The Clay Research Group

The Role of Abscisic Acid

A Suggested Qualitative Production Envelope

by

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ABA Production Cycle – Introduction

Abscisic Acid (ABA) is an important 'root to shoot' signalling hormone that has been well researched. Its role in stomatal regulation in response to drought stress is established.

The potential relevance of this important hormone in terms of subsidence claims is self-evident. Trees are claimed to be the cause of 70% of root induced clay shrinkage claims. These claims are both costly and can take many months, if not years, to resolve.

Understanding the regulatory mechanism with the aim of devising some form of intervention technique could lead to significant cost savings for insurers and improvements in service delivery.

Raising the pH of the moisture in the xylem and partial root drying (PRD) both appear to be beneficial in amplifying the effect of ABA (Prof. William Davies, Lancaster University and others). It has been shown that when the apoplastic pH of leaves is increased by introducing into the xylem artificial sap which has been buffered to a greater alkalinity than exists in a well-watered plant (10nM concentration), stomata closed in the presence of even minimal ABA concentrations as long as it can reach the receptor sites on the guard cell walls.

The response of the stomata is influenced by the pH of the apoplast locally (within the leaf) and within the xylem on its passage from the root system. A long-distance signal from the root and a locally generated signal within the leaf may both operate within the leaf at the same time, one enhancing or suppressing the signal of the other at the surface of the guard cell. The pH of the apoplast may determine what influence the ABA arriving from the root will exert.

As drying has the effect of raising the pH of the xylem water, and as ABA is slightly acidic, its influence is increased locally. Increases in pH also cause a reduction in leaf growth rates but on the negative side ABA may encourage root growth.

ABA analogues have been tested with varying (species dependant) success.

Evidence of stomatal regulation in response to environmental fluctuations, changing by the hour every day is readily available in the published literature – see Newsletter No. 29 for a case study.

Research at Aldenham and elsewhere has suggested that water uptake is greatest at the beginning of the summer. Using the 'by month' ground movement values as a proxy for 'effective moisture abstraction', we see that the tree water uptake (depending on the prevailing climate) is at its peak around July. It would appear that the physiological response of the tree is sensitive to even small variations in dryness. We have deduced from ground movement measurements that the tree seeks to absorb water at a greater rate from dry soils than from wet soils. That is to say, uptake commences earlier in a dry year.

It is an adventitious system taking account of local changes in the soil/root interaction as it finds them. It isn't the case that roots will uniformly exert a given suction at a moment in time driven by the tree. There is variability across the root footprint. The digital root map we have described in Newsletter 30 seeks to explain this numerically.

In this paper we postulate quantifying the ABA production envelope in terms of tension within the xylem. That is, the difference in negative pressure between climate (or more correctly, Vapour Pressure Deficit (VPD) micro-climate of the canopy) and soil moisture as measured in the tubes within the tree that conduct water from the roots to the canopy. We have used SMD as a proxy for climate and ground movement as a proxy for moisture loss.

If our assumptions are correct, production commencing shortly after the tree comes into leaf, increasing gradually until the 'moisture uptake by month' changes to a positive value following rainfall.

Where soil suctions are less than the wilting point (in the case of most trees, around 1,500kPa), cessation of transpiration, even for short periods must, we assume, be due to the intervention of ABA.

If transpiration stopped and the stomata remained open we assume that the plant would show considerable distress and eventually die due to irrecoverable cavitation within the water columns. Cell turgor is vital to the continued well-being of the plant, and closure of the stoma is central to achieving this. Where the wilting point is exceeded, then we suggest that any excess ABA is re-circulated via the phloem back to the root system or stored locally in the symplast of the cells where it is ineffective. It is effective in the apoplast of the guard cells at receptor sites.

If the re-circulated ABA encounters drought stress when it returns to the roots, then it may be passed back to the leaf via the xylem, or dissipated in the soil but again, this is an adventitious and self-regulating system, driven by a combination of climate and soil dryness.

Using data where we have it, we have modelled possible production for various years (see following page) using in particular the Aldenham levels from 2006 and data from Chattenden in 1990. Aldenham is unique due to the persistent deficit in the ground beneath the tree and the soil heterogeneity. However, the proposed relationship is fairly representative in terms of the relative profiles of SMD and ground movement.

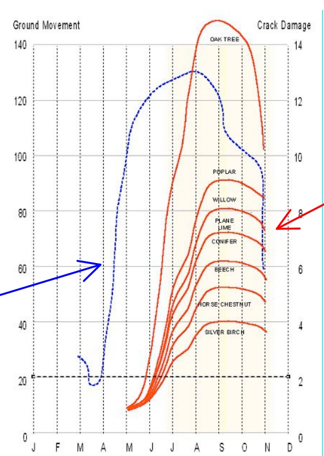
We propose the model as a starting point in developing targeted intervention techniques.

