# A quantitative approach to developing more mechanistic gas exchange models for field grown potato: A new insight into chemical and hydraulic signalling

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## ABSTRACT

In this study we introduce new gas exchange models that are developed under natural conditions of field grown potato. The new models could explain about 85% of the stomatal conductance variations, which was much higher than the well-known gas exchange models such as the Ball-Berry model [Ball, Woodrow, Berry, 1987. In: Nijhoff, M. (Eds.), Progress in Photosynthesis Research, vol. 4. Dordrecht, The Netherlands, pp. 5.221–5.224]. To overcome the limitations of previous models in simulating stomatal conductance when plants are exposed to drought stress, we proposed a down-regulating factor of chemical and hydraulic signalling on stomatal conductance as $\exp(-\beta[\text{ABA}])\exp(-\delta|\psi|)$ in which [ABA] and $|\psi|$ are xylem ABA concentration and absolute value of leaf or stem water potential. In this study we found that stem water potential could be a very reliable indicator of how plant water status affects the stomatal conductance regulation. While previous models considered the same weighting for relative humidity and photosynthesis rate, we found that relative humidity has a more pronounced regulating effect on stomatal conductance than photosynthesis rate and the weightings for relative humidity and photosynthesis rate, respectively, were significantly higher and lower than unity.

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## 1. Introduction

Crop water use or transpiration (water diffusion to the air through the stomata) is mainly controlled by stomatal conductance. In terms of the efficient use of water in agriculture, stomatal response to the water status of the soil and plant system has been a critical area in crop physiology; and considerable attention has been paid to learning more about its functionality before being implemented into mechanistic models to simulate drought cycles (Sperry et al., 2003; Tuzet et al., 2003).

In leaf gas exchange processes, stomatal conductance ($g_s$) and photosynthesis rate ($A_n$) are interrelated. They affect the simulation of crop yield and water balance. Any improvement in modelling the relationship between $g_s$ and $A_n$ may lead to more reliable simulations of stomatal conductance. First attempts to simulate the dependency of stomatal conductance on environmental and physiological factors are included in semi-empirical models such as the response–function approach of Jarvis (1976), which relates $g_s$ to leaf temperature, irradiance, and leaf and soil water potentials. More recently, Ball et al. (1987) and Leuning

(1995) developed empirical models that received wide attention, analysis, acceptance and applications compared to the other models (Seibt et al., 2008; Vitale et al., 2007; Gutschick and Simonneau, 2002; Gao et al., 2002; Dewar, 2002; Aphalo and Jarvis, 1993). However, these models basically respond to the local environment of the leaf, which is defined by temperature, humidity, $CO_2$ concentration and boundary layer conditions. Models exist that integrate distal (root-sourced chemical signals of drought stress or signals of hydraulic conductivity) responses of stomata (Tardieu, 1993; Tardieu and Davies, 1993; Tardieu et al., 1993; Gutschick and Simonneau, 2002). However, neither type of model could simulate $g_s$ satisfactorily in a wide range of environmental conditions (Auge et al., 2000; Aphalo and Jarvis, 1993; Tardieu et al., 1993, 1996).

The most commonly used models are those by Ball et al. (1987) and Tardieu (1993) that apply local and distal environmental responses to simulate $g_s$ (Vitale et al., 2007; Dewar, 2002; Auge et al., 2000). However, Tenhunen et al. (1990, 1994) suggested that Ball et al. (1987) model should be revised by a correction factor to account for drought stress so that it could include seasonal changes in leaf physiological efficiency when simulating plant performance under drought stress. Tenhunen et al. (1994) suggested that this modification has to consider the xylem [ABA], which has a down-regulating effect on $g_s$. Gutschick and Simonneau (2002) incorporated this correction factor as an exponential decaying function

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