Allometric relationships of canopy organ development in rice and maize

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Abstract

Functional-structural plant modelling requires the linkage of plant physiological function and its structure at organ level for improved ability in agronomic application. Allometric relationships among organ development represent endogenous coordination that can be used to bridge plant morphology and function. However, there are insufficient allometric relationships available. This study aimed to investigate allometric relationships between organ morphology and biomass (physiological phenotypes) using data from a glasshouse experiment of rice (Nippon Bare and a mutant with low tillering) and a field experiment of maize (Pioneer 34N43 and 31H50). Allometric relationships were determined with the highest coefficients of determination (R^2). Leaf area and fresh biomass relationship was fitted by a linear function for rice, and linear function for phytomers at the ear and below, but replaced by a curvilinear function for phytomers above the ear, in maize. Leaf lamina length and biomass was fitted by exponential functions for both rice and maize. Sheath length and biomass relationship was fitted by a logarithmic function for rice (maximum 9 sheaths) and for phytomers below 9 in maize and an exponential function for phytomers above 8 in maize. Internode length and biomass was fitted by two exponential functions separated at ear position in maize only, since no data exists on internodes in rice. This study indicated that organ morphology can be predicted from crop physiological process, which facilitates the establishment of feedback of structure and functions of plant modeling.

Key Words

Oryza sativa, *Zea mays*, plant -structural model, organ production

Introduction

Functional-structural plant modelling (FSPM) requires the linkage of plant physiological functions and plant structure at organ level for improved ability in agricultural application (de Reffye et al. 2009; Vos et al. 2010). Organ development is a key part of whole plant physiology and thus receives great attention (e.g. Room et al. 1994; Birch et al. 2007). Allometric relationships reflect endogenous coordination that may be genetically controlled (Reddy et al. 1998). Organ biomass is the accumulated photoassimilate allocated from the source i.e. leaves, representing outputs from a chain

of physiological processes. Organ dimension is the morphological aspect which is important in constructing the canopy during crop development. Allometric relationships between organ biomass and morphology will be very useful to link plant structure (morphology and architecture) and function (physiological activities).

However, there are insufficient allometric relationships at organ level available, which hinders the adequate development of crop growth modelling and FSPM. Within this context, our study aimed to develop allometric relationships between shoot organ dimensions and its biomass that can be used to establish robust linkages between plant functional activities and plant architecture.

Methods

The datasets were used from Luquet et al. (2007) and Song et al. (2010). Hence the experimental details of both are only reported in brief here. The rice experiment was conducted at CIRAD (Montpellier, France) between February and March, 2005 in a growth chamber on Nippon Bare (wild type, WT) and the *Phyllo* mutant. Plants were grown until 50 days after germination in a hydroponic system. Environmental conditions were 12 h (day)/12 h (night) photoperiod, relative air humidity between 55 and 75% during day and night, air temperature 28°C (day) and 23°C (night).

Maize was grown in a field experiment using two cultivars, Pioneer 34N43 and 31H50 under both fully irrigated and rainfed conditions at Gatton in southeast Queensland, Australia in 2006-07. In this paper, we focused on maize growth under fully irrigated conditions for both cultivars. The methods of measuring plant data were similar with rice sampling. The plant was first dissected into individual phytomers (a phytomer typically comprise a node where a leaf is attached, a subtending internode, and an axillary bud, used to indicate plant structural unit in whole plant physiology) numbered acropetally. The dimensions and fresh weight of individual organs were measured.

