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Spatial distribution of root activity and nitrogen fixation in sorghum/pigeonpea intercropping on an Indian Alfisol

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Abstract

A medium-duration pigeonpea cultivar (ICP 1-6) and a hybrid sorghum (CSH 5) were grown on a shallow Alfisol in monocropping and intercropping systems. Using a monolith method, spatial distribution of nodulation, acetylene reduction activity (ARA) and root respiration were measured.

The number, mass and ARA of nodules decreased exponentially with distance from the plant base except at the late reproductive stage. Nodulation and ARA tended to be higher in the intercrop than in the monocrop.

Respiration rate of roots increased with distance from the plant base and reached a maximum value at about 20-30 cm. The rate was higher in pigeonpea than in sorghum and also higher in intercrop than in monocrop.

This study suggests that pigeonpea roots are physiologically more active than sorghum roots, implying that pigeonpea may become a strong competitor for nutrients in the soil when intercropped. The nitrogen-fixing ability of pigeonpea may be enhanced by intercropping because the sorghum rapidly absorbed inorganic N which would otherwise inhibit N_2 fixation.

Introduction

The interaction between plant species in intercropping occurs both above and below ground. Much research has been focused on the spatial structure of above-ground parts of the component crops (Willey et al., 1981). The selection of crop species, sowing time, planting density, etc have been determined empirically largely based on minimizing competition for light. However, component crops also interact with each other underground through water and nutrient uptake, microbial activities and allelopathic substances. To improve the utilization efficiency of nutrient resources of soils by intercropping systems, the spatial distribution and activities of roots require elucidation.

We investigated how the rooting profiles and root activities would be modified by intercropping. Results for rooting profiles have been reported elsewhere (Ito et al., 1991). In this paper, the spatial distribution of root respiration, nodulation and N fixation were measured as indices of root activities in a sorghum/pigeonpea intercrop.

Materials and methods

A medium-duration pigeonpea cultivar (*Cajanus cajan* (L.) Millsp. cv. ICP 1-6) and a hybrid sorghum (*Sorghum bicolor* (L.) Moench cv. CSH 5) were sown in a shallow Alfisol at ICRISAT Center, near Hyderabad, India, on 12 June 1990.

The spacing was 60 × 15 cm for the sorghum monocrop (S), 60 × 30 cm for the pigeonpea monocrop (P) and 60 × 10 cm for intercrop (S+P) in a 2:1 row arrangement. Basal application of urea was given to each cropping treatment at either 25, 50 or 100 kg N ha^{-1}. A split-plot design was used with nitrogen treatments assigned to main plots and cropping patterns to sub-plots. There were three replications. The size of sub-plot for each treatment was 7.5 × 12 m, consisting of 13 rows. Phosphorus was applied before planting with single superphosphate at 20 kg P ha^{-1}.

Roots were sampled 90, 123 and 168 days after sowing (DAS) using a monolith method. Soil blocks were removed at 5 cm intervals to 25 cm depth and at 10 cm intervals between adjacent rows. The width of soil blocks was 15, 30 and 10 cm for S, P and S+P, respectively. Roots were immediately washed to remove soil and then placed in either a gas-tight bottle or a syringe for incubation. The size of the incubation containers differed from 5 to 250 mL depending on root volume. After the one hour of incubation at 30°C 5 mL of gas sample was injected into an oxygen analyzer (Toray F700) to estimate respiration. Acetylene (10% v/v) was added to the root sample and left to incubate for another hour. One mL of gas sample was injected into a gas chromatograph analyzer with a FID detector (F33 type, Perkin-Elmer Limited, UK) and Porapack Q for the estimation of acetylene reduction activity (ARA).

Results and discussion

Nodulation and nodule activity

Fresh nodule weight decreased exponentially with the distance from the plant base at 90 DAS (Fig. 1a). Few nodules were observed more than 30 cm away from the plants. The same exponential curve with less nodule weight per unit volume was obtained at 123 DAS (Data not shown). At 168 DAS, however, very few nodules were found immediately below the plants (Fig. 1b), suggesting that nodules found in this region at 90 DAS have disintegrated or been dislodged from the roots. At this growth stage, nodulation density did not decrease exponentially with distance from the plant base. The nodulation density was much higher in the intercrop than in the monocrop.

