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Field Crops Research 95 (2006) 234–249

Field Crops Research

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Nutrient and assimilate partitioning in two tropical maize cultivars in relation to their tolerance to soil acidity

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Received 26 November 2004; received in revised form 10 March 2005; accepted 11 March 2005

Abstract

The use of Al-tolerant and P-efficient maize cultivars is an important component of a successful production system on tropical acid soils with limited lime and P inputs. Grain yield and secondary plant traits, including root and aboveground biomass, nutrient content and leaf development, were evaluated from 1996 to 2002 in field experiments on an Oxisol in order to identify maize characteristics useful in genetic improvement. Here we present the results of the 2002 trial and compare them with previous results. The aim of this experiment was to assess the effect of assimilate and nutrient partitioning on the growth and grain yield of two tropical cultivars having different Al tolerance (CMS36, tolerant, Spectral, moderately tolerant). The soil had an Al saturation of 36% in topsoil (pH 4.5) and >45% below 0.3 m depth (pH 4.2). Measurements made from emergence to grain filling included: root, stem and leaf biomass, P and N content, leaf area index (LAI), radiation use efficiency (RUE), soil available N and root profiles at anthesis. The experiments consisted of two P treatments, zero applied or 45 kg P ha^{-1} (−P and +P). All the treatments received N and K fertilizers. In −P, root biomass and LAI at anthesis were twice as great in CMS36 as in Spectral. In +P the differences between cultivars were negligible. Roots were deeper in CMS36 due to its higher Al tolerance. Total biomass and grain yield were not strongly related to root biomass and LAI. Other factors such as the leaf biomass and the amount of nutrients per unit leaf area were highly correlated with RUE and biomass. In −P, Spectral had the same total biomass but a higher grain yield than CMS36 (2.1 Mg ha^{-1} versus 1.5 Mg ha^{-1}). This was due to a higher leaf P content (+40%), a greater RUE (+74%), and a lower number of sterile plants. In +P, CMS36 had higher total biomass and grain yield (4.1 Mg ha^{-1} versus 3.1 Mg ha^{-1}). This was due to its higher leaf P (+25%) and leaf N (+43%) contents, and an increased RUE (+130%) that were associated with higher P and N uptake. Our results indicated that although root tolerance to Al toxicity is necessary for good crop performance on acid soils, assimilate and nutrient partitioning in the aboveground organs play a major role in plant adaptation and may partially compensate for a lower root tolerance.
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Keywords: Aluminium toxicity; Leaf area index; Oxisol; Radiation-use efficiency; Rooting pattern; *Zea mays*

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doi:10.1016/j.fcr.2005.03.002

1. Introduction

Aluminium toxicity is a major problem for maize production on acid soils in the tropics, affecting about 8 million ha in central/south America and Asia. Exchangeable and soluble Al content are nil or negligible for soil pH greater than 5, but they increase exponentially below this pH value. The relationships between pH, exchangeable and soluble Al depend largely upon soil mineralogy, and for a given pH the amount of soluble Al may vary three times depending on clay content (Sierra et al., 2003). As pH generally decreases with depth, the subsoil layers of acid soils are currently more toxic that the topsoil. Liming is sometimes used to reduce Al toxicity, but lime is often too expensive or impractical in many parts of the tropics. In addition, because lime leaching is very small, liming currently affects only the topsoil and does not remove Al toxicity in the subsoil. For this reason, using germplasm improved for Al tolerance is an important step for developing maize-based systems on these acid soils (Clark et al., 1997).

Many investigations during recent years have shown that Al toxicity primarily affects root elongation and functioning (e.g. Horst et al., 1997). This finding led to the development of several indicators of root Al-tolerance in order to use them in maize breeding programs (Horst et al., 1997; Gunsé et al., 2000), and considerable progress has been made in identifying genes (Sibov et al., 1999) and physiological mechanisms (Hocking, 2001) involved in root Al-tolerance. Among these mechanisms, the exudation of organic acids by maize roots as a response to a high Al concentration has been intensively studied, mainly in relation to the timing of the response and the root region concerned in exudation and detoxification (Barceló and Poschenrieder, 2002).

Another constraint related to soil acidity is P deficiency. Phosphorus is relatively insoluble in acid soils and possesses a low diffusion potential that is associated with several fixation processes. This very low P status is sometimes exacerbated through the so called ‘‘soil mining’’ practice, that is, the continuous cultivation without addition of P inputs (Horst, 2000). However, P fertilizer is relatively less expensive and more available in the market than lime, and P application is a more common practice in tropics than liming. In response to P stress, plants have developed mechanisms for making soil P more available; e.g. mycorrhizal symbioses and the release of exudates (Ström et al., 2002). In addition, it is known that maize acquires P under P stress in acid soils by changes in root physiology and morphology; e.g. production of root hairs, P accumulation in roots (Gaume et al., 2001). However, information on the response of the aboveground organs and its interaction with roots in acid soils is scarce. It could be hypothesized that the relatively higher root biomass observed in tolerant plants might induce competition for assimilates and nutrients with the aboveground parts of the plant. The extent of this competition would be related to the availability of nutrients in the soil and to the ability of the plant to take them up. In a field experiment carried out in an Oxisol, Sierra et al. (2003) found that shoot-root competition for P could occur when P accumulated in roots during the early stages of maize growth, after which P was progressively more concentrated in the aboveground biomass. This process depended upon soil P availability. Similar results for P distribution in maize plants were reported for non-acid soils in temperate regions (Mollier and Pellerin, 1999). In addition, the ability to take up nutrients in real conditions depends largely upon the root distribution down the profile. As free Al concentration in acid soils generally increases with depth, Al-tolerant cultivars having roots in the more toxic subsoil might be able to obtain soil resources such as water and nutrients from that layer (Bushamuka and Zobel, 1998). Most of the experiments dealing with the response of the aboveground biomass of maize to Al toxicity have been performed in nutrient solution or in greenhouses in short-term experiments (e.g. Urrea-Gómez et al., 1996; Gaume et al., 2001). Although these experiments are helpful for the plant breeder to distinguish tolerant from susceptible genotypes, field experiments carried out throughout the crop cycle are necessary to evaluate the interactions between the below- and aboveground plant organs, and to assess the plant response in stratified acid soils.

Field experiments were carried out from 1996 to 2002 as a part of a breeding program developed in the humid region of Guadeloupe (French Antilles) concerning the genetic improvement of maize in very acid Oxisols. In this paper we mainly present the results of the more detailed experiment carried out in 2002 using two maize cultivars having contrasting Al tolerance,

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