Architectural Analysis and Modeling of Maize Growth and Development under Water Stress

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Keywords: maize (*Zea mays*), plant architecture, water stress, modeling, extension

Introduction

Crop structural development influences canopy production, assimilate partitioning and final yield. Substantial progress of improving architectural modeling has been achieved in maize 3D development (Fournier and Andrieu, 1998), in developing an architectural model of maize (Fournier and Andrieu, 1999), and in quantifying internode and leaf kinetics (Fournier and Andrieu 2000, Birch et al, 2002, Birch et al, 2007a). The enhancement of architectural modeling facilitates the introduction of functionality at the level of individual organs and whole plants (Hanan and Hearn, 2003; Yan et al, 2004; Guo et al, 2006; Birch et al, 2007b). Maize cultivation is often subjected to water stress in the areas of water limitation. Water stress during vegetative stage limits cell division and expansion (Granier and Tardieu, 1999; Reymond et al, 2003), and thus reduces stem elongation and leaf area growth. The objectives of this research are (i) to examine plant architectural development at organ level under water stress, (ii) to revise an individual-based maize model (ADEL-Maize) based on data from Gatton, Southeastern Australia, and (iii) to implement the simulation of plant architectural development under water stress.

Materials and methods

Datasets from field trials carried out at Gatton, Australia in 2003-04 (Exp1) and 2006-07 (Exp2) are used in this study. Three water regimes were implemented in each trial: (i) RF, fully rainfed treatment, which completely depended on natural rainfall; (ii) IRF, irrigated followed by rainfed treatment, which was irrigated until anthesis, then irrigation was withheld; and (iii) FI, fully irrigated and used as the control. A pre-planting irrigation to supplement rainfall was used to ensure that the soil is fully wet to 1.8 m prior to sowing (the expected limit of root exploration). Maize (Pioneer 31H50) was planted at a density of 70,000 (in Exp1) and 60,000 (in Exp2) plants ha^{-1}. The seeds were chemically treated to prevent damage from insects and soil borne diseases. Sufficient fertilizer was applied to prevent nutrient stress. Ten plants in each treatment were selected at the four fully expanded leaf stage and tagged to monitor plant growth and development by non-destructive sampling. The leaves at position 5 and 10 on these plants were respectively tagged to avoid errors in leaf identification after senescence of lower leaves commenced. Crop growth and development was measured using destructive sampling at 2 or 3 day intervals by counting fully expanded and expanding leaf number on the 10 tagged plants in each treatment to obtain guidance to select representative plants (ie similar to the tagged plants) for destructive sampling. Data on ontogeny, length of lamina, sheath and internode, width of lamina was collected at each sampling. Daily environmental data was recorded by weather station near the field, and data on soil water content in RF and IRF was collected using Neutron Probe in Exp1 and T-Bug (SM2000,UK) in Exp2.

Data analysis

Rainfall during canopy growth in two experiments was shown in Fig.1. There was a 35d period without rain in Exp2, which happened during canopy rapid development, whereas the rainfall in Exp1 is relatively even. In Exp1, phenology was not significantly affected in RF treatment; leaf extension was unaffected until late in canopy expansion (ie only the top few leaf sheaths were affected); whereas internodes above position 12 which extended after water stress occurred were affected (Fig.2a). In

Exp2, a slight delay of 1-2d from emergence to tasseling, anthesis was observed only in RF treatment. The extension and final length of leaves and internodes was reduced by water stress (Fig.2bc). The reduction degree in both experiments varied with intensity and timing of water stress, lengths in RF treatment was consistently shorter than in the irrigated (control) treatment, and the values in IRF treatment basically fell between RF and FI treatment(last few internodes in Fig.2c was not calculated as lack of enough data). As four days significant rainfall happened to later canopy development in Exp2, the length of last few leaves was not significantly affected in IRF treatment; the reduction degree in RF treatment was also a bit decreased as water stress was relieved (Fig.2bc). By contrast, the high rainfall in Exp1 happened to organ almost fully expanded, thus water stress relief did not make much sense to internodes extension (Fig.2a). Leaf and internode extension under water regimes is being analyzed based on four-phase model (Fournier et al, 2000a; Birch et al, 2002), the analysis aims to find new algorithms for the mechanism of canopy expansion, which will then be used to model canopy production, final leaf area and plant height, but the detail is not shown here due to the limitation of abstract.

