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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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ABSTRACT

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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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 phenyl phosphate solution at 37 °C in an incubator for 24 h. The formation of phenol was determined by a spectrophotometer at 660 nm wavelength, the activity of alkaline phosphatase was expressed as mg phenol g^{-1} soil 24 h^{-1} [28].

Microbial biomass was measured according to the $CHCl_3$ fumigation-extraction method [29,30]. Each soil sample was incubated in a closed container for 7–15 d under room temperature and dark condition. Fumigated (24 h) and non-fumigated soil samples were extracted with 0.5 M K_2SO_4 for microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) and with 0.5 M $NaHCO_3$ for microbial biomass phosphorus (MBP). Microbial biomass carbon, nitrogen and phosphorus were estimated by the variation of the concentration of each given element in the fumigated (24 h) and non-fumigated treatments for each soil sample. MBC was determined by titration with $FeSO_4$; MBN was determined by a spectrophotometer at 570 nm wavelength with ninhydrin reaction; MBP was determined at 882 nm wavelength with mixed colour reagent.

2.4. Data analysis

An analysis of variance (ANOVA) was performed using SAS Ver. 9.3 software (SAS Institute Inc., Cary, NC, USA). Tests of significant use the least significant difference (LSD) at $P \le 0.05$. Mean values are reported in the tables and figures.

3. Results

3.1. ANOVA of soil microbiological parameters

The ANOVA for different soil microbiological parameters is given in Table 1. The soil amendment treatment (T), year (Y), days after sowing (D) and soil layer (L) all had a highly significant effect ($P \le 0.01$) on all soil microbiological parameters. The interaction between L and T had a highly significant effect ($P \le 0.01$) on urease, MBC and MBP, and a significant effect ($P \le 0.05$) on catalase and invertase, but had no significant effect ($P > 0.05$) on alkaline phosphatase and MBN. The interactions of Y * T, Y * D * T, Y * L * T, D * L * T and Y * D * L * T had no significant effect ($P > 0.05$) on any of the parameters.

3.2. Soil microbial biomass

Soil microbial biomass carbon, nitrogen and phosphorus were all increased by soil amendments in different soil layers and days after sowing in 2010, 2011 and 2012 (Fig. 1, Fig. 2 and Supplementary Table 1); improvements ranged from 2.5 to 27.3% for microbial biomass carbon, 2.4–28.1% for microbial biomass nitrogen, and 3.5–31.6% for microbial biomass phosphorus. Soil microbial biomass carbon and alkaline phosphatase showed similar trend with the soil enzymatic activities, but soil microbial nitrogen first trended downward reaching the minimum value at 70 d in all three years, and then trended upward later in the growing season. Soil microbial biomass in different soil layers also showed a decreasing trend with increasing depth except 50 d and 70 d after planting in 2010 and 50 d in 2011. Soil amendments ranked in order of effect on soil microbial biomass showed a similar pattern to the ranking of effect on soil enzymatic activity in different days after sowing and soil layers in 2010, 2011 and 2012.

3.3. Soil enzymatic activity

Soil amendments improved soil enzymatic activity compared to the no amendment control in different soil layers and days after sowing in all of 2010, 2011 and 2012, including catalase, invertase, urease and phosphate (Fig. 3 and Supplementary Table 2–4). 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 in the three years. Soil enzymatic activity showed a similar trend first increasing early in the growing season, and then decreasing during the later part of the potato growing season in each of 2010, 2011 and 2012 except urease in 2010, but these peaks occurred at different times after sowing. The peaks were reached at a later time in 2010 and 2011 than in 2012 possibly because the low precipitation delayed the potato growth early in the growing season in 2010 and 2011. Soil enzymatic activity in different soil layers showed a decreasing trend with the depth increasing except 50 d and 70 d after planting in 2010 and 50 d in 2011. This may due to the low soil moisture content caused by the weather conditions (no precipitation) and soil was exposed without plant cover in the early growing season in 2010 and 2011. There was a similar pattern of the soil amendment effect on soil enzymatic activity at different times after sowing and soil layers in 2010, 2011 and 2012. The amendments listed in descending order of effect on soil enzymatic activity were T4 > T2 > T3 > T1 > T5 > CK.

3.4. Correlation among soil microbiological parameters

The correlation among soil microbiological parameters is given in Table 2. All of the soil microbiological parameters except MBC and MBN showed a highly significant ($P \le 0.01$) correlation. The high correlation is a result of activity of the parameters tracking potato growth. MBN showed a low correlation with other soil microbiological parameters; this might be because nitrogen is the main nutrient and plentiful in the early growing season, but is quickly taken up by potato growth.

