Movement of water through plants

How a plant uses water and the interaction between root zone and aerial environments

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Introduction

In this whitepaper, Grodan specialist ANDREW LEE provides an insight into the physiological process of water uptake by plants and describes how the root zone and aerial environment interact to drive this within the glasshouse.

Water movement through the plant

Quite simply, water moves through the plant from the roots to leaves within structures called xylem vessels, a process that is governed by transpiration. Of the quantity of water absorbed by a plant, around 90% is transpired while only 10% is used for growth.

To put this into perspective, a cubic metre of glasshouse air at 20°C can hold a maximum of 17g water. An actively growing crop can transpire as much as 4.5 litres water /m^2 on a sunny day of 2000 J/cm^2. Water evaporated from the leaf in this way acts to cool the glasshouse climate in the same way as a high pressure fogging system. Indeed, the temperature of a transpiring leaf can be 2-6°C lower than a non-transpiring one. This is why during the summer months it is essential to have a good quality root system and optimum leaf area index to achieve sufficient cooling capacity and thereby maximise production and fruit quality. However transpiration by the crop, because it adds so much moisture to the air, can create problems at other times of the year when ventilation is limited or in periods of dark and mild weather by increasing humidity levels beyond desired limits set by the grower. When the glasshouse climate is humid it is essential that the root zone is managed correctly to avoid the onset of plant (disease) and fruit quality issues.

Understanding how the root zone and aerial climates interact with each other is a fundamental requirement for any grower; only when these environments are working in balance is it possible to maximise returns.

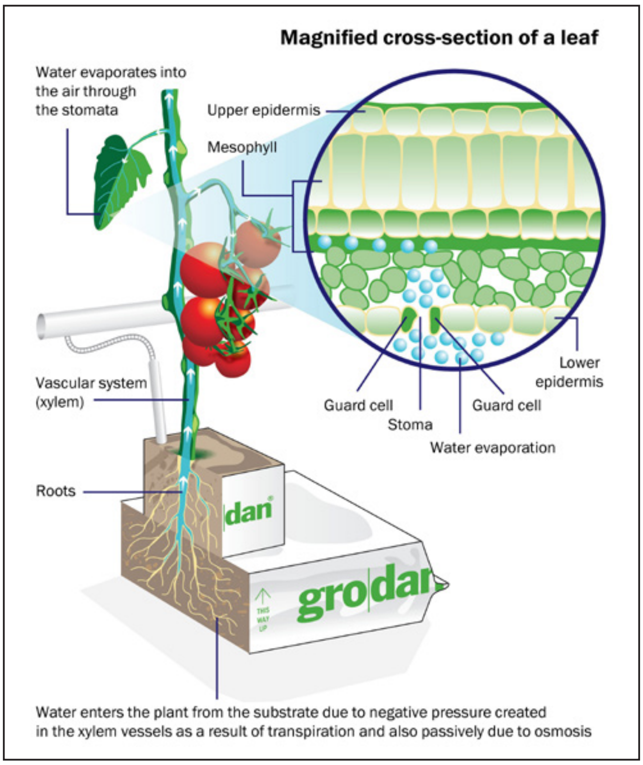
Picture 1.0
Understanding the root zone is a fundamental requirement for any grower.

Picture 2.0
It is essential that the root zone is managed correctly.

Transpiration

Transpiration begins with the evaporation of water through the stomata (tiny pores on the underside of the leaf) when they are open for the passage of CO_2 and O_2 during photosynthesis. This moisture is then replaced by water from adjacent cells located directly behind them. Water subsequently moves into these cells from the xylem vessels located within the leaf. As water moves into the leaf it pulls on the column of water held within the xylem all the way down to the roots. This draws the xylem walls inward creating a negative pressure and results in water moving into the root and up toward the leaves.

Picture 3.0
Magnified cross-section of a leaf.



