Impact of intercropping soybean and sorghum on shoot production and phosphorus use efficiency in a Vertosol soil

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Abstract
A glasshouse study was undertaken of the effect of phosphorus and water interactions on the productivity of intercropped sorghum and soybean grown in a Vertosol soil. Soybean or sorghum were grown alone or mixed. Difficulties in maintaining soil moisture near field capacity resulted in transient waterlogging in the sole soybean treatments which limited aeration in the root boxes. This resulted in reduced N_2 fixation with the lowest shoot yields being in inoculated treatments. The shoot dry yield data showed that the growth of mixed soybean with N fertiliser gained a benefit when grown with sorghum, most likely due to a reduction in waterlogging stress as a result of the greater water use by the sorghum. Fertiliser P uptake was similarly affected. Sorghum was more competitive for P fertiliser than soybean when the fertiliser was applied between the plants, but the competition was marginal when the fertiliser was applied beneath each plant.
Key words
Soybean, sorghum, intercropping, nutrient competition, fertiliser, fertilizer

Introduction

A wide range of practices following agro-ecological guidelines, such as intercropping, agroforestry, reduced tillage, green manure, cover cropping and crop rotations, have been developed to improve cropping systems (Wezel et al. 2014).

Many researchers have stressed the importance of legumes as a critical species in enhancing ecosystem efficiency in intercropping systems (Altieri, 1999). Intercrop yields can exceed the component yield sum of species grown alone by improving the use of available resources required for crop growth, such as water and nutrients (Miyazawa et al. 2010).

Previous studies have demonstrated that intercropped cereal with legumes enhanced P acquisition and growth. These studies include wheat with chickpea (Li et al. 2003), and wheat with corn (Gunes et al. 2007). These studies have reported between 25–70% increases in P uptake by wheat in comparison to sole wheat crops.

In many situations, cereals compete for soil N better than legumes due to their deeper and faster root growth, and considerably higher N demand (Ghosh et al. 2009). Therefore in intercropping systems, cereals can have a high dependence on legume symbiotic N_2 fixation (Li et al. 2009). Given this, the application of inorganic N and P might reduce the competition between intercropping species and improve their P uptake and growth. (Ghosh et al. 2009).

Vertosols have high holding water capacity and are susceptible to waterlogging after irrigation or rainfall (Ayele, 2001). This results in reduced soybean growth, reduced apical growth of roots and nutrient accumulation (Tamang et al. 2014). Sorghum is tolerant of wet conditions, and it consumes a considerable amount of water compared with legumes (Hochman et al. 2001). This higher water use and subsequent drying of the soil could help to improve the growth and nutrient uptake of intercropped soybean and sorghum.

This research examined P utilisation and plant growth in a sorghum/soybean intercropping system compared with individual soybean and sorghum plants grown in a moist Vertosol soil. Soybean was either inoculated with *Rhizobium* or N fertiliser and sorghum was N fertilised. The hypothesis was that N provided to soybean either by inoculation or fertiliser would increase P uptake and competitive ability of the intercropped soybean.

Materials and methods

Experiment design and setup

A glasshouse experiment was conducted in soil culture in root boxes (1 m wide x 1 m deep x 0.02 m thick) to determine P uptake and competition between sorghum and soybean when grown both individually and mixed, and the effect of N_2 fixation on this competition. Glasshouse temperature was maintained at 28^0C (day) and 18^0 (night). Phosphorus isotopes (^{32}P and ^{33}P) techniques were used to track the P competition in the individual and intercropped soybean and sorghum plants. A sample (0–0.2 m) of a Vertosol (Isbell, 2002) soil was collected from the Laureldale Research Station located at the University of New England, Armidale, Australia. The soil had pH (1:5 H_2O) of 5.7 and a Colwell P concentration of 38 mg/kg

A total of 22 kg of soil was placed into each root box at a bulk density was 1.1 g/cm^3. The soil was watered twice to settle it down in the root boxes before planting. The aim was to maintain the root boxes at 40% water content (80% of field capacity) by weighing weekly but difficulties with wetting the swelling soil made this impossible.

Two plants of soybean or sorghum were grown in a box in the sole treatment and one plant of each in the mixed treatment. Soybean plants were either inoculated with rhizobia or supplied with fertiliser N. The experimental design was a completely randomised design with seven treatments. Each treatment was replicated four times. The treatments used are shown in Table 1.

Table 1. Treatments used in the experiment

Plant system	Plant	P placement	N source	P isotope
Mixed	Soybean	Underneath	Inoculated	33
	Sorghum	Underneath	N	32
Mixed	Soybean	Underneath	N	33
	Sorghum	Underneath	N	32
Mixed	Soybean	Between	N	32
	Sorghum	Between	N	32
Mixed	Soybean	Between	Inoculated	32
	Sorghum	Between	N	32
Sole	Sorghum	Between	N	32
Sole	Soybean	Between	Inoculated	32
Sole	Soybean	Between	N	32

Fertilisation and ^{32}P and ^{33}P labelling

Potassium sulfate was added at the rate of 55 kg K/ha and urea was added at the rate of 10 kg N/ha (based on the mass of the soil in the box) to all boxes. An additional application of liquid urea at 40 kg N/ha (10 mL per plant) was made to the sorghum and non-inoculated soybean treatments and this was injected into the soil 25 days after sowing. All fertilisers were injected at a depth of 20 cm.

