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Advances in improving tolerance to waterlogging in *Brachiaria* grasses

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Abstract

An inter-institutional and multi-disciplinary project to identify *Brachiaria* genotypes, which combine waterlogging tolerance with high forage yield and quality, for use in agricultural land in Latin America with poor drainage, is underway. The aim is to improve meat and milk production and mitigate the impacts of climate change in the humid areas of Latin America. Researchers at the International Center for Tropical Agriculture (CIAT) have developed a screening method to evaluate waterlogging in grasses. Using this method, 71 promising hybrids derived from the species, *Brachiaria ruziziensis*, *B. brizantha* and *B. decumbens*, were evaluated. Four hybrids with superior waterlogging tolerance were identified. Their superiority was based on greater: green-leaf biomass production, proportion of green leaf to total leaf biomass, 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.

Resumen

Un proyecto inter-institucional y multidisciplinario para identificar genotipos de *Brachiaria* que combinen tolerancia a suelos encharcados con un alto rendimiento y calidad de forraje para uso en áreas agrícolas con mal drenaje está en curso. El objetivo es mejorar la producción de carne y leche y mitigar los impactos del cambio climático en las áreas húmedas de América Latina. Para el efecto, investigadores del Centro Internacional de Agricultura Tropical (CIAT) han desarrollado un método de invernadero para evaluar tolerancia a encharcamiento en gramíneas el cual se aplicó en 71 híbridos promisorios originados de las especies *Brachiaria ruziziensis, B. brizantha* y *B. decumbens*. Se identificaron 4 híbridos superiores por su tolerancia a encharcamiento, caracterizados por mayor producción de biomasa de hojas, proporción de hojas verdes con respecto al total de hojas, área foliar, contenido de clorofila, eficiencia fotosintética y menor biomasa de hojas muertas. Estos híbridos, junto a otros híbridos y accesiones de germoplasma previamente seleccionados, están siendo evaluados bajo condiciones de campo por su tolerancia a encharcamiento en colaboración con instituciones nacionales de investigación agrícola y productores de Colombia, Nicaragua y Panamá.

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

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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 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 temporarily 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 constrains 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 of 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 intraspecific variation has been documented (Rao et al. 2011). Therefore, the main objective of an inter-institutional and multi-disciplinary project was to identify genotypes of *Brachiaria* that combine waterlogging tolerance with high forage quality for improving meat and milk production and mitigate the impacts of climate change in humid areas of tropical Latin America.

Progress

The project aims to deliver 4 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-ECHAM), areas in Latin America are expected to experience more days of waterlogged soils by 2020, without any major further changes by 2050 (Figure 1). This includes grasslands such as the Colombian and Venezuelan Llanos, the Guyana savannas 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 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. humidicola* cvv. Tully and Llanero; moderately tolerant *B. decumbens* cv. Basilisk and *B. brizantha* cv. Toledo; sensitive *B. brizantha* cv. Marandu, *Brachiaria* hybrid cv. Mulato II and

