Advances in improving tolerance to waterlogging in *Brachiaria* grasses

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Abstract. Poor drainage is found on about 11.3% of agricultural land in Latin America where physiography promotes flooding, high groundwater tables, or stagnant surface water (waterlogging). Waterlogging drastically reduces oxygen diffusion into the soil causing hypoxia which is the main limitation that reduces root aerobic respiration and the absorption of minerals and water. Under waterlogging conditions plants can adapt with traits and mechanisms that improve root aeration such as production of aerenchyma and development of adventitious roots. During the rainy season *Brachiaria* pastures are exposed to waterlogging conditions that can severely limit pasture productivity and hence animal production. The main objective of an inter-institutional and multidisciplinary project was to identify *Brachiaria* hybrids combining waterlogging tolerance with high forage yield and quality to improve meat and milk production and mitigate the impacts of climate change in the humid areas of Latin America. Researchers at the Centro Internacional de Agricultura Tropical (CIAT) have developed a screening method to evaluate waterlogging tolerance in *Brachiaria*. Using this method, 71 promising hybrids derived from three *Brachiaria* species (*B. ruziziensis*, *B. brizantha*, and *B. decumbens*) were evaluated. Four hybrids were identified as superior in waterlogging tolerance. Their superiority was based on greater green leaf biomass production, a greater proportion of green leaf to total leaf biomass, greater green leaf area, leaf chlorophyll content, and photosynthetic efficiency, and reduced dead leaf biomass. These hybrids together with previously selected hybrids and germplasm accessions are being field-tested for waterlogging tolerance in collaboration with National Agricultural Research Institutions and farmers from Colombia, Nicaragua, and Panama.

Keywords: Brachiaria grasses, waterlogging, tolerance, screening, participatory evaluation.

Introduction

The frequency of extreme weather events, including heavy precipitation, will likely increase in the future due to climate change (Allan and Soden 2008; O'Gorman and Schneider 2009). Poorly drained soils are found in about 11.3% of agricultural land in Latin America where physiography promotes flooding, high groundwater tables, or waterlogging (Wood *et al.* 2000). Waterlogging drastically reduces oxygen diffusion into the soil causing hypoxia which is the main limitation reducing root aerobic respiration and the absorption of minerals and water (Rao *et al.* 2011).

Plants adapt to waterlogging conditions with traits and mechanisms that improve root aeration such as production of aerenchyma and development of adventitious roots (Jackson and Colmer 2005). Perennial *Brachiaria* grasses (*Brachiaria* spp. Griseb) are the most widely sown forage grasses in tropical America (Miles *et al.* 2004; Valle and Pagliarini 2009). During the rainy season, in a large number of locations in the tropics, *Brachiaria* pastures are occasionally exposed to waterlogging conditions that severely limit pasture productivity and therefore livestock production (Rao *et al.* 2011). In many humid zones, livestock producers use *B. humidicola* (cv. Tully) because of its high tolerance to waterlogging. However, a major limitation of this cultivar is its low forage quality, which limits animal performance.

CIAT has an on-going *Brachiaria* breeding program. Two selections from this program have been commercialized (cvv. Mulato and Mulato II). They have a number of positive attributes, but are not tolerant to waterlogging. The most economic way to reduce the negative impact of waterlogging may be to select or breed tolerant cultivars (Zhou 2010). Improving waterlogging tolerance in *Brachiaria* grasses has potential for success since inter- and intra-specific variation has been documented (Rao *et al.* 2011). Therefore, the main objective of an inter-institutional and multidisciplinary project was to identify hybrids of *Brachiaria* that combine waterlogging tolerance with high forage quality for improving meat and milk

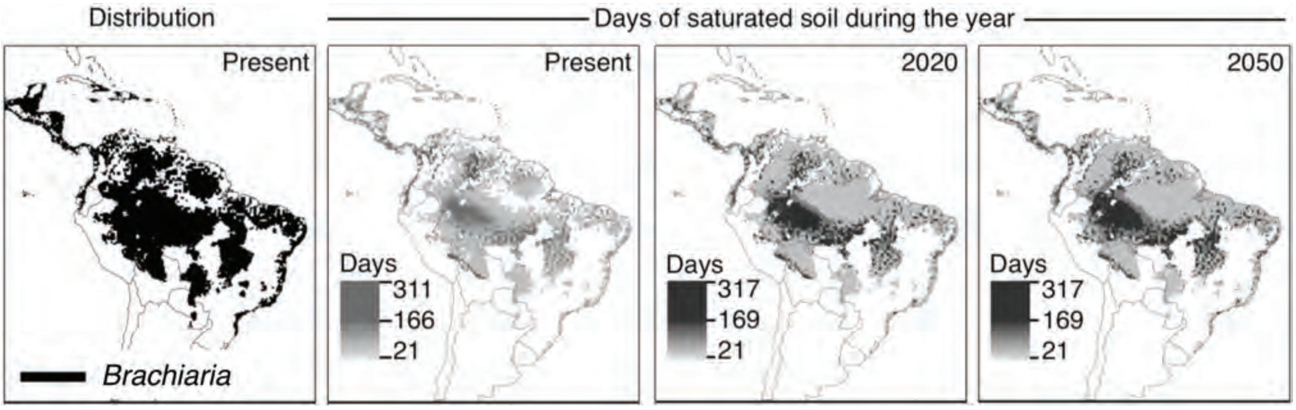

Figure 1. Estimated present areas (6,300,000 km^2) suitable for growing *Brachiaria* grasses in tropical Latin America and number of days of water saturated soils during the year, and the expected changes for the years 2020 and 2050.