Isotope labelling was used to determine the amount of fertiliser P taken up by the sorghum and soybean plants. Phosphorus was applied as KH_2PO_4 at a rate of 40 kg P/ha$^-$ and this was labelled with either ^{33}P or ^{32}P. The labelled KH_2PO_4 was applied in solution (10 mL per plant) at 0.3 m depth before sowing. The placements were either below or between the plant locations.

Plant shoot yield and plant sample analysis

The plants were harvested 60 days after sowing. The samples were dried and ground and analysed for nutrients in an Inductively Coupled Plasma Optical Emission Spectrometer (ICPOES) after acid digestion (Anderson and Henderson 1986). Radioactivity was determined by liquid scintillation counting. The contributions of ^{32}P and ^{33}P labelled fertiliser to shoot P were determined from the plant and fertiliser specific activity (Bq/mg P).

Statistical analysis

All data were tested for homogeneity of variance prior to ANOVA statistical analyses using the SPSS 23 statistical program (George & Mallery, 2016). Least significant difference *(lsd)* test comparisons were executed at the 95% probability level.

Results

Water use

It was extremely difficult to maintain a soil water content of 40% throughout the experiment despite the water being delivered through weeping tubes that were placed down the sides of each box. Despite the water being added slowly, saturation of the surface layers was often observed. From week 6 to 9 the box weight of the sole sorghum was 65.2% lower and the mixed treatment was 21% lower than the sole soybean.

Shoot yield

The sorghum shoot yield was notably higher than that of soybean for all treatments; however, there were no significant differences ($P>0.05$) between treatments. The shoot yield of sole and mixed soybean with N was higher ($p < 0.05$) than that in the inoculated treatment, increasing by 47% and 107%, respectively. The soybean shoot yield was 61% higher in the mixed compared to the sole treatment with N. By contrast this difference was only 7% in the inoculated treatments. These results indicate that soybean mixed with sorghum had a better soil environment than that in the sole soybean treatment. Box weight data show that soil water was notably lower in the treatments with sorghum and this would be expected to reduce the waterlogging stress on soybean which was greater in the inoculated treatment than in the N fertilised treatment. Carangal and Morris, (1986) reported that sorghum is more tolerant of wet conditions than soybean and Cabelguenne and Debaeke, (1998) found that the capacity of sorghum to extract water in clay soil is superior to that of soybean.

Table 2. Effect of soybean and sorghum planting system and N source on shoot dry matter yield (g/plant)

	Shoot dry matter yield (g/plant)					
Planting	Sole		Mixed		Mixed	
P placement	Between plants		Between plants		Beneath plants	
N source	N fertiliser	Inoculated	N fertiliser	Inoculated	N fertiliser	Inoculated
Soybean	4.15	2.81	6.25	3.01	7.14	2.40
Sorghum	7.28	-	7.07	7.00*	9.23	8.35*

Interaction lsd (0.05) = 1.74

* = sorghum mixed with inoculated soybean

Fertiliser P content of plant shoots

Placing the P at a depth of 20 cm between the plants resulted in an average 90% reduction in fertiliser P uptake of soybean shoots compared to the beneath N treatment (Table 3). This compares with an average of 33% in sorghum indicating that the sorghum root system was able to exploit the soil volume to access the P to a greater extent than the soybean root system.

Table 3. Effect of P placement on fertiliser P uptake by sorghum and soybean in sole and mixed plantings

	% reduction in fertiliser P content of shoots between treatment and beneath placement in N treatment			
Plant	P between plants		P beneath plants	
	N	Inoculated	N	Inoculated
Soybean	89	93	100	89
Sorghum	34	31	100	0

Table 4. Effect of mixed planting on fertiliser P content of shoots of sorghum and soybean

	Mixed as % of sole with between P placement			
Plant	Sole		Mixed	
	N	Inoculated	N	Inoculated
Soybean	100	65	28	18
Sorghum	100		98	

There was a reduction in fertiliser P uptake by soybean in the mixed treatment compared to the sole N treatment and when inoculation replaced N application (Table 4). Inoculated soybeans recovered less fertiliser P than those receiving fertiliser N in both sole and mixed plantings (Table 4) and when inoculated soybean was sown in mixed planting the fertiliser P recovery was reduced to only 28% of that when grown alone with fertiliser N where the recovery was 0.27% of the applied P. By contrast, there was no reduction in fertiliser P recovery in sorghum between sole and mixed planting (Table 4).

Conclusion

Sorghum was better able to exploit fertiliser P than soybean under the wet soil conditions of the experiment. Rhizobia activity was similarly affected which influenced soybean exploration of added P. This was partially overcome by applying N to the soybean.

The potential value in intercropping with a legume needs to be carefully considered, taking into account expected soil moisture conditions.

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