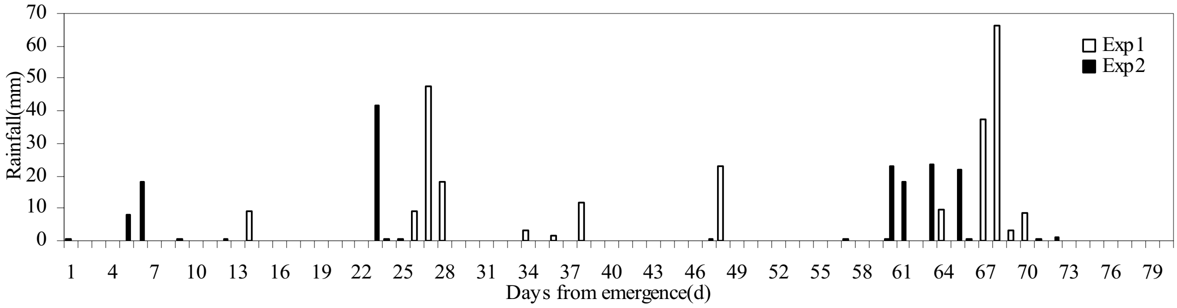

Fig.1. Rainfall during canopy development for two experiments

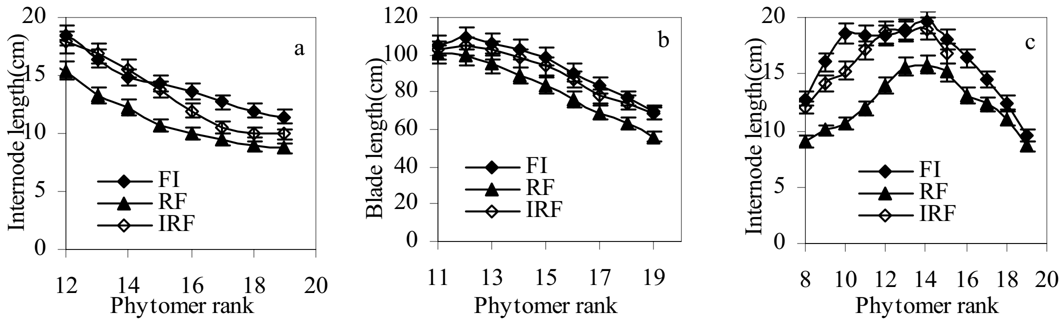

Fig.2. Final length of individual leaves, and internodes in 2003-04(a) and 2006-07(b and c) under three water regimes (vertical bars represent 95% confidence intervals).

Modeling analysis

The individual-based ADEL-Maize model was revised (Birch et al 2007b) to simulate maize crop growth under water stress. The revision required reexamining the model routines including phenology, organ development, leaf area growth and leaf senescence, which is sensitive to genotype or site-specific or water status. The revision was performed based on a subset of data of Exp1. Final plant height and leaf area in the Exp1 was fitted quite accurately with the revised model. However, the intermediate simulated values are lower than observed data (Birch et al, 2007b). The new dataset of Exp2 will be used to quantify the relationship of organ extension and soil water stress, and be incorporated in further incremental revision of the model to improve the simulation. This visualization of the crop canopy in Exp1 at completion of leaf expansion is realistic (Fig.3), it is now necessary to improve the estimation of earlier stages in the production of the canopy using the more intensive data from the experiment of Exp2. This will be achieved by better prediction of leaf area and plant height during canopy prediction.

Also, to further enhance the analysis and modeling, soil moisture extraction at different depths in two trials will be simulated by providing rainfall, irrigation and soil type using APSIM configured for maize (Keating et al, 2003). The analysis will supplement data on soil moisture collected in the trial of Exp1 and Exp2. This additional work aims to expand the range of analysis and thus applicability of data from the experiments reported here using extensively tested and validated approaches to prediction of soil water status in maize crops (APSRU, 2003, Madhiyazhagan, 2005). These approaches will facilitate improving modeling the responses by the canopy to environmental influences.

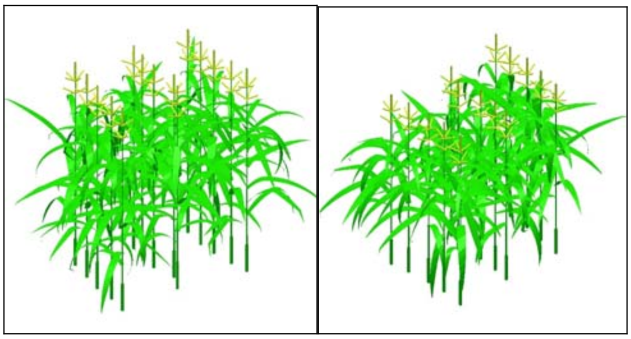

Fig. 3. Visualisation showing prediction of canopies for (a) left, fully irrigated and (b) right, rainfed maize crop grown at Gatton (Birch et al 2007b).

Acknowledgements

The financial support of the University of Queensland for the research and postdoctoral fellowship for the senior author is acknowledged.

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