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Microbial community response to soil solarization in Nepal's rice–wheat cropping system

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Abstract

The Indo-Gangetic Plains of South Asia support 13.5 million hectares of rice–wheat cropping systems, which currently feed over one billion people. Intensified agriculture has resulted in a more than two-fold increase in rice and wheat yields since the 1970s; however, this continuous cropping has also exacerbated weed, pest and disease problems. Soil solarization is an accessible, low-risk management practice for small-holder farmers that has ameliorated these problems in some settings and has the potential to dramatically improve yields. Field trials were conducted at two sites in Nepal to test whether soil solarization: (i) had a lasting effect on soil bacterial, fungal and nematode communities; (ii) altered the rhizosphere communities of rice nursery seedlings and (iii) improved crop growth and yield in the rice–wheat cropping system. Rice seedlings were grown in nursery plots that were solarized for 28 days or left untreated and were transplanted to field plots that were also either solarized for 28 days or not in a randomized complete block design with four replications. Rice was grown to maturity and harvested, followed by a complete wheat cropping cycle. Solarization of main field plots increased counts of fungal propagules and decreased root galling and nematode counts and decreased weed biomass. Terminal restriction fragment length polymorphism (T-RFLP) analyses of extracted soil DNA revealed significant shifts in fungal community composition following soil solarization, which was sustained throughout the entire rice cropping cycle at both field sites. The bacterial community composition was similarly affected, but at only one of the two sites. Despite the observed changes in soil microbial community composition over more than one cropping period, solarization had no impact on crop productivity at either site. Nevertheless, such changes in soil microbial communities in response to solarization may be responsible for increased yields observed at other sites with greater pathogen pressure. This practice has shown promising results in many farmers' fields in South Asia, but further elucidation of the mechanisms by which solarization increases productivity is needed.

Keywords: Additive main effects and multiplicative interaction model; AMMI; Indo-Gangetic plains; Nematodes; PCR fingerprinting; Rice–wheat; Soil bacteria; Soil ecology; Soil fungi; Soil microbial community; Solarization; T-RFLP

1. Introduction

The rice–wheat cropping systems of the Indo-Gangetic Plains encompass over 12 million hectares and account for 90% of the food produced in this area (Reeves, 2001). The intensification of agriculture in this region since the 1970s has rewarded farmers with more than a two-fold increase in rice and wheat yields. However, yields in some regions are stagnating and even declining despite increased use of agrochemical inputs (Harrington et al., 1989; Byerlee and Siddiq, 1994; Fujisaka et al., 1994; Gill, 1994; Singh and Paroda, 1994; Hobbs and Morris, 1996; Duxbury, 2001). This decline in productivity is attributed to the loss of soil organic matter and mineral nutrients, increased pressure from weeds, pests and diseases, and the loss of soil aggregate stability and subsequent decline in soil structure from continuous rice–wheat rotations (Gill, 1994; Hobbs and Morris, 1996; Cohen et al., 1998). Infestations of insects, pathogens, nematodes and weeds may lead to an estimated average yield loss of 20% in rice and 30% in wheat (Sehgal et al., 2001). Soil solarization is a management tool that has shown promise in ameliorating these biological constraints and increasing productivity in these

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systems (Dubin, 1992; Ganguly et al., 1996; Devare, M.H., unpub. Ph.D. Thesis, Cornell University, 2000; Duxbury, 2000; Duxbury and Lauren, 2004).

Soil solarization is the solar heating of moist soil by mulching with clear plastic sheeting. Heating the surface soil over a period of several weeks helps to control pathogenic fungi and oomycetes (Pullman et al., 1981; Kaewruang et al., 1989a; Le-Bihan et al., 1997; Lopez-Herrera et al., 1998), and phytoparasitic nematodes (Barbercheck and Von Broembsen, 1986; Stapleton and Heald, 1991; Pokharel, 1995; Lamberti et al., 2000). Solarization also effectively controls weeds, increases soil nutrient availability (Elmore, 1991; Katan and Devay, 1991; Linke, 1994; Schreiner et al., 2001) and increases populations of known beneficial bacteria (Kaewruang et al., 1989b; Gamliel and Katan, 1991) and fungi (Tjamos and Paplomatas, 1988; Kaewruang et al., 1989b). Soil solarization may also have several indirect effects on the soil biota. Many plant pathogenic organisms, such as oomycetes, may be weakened by heat stress, while saprophytic and/or antagonistic organisms may be less adversely affected. Through direct antagonism, or increased competition, thermal-tolerant organisms may then out-compete mesophilic pathogens (Devay, 1991).

