The rhizosphere biology of native shrub-based cropping systems: An unrecognized potential to optimize crop production in the Sahel

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The Sahel is a very vulnerable environment, threatened with desertification and soil degradation that now seriously reduce agricultural productivity and negatively impact local populations. A potential key for restoring these landscapes are two native shrub species (*Guiera senegalensis* & *Piliostigma reticulatum*) that can coexist with crops and have the ability to lift water from wet sub- to dry surface soil and improve soil fertility. Our hypothesis is that changes in soil microorganisms populations were associated with the observed improvement in crop yield when intercropped with local shrubs in Senegal.
Several companion studies were conducted by PhD students to test this hypothesis.

i) Soil microbiomes in millet-shrub intercropping systems (S. Debenport, OSU)
Objective –Profiling the microbiome of millet plants grown in order to identify populations of microorganisms associated with millet yield improvement when intercropping systems.
Materials & Methods – Two long term field sites were established in Senegal with a randomized complete block design intercropping millet with local shrubs (*Guiera senegalensis* at Keur Matar, near the city of Thiès, and *Piliostigma reticulatum* at Nioro, more in South). We focused on two treatment types: pearl millet (*Pennisetum glaucum*) in bare soil or when intercropped and mulched with shrubs. We performed high throughput sequencing using the Illumina MiSeq system of 16S and ITS amplicon libraries in order to profile both

soil bacterial and fungal communities. Sequence libraries were processed through the Quantitative Insights Into Microbial Ecology (QIIME) software package, where sequences were clustered into operational taxonomic units (OTUs) at 97% similarity and assigned taxonomy through the use of reference sequence databases.

Results & Discussion - Figure 1 shows an example of the output of this analysis. Each dot is a single OTU which differs significantly ($P < 0.001$ for bacteria and $P < 0.005$ for fungi) by treatment type. The x axis has these arranged by genera, and the y axis shows the log 2 fold change in abundance of these OTUs (positive values are enriched in the residue amended samples, negative numbers are enriched in the bare soil samples). Our data indicate that the rhizosphere activities of native shrubs can influence the structure of microbial communities in the surrounding soil. Future work will include identifying those OTUs which are consistently enriched across all sample sites and regressional analysis of OTU counts with soil chemical properties.

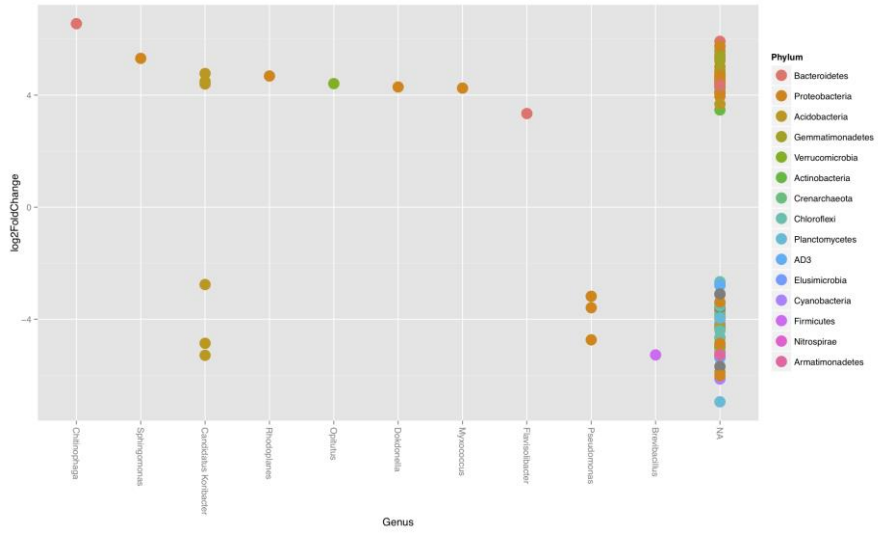

Figure 1. OTUs showing differential expression between millet rhizospheres amended with shrub residue or in bare soil.

ii) AM in roots of millet when intercropped with *G. Senegalensis* (M. Bright, OSU)

Objective – Identifying the Arbuscular Mycorrhiza (AM) species present and their colonization rates when the crop is planted within the rooting zone of the shrub across the rainfall gradient of Senegal.

Materials & Methods – Sampling was conducted on smallholder fields along a regional north-south transect to capture the major precipitation regimes (sites A & B near the city of Louga; D & E near Bambey;X & Y near Nioro). At each of the six research sites, 50 days post-millet planting, 6 full-grown *G. senegalensis* shrubs were chosen at random for sampling along with 2 millet plants growing within the rooting zone of the shrub (<1m radius) and 2 millet plants grown >5m radius. Fine, potentially mycorrhizable roots (<2mm diameter) were extracted

from 40cm-depth soil samples and prepared for microscopic observations of the extent of root colonization by AMF.

Main results & Discussion – Overall very high levels of millet AM colonization were observed in plants both near and far to the shrub (arbuscular colonization avg. near 50%; data not shown) indicating the crucial role of AM fungi in millet growth. The higher AM colonization rates (all AM structures: hyphae, vesicles, arbuscules and spores) in the drier and sandier northern sites indicating the efficacy and utility of AM fungi for plant growth in the Sahel region of Senegal. We also observed an inverse relationship between soil gravimetric water content and spore and vesicle colonization indicating a probable fungal advantage to the millet experiencing drought. The millet plants growing near the shrub at the northern (A & B) and middle (D & E) sites showed greater vesicle colonization rates in their roots than plants far from the shrub ($P < 0.1$; n=12; Fig 2). The significance of this is that vesicles are often a proxy for nutrient status or physiological age of the plant.

