e-GRO Alert

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Vapor Pressure Deficit? Why Should I Track That?

What is VPD?

The leaf to air humidity gradient controls crop growth just as much as light and temperature. We grow most of our ornamental plants in greenhouses so that our plants are protected from extreme cold, wind and unwanted moisture in the form of rain, snow, or fog. With modern greenhouse temperature controls and glazing we can do a pretty good job protecting our plants from the extremes. Unfortunately, we soon forget how the plan has adapted to the outside environment over the last few million years and how these controlled environments affects its physiology.

Plants outdoors need wind, sunlight and a low humidity level outside the leaf to transpire efficiently. This transpiration helps cool the leaf and also brings up nutrients to the leaf tissue as water evaporates from the leaf stomates. No one has proven that low transpiration reduces growth, but we do know is that with adequate transpiration, nutrients are readily brought up from the roots. According to one of the laws of physics, things (molecules) always move by passive diffusion from a place of high concentration to a place of low concentration. Happily, it is no different a situation in a leaf. The spongy tissue in the leaf mesophyll has pockets that contain water vapor saturated air. This is where gas exchange occurs in the leaf as CO2 uptake, O2 release occurs, and as water escapes the leaf tissue through evapotranspiration.

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Outside the leaf, the water vapor is much, much lower. This makes for a large, steep water vapor gradient between the leaf and the outside air, facilitating the movement of the water vapor out of the leaf and good water uptake from the roots along with nutrient uptake. Leaf temperature (sunlight on the leaf), as well as the air temperature and its capacity to hold water vapor (relative humidity), and the presence of air movement (wind) all affect this process dramatically.

When the relative humidity is low, the deficit between the leaf and the outside dry air is "high." Hence we often measure "high" vapor pressure deficit (VPD) on bright sunny days with moderately low humidity. (High = a value of 1.15 kPa or above). This can generate rapidly wilting plants, hard leaf tissue, deformed leaves and marginal edge burn. Conversely, in winter, on a cloudy day, in a closed-up greenhouse, the humidity levels can be very high in the greenhouse, and thus the deficit between the leaf and the greenhouse air is very low. A "low" VPD (a VPD of 0.1 to 0.45 kPa), meaning very high humidity, increases the potential for disease infection and generates very soft leaf tissue. New growers are often surprised that when maintaining high can actually cause soft growth, irregular crop maturation and even crops loss if the HAF fans are not run all day. Plant disease thrives when leaf surfaces are wet, and the external leaf environment is very moist.

Major growth issues also occur if the leaf cannot adapt to very dry. Bright sunlight, low ambient air humidity and a slightly

Figure 1. Edge of bench drying can occur rapidly and become a severe problem if bench edges are not monitored. Scouting daily is essential.

Figure 2. Leaf development can be interrupted when the VPD is very high, especially when accompanied by bright sunshine. Note expansion resumed later in the day..

> *"Relative **humidity** refers to the amount of water vapor in the air versus what it can hold. ...**VPD** is the difference between the amount of **moisture** in the air and how much **moisture** the air could potentially hold when it's saturated. It's often measured in pounds per square inch (psi) or **kilopascal (kPa)**." Ref #1*

Figure 3. The best definition. The idea range for VPD in a greenhouse is 0.45 kPa to 1.15 kPa, but like everything in our industry, can vary by crop species and your growing protocols. VPD is simply more accurate than RH because it is independent of air temperature.

pot-bound root system can be just as devastating a combination. Managing your macro-environmental issues in a greenhouse is not enough. One needs to be mindful of the leaf/outside air interface, and hence, the micro-climates around your leaf canopy!

Every grower has lost a plug tray that ran dry in just a few hours on a sunny day, or a flat of Salvia that dried out in a few hours after a quick watering on a hot May weekend. Onset of the dreaded "Permanent Wilting Point," or PWP, the point of no return for wilted plants, can occur rapidly with seedlings and large, pot-bound plants as these plants often have a small or dense, compromised root system and perhaps a large leaf to root ratio. The bigger your bedding plants get, the smaller the plug tray you are germinating, the more critical it is to manage VPD in your greenhouse.

Leaf Distortion

Another malady growers see all the time is newly expanded leaves that are malformed, crunchy, wavy, or have cracks, dead areas or even edge burn. This is due to the fact that plant cells need internal water pressure to expand properly. If the VPD is very high, water may be lost faster than the plant can replenish it from the roots. The leaf cell pressure drops, expansion for those cells slows, while other areas on the leaf may still be expanding normally. This micro-disparity causes leaf distortion. Leaf expansion effect is also the basis for large, super soft leaves grown in high humidity environments and crunchy tight leaves grown in dry air environments. If leaves of certain crops have distortions, look first at your vapor pressure deficits for solutions. Remember, VPD fluctuates wildly on cloudy days when the sun breaks through mid-afternoon and temperatures swing rapidly in a greenhouse. VPD should be scouted hourly or monitored electronically. (See Figure 3).

