European Journal of Soil Biology 57 (2013) 35–41

Contents lists available at SciVerse ScienceDirect

European Journal of Soil Biology

journal homepage: http://www.elsevier.com/locate/ejsobi

Original article

The influence of a shrub-based intercropping system on the soil nematofauna when growing millet in Senegal

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ARTICLE INFO

Article history:
Received 4 February 2013
Received in revised form
8 April 2013
Accepted 18 April 2013
Available online 7 May 2013
Handling editor: Bryan Griffiths

Keywords:
Piliostigma reticulatum
Pennisetum glaucum
Sahelian shrub
Soil nematodes
Trophic groups
Ecological indices

ABSTRACT

Woody shrubs commonly co-exist with annual food crops in farmers' fields throughout the Sahel. Management strategies that deliberately include the native shrub *Piliostigma reticulatum* in Senegalese cropping systems result in soil functioning enhancement that benefits to the associated cereal. The objective of this work was to evaluate shrub effect on soil nematode communities. Soil samples were collected from an experimental design where pearl millet (*Pennisetum glaucum*) was cultivated alone or with *P. reticulatum* stands and mulch. Soil nematofauna characteristics were determined and compared with results from soil under pure shrub stands and from bare soil. The analysis of soil nematofauna, characterized by the abundance of different trophic groups and related indices (MI, maturity index; EI and SI, enrichment and structure indices), allowed discrimination between treatments with or without shrub presence. 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. The shrub also impacted other nematode trophic groups. The abundance of opportunistic bacterial feeders (mainly Cephalobidae) was increased in shrub treatments. Further research should explore consequences on cereal nutrition and nematicidal properties of *P. reticulatum*.

1. Introduction

In Sub-Saharan Africa, food security remains a major concern [1,2]. West African soils exhibit a poor inherent fertility [3] while agriculture is based on small-scale farming with very low external inputs. Moreover agricultural systems in this semi-arid region are mainly rain fed and thus highly vulnerable to climate variability and drought. Such constraints encouraged the development of alternative cropping systems tailored to social and environmental local conditions.

Native perennial woody shrubs are dominant in the West Africa landscape. *Piliostigma reticulatum*, one of the most common Sahelian shrubs, provides rural people with fuel, materials for construction, fodder for livestock and traditional medicine [4]. Native shrubs co-exist with staple food crops in farmers' fields. The accumulation of fertile soil particles beneath the shrub canopies resulting from a landscape-scale redistribution of resources generates nutrient-rich soil plots known as "fertility islands" [5,6]. Shrubs also confer improved microclimatic regimes within the vicinity of their canopy due to their deep rooting systems and associated hydraulic lift [7–9]. In semi-arid Senegal, traditional management of native perennial woody shrubs involves coppicing and burning aboveground residues in the spring, prior to the planting of row crops, to clear fields. Alternative systems in which annual crops and shrubs are intercropped while shrub residues return to soil as mulch are receiving increasing attention all over Sub-Saharan Africa [10]. Such a shrub management resulted in both nutrient and moisture-related benefits to pearl millet (*Pennisetum glaucum*) when associated with common shrubs in the Senegalese peanut basin [8,11]. Better carbon storage and nutrient cycling, and higher soil moisture improved cereal yields [8,9,11,12]. Microbial communities beneath shrubs are more diverse, more active, and different from soil outside the influence of the shrub [11,13].

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http://dx.doi.org/10.1016/j.ejsobi.2013.04.003

Abundant and functionally diverse, soil nematodes are important members of the soil biotic community and play an essential role in ecosystem functions [14–16]. Different nematode trophic groups are defined according to their feeding habits. Plant feeding nematodes, i.e. plant parasitic and root-hair feeders, cause damage to roots that alter the plant's ability to take up nutrients and water [17]. Bacterial and fungal feeding nematodes affect soil organic matter decomposition and nutrient cycling [14,18]. Other important trophic groups of free-living nematodes are the predators and omnivores for their role in regulating the populations of other soil organisms [15]. While plant species identity and diversity may affect soil nematode community [19], its analysis provides useful indicators to document soil processes and assess changes in soil conditions of agricultural systems [20].

This study aims at evaluating the response of soil nematode communities, as well as key food web indices, to intercropping pearl millet with *P. reticulatum*. We attempted to highlight possible impacts on plant feeding nematodes when millet is cultivated with shrub. We also postulated that beneficial nematode communities vary as a result of the acknowledged impacts of shrubs on soil water balance, increased biological activity, soil organic matter build-up, and fertility replenishment.

2. Materials and methods

2.1. Experimental field site

The study site was located at Nioro-du Rip in the Southern region of the Senegalese Peanut Basin (13°45 N, 15°47 W, and 18 m above sea level). The climate is semi-arid with mean annual precipitation of 750 mm distributed from July to September and mean air temperatures ranging from 20 °C in December–January to 35.7 °C in April–June (i.e. BSh climate unit according to the Köppen–Geiger's classification). The soil is a fine-sandy, mixed Haplic Ferric Lixisol [21], locally referred to as a Deck-Dior [22]. The dominant native shrub species at the site is *P. reticulatum* (DC.) Hochst (Caesalpinioideae), with stand of about 185 shrubs ha^{-1}.

