Science of the Total Environment 626 (2018) 776–784

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Soybean supplementation increases the resilience of microbial and nematode communities in soil to extreme rainfall in an agroforestry system

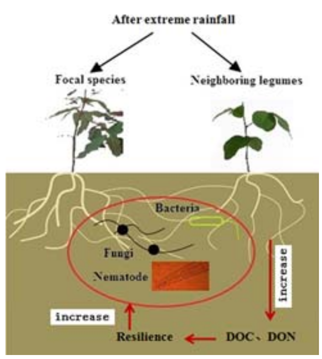
Feng Sun [a,b], Kaiwen Pan [a,*], Zilong Li [a,b], Sizhong Wang [a,b], Akash Tariq [a,b], Olusanya Abiodun Olatunji [a,b], Xiaoming Sun [a], Lin Zhang [a], Weiyu Shi [c,*], Xiaogang Wu [a]

[a] CAS Key Laboratory of Mountain Ecological Restoration and Bioresource Utilization & Ecological Restoration Biodiversity Conservation Key Laboratory of Sichuan Province, Chengdu Institute of Biology, Chinese Academy of Sciences, Chengdu 610041, People's Republic of China
[b] University of Chinese Academy of Sciences, Beijing 100039, People's Republic of China
[c] Chongqing Key Laboratory of Karst Environment, School of Geographical Sciences, Southwest University, Chongqing 400715, People's Republic of China

HIGHLIGHTS

- Intercropping with legumes increased the resilience of soil microbial community.
- Soil nematode community was more resilient in prickly ash and Soybean mixed culture.
- Plant composition was the driver to the resilience of soil biota communities.
- Soil dissolved organic carbon increased the resilience of biota communities.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 October 2017
Received in revised form 30 December 2017
Accepted 8 January 2018
Available online xxxx

Editor: Holden

Keywords:
Extreme rainfall
Zanthoxylum bungeanum
Resilience
Nematodes
Microorganisms

ABSTRACT

A current challenge for ecological research in agriculture is to identify ways in which to improve the resilience of the soil food web to extreme climate events, such as severe rainfall. Plant species composition influence soil biota communities differently, which might affect the recovery of soil food web after extreme rainfall. We compared the effects of rainfall stress up on the soil microbial food web in three planting systems: a monoculture of the focal species *Zanthoxylum bungeanum* and mixed cultures of *Z. bungeanum* and *Medicago sativa* or *Z. bungeanum* and *Glycine max*. We tested the effect of the presence of a legume on the recovery of trophic interactions between microorganisms and nematodes after extreme rainfall. Our results indicated that all chemical properties of the soil recovered to control levels (normal rainfall) in the three planting systems 45 days after exposure to extreme rain. However, on day 45, the bulk microbial community differed from controls in the monoculture treatment, but not in the two mixed planting treatments. The nematode community did not fully recover in the monoculture or *Z. bungeanum* and *M. sativa* treatments, while nematode populations in the combined *Z. bungeanum* and *G. max* treatment were indistinguishable from controls. *G. max* performed better than *M. sativa* in terms of increasing the resilience of microbial and nematode communities to extreme rainfall. Soil microbial biomass and nematode density

* Corresponding authors.
E-mail addresses: pankw@cib.ac.cn (K. Pan), shiweiyu@swu.edu.cn (W. Shi).

https://doi.org/10.1016/j.scitotenv.2018.01.063
0048-9697/

were positively correlated with the available carbon and nitrogen content in soil, demonstrating a link between soil health and biological properties. This study demonstrated that certain leguminous plants can stabilize the soil food web via interactions with soil biota communities after extreme rainfall.

1. Introduction

Agroforestry systems can promote agricultural production by minimizing nutrient loss, maximizing internal cycling of nutrients, improving the nitrogen (N) and carbon (C) content of the soil for C sequestration, enhancing soil biodiversity, and reducing the threat of extreme weather to target plants (Tsonkova et al., 2012).

A tree-based agroforestory system has been promoted as an ecologically-sustainable system that allows the use of conventional agricultural practices (Bainard et al., 2013). This system involves planting crops between widely-spaced rows of trees. The incorporation of trees as just one agroforestry property, can increase crop yields by reducing evaporation losses and by protecting of crops from excessive heat (Coulibaly et al., 2017). Moreover, crop yields are more stable under tree cover systems due to the ability of tree to modify microclimates by mitigating the effects of climate change, particularly extreme weather fluctuations within the cropping alley (Schoeneberger et al., 2012). However, the existence of trees in an agricultural system can also result in strong competition between trees and crops for soil nutrients and light (Friday and Fownes, 2002). These could, in turn, alter the resilence of soil microorganisms including microbial and nematode communities, to extreme weather fluctuation in a tree-based agroforestry system (Bainard et al., 2013). However, the consensus within the literature is that the positive aspects of tree cover to increase the general environment for crop growth becomes less suitable, especially when climate extremes increase (Lin et al., 2008). More studies are required to evaluate the specific impact of crops on the soil environment under extreme weather conditions. This will help to formulate more appropriate recommendations for tree cover management.