Plant nutrient uptake is strongly affected by a high VPD. Too high of a VPD for a long period of time and you hyper-accumulate minerals in the leaf. This can lead to edge burn and what appears to be phytotoxity. It can also cause nutrient imbalances in the leaf tissue, generating what looks like deficiencies, when in reality, its hyper accumulation of a particular element due to dry air. Too low of a VPD (meaning very high relative humidity) can make it easier for plant pathogens to be get established, and very soft growth can easily occur if the conditions are sustained for many days. Beware condensate covered greenhouse interiors. It's a clue you have low VPD.

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So what can we do to reduce the occurrence of VPD induced issues?

Run those HAF fans during the day, every day! The constant air movement pulls the saturated air that forms just outside the stomate away, renewing the relative humidity gradient. The fans also prevent high-humidity pockets from forming over/around newly planted pots benched pot to pot, or plug trays edge to edge. Canopy humidity can be measured by placing a store-bought sensor in the middle of the crop canopy. By running those fans, and allowing air to penetrate the canopy, you reduce the high humidity trapped around the canopy, and your relative humidity readings taken at the macro-level by your greenhouse control system is that much more accurate.

Avoid large, swings in house temperature if at all possible, especially early Spring and Late Fall. This comment is directed towards late spring/summer production where inefficient cooling systems can allow greenhouse temperatures to rise or drop rapidly. This happens just about the time roots systems have filled out the pots/trays. If this happens often, you likely need to re-design your cooling system, or better manage venting. It is most critical that the irrigation person be doubly attentive to scouting for dry plants.

Sequential Venting

When needed this old timey greenhouse trick can help on days when the greenhouse is tightly closed up, or on rainy days when condensate is just making things a wet mess. The traditional method is to raise the greenhouse air temperature by 5 degrees, for about 15-20 minutes, and then perform a controlled (manual),

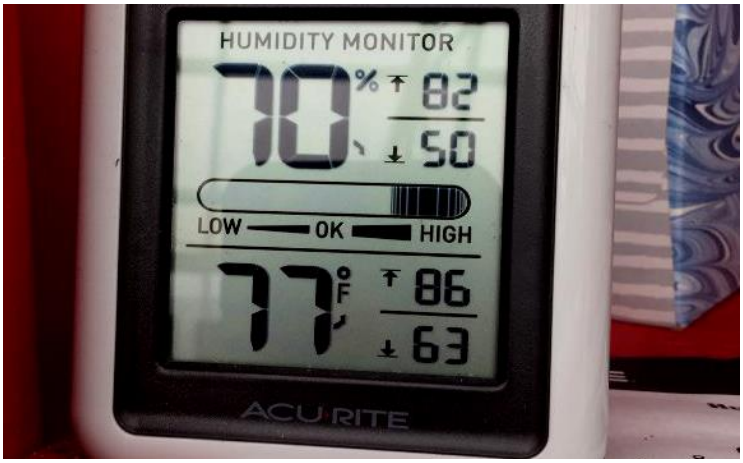

Figure 4. High humidity and warm temperatures can generate conditions where there is a very low VPD. Unless Haf fans are running, you risk reduced nutrient uptake and even increased potential for disease as night temperatures cool and condensate forms of leaves.

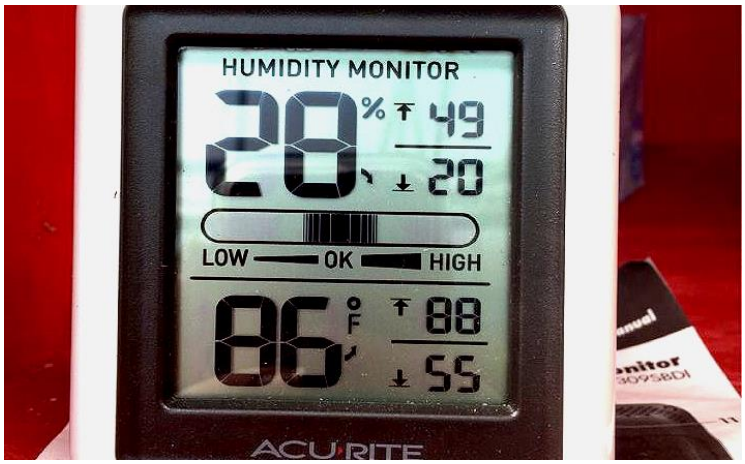

Figure 5. High temperatures and relatively low humidity means rapid water loss and excellent nutrient uptake, so long as there is ample water in the soil. If crops are dry, afternoon heat can induce leaf distortion, permanent wilting and slowed growth rate due to temporary drought.

