Dual roles of spent mushroom substrate on soil improvement and enhanced drought tolerance of wheat *Triticum aestivum*

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Key words: drought, spent mushroom substrate, soil remediation, wheat

Abstract

This study examines the effects of the spent substrate of oyster mushroom (SMS) for growing wheat at different drought conditions. The SMS not only served as the sole fertilizer to produce normal growth and grain yield of wheat but also improved the soil quality after harvest to raise the soil organic matter, maintain the soil alkalinity and increase field capacity unlike the synthetic fertilizer amendment. Simultaneously, SMS treatment enhanced drought tolerance of wheat by enabling germination at 8.5% soil water content and completing sexual reproduction to grain production even at 6.3% soil water content.

Introduction

Water shortage is a cosmopolitan problem that one person in five is inaccessible to safe drinking water. 70% fresh water of human activities are used in agriculture (http://www.epa.gov). Drought attacks 14% wheat fields in Europe and affects over 12-million acres of agricultural soil in China (http://www.fao.org; http://www.agri.gov.cn). Nevertheless, being an active and rapid nutrient depletion process, more than 140-million tons of inorganic fertilizers were used for agricultural activities (http://www.fao.org), application of which inevitably introduces contaminants especially heavy metals to the farmlands (Gimeno et al.1995). About 13.4% of farmlands worldwide suffer from heavy metal contamination (http://www.epa.gov). Spent mushroom substrate (SMS) is the solid residue left after harvest of the aerial crop in mushroom industry and is generated at a ratio of 2 - 5 to 1 of the edible crop (Chiu et al. 2000). Over 3.3 million tonnes of edible mushrooms were produced in 2005, and over 34% were grown in Europe (http://www.fao.org). With the readily available nutrients released from substrate degradation and high organic matter content, SMS has been employed as a soil amendment agent (Gong et al. 2006, Lau et al. 2003 and Law et al. 2003). In this study, oyster mushroom of the genus *Pleurotus* was used as it could grow worldwide on a variety of substrates (e.g. coffee pulp, sawdust, straw) (Chang et al. 2004 and Chiu et al. 2000). Wheat *T. aestivum* is the champion crop produced in China who is also the champion producer and exporter of edible and medicinal mushrooms. Thus, we aim to test the feasibility of substituting synthetic fertilizer (SYN) with the SMS of mushroom *P. pulmonarius* in growing wheat and assess the impacts on soil properties as well as determine any protective effect of the SMS on wheat from drought stress.

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Materials and methods

Preparation of the P. pulmonarius SMS

Straw, wheat bran and lime were mechanically mixed in a ratio of 86:13:1 (w/w/w) and piled up for one-week fermentation with two turnings to avoid overheat. After packed, autoclaved at 121 and inoculated with *P. pulmonarius* strain PL-27, the culture was incubated in darkness at 28 until the mycelium fully colonized the substrate. Then the culture was transferred to an environmental chamber under 12 hr dark and 12 light illumination cycles at 28 with 80% relative humidity. The solid residue after mushroom harvest, called SMS was collected for later use (Chiu et al. 1998). The characteristics of SMS in this study were listed in Table 1.

Tab. 1: Characterization of SMS used in this study (Mean±SD,n=5)

Parameter	$NOx_{water-soluble}$ (mg/kg)	$N_{Kjeldahl}$ (mg/kg)	P_{total} (mg/kg)	K (mg/kg)	pH	Salinity (%)
SMS	452 ± 101	1277 ± 82	1300 ± 50	3280 ± 346	8.0 ± 1.3	nd*

* “nd” represents “non-detectable”

Drought stress on wheat and the protective effect of SMS

Garden soil (pH 7.0, 0.7% total carbon content and sandy clay loam soil) was used for wheat germination. The soil was mixed with SMS to 5 different ratios from 0.0 to 10.0% (SMS in soil, w/w). The optimal soil water content (SWC) for growing wheat had previously been found to be 17.0% with the saturated water moisture at 34.0%. Five constant irrigation amounts were chosen to maintain soil water contents at 6.3, 8.5, 11.9, 17.0 and 25.5% (v/w) during the observation period. The germination frequency and seedling growth were measured according to USEPA method 712-C-96-154 (OPPTS 850.4200) (Chiu et al. 2006).

Effects of SMS and SYN on wheat cultivation

Synthetic fertilizer (Nitrophoska® 15-15-15, BASF Chemical Co., Germany) was added to soil to provide: 20 g N/m^2, 20 g P/m^2 and 20 g K/m^2. 5.3% SMS providing an equivalent N amount were studied in parallel. Wheat was cultivated in the University greenhouse in pots (15 cm radius and 30 cm height) from Nov. 2005 to Apr. 2006. Three replicates of each treatment were put in a completely randomized design. Five seeds per pot were sown directly to the soil amended with fertilizers or SMC and irrigated until pre-tillering stage. Drought treatments were then imposed by irrigating to different SWC at 3 day intervals. Growth and grain yield of wheat were recorded. The corresponding soil samples at different developmental stages of wheat were collected at depths of 0-20 cm for chemical and physical analyses (Chiu et al. 2006). Field capacity defined as the water content held in pores by capillary force was also examined (Zheng et al. 2000).