production and mitigate the impacts of climate change in the humid areas of Latin America.

Progress

The project aims to deliver four major outputs; progress towards those research outputs is described below.

Estimation of areas in Latin America with poorly drained soils to target improved Brachiaria grasses

Areas in tropical Latin America suitable for *Brachiaria* grasses based on soil conditions and precipitation are shown in Figure 1. Based on global climate models (GCM), areas in Latin America are expected to experience more days of waterlogged soils in the future (Fig. 1). This includes grasslands such as the Colombian and Venezuelan Llanos, the Guianna savannah and the Brazilian Cerrados.

Traits associated with waterlogging tolerance in Brachiaria grasses

Definition of morpho-physiological and biochemical traits associated with waterlogging tolerance will contribute to developing reliable screening procedures. Moreover, efficient screening procedures are required to recover the desirable traits through accumulation of favorable alleles over repeated cycles of selection and recombination (Rao *et al.* 2001; Wenzl *et al.* 2006). Work has been carried out at CIAT to assess the responses of *Brachiaria* genotypes with different levels of tolerance to waterlogging (tolerant *B. humdicola* cvv. Tully and Llanero; moderately tolerant *B. decumbens* cv. Basilisk, *B. brizantha* cv. Toledo; sensitive *B. brizantha* cv. Marandu, *Brachiaria* hybrid cv. Mulato II, *B. ruziziensis* Br 44-02). Short-term (< 3 days) adaptation to hypoxic/waterlogged soil conditions involves a switch from aerobic respiration to fermentative catabolism in roots. However, longer term adaptation is achieved by the development of aerenchyma in roots that allows oxygen transfer to improve aerobic respiration. Differences in tolerance to waterlogging among *Brachiaria* grasses are likely a consequence of differences in morphology and anatomy of roots, including aerenchyma formation, root diameter, relative volume of stele (vascular tissue) (Fig. 2) and lateral root formation, all of these acting synergistically to improve root aeration and sustain root elongation. Presence of constitutive aerenchyma in roots is of

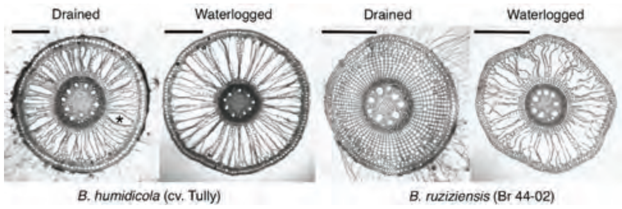

Figure 2. Root cross sections of 2 contrasting *Brachiaria* grasses (tolerant *B. humdicola* and sensitive *B. ruziziensis*) grown under drained or waterlogged soil conditions for 21 days. Sections taken at 10 cm from the root tip. * represents aerenchyma. Scale bar = 0.5 mm.

immediate advantage to plants when initially exposed to oxygen shortage (Colmer and Voesenek 2009). This may explain the superior tolerance of *B. humidicola* cv. Tully to temporary waterlogging. Maximum rooting depth has been found to be positively associated with aerenchyma development at 1 cm from the root tip in commercial Brachiaria grasses (r = 0.4; P<0.05). As determination of aerenchyma in roots is a time-consuming process, maximum rooting depth could be a more efficient indicator of internal aeration efficiency.

Screening for waterlogging tolerance

Researchers at CIAT have developed a screening method based on morphological and physiological traits to evaluate waterlogging tolerance in *Brachiaria* grasses. Screening is carried out using soil (from target environments) in a double pot system with a plastic bag to prevent water leakage while maintaining a water lamina of 3 cm over the soil for 21 days. Using this method, a large number of germplasm accessions and hybrids have been evaluated. (Table1). Some of these hybrids have shown higher level of tolerance to waterlogged soil than comercial cultivars based on higher values of leaf chlorophyll (SPAD chlorophyll meter reading units: SCMR) and the proportion of green leaf biomass to total leaf biomass (Fig. 2).

A set of 71 *Brachiaria* hybrids (*Brachiaria ruziziensis* x *B. brizantha* x *B. decumbens*) was evaluated at CIAT for tolerance to waterlogging using the same screening method method; four hybrids were superior to the others in their tolerance to waterlogging (Rincón *et al.* 2008). The superior performance of these hybrids was based on

Table 1. *Brachiaria grasses* evaluated for waterlogging tolerance from 2010 under controlled conditions at CIAT.

