Tolerance and avoidance of Al toxicity by *Mucuna pruriens* var. *utilis* at different levels of P supply

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Abstract

Previous laboratory experiments showed that velvet bean *Mucuna pruriens* is moderately tolerant to the presence of Al (up to 185 μM) in the root environment, but that it only develops a shallow root system in acid soils. Field experiments showed that *Mucuna* can tolerate acid subsoil conditions in a homogeneous root environment, but avoids subsoil if topsoil is present. Subsequent split-root experiments with a recirculating nutrient solution showed that this subsoil avoidance may be based on an Al avoidance mechanism in the root system. This Al avoidance mechanism, however, was not evident when phosphorus (P) supply to the whole plant was adequate. We thus hypothesized that surface application of P may help to overcome Al avoidance in the subsoil.

In a field experiment on an ultisol in Lampung (Indonesia), only a moderate increase in aboveground biomass production was found for a wide range of P application rates, although the soil was low in available P, and the P adsorption isotherm was very steep. An increased P status of the topsoil and an increased P concentration in the aboveground biomass (from 50 to 75 mmol kg⁻¹) had no effect on root development in the subsoil.

Introduction

The most common upland soils in the humid tropics are acid and have a low phosphorus (P) status. These two problems for agricultural production are related, as P in the soil is strongly adsorbed to aluminium (Al) or iron (Fe) at low pH (Blamey and Edwards, 1989). Al toxicity in acid soils hampers root development of many crops, and thus reduces the ability of crop plants to acquire P from the (sub)soil (Edwards, 1991). Phosphorus may be precipitated as Al-PO₄ either on the root surface or in root cell walls (Barlett and Riego, 1972; McCormick and Borden, 1974). Shortage of P depresses legume production and nitrogen (N) fixation and thus strongly affects N supply to food crops in the low-external-input agriculture that is common in the humid tropics. Deep-rooted crops are needed for efficient N uptake under high rainfall conditions (van Noordwijk et al., 1992).

The velvet bean, *Mucuna pruriens* var. *utilis*, is useful as a green manure, reducing the need for N fertilizer and controlling weeds such as *Imperata cylindrica* (alang-alang). *Mucuna* had a shallow root system in ultisols in Nigeria and Sumatera (Indonesia) (Hairiah and van Noordwijk, 1989). *Mucuna* was, however, moderately tolerant to the presence of Al in solution cultures at pH 4.2 (Hairiah et al., 1990). A (nominal) Al concentration of 110 μM even increased root fresh weight, while Al concentrations above 185 μM hampered root growth. In a field experiment on an ultisol in Lampung (Sumatera), a large root system was formed in the subsoil when *Mucuna* was sown directly into the subsoil, after removal of the top soil. P fertilization and higher liming rates placed in local pockets of soil had a positive effect on root length density (Hairiah et al., 1991a). The hypothesis that ‘subsoil avoidance’ of *Mucuna* roots in the presence of topsoil was based on ‘Al avoidance’, in combination with moderate Al tolerance in homogeneous media, was tested in a split-root experiment with recirculating nutrient solution (Hairiah et al., 1992). An Al concentration of 185 μM applied to both sides of a root system increased root dry weight and reduced shoot dry weight and shoot:root ratio compared to the control. Application of such Al containing solution to half of the root system led to a significant shift in root growth to the control side. The
Al-avoidance reaction appeared to be a complement of the preferential local root development at high P sites by P-stressed plants. An increase of the P supply to the plants resulted in the disappearance of the Al avoidance reaction (Hairiah et al., 1993a). By analogy, we hypothesize that deep root development in the field may be stimulated by surface application of P, even when the P does not directly reach the (acid) subsoil.

Support for this hypothesis can be found in other plant species. In split-root experiments with wheat, surface application of P improved root penetration into an acidic subsoil (McLaughlin and James, 1991). Rowell (1988) showed that P can be translocated from the topsoil to root tips in the subsoil, where Al is limiting growth.

The objectives of this paper are: (1) to examine the effect of P fertilization on Mucuna growth on an acid soil; and (2) to test the hypothesis that adequate P supply in the topsoil can stimulate deep root development in an acid subsoil. Given the function of Mucuna in a cropping system, special attention was given to light interception, as this determines the effectiveness of Mucuna in controlling weeds, and total biomass production, as this determines its role in improving soil fertility to subsequent crops.

Material and methods

Field experiment

The experiment was carried out at Karta (4° 30'S, 104° 98'E) in N. Lampung (Sumatera, Indonesia), on a Grossarenic Kandiudult. The shallow topsoil layer of about 15 cm and the subsoil had a pH(H2O) of 4.5–5.0 and 4.5, an organic carbon (C) content of 1.5–2 and 0.5%, a Bray II extractable P content of 20 and 5 mg g⁻¹ and an Al saturation of the exchange complex of about 20 and 60%, respectively. Further description of the soil profile, field site and climate were given by Hairiah et al. (1991a) and van Noordwijk et al. (1992).

P fertilizer was applied as triple super phosphate (TSP) at first planting of cowpea in June 1988, at 7 levels: 0, 20, 40, 60, 80, 100 and 120 kg P ha⁻¹. Urea, potassium chloride (KCl) and zinc sulphate (ZnSO₄·7H₂O) were applied as basal fertilizer before planting of grain crops. The cropping sequence over a period of two years was cowpea–maize–Mucuna–upland rice–cowpea–maize–Mucuna–maize. Data will be discussed mainly for the second Mucuna crop, grown from November 1989 till January 1990. Mucuna was sown at a spacing of 25 × 25 cm, 1 seed per hole. The treatments were arranged in a randomized block design with 3 replications. Results were analyzed with analysis of variance (ANOVA) routines of GENSTAT 5 (Payne et al., 1987).

At 12 weeks after planting (WAP), aboveground biomass samples (green and dead combined) were collected from 1 m² of every plot, dried, weighed, ground and subsequently analysed for N, P, K, Ca, Mg and Al. Light interception by the canopy was measured with a Lux meter at 20 points in each plot, alternating with measurements above the canopy. Results are expressed as a light transmission fraction.

Root samples were taken at the same time with a pinboard in one replication only. After washing away the soil, the root sample was cut into layers of 10 cm depth, and dried at 80 °C. Fresh root samples were collected and stored in ethanol for mycorrhizal observation (Anderson and Ingram, 1993).

Chemical analysis

Composite soil samples were collected from every plot at 12 WAP at 0–10 cm depth. Dried soil samples were analyzed for Bray II extractable P. Concentrations of monomeric Al in soil solution (centrifuged from soil rewetted to field capacity) were measured colorimetrically after 1 minute reaction with pyrocatechol violet (PCV) (Kerven et al., 1989). A simplified calibration procedure was used, however, as we found that the