In tree-based agroforestory systems, the repeated decline of soil nutrients over time is inevitable, hence the introduction of leguminous plants, as an alternative to replenish the soil fertility, has become common-place, largely due to their ability to fix nitrogen (Gmezmuoz, 2014; Coulibaly et al., 2017). The presence of nitrogen-fixing leguminous plants has been reported to increase soil carbon and nitrogen content by increasing net primary productivity and the rapid turnover of high quality litter and root exudates (Zhao et al., 2014). Specifically, legumes can intensify the complexity of the soil environment (Gao et al., 2017). However, whether the intensified complexity of a soil environment can promote the resilence of microbial and nematode communities in soil to extreme climate stress is poorly understood. Different leguminous species may adopt differential strategies which may be more or less suited to mitigating the effects of extreme climate stress, such as heavy rainfall. For example, stressed plants tend to invest in defense compounds (e.g., phenols in leaves) and in storage compounds (e.g., root carbohydrates) to increase their resilience to short-term disturbance (Chen et al., 2013). The potential effect of plant compensation to water-saturated soil stress on soil communities may similarly build resilience, a phenomenon that necessitates further study.

Resilience has been well described in the literature as one of the components of ecological stability. Pimm (1984) defined resilience as how fast parameters return towards their equilibrium following a perturbation. Orwin and Wardle (2005) further presented a new resilience index by calculating the absolute difference that exists between disturbed soil and control relative to the initial absolute effect of disturbance. Griffiths and Philippot (2013) further suggested that engineering resilience is where the behaviour of a system is treated like an engineering material that will recover towards its predisturbance state or a new stable state; this engineering resilience approach now predominates in studies of soil biology. More recently, Wagner et al. (2015) used the concept of proportional resilience to describe the ability of a system to reach its original condition prior to disturbance. In the present study, we defined resilience as when the individual species abundance, species composition, and total density or biomass returns to control levels. The use of control and disturbed samples at the same time could take into account any changes occurring in the control and disturbed soils over time in the field (Griffiths and Philippot, 2013).

The adaptations of plants to extreme climate stress could significantly change the allocation of carbon to defense and storage and can also alter litter quality and quantity (Mariotte et al., 2016). These changes have the potential to affect the resilience of the soil community (Griffiths and Philippot, 2013). Although microbial resilience to drought has been reported to be related to the biomass of plant shoots and roots in a legume monoculture (Orwin and Wardle, 2005), the benefit of plant cover upon the resilience of a soil community to extreme rainfall, which has been predicted to increase under climate change, remains ambiguous. In this study, we tested the resilience of a microbial and nematode community in soil to an extreme rainfall event in three different agroforestry systems with legumes. Moreover, little is known about the effects of crops within an agroforestry system upon the stability of microbial and nematode communities in soil, since previous studies mostly focused on how different species of trees in agroforestry management can stabilize primary productivity.

Soil microbial and nematodes occupy central positions in the soil biota community and are considered as representing sensitive indicators for changes in soil health (Tom and Howard, 1999; Wagner et al., 2015). Moreover, these organisms play roles in carbon and nitrogen cycling that are vital to agricultural productivity. Soil nematodes span several trophic levels and play an important role in nutrient flow by grazing microbes, decomposing organic material and preying upon other animals in the soil (Bardgett and van der Putten, 2014). Similarly, the composition of the soil microbial community plays a key role in the decomposition of plant materials, nutrient cycling, soil carbon storage, conservation of soil structure and primary productivity (Fang et al., 2016). It has been suggested that microbial resilience is positively related to the dissolved organic carbon content of soil (de Vries et al., 2012) and that supplements of organic matter increase nutrient acquisition and the resilience of microbes to drying-rewetting stress (Sun et al., 2017). The resilience of bacterial-feeding nematodes has also been suggested to be positively correlated with both the dissolved organic carbon content of soil (de Vries et al., 2012) and plant species (Viketoft et al., 2009; Cesarz et al., 2013), with the latter appearing to exert the strongest influence of the two. We sought to test whether the resilience of microbial and nematode communities in soil are more dependent on plant identity or soil properties, such as dissolved organic carbon and nitrogen.

This field study examined the resilience of microbial and nematode communities in soil to severe soil wetting in monoculture plantations of prickly ash and plantations mixed with leguminous species (alfalfa and soybean). We hypothesized that the presence of legumes would have a positive effect on the resilience of microbial and nematode communities in soil and that the effect would depend on the species of legume. Our results should shed light on our potential to strengthen the resilience of agricultural ecosystems using ecological principles and provide evidence for the application of agroforestry for leguminous crops.