B. humidicola		Interspecific Brachiaria hybrids (*Brachiaria ruziziensis* x *B. brizantha* x *B. decumbens*)	
High fertility	Low fertility	High fertility	Low fertility
66 accessions 492 hybrids	66 accessions	902 hybrids	109 hybrids

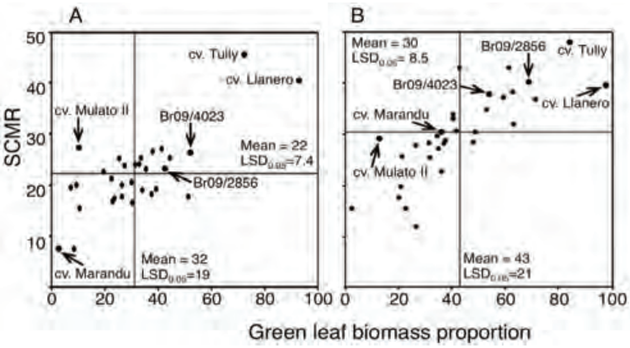

Figure 3. Genotypic variation for waterlogging tolerance in 26 *Brachiaria* hybrids and four commercial cultivars (*B. humidicola* cvv. Tully, Llanero; *B. brizantha* cv. Marandu and *Brachiaria* hybrid cv. Mulato II) grown in pots for 21 days in a fertilized top soil (Oxisol) from A (Santander de Quilichao, Department of Cauca, Colombia) and B (Matazul, Department of Meta, Colombia). SCMR: SPAD chlorophyll meter reading units; green leaf biomass proportion: proportion of green to total leaf biomass.

greater green leaf biomass production, a greater proportion of green leaf to total leaf biomass, greater green leaf area, leaf chlorophyll content, and photosynthetic efficiency, and on lower levels of dead leaf biomass. These four hybrids together with seven other *Brachiaria* hybrids and 19 germplasm accessions of *B. humidicola* are being evaluated under field conditions for tolerance to waterlogging with participation of National Agricultural Research Institutions and farmers from Colombia, Nicaragua, and Panama.

Field evaluation of Brachiaria grasses

Researchers from CIAT and Corpoica (Colombia) have developed a methodology to evaluate waterlogging tolerance in brachiaria grasses under field conditions (Fig. 3). This methodology is being used by researchers from INTA (Nicaragua) and IDIAP (Panama). Selected Brachiaria grasses (31 in total including 11 Brachiaria hybrids, 19 *B. humidicola* accessions, and cv. Toledo) are being evaluated under field conditions at three sites in Colombia, two in Nicaragua, and one in Panama. As expected, *B. humidicola* accessions have shown better tolerance to waterlogged soil conditions than the *Brachiaria ruziziensis* x *B. brizantha* x *B. decumbens* hybrids. Researchers from these National Agricultural Research Institutions have conducted interviews with livestock producers to make a quick assessment of their perceptions of problems associated with excess water in the rainy season and the desirable characteristics needed in new cultivars to confront climate variability and change.

Farmers associated waterlogging tolerance in grasses with a stoloniferous growth habit and indicated the need to improve pest and disease resistance in new grass cultivars

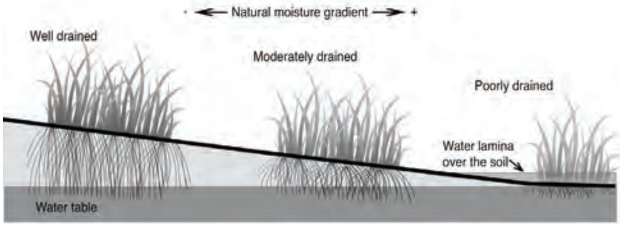

Figure 4. Methodology to evaluate Brachiaria grasses for tolerance to waterlogged soils under field conditions. Evaluations are carried out at monthly intervals and include determination of various parameters such as dry matter yields, forage cover, height, visual appraisal and presence of pests and diseases.

that are targeted to poorly drained soils in Latin America. Agronomic evaluation of promising Brachiaria genotypes with participation of farmers is in progress.

Conclusions

Significant progress has been made for estimating areas of Latin America with poorly drained soils and for using climate models to develop scenarios for estimating waterlogged areas associated with climate change in the years 2020 and 2050. Differences in tolerance to waterlogging among *Brachiaria* grasses were associated with root traits such as aerenchyma formation, root diameter and relative volume of stele. A screening method was used and 71 *Brachiaria* hybrids were evaluated; four hybrids were identified as superior to the others in their tolerance to waterlogging based on a greater proportion of green leaf to total leaf biomass and other leaf traits. These hybrids are being tested under field conditions for their tolerance to waterlogging in Colombia, Nicaragua and Panama.

Acknowledgements

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