venting. The warmer air holds more moisture and when vented, can reduce internal relative humidity by venting the water laden air out of the greenhouse. In our greenhouses here in Georgia, it takes two to three cycles of controlled heating/venting to eliminate glazing condensate and jungle-like conditions on cloudy wet days. A good indicator that you need to vent is guttation, the forming of water droplets on leaf tips. Some plants have glands at the edges of leaves that express water when evaporation is reduced but root uptake pressure continues. When you see this…its time to vent.

Syringing

When humidity is very low, this simple method is needed and is advisable when you have bright sun, very low humidity levels and sensitive crops such as plugs, ferns and rooting liners. By definition, syringing means just passing over the plants with a brief wave of irrigation water. This will dramatically raise the relative humidity, reduce VPD and prevent pot-bound or newly transplanted plugs from drying out to due to excessive water movement through the leaves. This is most often done between 11:00 am and 3:00 pm. Do not syringe after 3:00 pm as leaves may not dry off and pathogens just love that moist warm environment leaf surface.

Avoid pot-bound root systems if at all possible. Once a crop becomes root-bound, it means the roots have far less water reserve from free, non-root bound soil medium. It means the volume of roots can strip the water from the soil in a very short period of time. It also usually means the leaf to root ratio favors the leaves, which increases the rate of water loss to potential water uptake. This is NOT GOOD! If you have a crop that is delayed in shipping, or hasn't sold, observing your relative humidity, and scouting soil moisture must be a top priority. Better to be aware of the need to pre-emptively water a crop and avoid drought effects.

Plant Spacing

Be mindful of plant spacing. The more densely you position pots/trays on a bench, the more likely the relative humidity will be high at the plant canopy level. This is especially true of plug trays and newly transplanted bedding plants. High local humidity, hence low VPD can also slow the evaporation of water from the soil of the seedlings, liners or young transplants. We want the young plants to have moist soil, but high humidity can slow essential soil drying, and aid in algae formation on the soil surface. Of course, you don't want a very high VPD around newly transplanted plugs/seedlings either. Leaving a half inch between units does increase air circulation and improves the efficiency of air directed by HAF fans, and can make it easier for you to manage soil moisture and local vapor pressure deficit levels.

Crop orientation and the bench location itself can affect micro VPD conditions. Are spaces between pots oriented parallel to the HAF flow? If staggered, the airflow may be interrupted or reduced, leaving high humidity pockets down wind. Are there poles, instrument boxes or screening blocking air flow to certain parts of a bench? This is a perfect scenario for mid-crop disease expression. Conversely, wind sources in the greenhouse can dramatically affect (increase) VPD. Doors, Heater Fans, and even frequent electric carts passing by benches can quickly increase the VPD in plants closest to those sources. One can use an anemometer to test air flow, but often a simple candle can be used to identify dead air zones, and windy areas.

Bench Edge Effects

I often have to follow up with students whom are not aware of edge effects plants experience on benches. Plants on the bench edge simply get more airflow and usually more light exposure per plant than the mid-crop plants. Simply put, more light, more air means faster drying. If you don't carefully spot water, the edge crops higher VPD can induce very rapid wilting even though the rest of the crop is moist and happy. If you have areas that dry out quickly, often, and have frequent quality issues, look towards the air movement as a possible reason. (See figure 1).

Figure 6

Table 3. References VPD (kPa) for greenhouse production, recommended by Argus Ltd, (2009)

