows that temperature has multiple consequences that cannot be represented by a humidity percentage. For leaf-atmosphere water exchange, VPD accounts for the temperature-dependent vapour-pressure difference, while root-zone oxygen status remains a distinct environmental consideration.

The same body of work links temperature, oxygen limitation and disease risk in strawberry nutrient-film systems, but does not demonstrate VPD-driven thresholds for evaporative demand [3]. Maintaining this boundary is necessary for precise interpretation. The present discussion concerns atmospheric moisture conditions and their relation to leaf water demand, rather than a general model of crop health. VPD can assist interpretation where evaporation is relevant, but claims concerning oxygen limitation or disease require their own supporting evidence. This scope prevents a physically useful variable from being overstated as a universal indicator of production risk.

III. Core Concepts and Mechanisms

The defining relationship is straightforward: VPD equals saturation vapour pressure minus actual vapour pressure. Relative humidity uses the same two quantities differently, expressing actual vapour pressure relative to saturation vapour pressure as a percentage. The variables are related, but they answer different questions. Relative humidity asks how close air is to saturation at its current temperature; VPD asks how large the vapour-pressure gap remains. Reviews of soilless production identify VPD as part of controlled-environment management and report crop-specific environmental ranges, although they do not establish comprehensive biological response limits [4].

The distinction has practical meaning because the vapour-pressure gap is associated with the evaporative demand placed on leaves. When VPD increases, the atmospheric gradient for water vapour loss becomes larger. Plant responses can moderate this demand through stomatal regulation, meaning that VPD is not identical to measured transpiration. Nevertheless, VPD describes the external atmospheric condition to which the leaf must respond. Controlled-environment modelling treats VPD as a variable alongside temperature when considering dehumidification, cooling, crop yield and energy load [5]. This confirms its relevance to environmental analysis, while leaving crop-specific physiological interpretation unresolved.

At constant relative humidity, a temperature change alters saturation vapour pressure and therefore alters VPD. This explains why the same humidity percentage can correspond to different atmospheric drying demand. The calculation is not merely a technical adjustment: it changes the meaning assigned to a relative humidity reading. Modelling studies that include temperature and VPD recognise their linked influence on controlled-environment conditions, but the modelling profile alone does not provide a complete general explanation of plant behaviour at fixed relative humidity [5]. The physical relationship is robust, whereas biological consequences still depend on the crop and context.

IV. Evidence Synthesis

The available evidence supports VPD as an integrative environmental variable rather than a stand-alone predictor of crop outcomes. Controlled-environment modelling links VPD with dehumidification, cooling requirements, energy load and yield, which demonstrates that atmospheric moisture conditions have implications beyond a single humidity reading [5]. However, those results are conditioned by the crop and model assumptions used in the analysis. It would therefore be inappropriate to infer that a VPD associated with one modelled setting will produce the same physiological or operational result elsewhere. The principal value of the evidence lies in showing why VPD assists integrated environmental interpretation.

Evidence on plant responses provides the direct physiological connection. Rising VPD increases evaporative demand and may be associated with altered transpiration, stomatal closure, photosynthesis, growth and hydraulic risk [1]. The relationship does not imply a simple linear rule. Stomatal regulation can constrain water loss, and the response of one plant type or ecosystem cannot automatically be applied to another. VPD is consequently best understood as a driver of atmospheric demand that interacts with plant regulation. This distinction helps explain why a higher VPD may signal greater drying force while not guaranteeing one fixed response in all plants.

Greenhouse literature also identifies VPD as a control variable related to atmospheric humidity conditions [6]. This supports its use in environmental descriptions, but descriptions of greenhouse ranges often do not explain why temperature changes the vapour-pressure relationship at constant relative humidity. Without that explanation, VPD can appear to be simply another humidity value. Its analytical advantage is instead conceptual: it translates temperature and humidity into a measure of the gap between actual air moisture and saturation. That gap is the feature relevant to the air's potential to accept water vapour from leaves.

V. Practical Implications and Limitations

Relative humidity should be interpreted as a temperature-dependent proportion, not as an independent measure of leaf drying demand. VPD should be interpreted as the corresponding vapour-pressure difference, which makes it more suitable for comparing atmospheric demand across temperatures. Greenhouse reviews identify VPD among the variables used to characterise environmental conditions and report operational ranges in controlled systems [6]. These reports justify including VPD in environmental assessment, but they do not establish that a published range is inherently suitable for every crop, cultivar or growing condition.

The use of operating ranges requires careful qualification. A reported greenhouse VPD range describes conditions considered within a particular environmental context, yet the supporting evidence offers limited basis for universal plant-response thresholds [6]. This limitation is consistent with evidence that plant responses to increasing VPD vary across species and ecosystems [1]. A VPD reading can therefore inform questions about atmospheric drying demand, but it cannot replace observation and crop-specific knowledge when interpreting transpiration, stomatal behaviour or growth. The measure is most valuable when used to sharpen environmental reasoning rather than to impose a uniform rule.

Further validation should connect specified temperature and humidity conditions with observed plant responses under clearly defined production settings. This need follows from the gap between physical definition and broad biological generalisation. Controlled-environment modelling can examine VPD alongside energy and yield outcomes, but model assumptions limit transferability [5]. Likewise, greenhouse range reporting identifies VPD as a relevant control variable but does not resolve universal thresholds [6]. The strongest future evidence would therefore test how particular plants respond to defined VPD conditions, rather than assuming that atmospheric demand alone predicts performance.

VI. Conclusion

Relative humidity and vapour pressure deficit are related descriptions of atmospheric moisture, but they are not equivalent. Relative humidity reports the proportion of saturation at a given temperature, whereas VPD reports the difference between saturation and actual vapour pressure. Because saturation vapour pressure changes with temperature, identical relative humidity values can conceal different VPD values and different atmospheric drying demand [1]. VPD consequently provides a clearer explanation of why air may pull water from leaves more strongly under one set of conditions than another.

The evidence supports VPD as a meaningful environmental variable for interpreting evaporative demand and associated plant responses, while also establishing important limits on generalisation. Crop-specific ranges, greenhouse practice and controlled-environment models provide useful context, but cannot establish a universal crop-control target [4], [5], [6]. Reliable application requires crop-specific validation that relates defined VPD conditions to observed responses. This approach preserves the physical value of VPD without overstating what it can predict.

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