Mechanisms of Phosphorus Efficiency in Maize - Embrapa Maize and Sorghum Experience

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The occurrence of environmental stress is one of the most important factors that limit crop production in the world. In Brazil, savannas areas or "Cerrados" occupy approximately 205 million ha, representing 24 % of the Brazilian territory, of which 127 million ha are appropriate for agriculture activities. At the moment, 12 million ha of Cerrado are responsible for 25% of the Brazilian production of maize, soybean, rice, bean and coffee. The Cerrado ecosystem is characterized by two important factors: 1) a great majority of soils are acid with low fertility and 2) a seasonal distribution of the precipitation with two well defined season, a dry season and a rainy season. The occurrence of short dry periods during the rainy season called "veranicos" are also common. Therefore, crops cultivated in this region are exposed to multiple stresses, especially aluminum toxicity and phosphorus, nitrogen and water deficiencies. These problems are critical points in terms of initial investment and management of soil fertility, to bring these soils into the productive process. However, fertility problems and water stress are not restricted to "Cerrado" soils, because tropical soils are in general highly weathered and poor in fertility. Crops produced on these soils are exposed to several forms of stress during the crop cycle. The development of sustainable agriculture in tropical areas should be based on using cultivars more adapted to environmental stress conditions

in association with adequate management of water and nutrients.

The Abiotic Stresses Theme Nucleus (NEA) of Embrapa Maize and Sorghum was created in order to develop research directed towards: 1) characterization and quantification of abiotic stresses, 2) screening maize and sorghum genotypes for aluminum tolerance and better P, N and water use efficiency, and 3) develop research on physiological, biochemical and molecular mechanisms involved in adaptation of plants to multiple stress. The understanding of these mechanisms will facilitate the process of developing better adapted genotypes to environmental limiting factors and to the development of new screening techniques that can increase the efficiency of the selection process.

Embrapa Maize and Sorghum has been working in the plant adaptation to low levels of phosphorus in soils since 1979, when Bahia Fº et al. verified that there was differential response to added phosphorus fertilizer in maize hybrids. These results showed the possibility of selecting cultivars more tolerant to aluminum toxicity and more efficient to phosphorus. The authors suggested that this result might be related to the high density of the fine roots in the root system, which was a typical characteristic of the parents lines of those hybrids. Various morphological, physiological and biochemical mechanisms have been suggested to explain the differences between genotypes in relation to phosphorus efficiency. Some of these mechanisms have been studied by NEA's research group.

In one of the first experiments conduced in nutrient solution, twelve maize hybrids were evaluated in a Steinberg's nutrient solution with four P concentrations (0.3; 0.9; 2.7 and

5.4 mg.L^{-1}). The results showed a significant difference among hybrids in P utilization efficiency. However, these differences were closed related to the P contents in the seeds rather than the genotypic variability for P uptake or P utilization efficiency. It was observed that when the remaining endosperm was removed, the seedlings did not overcome the seed effect. From these observations it was suggested that more efficient plants should be selected under field conditions, were mature plants better characterize P efficiency, rather than in nutrient solution.

In various experiments utilizing the P efficient doublecross hybrid, BR 201, we concluded that this hybrid had a lower reduction of root growth rate when phosphorus was omitted in nutrient solution for 10 days, in relation to P inefficient hybrids. This lower reduction in root growth rate was due to a higher soluble sugars concentration in the roots in this hybrid. Higher rates of root growth and a larger root system both increase the volume of soil exploited by the plant, enhancing the absorption of phosphorus. This is especially so when the supply of phosphorus is not continuous in function of reduced soil moisture caused by periods of drought during the growing season (veranicos), common in the Cerrado. Moreover, BR 201 presented a higher stability of total P soluble in acid and of organic phosphorus soluble in acid in the root system with the increase of P omission period when compared with a P inefficient hybrid.

The activity of phosphatase increases when tissue of plants becomes deficient in P. Studies have demonstrated that the activity of phosphatases of intact roots have a significant roll in transforming unavailable P forms to available forms for use by plants. Four maize hybrids; AG 510 and HD 22x18, P inefficient and, BR 201 and HD 36x16, P efficient; were

evaluated in nutrient solution for the effect of P omission intervals on the activity of acid phosphatases in leaves and intact roots after 2, 4 and 6 days of P omission. There was a increase in the acid phosphatase activity in the leaves of HD 22x12 and HD 36x16 after the second day of P omission. From the fourth day, the acid phosphatase activity in the leaves increased in all genotypes. There was also a significant increase in acid phosphatase of intact roots in all hybrids after 4 days of P omission. However, no difference between P efficient and P inefficient genotype was observed in relation to acid phosphatase activity in leaves and intact roots. These results are preliminary and more conclusive information is necessary.

The characterization of the root system was studied in eight contrasting genotypes, four P efficient and four P inefficient. Seedlings grown in a Steinberg nutrient solution at pH 5.5 for seven days were submitted to P omission for 3, 6 and 9 days. Total root length was determined using the SIARCS software. It was concluded that the best period for evaluating genotypes in relation to root weight and root length was on the sixth day of P omission. The omission of P in nutrient solution after six days increased the weight of root dry matter and the root length in three P efficient genotypes. The triplecross hybrid BRS 3060 increased root length by 112%, the doublecross hybrid BR 201 by 61%, and the singlecross hybrid HS 20x723, by 55%. In contrast, the P inefficient genotypes, did not have significant changes root length, suggesting that the root length can be one of the possible mechanisms for P efficiency.

In other experiment using the same genotypes the kinetics of P absorption was studied. The P omission in nutrient solution increased the maximum influx for P absorption (Imax) in six

genotypes after three days of P omission and in five genotypes after six days of P omission. However, there was no correlation between P efficiency and an increase in Imax, since the P inefficient genotypes also increased the Imax. The Km was not modified by the omission of P in nutrient solution during the periods studied.

The translocation of P was studied in three maize hybrids grown in nutrient solution at two P concentrations, 0.02 mM and 0.10 mM. The weight and the P content in xylem exudate and the P translocation from roots to shoots were evaluated. Phosphate starvation decreased the weight and the P content of xylem exudate and P translocation from roots to shoots in all hybrids. The hybrid BR 201 had a higher P content in xylem exudate at low P when compared with the other hybrids.

An experiment was conducted in Dr. Kochian's laboratory (USDA/ARS) to evaluate organic acid exudation in P efficient maize genotypes in P stress. The results are preliminary, but no induction of organic acid exudation by P omission in nutrient solution in P efficient or P inefficient genotypes was observed. The results obtained so far indicated that adaptation to low levels of P in soils are intimately related to the better development of the root system. Higher translocation of sugars to the root system in efficient materials may explain their better growth. Internal P cycling may also be involved.

Phosphorus deficiency induces various effects on the metabolism of plants, especially on nitrogen metabolism. NEA's research group has developed studies on N x P interaction in maize. Alves (1996) observed substantial reduction on the total concentration of N in leaves of maize plants grown in nutrient solution and submitted to increasing periods of P omission. Magalhães et al. (1995) verified that periods of P

omission of two days reduced nitrate uptake by 65%. Reduction of ammonium uptake was also observed, but at a much lower level. In subsequent studies, shorter periods of P omission were evaluated by Pereira et al (1998). A depressive effect (20%) on the rate of nitrate absorption was observed after three hours of P suppression as well as 6, 12, and 24 hours. The depressive effect of P omission on the rate of nitrate absorption was not altered between 3 and 24 hours of P omission.

REFERENCE

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