PLANT WATERLOGGING:

CAUSES, RESPONSES, ADAPTATIONS AND CROP MODELS

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ABSTRACT

Waterlogging has been reported to reduce crop yields by up to 80 %, although the lack of a consistent definition of waterlogging or specific effects on plants makes it hard to accurately ascribe crop yield losses to waterlogging relative to other abiotic stresses. After reviewing the available literature I suggest that recording soil profile information, topographic data, meteorological information, plant morphological appearance and areas with visible surface water are the most important factors for describing waterlogging in the field.

An above ground plant response to waterlogging that is easily identifiable in some species is leaf wilting. Reduced root hydraulic conductance was investigated as the possible cause of leaf wilting by waterlogging *Glycine max* L. and *Nicotiana glutinosa* L. under greenhouse conditions. During these experiments a defined sequence of plant responses and adaptations to waterlogging was established. Waterlogged soybean showed very little change in plant physiology or morphology implying a low sensitivity to reduced root zone soil oxygen concentration [O_2]. At the other end of the waterlogging sensitivity scale before [O_2] reached 10 % there was a 50 % reduction in root dry weight of *N. glutinosa* on day 2 of waterlogging. On day 3 of waterlogging there was decreased stomatal conductance and leaf water potential, both measures indicating water deficit stress. However, apparent root hydraulic conductance measured with a hydraulic conductance flow meter (HCFM) increased, as did petiole and leaf hydraulic conductance. There was no evidence of aerenchyma formation in roots although there was extensive breakdown of endodermal cells in the waterlogged roots. It is suggested that root water uptake was severely impaired by this loss of cellular integrity. An implication from this is that water uptake is primarily in response to osmotic gradients and active water transfer across root cell membranes rather than a response to the hydrostatic potential gradient from the free water surrounding the roots into the root xylem. The breakdown of root anatomical integrity seems likely to be associated with the apparent increase in measured root

hydraulic conductance. Care should be taken in applying the HCFM measurement technique to root systems that are anatomically damaged.

Evidence from the literature and observations from the current experiments highlight the multiple and varied responses of different species to waterlogging. This apparent variation makes the development of general plant waterlogging response models very challenging. To address this, a framework was developed that identifies three stages of response by plants to the onset of waterlogging; an initial increase in plant growth and function, followed by decreased growth and function as [O_2] decreases, and finally, a species specific adaptation phase that places the species in a range from highly sensitive to highly tolerant.

Using this response framework, the generic crop growth and yield simulation model SWAGMAN Destiny was modified to improve the representation of waterlogging response in common crop species with a particular focus on wheat. An empirical representation of decreased gas filled pore space by soil layer, the depth of the layer, the root length and the duration of saturated conditions were used to derive a waterlogging stress factor. This stress factor was then used to change the distribution of roots in the soil profile and aggregated to provide a plant stress factor that modified carbohydrate production from the plant leaf area. In essence, the waterlogging stress factor is used as a collective representation of the above empirical processes, and changing root hydraulic conductivity that we observed in response to low [O_2]. The simulated output yields were consistent with experimental results and published field trial results.

In compiling information on specific species sensitivity to waterlogging in field conditions it became obvious that rigorous comparison was extremely difficult since there is a lack of consistency around the duration and timing of waterlogging, the soil profile, topography and climate. This reality means that simulation modelling that represents the physiological processes of waterlogging and the response processes of plants has an important role in assisting understanding of a waterlogged soil plant system. I recommend any crop model that explicitly includes waterlogging as an abiotic stress should demonstrate the three stage response as supported by outputs from SWAGMAN Destiny.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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LIST OF PUBLICATIONS

Shaw RE, Meyer WS, Mcneill A, Tyerman SD (**2013)** Waterlogging in Australian agricultural landscapes: a review of plant responses and crop models. *Crop & Pasture Science*, **64**: 549-562.

Shaw RE, Meyer WS Empirically representing plant responses to waterlogging for simulating crop yield. *Agronomy Journal.* Submitted, manuscript ID AJ-14-0625-A.