The role of the stomata in transpiration

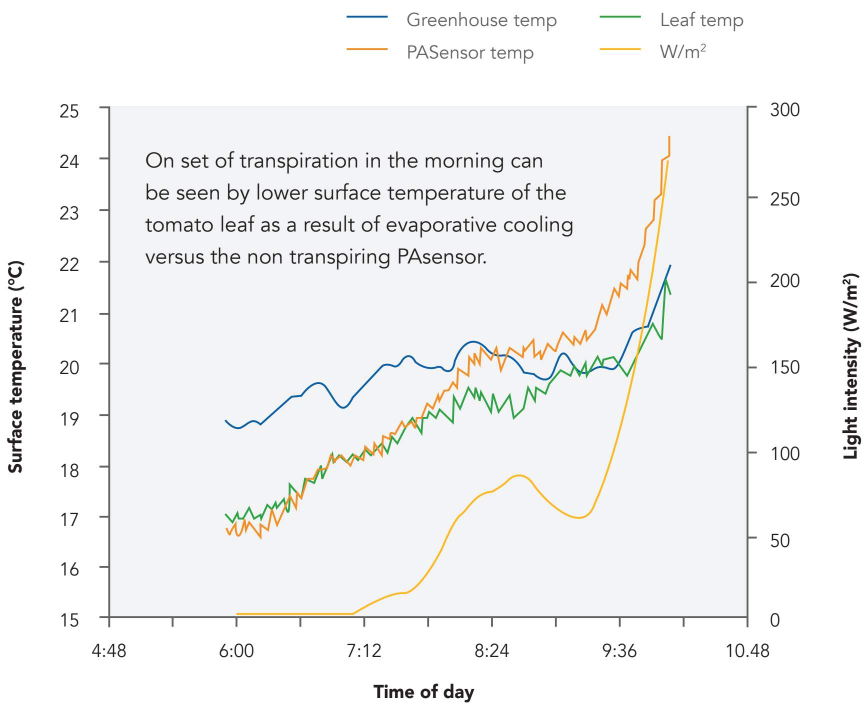
Evaporation through open stomata is the major route of water loss in the plant. The stomata must open for the passage of CO_2 and O_2 during photosynthesis, however a balance must be maintained between the gain of CO_2 and the loss of water. The plant achieves this balance by regulating how wide the stomata open.

Opening and closing of stomata is stimulated by light. Other parameters can influence the rate of transpiration such as heat and not least, relative humidity or more precisely, from a plants perspective, the vapour pressure deficit (VpD), defined as the difference between the vapour pressure inside the stomata and the vapour pressure of the glasshouse air. Consequently, changes in the aerial environment - light, heat and humidity - will influence the time that transpiration starts and rate of transpiration during the day. This will impact on how the root zone is managed.

Stomata open when light strikes the leaf surface in the morning. In glasshouse situations we see transpiration or plant activity starting at approximately 150-200W/m² outside radiation. This is clearly shown in Figure 1.0 by the difference in surface temperature, as a result of evaporative cooling, between a tomato leaf and a non-transpiring leaf sensor. The first irrigation of the day should be timed to coincide with this. This relationship also has implications for the minimum pipe strategy in the morning. Astute growers reading this article will now understand why the minimum pipe strategy is reduced on light, not time, in the range 200-400W/m², depending on glasshouse structure. Using a minimum pipe above 400W/m² under these circumstances would just cost the grower extra money as the plant is already activated by the sun. However, there is a notable exception. When the root zone is cold, 12°C, there can be a delay in transpiration of up to 2 hours compared to a root zone temperature of 17°C. In these situations the start time of irrigation and minimum pipe strategies should be adjusted.

The rate of transpiration during the day will be governed by how active the climate inside the glasshouse is, i.e. the higher the temperature and lower the relative humidity the greater the rate of transpiration. I will briefly describe two contrasting situations.

Figure 1.0
Relationship between the temperature of a tomato lead and plant activity sensor (PASensor) in relation to outside radiation at the start of the day. (Source: Peter Stradiot, Innogreen)



Sunny day

During the day if the absorption of water by the roots is less than the rate of transpiration, loss of cell turgor occurs and the stomata will close to prevent the plant from wilting. This immediately reduces the rate of transpiration, as well as photosynthesis, resulting in a potential loss of fruit quality and production. Plant (and air) temperature will increase as a result leading to higher and higher respiration rates until the plant effectively burns itself up. For this reason it is important to maintain the quality of the root system, especially from over-wintered crops entering the spring.

It is also advisable under high light conditions (>1000 J/cm²/day) to link irrigation volumes to the radiation sum (Figure 2.0). Under normal circumstances this will be in the region 2.5-3.5mL per joule depending on greenhouse structure and outside relative humidity, in order that the crop is supplied with the correct amount of water. Indeed, in extreme circumstances growers can use the water uptake of their crop as an indication of how well the crop is performing and thereby adapt their fogging and screening strategies accordingly. In this respect it is important to remember that water uptake by the crop should not decrease when using these tools. They should only be used to help the plant (roots) keep pace with the high transpiration demand. Over use of the fogging system can create a weak crop and excessive screening reduces light penetration, and light, quite simply, equals production!