Results

Lamina area and biomass

The relationship between lamina area and lamina biomass is presented as Figure 1. Lamina area was linearly related to lamina biomass for both Nippon Bare (wild type) and its mutant (Figure 1a). The ratio was 94.303 for wild type and 115.97 for mutant. The relationship for 34N43 and 31H50 was linear for phytomers below ear similar to rice, but changed to a curvilinear form for phytomers above ear (see Figure 1bc).
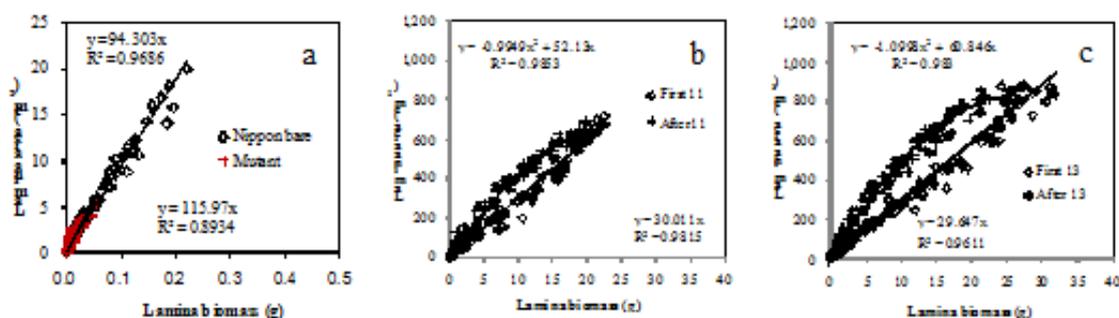

Figure 1. Relationships between lamina area and lamina biomass in rice (wide type and mutant) (a) and maize (b, 34N43 and c, 31H50).

Lamina length and biomass

The relationship between lamina length and biomass is presented as Figure 2. Lamina length increased as lamina biomass was accumulated. The relationship of lamina length and biomass was fitted by exponential functions for both rice and maize though the parameters varied in species and cultivars. \
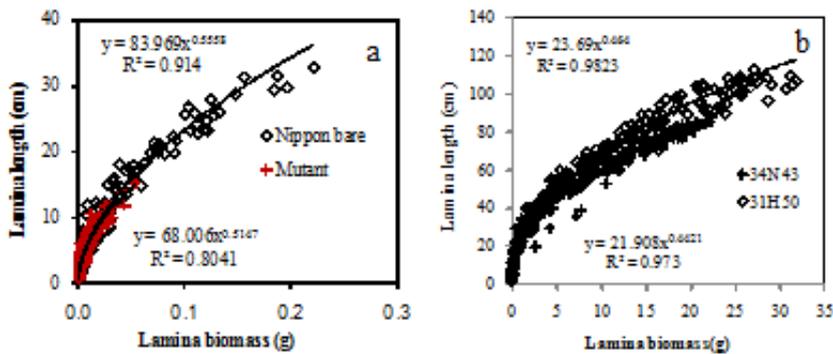

Figure 2. Relationships between lamina length and biomass in rice (Nippon Bare and mutant) (a) and maize (34N43 and 31H50) (b).

Sheath length and biomass

Sheath length and biomass was fitted by a power function for main stem and tillers up to a maximum sheath number of 8 (rice), a power function for phytomers below the eighth sheath which was longest and a logarithmic function for phytomers above the eighth sheath (maize). The results suggest that sheath length can be predicted from sheath biomass accumulation.
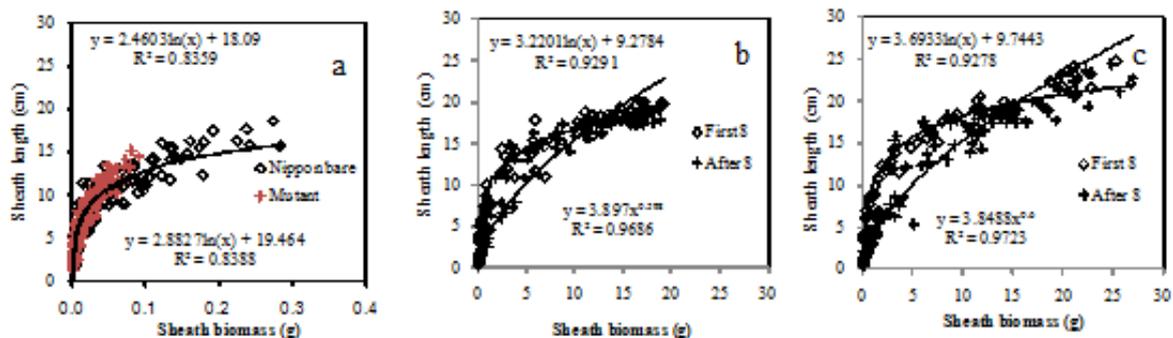