4. Discussion

In this study, results showed soil enzymatic activity and microbial biomass was highly significantly ($P \le 0.01$) affected (Table 1) and improved by soil amendment treatment (both single and compound) in different days after sowing and soil layers indicating the higher metabolic activity of microorganisms. This is in agreement with previous results which reported soil enzymatic activity and microbial biomass were improved by organic amendments in a semi-arid climate [2,31–33]. This is also consistent with other

Table 1
ANOVA of effect of soil amendment treatments, days after sowing, soil layer depth and year on soil microbiological parameters in 2010–2012.

Factor	DF	Catalase	Invertase	Urease	Phosphatase	MBC	MBN	MBP
T	5	***	***	***	***	***	***	***
Y	2	***	***	***	***	***	***	***
Y*T	10	NS	NS	NS	NS	NS	NS	NS
D	3	***	***	***	***	***	***	***
D*T	15	*	*	***	NS	**	NS	***
Y*D	6	***	***	***	***	***	***	***
Y*D*T	30	NS	NS	NS	NS	NS	NS	NS
L	2	***	***	***	***	***	***	***
L*T	10	***	***	***	***	***	***	***
Y*L	4	***	***	***	***	***	***	***
Y*L*T	20	NS	NS	NS	NS	NS	NS	NS
D*L	6	***	***	***	***	***	***	***
D*L*T	30	NS	NS	NS	NS	NS	NS	NS
Y*D*L	12	***	***	***	***	***	***	***
Y*D*L*T	60	NS	NS	NS	NS	NS	NS	NS

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels. NS means not significant. T, D, L and Y refer to amendment treatment, days after sowing, soil layer and year respectively. MBC, MBN and MBP refer to microbial biomass carbon, nitrogen and phosphorus respectively.