Look to the activity (transpiration) of the crop on both mornings as indicated by the change in slope of the water content line about 07:00 hrs and compare this to 16 and 17 May (Figure 3.0).

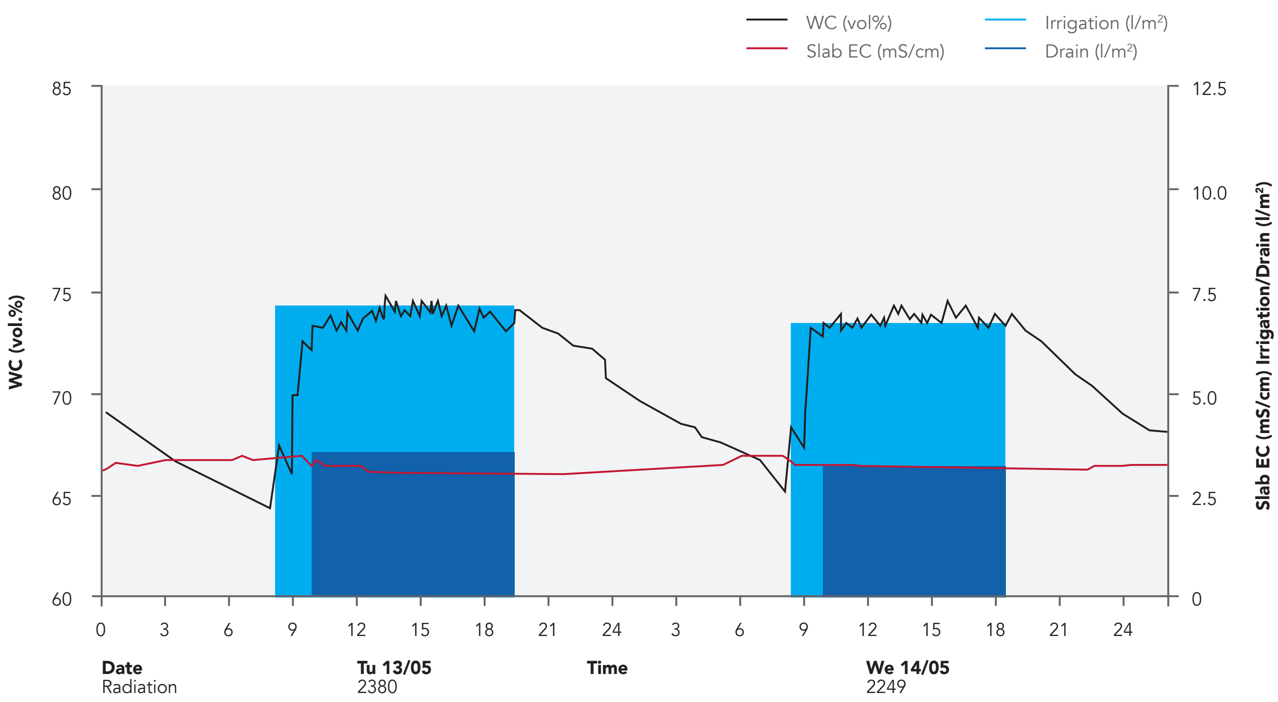


Figure 2.0
Irrigation strategy over two sunny days for a pepper crop in Holland. Data generated using Grodan GroSens system. Water content = black line. Substrate EC = red line. Blue bars = total volume of water applied and drain achieved