T(°C)	rH (%)													
	35	40	45	50	55	60	65	70	75	80	85	90	95	100
15	1.11	1.02	0.94	0.85	0.77	0.68	0.60	0.51	0.43	0.34	0.26	0.17	0.09	0
16	1.18	1.09	1.00	0.91	0.82	0.73	0.64	0.55	0.45	0.36	0.27	0.18	0.09	0
17	1.26	1.16	1.06	0.97	0.87	0.77	0.68	0.58	0.48	0.39	0.29	0.19	0.10	0
18	1.34	1.24	1.13	1.03	0.93	0.83	0.72	0.62	0.52	0.41	0.31	0.21	0.10	0
19	1.43	1.32	1.21	1.10	0.99	0.88	0.77	0.66	0.55	0.44	0.33	0.22	0.11	0
20	1.52	1.40	1.29	1.17	1.05	0.93	0.82	0.70	0.58	0.47	0.35	0.23	0.12	0
21	1.62	1.49	1.37	1.24	1.12	0.99	0.87	0.75	0.62	0.50	0.37	0.25	0.12	0
22	1.72	1.59	1.45	1.32	1.19	1.06	0.92	0.79	0.66	0.53	0.40	0.26	0.13	0
23	1.82	1.68	1.54	1.40	1.26	1.12	0.98	0.84	0.70	0.56	0.42	0.28	0.14	0
24	1.94	1.79	1.64	1.49	1.34	1.19	1.04	0.89	0.75	0.60	0.45	0.30	0.15	0
25	2.06	1.90	1.74	1.58	1.42	1.27	1.11	0.95	0.79	0.63	0.47	0.32	0.16	0
26	2.18	2.02	1.85	1.68	1.51	1.34	1.18	1.01	0.84	0.67	0.50	0.34	0.17	0
27	2.32	2.14	1.96	1.78	1.60	1.43	1.25	1.07	0.89	0.71	0.53	0.36	0.18	0
28	2.46	2.27	2.08	1.89	1.70	1.51	1.32	1.13	0.94	0.76	0.57	0.38	0.19	0
29	2.60	2.40	2.20	2.00	1.80	1.60	1.40	1.20	1.00	0.80	0.60	0.40	0.20	0
30	2.76	2.54	2.33	2.12	1.91	1.70	1.48	1.27	1.06	0.85	0.64	0.42	0.21	0
31	2.92	2.69	2.47	2.24	2.02	1.80	1.57	1.35	1.12	0.90	0.67	0.45	0.22	0
32	3.09	2.85	2.61	2.38	2.14	1.90	1.66	1.43	1.19	0.95	0.71	0.48	0.24	0
33	3.27	3.02	2.76	2.51	2.26	2.01	1.76	1.51	1.26	1.01	0.75	0.50	0.25	0
34	3.46	3.19	2.92	2.66	2.39	2.13	1.86	1.59	1.33	1.06	0.80	0.53	0.27	0
35	3.65	3.37	3.09	2.81	2.53	2.25	1.97	1.69	1.40	1.12	0.84	0.56	0.28	0

Source: http://arguscontrols.com/resources/VPD_Application_Note.pdf
Argus Control Systems, A Conviron Company. Surrey, British Columbia

Once a crop fills out, high density foliage begins to trap humidity within the canopy. In the hectic weeks before Mothers Day, maximizing airflow is essential. Note where edge crops dry quickly and hang a flag over the spot to remind irrigators to check.

Light reflection pockets (LRP) can also increase the VPD as strong reflected sunlight can increase leaf temperature and hence the driving force for evapotranspiration. It means that even if you have very uniform air humidity, the sunlight-enhanced plants in the pocket will dry out much faster. This is often seen in glass houses oriented east to west, on the north side of the glass. I often hear growers refer to a "warm bench" and it can sometimes happen on south facing wall benches also. Localized, high light-induced VPD variances can be found anywhere glass is angled enough to bounce light unto a crop (a bright spot is what my mentor called it). If you see such areas, scrutinize them throughout the year to see if it is affecting growth.

So How Do I Measure VPD?

There are many companies that make and service highly accurate systems for measuring VPD. All of these systems have a cost, but when tied into computer software, it can greatly increase your ability to control your entire greenhouse environment. However, these systems are not economically useful for small family operations. A reasonable way to be aware of your VPD is actually very simple and inexpensive. The first items you need are a few temperature/humidity readers. I purchased mine from a big-box store for under $20.00 ea. They give you current, min and max temperature and current, min and max humidity readings. They can be placed in the canopy, at bench edges and suspended mid-air in the greenhouse. They may not be super accurate for scientific data use, but they are 100% useful for estimating VPD!

The next thing you need is to download a simple VPD chart. (See Figure 6.) There are dozens on the web that you can print off at no cost. Laminate a few copies and hang/post them next to your temperature/humidity readers. The chart allows you to quickly correlate the current relative humidity, and the current temperature to an estimated VPD. A VPD chart (in kPa) will tell you if the environment is outside of the range (bad or good or most plants. As long as your grower/irrigation person checks 4 -5 times a day, decisions can easily be made to syringe, ventilate, or initiate shade cloth. (See Figure 6). Once you start working with VPD, you'll understand why the major growers all have invested in automated VPD sensors and software.

Reference:

1). Wollaeger, H, and E. Runkle. 2015. VPD vs Relative Humidity. Michigan State University Extension Publication: http://msue.anr.msu.edu/news/why_should_greenhouse_growers_pay_attention_to_vapor_pressure_deficit_and_n

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