Figure 3. Relationships between sheath length and biomass in rice (Nippon Bare and mutant) (a) and maize (b, 34N43 and c, 31H50).

Internode length and biomass

The relationship between internode length and biomass is presented in Figure 4. The relationship was fitted by two power functions separated at the ear (maize). Rice internode was not considered due to the glasshouse trial designed for early canopy establishment only.
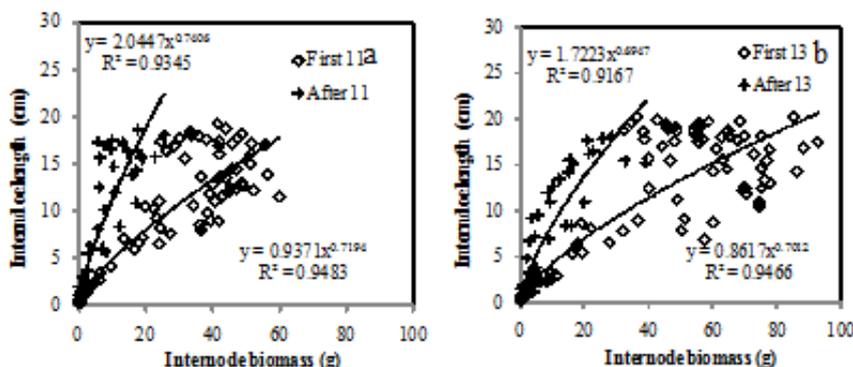
Figure 4. Relationships between internode length and biomass in 34N43 (a) and 31H50 (b).

Discussion

Allometric relationships between organ size and fresh weight were developed for two typical grass species i.e. rice with has a terminal floral structure, with both male and female structures), and maize which has separate male (terminal tassel) and female (lateral ear) structures on the same plant. Allometry relationships are continuous across phytomers in rice and quantified with mathematical functions. However, the relationships regarding leaf area and weight, and internode length and weight were changed at the phytomer where the ear was located in maize, which is consistent with findings in leaf appearance rate and organ extension (Song et al. 2010). This suggested that ear development as the largest sink changed the allometry during late vegetative development, presumably due to competition among sinks for photosynthate. Allometric relationships of sheath length and biomass were changed at the 8th sheath where its length peaked, with two different types of functions.

However, as forms of the relationships and associated coefficients differ among species and cultivars, further research is needed to elicit groups that have similar relationships. The findings of allometric relationships also need to be tested against different environments such as water stress for wider modeling application. Also, rapid growth of the panicle of rice (and other species of similar morphology) may cause discontinuities in allometric relationships for internodes that are extending concurrent with panicle growth, giving rise to competition for photosynthate. The findings in this study suggested that feedback required by FSPM can be introduced through allometric relationships, and the challenge now is to develop sufficient relationships for them to be of operational use, probably by finding general applicable relationships across types of crops. It is noted that this study is only focused on allometry in canopy development and research on root system is necessary in the future.

Conclusion

Allometric relationships between canopy organ morphology and fresh biomass were developed for rice and maize. These relationships of organ development were also described with simple mathematical models. The form of the relationships and associated coefficients differ between species and cultivars. In summary, the finding in this study can be directly used for prediction of organ morphology based on its fresh biomass, which facilitates to communicate the information between plant structural development and physiological activities in modelling studies.

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