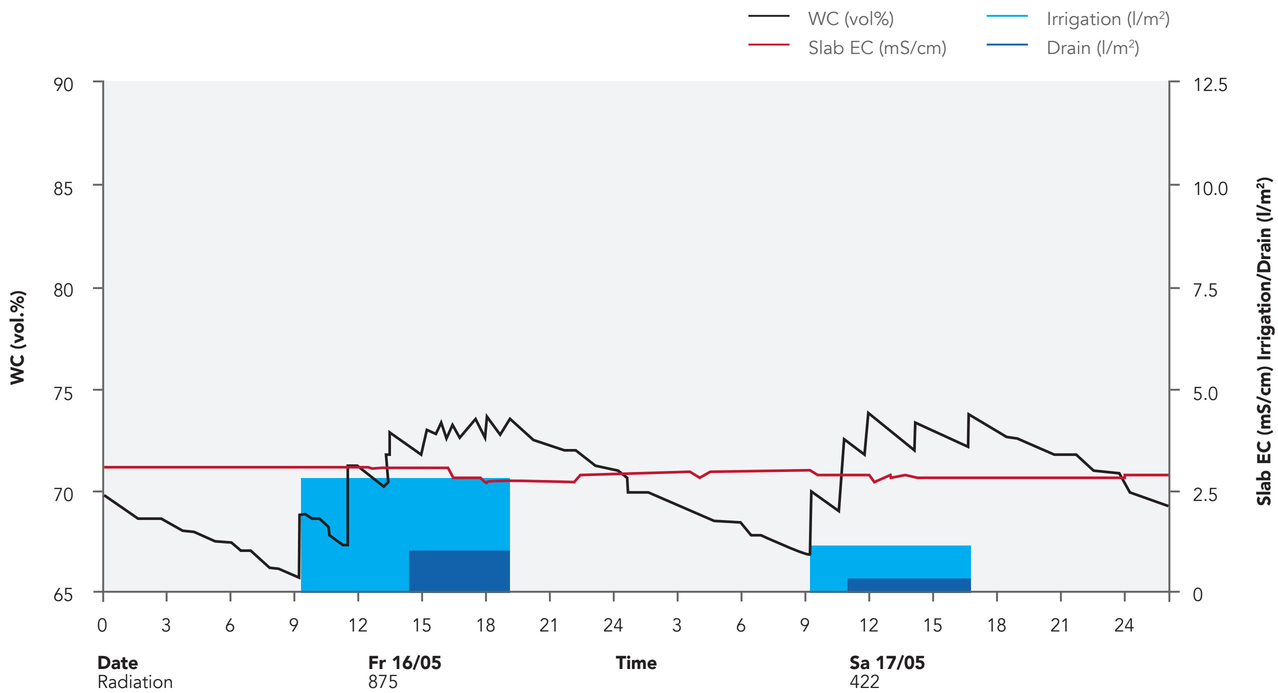


Figure 3.0
Irrigation strategy over two dark mild days for a pepper crop growing in Holland. Data generated using Grodan GroSens system. Water content = black line. Substrate EC = red line.

Dark mild day

On a dark mild day transpiration will be low, therefore the start and particularly stop times of irrigation should be adjusted accordingly. This is easy to implement given today's modern climate computers used in combination with tools such as the GroSens system. On dark mild days the use of the minimum pipe temperature settings (50-60°C) for a few hours in the afternoon along with some ventilation *maybe* required to stimulate plant activity. This ensures that essential nutrients are still supplied to the plant and will also maintain the crop in the right generative balance. I will explain how to steer plant balance using the root zone in the whitepaper '*Understanding and steering the root zone in response to the six phase life cycle of a crop'*. In the meantime, readers who wish to know more about the six phase life cycle can visit www.grodan.com.
However it is important not to over stimulate the crop with a large temperature influence on the humidity pipe. This will often make the relative humidity worse, by increasing transpiration rates, and will also increase the risk of creating a weak crop. For humidity control a minimum pipe of 40°C is normally sufficient - taking account of today's energy prices, a humidity pipe no higher than 45°C should be used. For example, the minimum pipe setting may be 35°C with +10°C influence for humidity increase in the range 80-90%. If you are alarmed by these numbers investigate this in the coming winter/spring. Look to your graphics on the climate computer, particularly the relation between air humidity and humidity pipe temperature. I would anticipate that glasshouse humidity will not change if the humidity pipe is 40°C or 60°C. The only difference will be the heating bill! It is important to remember that the only way to let moisture out of the glasshouse is to open the vents, so keep heating and venting lines in these situations close together - this will also keep the glasshouse active. However avoid aggressive venting when it is cold outside by linking the vent strategy to outside weather conditions, because cold air (<13°C) falling on the heads of the crop can impact negatively on transpiration.

