European Journal of Soil Biology 75 (2016) 8–14

Contents lists available at ScienceDirect

European Journal of Soil Biology

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

Original article

Effect of synthetic and natural water absorbing soil amendments on soil microbiological parameters under potato production in a semi-arid region

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A R T I C L E I N F O

Article history:
Received 25 January 2016
Received in revised form
29 March 2016
Accepted 4 April 2016
Available online 19 April 2016

Handling Editor: Prof. C.C. Tebbe

Keywords:
Soil amendment
Soil microbiological properties
Soil enzymatic activity
Soil microbial biomass

A B S T R A C T

The effect of water absorbing soil amendments on soil microbiological properties (soil enzyme activity and soil microbial biomass) was investigated in a field experiment under potato production in a semi-arid region in northern China in 2010–2012. Treatments included two different synthetic water absorbing amendments (potassium polyacrylate-PAA, polyacrylamide-PAM) and one natural amendment (humic acid-HA), both as single amendments, and combined amendments (natural combined with a synthetic) and a no amendment control. Soil amendments had a highly significant effect ($P \leq 0.01$) on soil enzyme activity (catalase, invertase, urease and phosphatase) and soil microbial biomass (carbon, nitrogen and phosphorus). The PAM + HA amendment treatment achieved the greatest effect on soil microbiological properties of all of the amendment treatments, both in all soil layers between 0 and 40 cm, and at all four measurement periods during the growing season. Soil amendments improved the catalase, invertase, urease and phosphate by 4.6–39.8%, 4.4–27.7%, 3.7–40.4% and 0.9–29.8% respectively and increased soil microbial biomass carbon, nitrogen and phosphorus by 2.5–27.3%, 2.4–28.1% and 3.5–31.6% respectively in all three years. Water absorbing soil amendments improved soil quality by increasing soil moisture content and its microbiological status, as reflected in the values of microbial biomass and enzymatic activity.

1. Introduction

Soil is living, dynamic, material, and non-renewable on the human time scale and plays many key roles in terrestrial ecosystems; it is a natural resource of great importance, and need to restore for sustainable utilization in agriculture [1]. Soil management strategies can play a critical role in sustainable agriculture, and influence soil quality by altering soil properties [2]. In semi-arid and arid areas, climate is often characterized by periods of high rainfall followed by long periods of little or no rain, intermittent dry spells, recurrent drought years, high evaporative demand and often soils with inherent low-fertility which are vulnerable to erosion [3]. Application of water absorbing soil amendments is an effective soil management to restore the degraded soils, which is a viable alternative and practical strategy for sustainable agricultural production in these areas [4,5]. Synthetic polymer such as polyacrylamide (PAM) is one kind of water absorbing soil amendment; it can absorb water, up to 400 times or more of its than own weight [6,7], retains the limited and intermittent rainfall, reduces the evaporation and provides more plant available water and nutrients for crop growth [8–11]. Another potential natural soil amendment is humic acid (HA) which can improve water availability for crops in arid and semi-arid water stressed soils [12]. HA also can improve unfavorable soil properties and nutrient uptake by increasing macro aggregation, organic carbon, and macronutrients and also can result in a short-term increase in electrical conductivity levels [13,14]. In previous

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http://dx.doi.org/10.1016/j.ejsobi.2016.04.002
1164-5563/

research, both synthetic polymer and natural soil amendments exhibited beneficial effects on soil properties [13,15,16].

Microbial biomass and soil enzymes have been cited as potential indicators of soil microbiological properties because of their highly sensitive response to temporal variations of soil quality [17,18]. Moreover, microbial biomass and soil enzymes are related to biochemical processes in soil biology [19]. Microbial biomass and soil enzymes could be affected by environment conditions including proximal factors (soil moisture, temperature, pH) and site factors (elevation, latitude, soil texture, climate) [20]. Furthermore, soil moisture content and temperature were usually considered as the two critical factors for soil microorganisms [21]. Soil moisture content was identified as the major factor influencing soil microorganisms in the semi-arid areas [20]. Soil microorganisms are involved in soil nutrient cycling and play an important role in soil ecosystems [22,23]. Nevertheless, the metabolic activity of most soil microorganisms will decline with the onset of unfavorable soil environmental conditions such as decreasing available soil water [24]. Consequently, improving soil available water would be an appropriate strategy to improve metabolic activity and crop productivity during drought stress in a semi-arid region. As microbial activity is known to be sensitive to temporary variations in soil parameters, information on microbiological indicators of soil treated with soil amendments would provide valuable insight into the effect of the amendments on the extent of soil quality variation. There is presently insufficient information on water absorbing soil amendment effects on soil microbiological property attributes in semi-arid region.

In the semi-arid regions of northern China, potato is an important cash crop. We hypothesized that water absorbing soil amendments (PAA, PAM and HA) would enhance soil microbial community activity and provide more ecosystem services in the fragile environment in these regions. The objective of this study was to ascertain soil enzymatic activity (catalase, invertase, urease and alkaline phosphatase) and microbial biomass (carbon, nitrogen and phosphorous) in a rain-fed potato field treated with water absorbing soil amendments in a semi-arid region. Both soil enzymatic activity and microbial biomass measured in this study are involved in soil nutrients cycling, i.e., C, N and P mineralization, nitrification potential, and these parameters can help us to reveal the mechanism of soil amendments effect on soil quality. We hypothesized that soil amendments enhanced soil microbial community and the activities. Furthermore, soil amendments will provide more ecosystem services with the fragile environment in these regions.