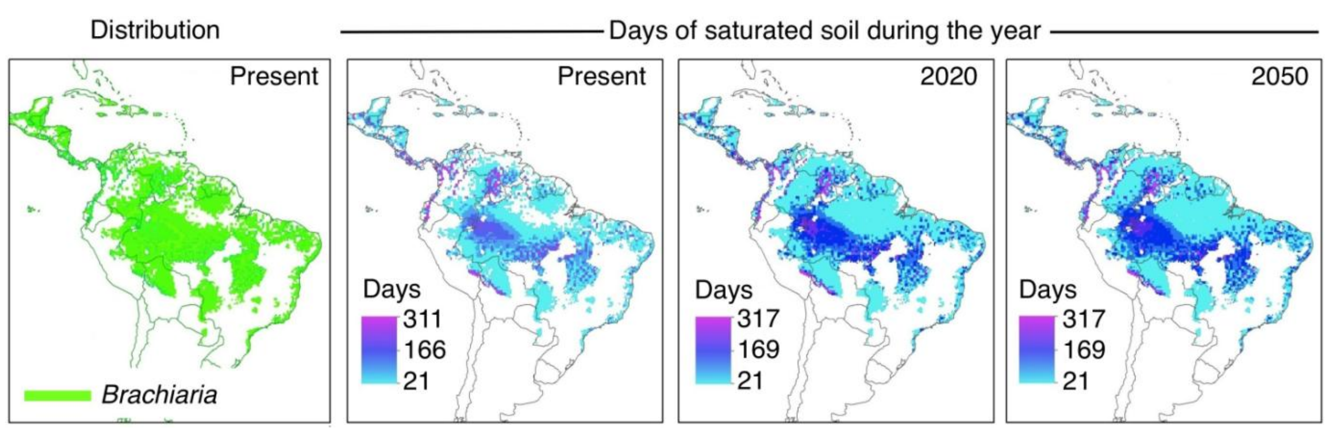

Figure 1. Estimated present areas (6 300 000 km^2) suitable for growing *Brachiaria* grasses in tropical Latin America and number of days of water-saturated soils during the year: at present and expected changes for the years 2020 and 2050.

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) (Figure 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 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 under 2 fertility levels: high (mg element per kg of soil: N 40, P 50, K 100, Ca 101, Mg 35, S 28, Zn 2, Cu 2, B 0.1, Mo 0.1) and low (P 20, K 20, Ca 47, Mg 14, S 10) (Rao et al. 1992) (Table1). Some of these hybrids have shown higher level of tolerance to waterlogged soil than commercial 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 (Figure 3).

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; 4 hybrids were superior to the others (Rincón et al. 2008). The superior performance of these hybrids was based on greater green-leaf biomass production, greater proportion of green-leaf to total leaf biomass, greater green-leaf area, leaf chlorophyll content and photosynthetic efficiency, and lower levels of dead-leaf biomass. These 4 hybrids together with 7 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 in Colombia, Nicaragua and Panama.

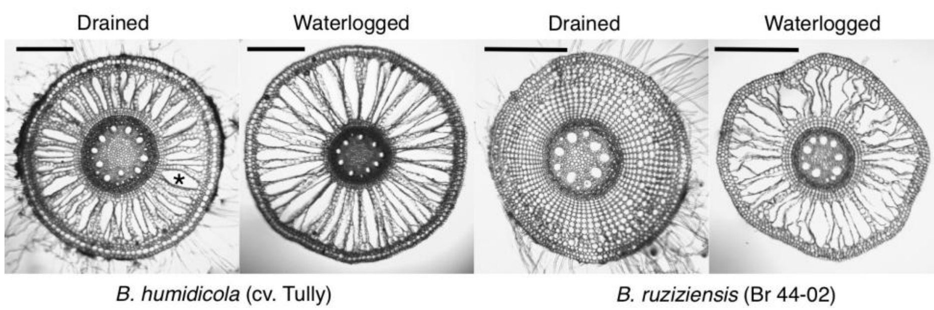

Figure 2. Root cross sections of 2 contrasting *Brachiaria* grasses (tolerant *B. humidicola* and sensitive *B. ruziziensis*) grown under drained or waterlogged soil conditions for 21 days. Sections taken at 10 cm from the root tip. * represents aerenchyma. Scale bar = 0.5 mm.

