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Reducing environmental risk of excessively fertilized soils and improving cucumber growth by *Caragana microphylla*-straw compost application in long-term continuous cropping systems

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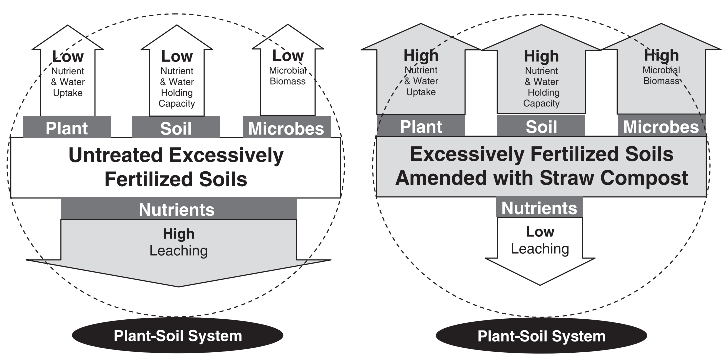
HIGHLIGHTS

- Excessively-fertilized soils had high nutrient leaching in monoculture systems.
- Straw compost decreased nutrient leaching in excessively-fertilized soils.
- Straw compost reduced pathogens in soils with very high mineral nitrogen level.
- Cucumber growth was enhanced by straw compost in excessively-fertilized soils.

GRAPHICAL ABSTRACT



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ABSTRACT

Continuous cropping is a common agricultural practice in the word. In China, farmers often apply excessive fertilizers to fields in an attempt to maintain yields in continuous cropping systems. However, this practice often results in high nutrient concentrations in soils, nutrient pollution in leaching water and more crop disease. Here, we investigated 8 different soils from continuously cropped cucumbers in Northern China that grouped into those with extremely high nutrient levels (EHNL) and those with lower nutrient levels (LNL). All soils were treated with *Caragana microphylla*-straw (CMS) compost addition, and then were used to measure soil physiochemical and microbial properties, leaching water quality, plant root growth and cucumber fruit yield. In general, the EHNL-soil showed higher nitrate, phosphorus and potassium concentrations in the leaching water compared to the LNL-soil. However, the CMS compost application increased soil nutrient and water holding capacities, total microbial biomass (bacteria and fungi), root length, plant biomass and fruit yields, but decreased nutrient concentrations in the leaching water from the EHNL-soil. In addition, the CMS compost decreased the number

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Caragana microphylla-straw compost
Plant growth

of *Fusarium oxysporum* f. sp. *cucumerinum* in soils with very high concentration of mineral nitrogen. Our results infer that CMS compost application was an effective method for reducing environmental risk of excessively fertilized soils.

1. Introduction

Continuous cropping of one crop without rotation with other crops is a common agricultural practice in the world, especially when there is a high demand for the one crop. This agricultural practice is becoming more prevalent due to factors such as improved mechanization, availability of external chemical inputs, favorable economic market trends, and government policies (Bennett et al., 2012). However, continuous cropping often leads to yield declines over time due to replant disease, deleterious rhizosphere microorganisms, nutrient imbalance and more (Ray et al., 2012; Bennett et al., 2012). Although many agricultural practices have been suggested and evaluated to overcome this yield decline (Ray et al., 2012), continuous cropping remains a challenge.

In China, farmers often apply excessive fertilizers to fields (Vitousek et al., 2009; Guo et al., 2010) in an attempt to maintain yields in continuous cropping systems. A national survey demonstrated that most Chinese agricultural fields have been degraded because of large and excessive inputs of chemical fertilizers (Guo et al., 2010). Under excessive fertilization, nutrient uptake efficiency begins to decline and, consequently, the unused nutrient is released into the environment through leaching and biogeochemical processes such as denitrification and ammonia volatilization (Ju et al., 2009). This means that the excessive fertilizer application can result in high nutrient concentrations in soils and nutrient pollution. In addition, the excessive fertilizer application tends to cause more disease (Huber and Watson, 1974; Van Bruggen, 1995).

Due to the desire to produce both high yields and have low environmental pollution, it is necessary to make nutrient use more efficient and to simultaneously solve the problems of replant disease in continuous cropping systems. One effective method is to amend soil with organic composts. Organic composts increase soil water-holding capacity, improve soil aggregate stability (Chalhoub et al., 2013) and enhance the overall soil microbial community diversity and activity so that it is better able to suppress soil-born plant pathogens (Hadar, 2011). This benefit has been sufficiently proven. However, little information is available regarding the effects of compost on the properties of excessively fertilized soils, especially in continuous cropping systems.