It is also worth remembering that often on a dull day it will be the maximum rest time (i.e. the maximum length of time between irrigations) that will determine the total quantity of water supplied to the crop (Figure 3.0). So in combination with late start and early stop times and the minimum pipe strategy, make sure this is not too short. I will describe how this can be achieved in the whitepaper within the series entitled, *Making informed decisions in respect to water an EC management.* This will prevent fruit physiological quality problems such as splitting and uneven colour.This will prevent fruit physiological quality problems such as splitting and uneven colour. You will know if the maximum rest time is too short because the substrate EC most likely will decrease too far, note on dark days it is fine slab EC actually increases a little.

The role of active root uptake

A plant can also take up water even when it is not transpiring. This phenomenon is normally referred to as 'active root uptake' and results in what crop consultants call 'root pressure'. Root pressure is strongest when transpiration ceases during the night or when plant 'activity' is low.

What causes root pressure?

On the surface of the root there is a single layer of cells that contain transport proteins. These allow ions (i.e. Ca^{2+}, K^{+}) to cross from the surrounding substrate into the roots. This active process burns the sugars (via respiration) that are made during photosynthesis but more importantly it creates a concentrated sugary solution of ions inside the root cell. Water then follows the flow of minerals into the roots by a passive process called osmosis. The plant can do nothing to stop this, but a grower can limit its potential negative impact on fruit quality (i.e. splitting and radial cracking in tomatoes) with correct root zone management. I will discuss in greater detail about fruit quality issues and the role of root zone management in the fifth whitepaper of the series entitled, *Root zone management and the impact for fruit quality.* In this respect I always advise growers not to have an aggressive EC reduction of the irrigation solution based on light intensity (W/m^2) and to stop the irrigation sometime before sunset. This ensures that the substrate EC is not at its lowest when transpiration ceases, because a higher substrate EC at night acts to limit the flow of water via osmosis into the roots. I always remind growers that EC in the substrate should be at its lowest when light intensity is at its highest! There are many factors that can influence root pressure and I have summarised these in Table 1.0.

Factor	Reason
Grafting root stocks for improved vigour	A larger root system can access more water
Warm slab temperatures	Increased respiration within the root system resulting in greater ion transport
Low fruit load	Less water buffering capacity within the plant
Cool or cloudy weather conditions	Less transpiration
Low substrate EC	When transpiration ceases at the end of the day a low substrate EC allows more water to pass into the roots via osmosis

Table 1.0
Factors influencing root pressure of a tomato crop

Summary

In conclusion, the root zone environment can be described as the engine room of the crop. A good quality root system will allow the crop to transpire. However the time that transpiration starts and the rate of transpiration during the day are governed by interaction with the aerial environment. The root zone climate needs to be managed accordingly in order to maintain optimum plant balance, production and fruit quality. This can be achieved by understanding what functionalities the substrate has and how the grower can take advantage of these when developing an irrigation strategy on the climate computer.

Grodan has, over the years, developed a lot of knowledge in this area. In this whitepaper I will define the key design features of Grodan substrates, why they are important and how these are used by growers to achieve specific objectives in root zone steering.

About the author
Andrew Lee works for Grodan Technical Services. He is a PhD graduate from the University of London, England, and has been working for Grodan over the past 19 years providing consultancy and technical support for its customer base worldwide.

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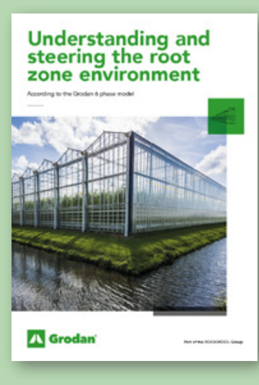

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Goals and targets for crop and root zone management in response to changes in plant development, fruit load and light levels.

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Some decisions and actions we make in starting a new crop can have a big impact later in the cultivation.

Improving tomato fruit quality

For the most common physiological disorders namely blossom end rot (BER) and uneven colour (blotchy ripening) this whitepaper explains their cause and prescribes simple solutions to avoid / minimise risk of symptom expression in the first place.

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Grodan supplies innovative, sustainable mineral wool substrate applications for professional horticulture, based on the Precision Growing principle. These applications are used for the growing of vegetables and flowers, such as tomatoes, cucumbers, capsicums, aubergines, roses and gerberas. Grodan supplies stone wool substrates in combination with customized advice and innovative tools to support growers with Precision Growing. This facilitates sustainable production of healthy, safe and delicious fresh produce for consumers.

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