Increases in productivity are commonly observed in crops planted in solarized soil, and several experiments have shown that the beneficial effects of soil solarization can last for more than one cropping cycle (Katan, 1987; Abdel Rahim et al., 1988; Tjamos and Paplomatas, 1988; Devay and Katan, 1991). This suggests that solarization may invoke a more permanent change in the soil, most likely biological, that is not solely attributable to a short-term increase in nutrient availability following solarization (Devay and Katan, 1991).

Most soil solarization research has been conducted on vegetable and legume crops. It has rarely been tested in cereal cropping systems. There is good reason for this—it is generally neither feasible nor cost-effective to solarize entire cereal fields. However, this management practice may be applied readily as a pre-plant treatment in rice nurseries. The dense seeding rate and relatively small area planted make solarizing rice nursery soils a low-cost, and thus, low-risk investment that has the potential to bring high returns.

Solarization in rice has been used in South Asia in both farmers' fields and experimental research plots and has resulted in increased rice seedling establishment, increased vegetative growth and greater grain yields (Dubin, 1992; Ganguly, 1996; Devare, loc. cit.; Duxbury, 2000; Banu et al., 2005). Use of rice nursery soil solarization by farmers in Nepal and Bangladesh is presently being advocated as a practical, accessible and effective approach for improving productivity in the rice–wheat system (Duxbury and Lauren, 2004).

We aimed to gain a better understanding of the changes in soil bacterial, fungal and nematode communities that occur as a result of soil solarization in the rice–wheat cropping systems of Nepal. The objectives of this study were to test whether: (i) the process of soil solarization had an immediate and lasting effect on soil bacterial, fungal and nematode communities, (ii) solarized rice nursery soils contained an altered (less pathogenic/more beneficial) rhizosphere community within and around the roots of the rice seedlings and (iii) rice and wheat yields increased in response to solarizing rice nursery soil or field soil prior to transplanting rice or a combination of these treatments.

2. Materials and methods

2.1. Site description

Field trials were established at two sites in Nepal. The Khumaltar field site is located at the Nepal Agricultural Research Council (NARC) Agronomy Station in Kathmandu (altitude 1350 m; 27°7′N; 85°3′E). The soil is a silty clay loam with 2.1% organic matter and pH 5.6. Khumaltar lies within the Kathmandu Valley, in the Hills, which comprise 24% of total rice-producing area and 42% of total wheat-producing area in Nepal (Mathema, 1994). The field site at Rampur is situated in the experimental farm at the Institute of Animal and Agricultural Science (190 m; 27°7′N; 85°3′E). The soil is a sandy loam with 2.4% organic matter and pH 5.4. The Rampur site is located in the Terai plains bordering India, where 73% of the rice and 51% of the wheat is produced in Nepal (Mathema, 1994).

2.2. Experimental design and agronomic management

A two-way factorial was used at both sites, arranged in a randomized complete block design with four replicates. The treatments were: (i) rice seedlings from a **S**olarized nursery soil transplanted into **S**olarized field soil (**SS**), (ii) rice seedlings from a **S**olarized nursery soil transplanted into **N**on-solarized field soil (**SN**), (iii) rice seedlings from a **N**on-solarized nursery soil transplanted into **S**olarized field soil (**NS**) and (iv) rice seedlings from a **N**on-solarized nursery soil transplanted into **N**on-solarized field soil (**NN**). Each main field plot measured $3\times4\,\mathrm{m}^2$ and was surrounded by a ~0.5 m-wide bund.

Soil in the nursery and field plots was tilled manually and wetted to field capacity. Two hundred gauge transparent polyethylene sheeting was laid over randomly selected nursery and field plots and sealed around the edges. During the 28 day solarization period, soil temperature was measured at 5 and 10 cm depths 3 days a week between 13:00 and 15:00 h. After 28 days, the plastic was removed from the treated plots. Three days after removing the plastic, the rice nursery plots were tilled manually to 15 cm depth and fertilizer was applied. At Khumaltar, urea was applied at $80\,\mathrm{kg\,N\,ha^{-1}}$. At Rampur, urea, diammonium phosphate (DAP), and muriate of potash, (MOP) were applied at $100{:}60{:}40\,\mathrm{kg\,NPK\,ha^{-1}}$.

Rice seed was broadcast in the nursery plots at a rate of $120\,\mathrm{kg\,seed\,ha^{-1}}$, and covered with 3–5 cm soil. The rice