The beneficial effects of composts may not be realized, however, if high levels of inorganic fertilizers are also added with the compost. In such case, there is no need for biological activity to mineralize the composts and release nutrients for plant uptake. Several recent studies have demonstrated this link between nutrient cycling and mineral nutrient levels in soils, and that the growing plant and soil microorganisms affect this process. For example, when nitrogen (N) is limiting in soils, net N mineralization rate approximately matches the N uptake demands of plants and microorganisms, and N leaching and gaseous losses are negligible (Thomas et al., 2015). However, excessive N inputs leads to reduced N cycling activity associated with N mineralization while stimulating activity related to soil ecosystem N loss (Liu et al., 2013; Thomas et al., 2015).

The combination of excessive mineral fertilizer application and continuous cropping generally results in extremely high and variable mineral nutrient levels in soils (Guo et al., 2008; Tian et al., 2010). We hypothesize that very high mineral nutrient levels will reduce the activity of some soil microorganisms and induce soil ecosystem nutrient loss compared to soil with much lower mineral nutrient levels. Compost applications are also hypothesized to reduce environmental risk related to nutrient loss in excessively fertilized soils.

The cucumber rhizosphere microcosm is a useful model system for the study of microbiological and biogeochemical processes in soil with high mineral nutrient content during vegetable production. Cucumber can be rapidly grown and is a commonly consumed vegetable throughout the world. In China, continuous cropping is a common agricultural practice in cucumber production systems and often leads to yield declines over time (Tian et al., 2010). Farmers often apply excessive mineral fertilizers in an attempt to maintain yields in cucumber production systems (Guo et al., 2008). In this study, we investigated 8 different soils from continuously cropped cucumbers in Northern China. Those soils were divided into those with extremely high nutrient levels and those with lower nutrient levels. All soils were treated with *Caragana microphylla*-straw compost application and then were used to measure plant growth, soil nutrients, microbial biomass and abundances and water quality. *C. microphylla* is a perennial leguminous shrub highly tolerant to drought, salt and extreme cold in poor, sandy and well-drained soils (Dai et al., 2014). It has been widely used as high-energy firewood and the forage for live-stock, as well as a windbreak to protect soils from desertification in the northern China (Yan et al., 2007). The objectives of this study were to examine (1) whether soils with extremely high mineral nutrient levels have different environmental risk, soil microbial properties, plant biomass and cucumber yield compared to soils with lower mineral nutrient levels, and (2) how environmental risk and plant growth may be affected by amending soil with *C. microphylla*-straw compost.

2. Materials and methods

2.1. Site description and experiment design

The study was conducted with continuously cropped cucumber soils sampled from 8 vegetable farming sites in northern China (Beijing area) in July 2012. Mean annual rainfall in this area is about 480 mm and mean air temperature is 14.0 °C. The soils under greenhouse conditions were selected to cover a wide range of cucumber cropping history (i.e. from 7 year to 17 years). A description of land use history, including selected chemical properties is given in Table 1. Methods used to measure the soil properties are also provided (see the Section 2.2).

The soils were divided into four groups based on mineral nutrient concentrations (Table 1). For the group N, the HN soil had very high concentrations of mineral N (323 mg kg^{-1} soil) compared to the LN soil with lower mineral N concentrations (47.9 mg kg^{-1} soil). For the group P, the HP soil had very high concentrations of available P (350 mg kg^{-1} soil) compared to the LP soil with lower available P concentrations (58.3 mg kg^{-1} soil). For the group K, the HK soil had very high concentrations of available K (450 mg kg^{-1} soil) compared to the LK soil with lower available K concentrations (42.1 mg kg^{-1} soil). For the group NPK, the HNPK soil had very high concentrations of available nutrients (mineral N, available P and available K were 684, 358 and 687 mg kg^{-1} soil, respectively) compared to the LNPK soil with lower available nutrient concentrations (mineral N, available P and available K were 49.2, 79.1 and 31.0 mg kg^{-1} soil, respectively). The soils were grouped in this way to provide a means of determining the effects of soil nutrients on environmental risk and plant growth.

All soils were treated with/without compost application. The characteristics of compost, prepared from *C. microphylla*-straw and chicken manure (the initial and final C/N ratios were 30 and 17.5, respectively), are listed in Suppl. Table 1. Cucumber plants were allowed to grow with different soil amendment treatments. The treatments were (1) the