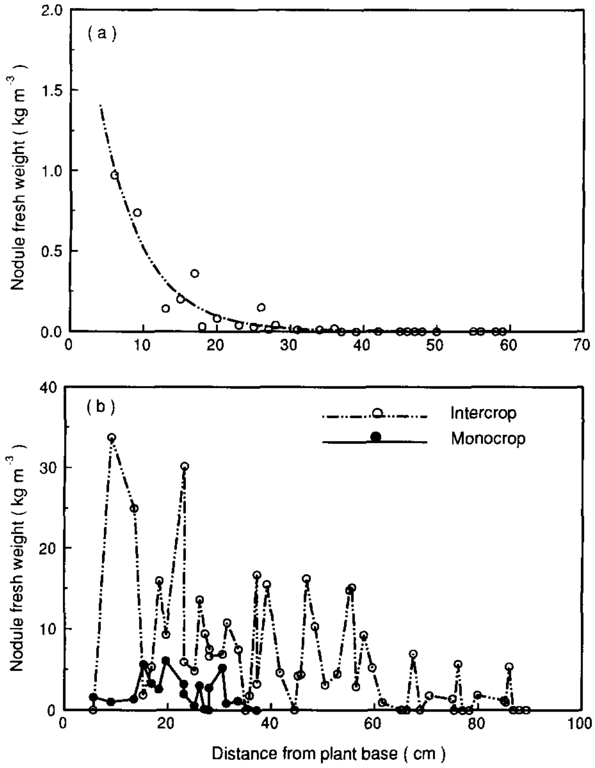

Fig. 1. Fresh nodule mass in unit soil volume with distance from plant base at 90 days after sowing for intercrop (a) and 168 days after sowing for monocrop and intercrop (b). The curve for (a) is described by Y=1.91 Exp(-0.168X)+0.00224 (n=27).

The specific nitrogenase activity (SNA) was highest at some distances away from the plant base (Fig. 2). Since nodule formation takes place along the root axis from base to tip, the average age of nodules in a soil block would be younger in more distal roots. Younger nodules usually have a higher SNA than older ones.

Nitrogen application reduced the maximum SNA in intercrop, but the effect was not clear in the monocrop. The SNA in the intercrop was higher than in the monocrop. The presence of sorghum in an adjacent row and the higher planting density in intercrop than in monocrop may decrease available N in soil between rows, thereby alleviating the inhibitory effects of mineral N on N2 fixation.

An intercrop of soybean with sorghum reduced

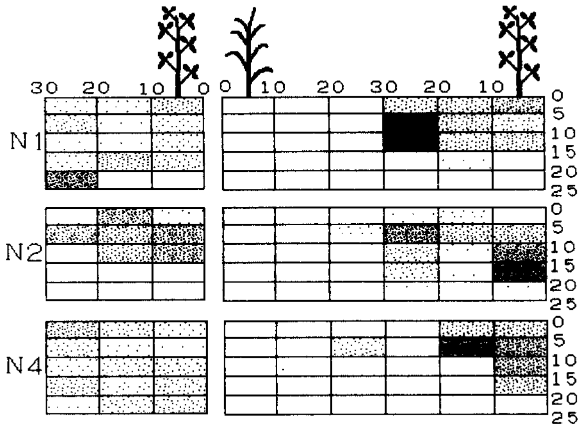

Fig. 2. Two dimensional profile for specific nitrogenase activity of pigeonpea in monocrop (left) and intercrop (right) at 90 days after sowing. The activity is proportional to the density of dots in a square with 64 levels. The maximum density corresponds to 52.1 mmole kg^{-1} FW hr^{-1}.

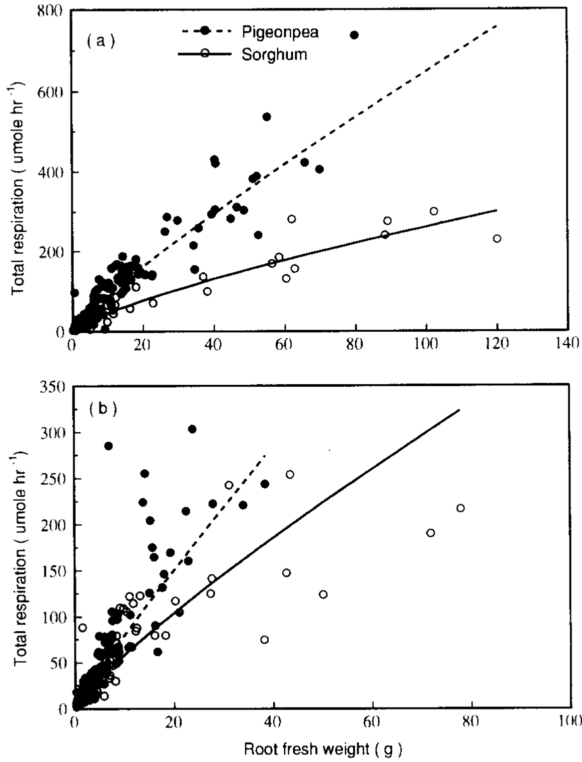

Fig. 3. Root respiration and root fresh weight of pigeonpea and sorghum (a), and intercrop of those two crops (b) at 123 days after sowing. The equations for fitted curves in (a) are $Y=12.4X^{0.859}$ ($R^2=0.90$) for pigeonpea and $Y=8.07X^{0.756}$ ($R^2=0.87$) for sorghum. The equations in (b) are $Y=9.72X^{0.915}$ ($R^2=0.79$) for pigeonpea and $Y=8.67X^{0.831}$ ($R^2=0.71$).