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

B. humidicola		Interspecific *Brachiaria* hybrids (*B. 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

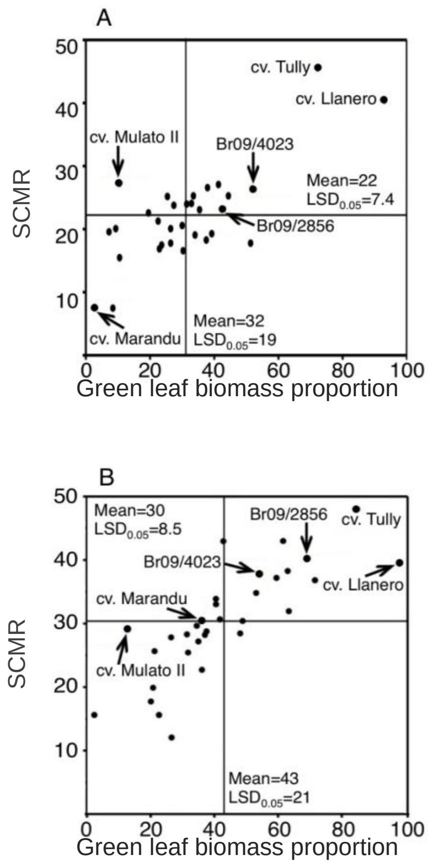

Figure 3. Genotypic variation for waterlogging tolerance in 26 *Brachiaria* hybrids and 4 commercial cultivars (*B. humidicola* cvv. Tully and Llanero; *B. brizantha* cv. Marandu; and *Brachiaria* hybrid cv. Mulato II) grown in pots for 21 days in a fertilized top soil (Oxisol) from A (Santander de Quilichao, 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.

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 (Figure 4). This methodology is being used by researchers from INTA (Nicaragua) and IDIAP (Panama). Selected *Brachiaria* grasses (11 *Brachiaria* hybrids, 19 *B. humidicola* accessions and *B. brizantha* cv. Toledo) are being evaluated under field conditions at 3 sites in Colombia, 2 in Nicaragua and 1 in Panama. As expected, *B. humidicola* accessions are showing better tolerance to waterlogged soil conditions than the hybrids.

Researchers in Colombia, Nicaragua and Panama have also conducted interviews with livestock producers to make a quick assessment of their perceptions of problems associated with excess water in the rainy season and 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 cultivars targeted to poorly drained soils. Agronomic evaluation of promising *Brachiaria* genotypes with participation of farmers is in progress.

Conclusions

Progress with estimating areas of Latin America with poorly drained soils and using climate models to estimate the possible increase in waterlogged areas has highlighted the significant impact on pasture and animal production that climate change could have by the years 2020 and 2050. The identification of some

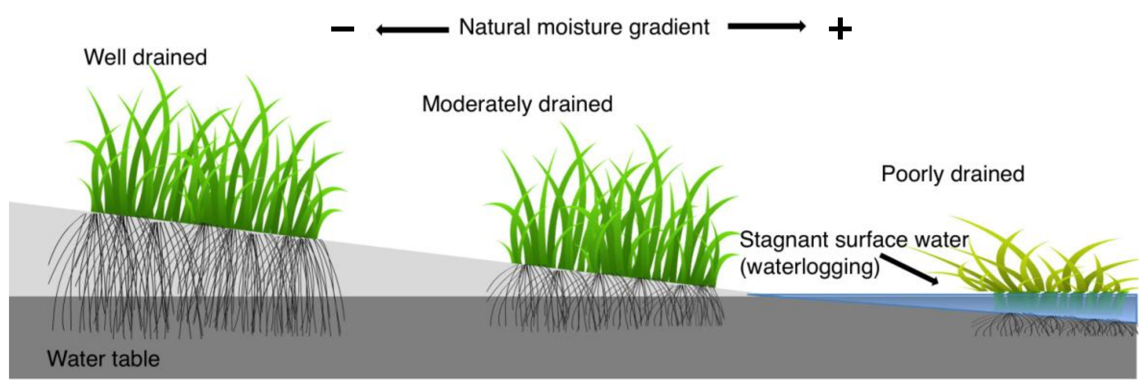

Figure 4. Methodology to evaluate *Brachiaria* grasses for tolerance to waterlogged soils under field conditions. Evaluations are carried out at monthly intervals and include determination of various parameters, such as dry matter yield, forage cover, height, visual appraisal and presence of pests and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

Brachiaria genotypes with improved tolerance to waterlogging suggests that there are ways to minimize this impact. The field-testing in Colombia, Nicaragua and Panama should indicate how well these genotypes might achieve this aim. Further screening is needed to identify more potential genetic material to combat the increase in waterlogging which will inevitably occur with climate change.

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