2. Materials and methods

2.1. Experimental site and design

The experimental field was located in Dadoupu village (41°10′N, 111°36′E) of Wuchuan County, Hohhot, Inner Mongolia, China. It was typical of arid and semi-arid regions. The mean precipitation was about 350 mm, mean annual pan evaporation at the site was more than 2000 mm, mean annual temperature was 3.0 °C, frost-free period was around 125 d, and altitude was 1621 m. The soil was sandy loam and alkaline (pH 8.2) containing 8.3 g kg^{-1} organic carbon, 0.97 g kg^{-1} total nitrogen, 0.026 g kg^{-1} alkaline nitrogen, 0.0102 g kg^{-1} available phosphorus, and 0.084 g kg^{-1} available potassium.

This experiment was a randomized complete block (RCB) factorial design with three replications; each plot was 30 m^2. The study was conducted from 2010 to 2012 in the potato phase of an oat-potato rotation field started in 2006. In this study, soil amendments were two different synthetic water absorbing amendments (potassium polyacrylate-PAA, polyacrylamide-PAM) and one natural amendment (humic acid-HA). There were six treatments consisting of different combinations of water absorbing soil amendments: control with no amendment application (CK), 45 kg ha^{-1} PAA (T1), 45 kg ha^{-1} PAA plus 1500 kg ha^{-1} HA (T2), 45 kg ha^{-1} PAM (T3), 45 kg ha^{-1} PAA plus 1500 kg ha^{-1} HA (T4) and 1500 kg ha^{-1} HA (T5). T1, T3 and T5 were single amendment treatments; T2 and T4 were combined amendments treatments each with two amendments, one synthetic and one natural (HA). All amendments were applied annually as a single treatment and were broadcast with fertilizer prior to seeding and incorporated into the soil by cultivating. The one time rate of different soil amendments was determined by previous unpublished research in our laboratory. The same soil amendments were applied in both oat and potato phases of the rotation each year since 2010.

2.2. Experimental protocol

The tillage system was fall plow and spring cultivate. Compound granular fertilizer (17-6-23) was applied each year at 400 kg ha^{-1} resulting in 68 kg ha^{-1} nitrogen, 24 kg ha^{-1} phosphorous and 92 kg ha^{-1} potassium. The compound granular fertilizer was specially formulated for potato production and was used by local farmers. Each year, the potato variety was Kexin No.1 and the oat variety was Yanke No.1 in the rotation field; both cultivators were commonly grown in arid and semi-arid regions in Inner Mongolia. Both the potatoes and oats were planted by planter with conventional flat planting (i.e. not ridged) on 16 May 2010, 17 May 2011 and 14 May 2012. The tuber seed pieces were placed 10 cm deep with plant spacing 30 cm and row spacing 60 cm. Weed control was by manual hoeing when required. Harvest was in late September, 2010 and 2011, 130 d after sowing; harvest was 20 d earlier (110 d after planting) in 2012 due to an early frost.

2.3. Field and laboratory measurements

Soil samples were retrieved from each plot from at least three random positions with a manual soil auger, at depths of 0–10, 10–20 and 20–40 cm at 50, 70, 90 and 110 d after sowing; the three samples from each plot at each depth were combined to form a composite sample. A portion of each composite was packed in an aluminum box for subsequent soil moisture content measurement by the oven dry method. The remainder of the soil was sieved (<2 mm), approximately 250 g of each sample was stored at 4 °C and subsequently used for microbial biomass assays, and approximately 100 g was air-dried for enzyme activity assays.

Soil catalase activity was measured by incubating a 2 g air-dried soil sample with 2 ml of 0.3% H_2O_2 solution at 30 °C. After 30 min, 0.1 M $KMnO_4$ was used to titrate the suspension solution, the activity of catalase was expressed as 0.1 M $KMnO_4$ ml g^{-1} soil 30 min^{-1} [25]. Soil invertase activity was measured by incubating 5 g air-dried soil sample with 15 ml of 8% sucrose solution at 37 °C in an incubator (Model: RXZ500D, Ningbo Jiangnan Instrument Factory, Ningbo, Zhejiang, China). After 24 h, the suspension was reacted with 3, 5-dinitrosalicylic acid and the absorbance was measured by a spectrophotometer (Pharmaspec UV-1700, Shimadzu, Kyoto, Japan) at 508 nm wavelength. The activity of invertase was expressed as mg glucose g^{-1} soil 24 h^{-1} [26]. Similarly, 5 g air-dried soil sample was incubated with 10 ml of 10% urea solution at 37 °C in an incubator for measuring soil urease activity. After 24 h, the suspension reacted with 3, 5-dinitrosalicylic acid and the absorbance was detected by spectrophotometer at 578 nm wavelength, the activity of urease was expressed as mg NH_3–N g^{-1} soil 24 h $^{-1}$ [27]. Soil alkaline phosphatase activity was measured by incubating 1 g air-dried soil sample with 4 ml of 5% disodium