both nodule number and SNA (Wahua and Miller., 1978) as compared with those for the monocrop. Groundnut intercropped with sorghum, pearl millet and maize showed poor nodulation, but SNA was similar in a monocrop (Nambiar et al., 1983). Effects of intercropping on nodulation and N_2 fixation were considered to be due to competition for light in the canopy. However, no difference in N_2 fixation was reported in a maize/bean intercropping system (Graham and Rosas, 1980). Using a ^{15}N natural abundance method to estimate N input by N_2 fixation in pigeonpea intercropped with sorghum, it was observed that intercropping increased the contribution of N_2 fixation especially at low levels of N fertilization (Unpublished data).

Root Respiration

Root respiration as a function of root fresh weight was expressed using a power function ($Y=aX^b$, where Y is total root respiration, X is root fresh weight, and a and b are coefficients, Fig. 3a). The curve for pigeonpea has the highest coefficient a and that for sorghum the lowest. This indicates that pigeonpea had a higher respiration rate per unit weight than sorghum. The smaller b found in sorghum means that the slope of curve becomes smaller compared with pigeonpea as root fresh weight increases.

Total respiration within the intercrop plotted against root fresh weight could be grouped for each component crop (Fig. 3b). Although parameters for the curves are slightly different from those obtained for the monocrops, a and b were higher for pigeonpea than for sorghum, indicating that the characteristic features of root respiration were maintained even in an intercrop.

Respiration rates were plotted against distance from the plant base (Fig. 4). The respiration rate in pigeonpea roots was significantly higher than that in sorghum roots at 90 DAS (Data not shown) and at 123 DAS (Fig. 4a). One of the reasons for the higher respiration rate found in pigeonpea might be additional respiration of nodules formed on its roots. Nodules consume substantial amounts of carbohydrates for their growth and metabolism, so that their respiration

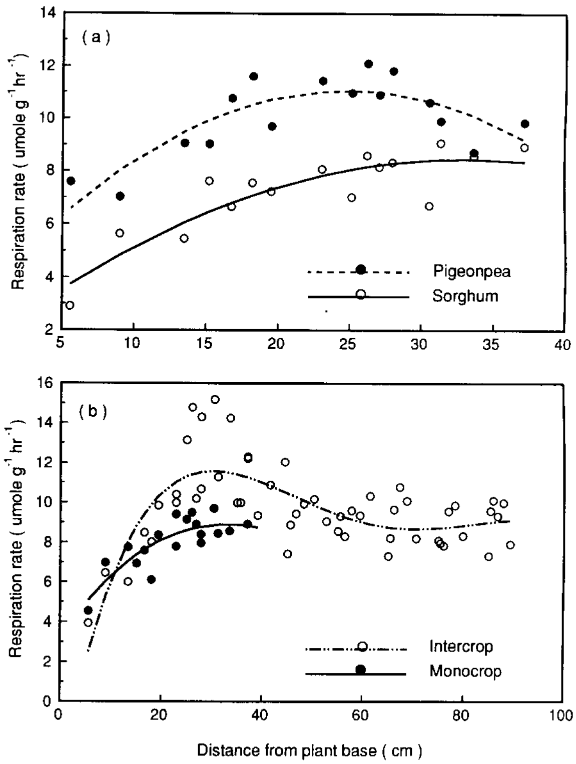

Fig. 4. Root respiration rate with distance from plant base. (a) is for roots of pigeonpea and sorghum at 123 days after sowing and (b) is for roots of pigeonpea in monocrop and intercrop at 168 days after sowing.

rate is usually several times higher than that of roots without nodules (Hooda et al., 1986). However, the curve for respiration rate was different from the curve for fresh nodule weight which was exponential with distance (Fig. 1a). It is thus concluded that the respiration curve mainly reflects root activity *per se* and nodules have little contribution to total root respiration. Rao et al (1984) reported that during vegetable growth, roots of pigeonpea accounted for 23%, of total respiratory loss while nodules accounted for 12%. The contribution of nodule respiration drastically decreased later due to a sharp decline in N_2 fixing activity. Since the respiration rate is expected to be highest in root tips and to decrease towards the plant base, it is most likely that a soil block further from the plant base would contain a larger proportion of root tips and young roots, causing higher respiration rates.

The respiration rate of pigeonpea roots was significantly higher in the intercrop than the monocrop at 168 DAS (Fig. 4b). Mutual competition for light was probably lower in the intercrop than in the monocrop due to the harvesting of sorghum plants at 127 DAS and poor canopy development during the intercropping period. Pigeonpea in the intercrop may have higher photosynthesis and translocate more carbon to the roots for their physiological activity during later growth stages.

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