Climate –v- Ground Movement

The generally accepted relationship between climate (using SMD as a proxy to combine all of the various elements including wind, rainfall, hours of sunshine etc.) and ground movement is shown below. SMD values increase early in the year - sometimes a month or so prior to the tree coming into leaf.

The *effective* SMD values (broken blue line) are those related to root activity, commencing when the tree comes into leaf, typically in late April or early May. If the weather is wet at that time, ground movement will be nominal.

SMD



Ground movement (red) will vary as a function of tree height, species, health and climate as well as soil mineralogy – indicative plots only.

Graph 1
The General Relationship (variable) between Soil Moisture Deficit (SMD) and Ground Movement

Alternatively, if the SMD values are particularly high then the tree will seek water quickly and trigger ground movement. A high SMD value in May, coincident with when a tree comes into leaf, will generate large tensile forces in the xylem and for this reason, 'sets the scene' which is then built on throughout subsequent months.

Once in leaf, moisture abstraction (transpiration) takes place and ground movement follows. The amount of ground movement is closely linked to climate and of course, soil mineralogy. The 'ground movement by month' value is a proxy for moisture uptake by the tree and indirectly takes account of soil mineralogy.

ABA Production

What triggers eABA? When does it begin to exert an influence and for how long? When does it 'turn off'? ABA is produced at quite low soil suctions. Wright & Hiron (1969) measured a forty-fold increase in ABA production within the first 30 minutes of recording drought stress.

When water is readily available, ABA produced by the roots will dissipate into the surrounding soil unused. Uptake is regulated by the soil pH. The process is 'automated' by the prevailing environmental conditions.

We have used the term 'effective ABA' (eABA) to distinguish between that which is 'lost' (ABA) and that which circulates in the tree sufficient to regulate stomatal activity (eABA).

The pH anywhere along the path from root to shoot influences the hormone, either strengthening it or weakening it. The presence (or absence) of water may be secondary. That is to say, ABA can still trigger stomatal closure even when water is available.

As a general rule, cell turgor is retained on stomatal closure. Otherwise innefective ABA can be 'enabled' by pH gradients within the leaf, between the symplast and apoplast, and re-circulated to the roots via the phloem in cases where its production has exceeded demand. Receptors on the wall of the guard cell respond to ABA.

The Soil

The model takes account of the moisture retention properties of the soil. Highly plastic soils have finer grains and retain moisture more readily than the less plastic soils. How much negative pressure is required to abstract moisture from the soil? In soils with high water retention properties, *e*ABA will be triggered earlier.

Negative porewater pressure in the soil leads to ground movement, and there is a direct non-linear link between ground movement and SMD.

The higher the SMD and the greater the ground movement, the more we might assume is the production of *e*ABA. The limiting suction value in the ground is 1,500kPa – the so-called wilting point of vegetation. The level at which trees struggle to abstract further moisture.

The Tree

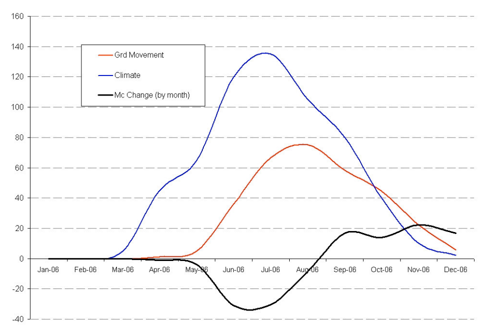
If a tree is drought stressed and left without any form of regulatory control it may be a natural assumption that soil suctions of 1,500kPa, corresponding to the wilting point, would be encountered often in hot summers. In fact, they are not.

If there is a regulator we assume it must lie in the stomata and *e*ABA would be the controlling influence. The proposed model is based on these assumptions.

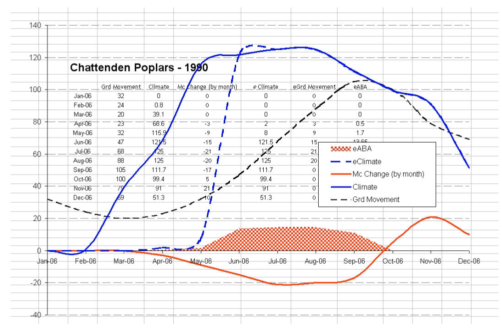
We assume (but do not know) there will be a significant variation in the threshold at which ABA production commences between species. Trees with a low tolerance to drought stress – low water demanders - would, we assume, produce ABA at lower suctions.

The Model

We propose that by subtracting ground movement from SMD values we build a qualitative outline of tensions sufficient to model the production of *e*ABA.



Graph 2



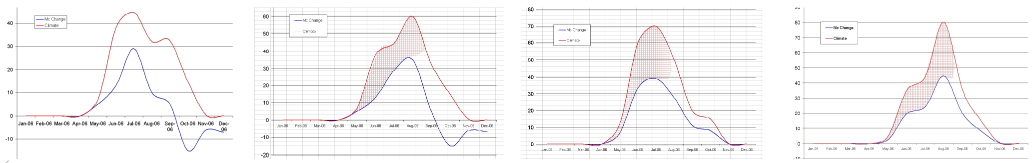
Graph 3

The SMD is represented by the solid blue line in the graph above. The effective climate values (those that influence root activity) appear as a broken blue line, commencing in May. The ground movement by month is plotted as a red line. The broken black line is cumulative ground movement, peaking around September and the ABA production phase is the red hatched shaded area.