Results and discussion

Protective effect of SMS on wheat germination

6.3% SWC caused extremely drought and totally inhibited seed germination (Figure 1). However, without SMS amendment, no germination at 8.5% SWC was observed while the inclusion of 5.3% SMS enabled 40% seeds to germinate. In the presence of 7.7% SMS or above, seed germination was raised to 100% even at 11.9% SWC.

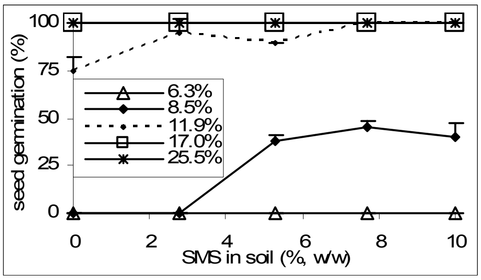

Figure 1: The protective effect of the SMS of *P. pulmonarius* on seed germination of wheat under 6.3, 8.5, 11.9, 17.0 and 25.5% soil water contents

Soil improvement and protective effect of the SMS against drought

Tab. 2: Characterization of soil before sowing (BS) and after harvesting (AH)

Parameters	**SWC (%)**	**Soil + SMS**		**Soil + SYN**	
		BS	AH	BS	AH
NOx water-soluble (mg/kg)	6.3	16.4± 4.6	47.6± 14.1	48.4± 4.8	14.1± 4.1
	17.0		43.6 ± 10.7		8.1 ± 5.3
$N_{Kjeldahl}$ (mg/kg)	6.3	126± 49	46 ± 4	112 ± 57	50 ± 5
	17.0		45 ± 4		20 ± 2
P_{total} (mg/kg)	6.3	344 ± 48	1734 ± 15	302 ± 25	131 ± 28
	17.0		180 ± 31		124 ± 11
K (mg/kg)	6.3	990 ± 71	482 ± 58	1007 ± 797	434 ± 90
	17.0		488 ± 98		504 ± 45
pH	6.3	7.2 ± 0.2	7.0 ± 0.1	6.8 ± 0.1	6.7 ± 0.0
	17.0		7.0 ± 0.1		6.9 ± 0.1
Field capacity (%)	6.3	36.8 ± 8.5	26.2 ± 4.8	19.4 ± 5.0	22.6 ± 4.2
	17.0		31.3 ± 7.6		17.8 ± 1.3
Aerial biomass (g/plant)	6.3	/	1.2 ± 0.1	/	0.6 ± 0.1
	17.0	/	3.9 ± 0.2	/	4.0 ± 0.2
Grain yield (mg/plant)	6.3	/	585 ± 110	/	22 ± 37
	17.0	/	8242± 441	/	6602 ± 425

Table 2 shows the soil properties of both SMS and SYN treatments and also the plant harvested under extreme drought condition (6.3% SWC) and optimal irrigation condition (17.0% SWC). SMS provided equivalent N, P and K to soil as SYN. However, the latter dropped soil pH to < 7.0 during cultivation, while SMS buffered pH above 7.0 at all soil water conditions. Furthermore, significant increases of field capacity in SMS treatment versus SYN amendment were detected at four soil water conditions (except 25.5% SWC). The greatest effect was observed before sowing: the field capacities of SMS- and SYN-amended soil were 38.6 and 19.4%, respectively. As to wheat growth, 2-fold increase of aerial biomass was observed in SMS treatment under extreme drought condition of 6.3%, while similar growth was shown at 25.5% SWC of both the SMS and SYN treatments. Almost no seeds were borne in headings of wheat grown in SYN-amended soil at 6.3% SWC while wheat produced normal seeds at the same water content but with SMS amendment. No differences of grain yields showed between 17.0% and 25.5% soil water contents (6691 kg/ha) but drought conditions of 11.9% SWC or lower significantly decreased grain yield to 20% or less in both SMS and SYN treatments. However, SMS increased grain yield by 1.1 fold (at 25.5% SWC) to 2.5 fold (at 8.5% SWC) over SYN amendments.

Discussion and conclusions

This study shows that SMS could protect wheat under drought stress at various stages: seed germination from 8.5% SWC onwards, wheat growth from tillering stage onwards and seed production from 6.3% SWC onwards. Also, the SMS could totally substitute SYN in wheat cultivation and increase the grain yields. The wheat grain yield obtained in this study was comparable to those reported in literature (6552-6772 kg/ha) (Eitzinger et al. 2003). Besides, such application of SMS also improves soil properties, namely: pH buffering effect and field capacity which, in return, improved water availability to plants, as well as water using efficiency and arrests yield declines and sustain agricultural productivity.

Mushroom cultivation utilizes mostly agricultural waste for production, and SMS is a waste generated from mushroom production. This waste, SMS is now demonstrated to be applicable in organic farming as a waste treatment method and also a sustainable practice.

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