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Introduction

Phosphorus (P) is a major limiting factor in many agroecosystems, and the finite character of rock phosphate resources call for the need to design more P-efficient crops. For this purpose, and especially to breed genotypes that are less reliant on P-fertilisers, as stressed by Lynch (2007), there is a need to identify root traits and rhizosphere attributes contributing to P acquisition efficiency. P being poorly available and mobile in soils, total root length is often considered as an important feature of root system architecture to efficiently acquire soil P (Pagès 2011), while mycorrhizal symbiosis may provide an alternative option (Richardson *et al.* 2011), especially under low P supply. Many former works have been carried out in laboratory conditions. Here we used a long-term P-fertiliser trial to evaluate a broad range of maize genotypes under field conditions. Besides phenotyping root traits such as length and diameter, we determined rhizosphere properties and microbial activities, as well as the arbuscular mycorrhizal (AM) status of maize genotypes as affected by P fertilisation. Genotypes exhibiting the largest root length would be expected to exhibit a greater P acquisition efficiency. It is also generally accepted that AM colonisation of roots is depressed by P fertilisation.

Methods

We tested these hypotheses in a long-term field trial with 23 genotypes (hybrids sharing a common parent) of maize at two contrasting P levels. This experiment was carried out at INRA-Auzeville (near Toulouse, SW France) in the two extreme treatments: P0, which had not been fertilised for 45 years and P4, which had received 3- to 4-fold the annual P offtake by crops. Plants were harvested at the 6-8-leaf stage and the root systems were collected and washed, after careful sampling of root-adhering soil (thereafter called rhizosphere), for being scanned with WinRhizo. The level of root colonisation by AM fungi was examined by microscopy observations by trypan-blue staining and quantified by qPCR targeting three different AM species. Rhizosphere and bulk soil were assayed for various microbial activities, including alkaline and acid phosphatase activities. Substrate-Induced respiration was measured with the MicroRespTM technique.

Results and Discussion

Shoot biomass was 80% higher and P uptake was more than double in P4 compared to P0, yet, root biomass was not modified by P level. Although root biomass was comparable, roots tended to be finer and longer at low P (P0). Microbial biomass and respiration significantly increased in the rhizosphere, the greatest microbial activity being found in P4. In the bulk soil however, microbial activity was not modified by P fertilisation. In contrast, alkaline phosphatase activity was similar in rhizosphere and bulk soil, being slightly smaller in P0. In accordance, acid phosphatase activity was also lowest for P0. Interestingly, although the total length of fine roots was increased under P-deficient conditions, the colonisation of roots by AM fungi was comparable between the two P levels, whatever the method used. The root colonisation rate was not affected by P across all genotypes, but the intensity of root colonisation by AM was higher in P0. The consistently higher microbial activity suggests that co-limitation of soil microbial communities by P and carbon may occur in the unfertilised soil. Our results obtained under field conditions also challenge the hypothesis that the AM colonisation of roots is depressed by P fertilisation. Across the 23 maize genotypes, P acquisition in P-limited conditions (P0) was not correlated to the total root length, but there was a significant correlation with root diameter, and hence with the root surface area.

Conclusion

Total root length, in spite of being increased as a response to P deficiency, was surprisingly not explaining the P acquisition efficiency, which varied more than two-fold across the 23 genotypes. The mycorrhizal status did not seem to explain it either, in contrast with root diameter. Other root traits such as aerenchyma and root hairs need to be assessed.
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