The scales are illustrative only - 10nM is the usual level of ABA in the xylem of a well watered plant.

Beyond the point of summer contraflexure – August or September – rainfall reduces the influence of the hormone. This reduction would take a month or so following a decrease in the SMD due to the time it would take for moisture to percolate into a desiccated soil.

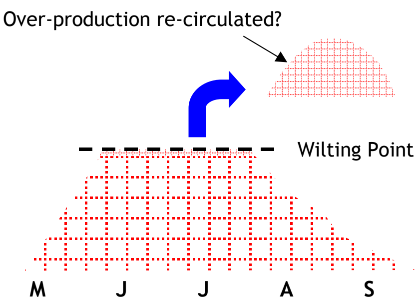
On the following page are plots of the *e*ABA envelopes for the Oak and Willow at Aldenham. Both share the same climatic conditions (blue line) but more movement was recorded at the site of the Willow suggesting a small increase in tensile forces within the xylem when compared with the Oak, but not up to (or exceeding) the value of the wilting point.



Graph 4

Below we see how a limiting value might apply to eABA production in cases where the soil suctions are at the plant wilting point. Over-production in such cases is likely to be re-circulated to the roots via the phloem.

Graph 5

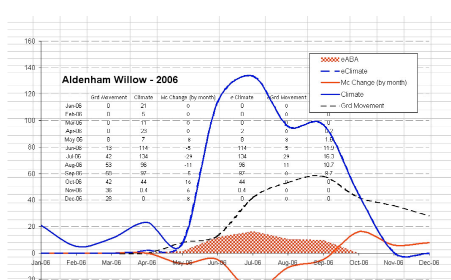


Along the top of the page are a series of envelopes for different years, including 2006. By entering SMD data and ground movement profiles from the earlier work at Chattenden and Aldenham we can understand the mechanism behind root induced clay shrinkage, and model likely outcomes.

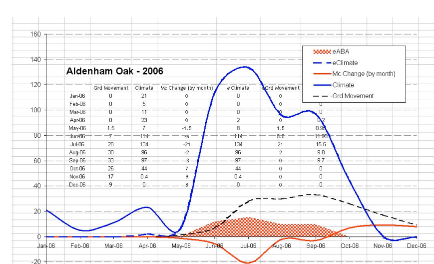
Our work suggests that ABA is triggered early in dry years, and its production increases as some function of the difference between climate and moisture uptake as estimated by ground movement.

What is the purpose? An understanding of the mechanism and interaction between the various elements is essential if we are to develop an effective intervention technique.

Understanding why May is important – the relationship between the SMD and trees coming into leaf – water uptake in July and how eABA peaks in the summer may assist us in arriving at a solution.



Graph 6



Graph 7

Summary

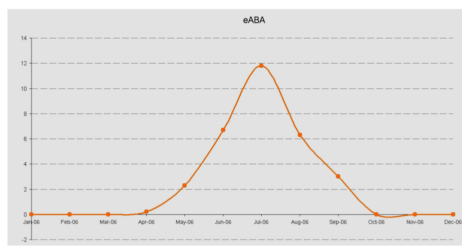
Research by Prof. William Davies informs us that *"the response of the stomata isn't determined by the amount of ABA produced by the root alone, but is influenced by the pH of the apoplast locally in the leaf and within the xylem on its route. A long-distance signal from the root and a locally generated signal within the leaf may both operate within the leaf at the same time. The pH of the apoplast may determine just how significant the amount of ABA arriving from the root will be".*

He goes on to suggest a strategy that would *"increase the efficiency of water use (i.e. reduce transpiration) by allowing maximum photosynthesis under mild environmental conditions and reducing transpiration in stressful conditions."*

His thoughts were directed towards crop production and the conservation of water associated with climate change but this is a strategy that is equally relevant to the subsidence industry.

Graph 8

The proposed *e*ABA production envelope at very low drought stress.



Taking prompt and direct action with trees might, in time, change our thinking on how we resolve root induced clay shrinkage claims.

The suggestion put forward by plant physiologists is that water uptake by vegetation can be reduced – safely in certain circumstances. It would appear from our own study of 'water uptake by month' and ensuing flexure over time, that small reductions could be beneficial.

PRD offers the potential to consider selective irrigation. Promoting effective ABA production and enhancing and prolonging its influence by raising the xylem pH would, on the face of it, appear to be achievable. Exogenous ABA analogues have a longer life than those produced naturally. Endogenous production probably assures/increases species effectiveness.

All remain to be proven as an effective intervention technique on trees.

END