The study was carried out on an existing experiment established in 2003 at a local agricultural research station. A 2500 m^2 area was fenced to prevent cattle grazing and public access. Pearl millet (*P. glaucum* (L.) R. Br.) was planted with presence or absence of *P. reticulatum* (four plots each). Plots (10 m × 4.5 m in size) were neither tilled nor fertilized. In the four plots randomly assigned to shrub and millet association, *P. reticulatum* stands were periodically pruned according to farmers' practices to minimize competition for light between shrub and crops: it was cut at the starting of the rainy season to install the main crop and the pruned biomass was chopped to approximately 1 cm length and surface-applied as a mulch to the plot from which it was harvested. Then subsequent sprouts were allowed to continue growing and reform into the shrub. The millet grain yields in 2011 were 500 kg ha^{-1} in no shrub plots (M) and 886 kg ha^{-1} when millet was associated with *P. reticulatum* (M + S), along with chopped shrub residues at the soil surface. Two additional treatments were randomly selected in the untouched part of the fenced area: Four shrubs with canopy diameter of approximately 2 m serving individually as a replicate for shrub (S) treatment and four areas of bare soil (5 m^2 each) as a control (C).

2.2. Soil sampling

Soils were collected from each subplot in August 2011 when ears were emerging in treatments with millet. Ten individual soil cores (3 cm in diameter) were randomly sampled at a depth of 0–10 cm in the individual root system for the shrub or millet treatments and between interlacing roots for shrub-millet association. The soil cores were mixed to make one composite sample per subplot. Fresh soils were transferred to the laboratory in a cooler and stored at 4 °C for a maximum of 5 days before analysis. A small portion of each soil sample was air-dried and sieved prior to soil physico-chemical analyses.

2.3. Soil parameters

Soil moisture was determined gravimetrically by drying at 105 °C for 48 h. Total carbon and nitrogen contents were quantified after dry combustion using an elemental analyzer (Flash *EA 1112* series, Thermo Finnigan, France) and total phosphorus was determined by colorimetry [23]. Soil pH values were measured in 1:2.5 (w:v) soil-to-water suspensions. Soil mineral N content was determined colorimetrically in KCl 1 M extracts by flow injection analysis [24]. Microbial biomass carbon was estimated by the fumigation–extraction method, using the gain in ninhydrin-reactive N after fumigation and multiplied by 21 [25].

2.4. Nematode community characterization

For each sample, nematodes were extracted from approximately 250 g of wet soil using a modified Seinhorst method [26]. Collected nematodes were counted at 40× magnification using a dissecting microscope before being fixed in a formaldehyde–glycerol mixture. A representative sub-sample mounted on mass slides was used for identification to genus or family level at a higher magnification (400×). Nematode taxon richness (S) was calculated based on the number of taxa identified. The Shannon–Weaver diversity index (H′) was used to evaluate the taxonomic diversity of the nematode community [27]. Nematode taxa were assigned to one of five trophic groups: bacterial feeders (Ba), fungal feeders (Fu), plant feeders (H), omnivores (Om) and predators (Pr) [28]. The Nematode Channel Ratio (NCR) was calculated to quantify the relative importance of fungal-fed and bacterial-fed trophic channels of the soil decomposer food web [29]. Nematodes were categorized into a 1–5 colonizer–persister (cp) series [28,30], ranging from extreme r- to extreme K-strategists. The cp classification allows the calculation of the free-living nematode Maturity Index (MI) as the weighted mean frequency of the cp classes for non-plant feeding taxa [28]. The Plant Parasitic Index (PPI) is comparable to the MI but computed only for the plant feeding nematodes [28]. The PPI/MI ratio was calculated [31] as a useful indicator of nutrient status in the soil [32]. Other nematode ecological indices [33] were also used to evaluate the soil nematofauna under the different plant treatments. The Enrichment Index (EI) measures the number of opportunistic bacterial and fungal feeders that respond quickly to the input of C and N sources [33]. The Structure Index (SI) indicates soil food web length and connectance.

2.5. Statistics

The treatment effects were analyzed with a one-factor ANOVA. Data normality was checked to ensure that the distribution met the underlying assumptions for further statistical analysis. If the variance was not sufficiently homogeneous even after logarithmic transformation, data were analyzed using the non-parametric Kruskal–Wallis test in combination with an appropriate post hoc analysis. Statistical analyses were performed with XLStat-Pro (v2010 AddinSoft®) to test for significant differences between the different treatments (at $P < 0.05$ unless otherwise stated). In order to assess the similarity of the nematode communities between treatments, cluster analysis (hierarchical agglomerative clustering, group average method) of Bray–Curtis similarity matrices was conducted on square-root transformed abundance data (64 taxa)