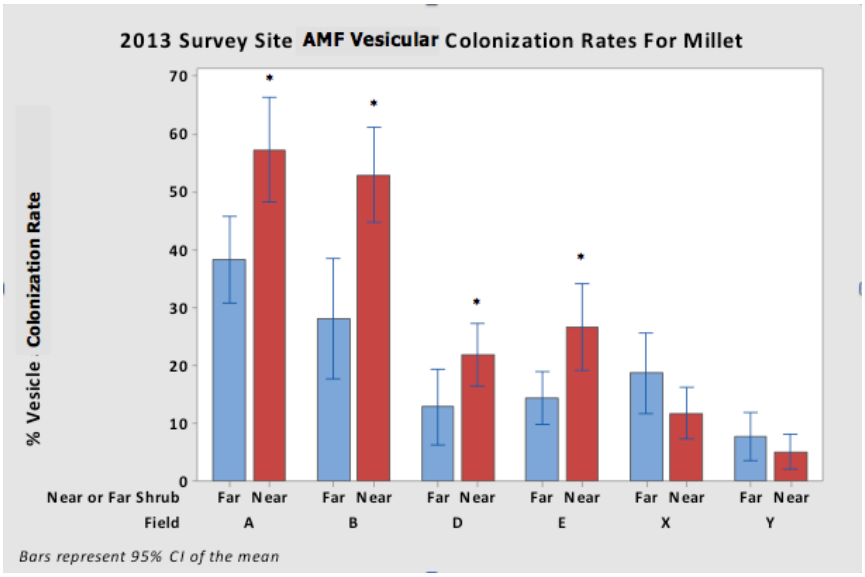

Figure 2. AM vesicle colonization rates in millet grown < 1m from base of shrub (Near) and millet grown > 5m from base of shrub (Far) at survey sites (n=12; from North to South (A&B; D&E; X&Y)

iii) Soil nematofauna and the associated soil food web (S. Diakhaté, UCAD)

Objective – Evaluating the response of soil nematode communities, as well as key food web indices, to intercropping pearl millet with *P. reticulatum*.

Materials & Methods – Top soil (0-10 cm) was collected in four treatments from a long-term experimental design at Nioro (Senegal): (i) bare soil (treatment serving as a control, C), (ii) millet cultivation without external inputs (M treatment), (iii) shrub canopy (noted as P for *Piliostigma reticulatum*) and (iv) millet and *P. reticulatum* association with shrub cutting at millet seedling and mulching. Nematodes were extracted from fresh soil, counted under

microscope and mounted on slides for taxon identification and assignation to trophic groups (bacterial feeders, fungal feeders, plant feeders, omnivores and predators.

Main results & Discussion – The soil nematode community in millet cultivation was dominated by plant feeding nematodes, mainly from the Hoplolaimidae family, but their abundance decreased when *P. reticulatum* was associated to the cereal (Fig 3). The shrub also impacted other nematode trophic groups. The intercropping provided more bacterial-feeders (mainly the opportunistic Cephalobidae) with potential indirect effect on nutrient cycling in soil.

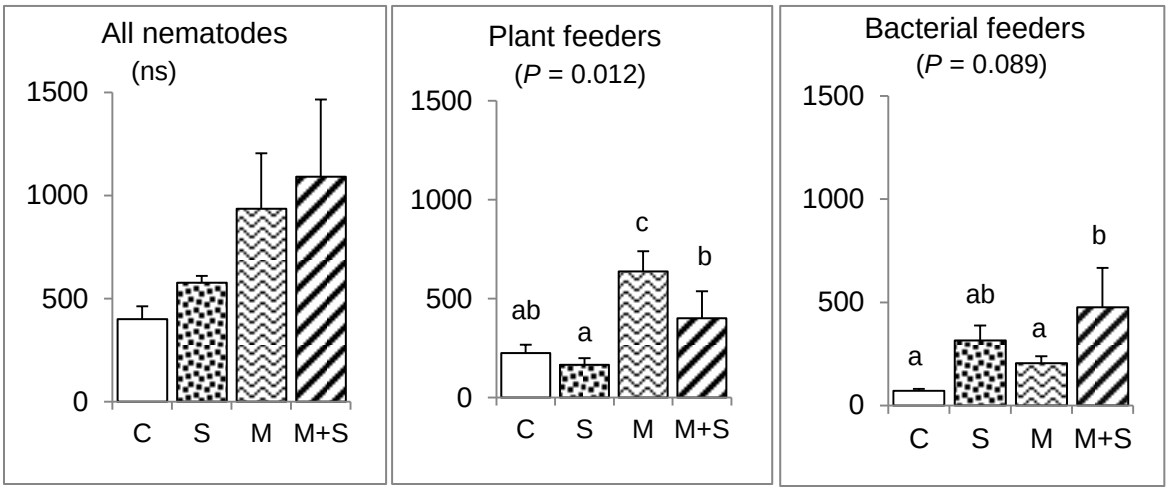

Figure 3. Abundance of nematodes (number of individuals 100 g dry soil^{-1}; means with SE as bars) for the different treatments (C: control soil; S: shrub; M: millet; M + S: millet intercropped with shrub). Different letters between columns indicate significant difference between treatments at $P < 0.05$ (from Diakhaté et al., 2013)

Take-home message

Native shrubs of the Sahel region influence soil biological composition - and probably its functioning - in the benefit of the associated food crops (improved growth and increased yields). This might represent a new biologically-based way to improve production in semi-arid agroecosystem and adaptation to climate change.

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