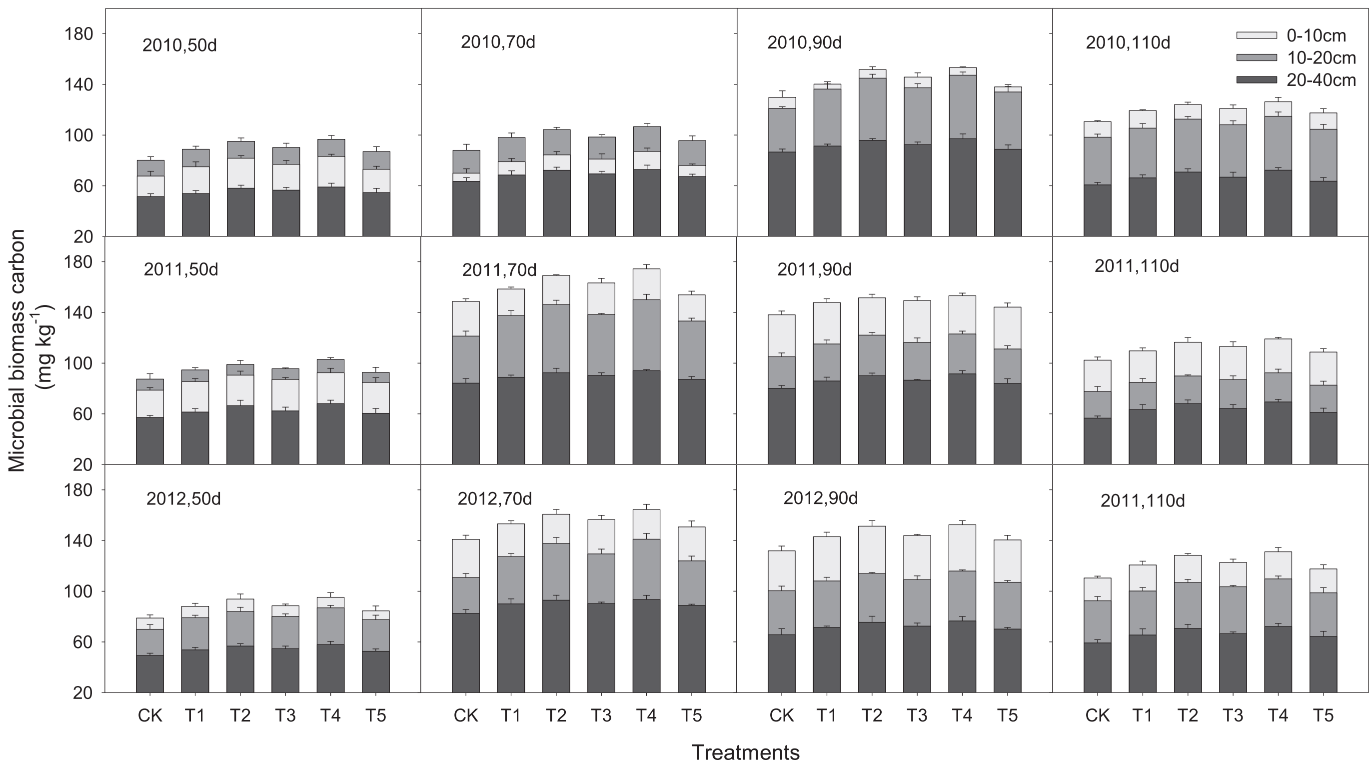

Fig. 1. MBC with soil amendments in different soil layers and days after sowing in 2010, 2011 and 2012. Treatment code: CK, no amendment control; T1, PAA; T2, PAA + HA; T3, PAM; T4, PAM + HA; T5, HA. Small bar shows standard deviation. Previous results showed that soil amendments increased field water holding capacity by 0.7–17.7%, and improved soil moisture content respectively by 2.1–24.0% in 0–40 cm soil layer in the three years.

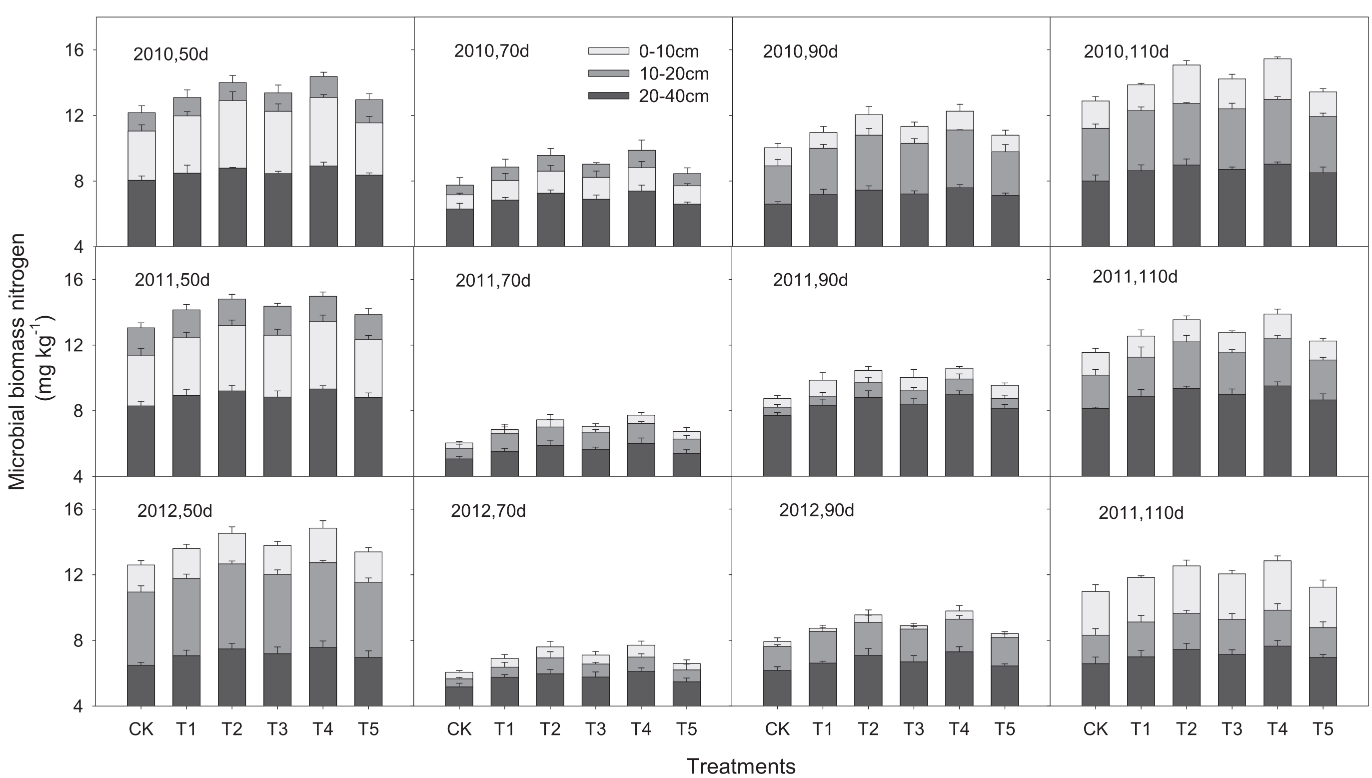

Fig. 2. MBN with soil amendments in different soil layers and days after sowing in 2010, 2011 and 2012. Treatment code: CK, no amendment control; T1, PAA; T2, PAA + HA; T3, PAM; T4, PAM + HA; T5, HA. Small bar shows standard deviation. Previous results showed that soil amendments increased field water holding capacity by 0.7–17.7%, and improved soil moisture content respectively by 2.1–24.0% in 0–40 cm soil layer in the three years.

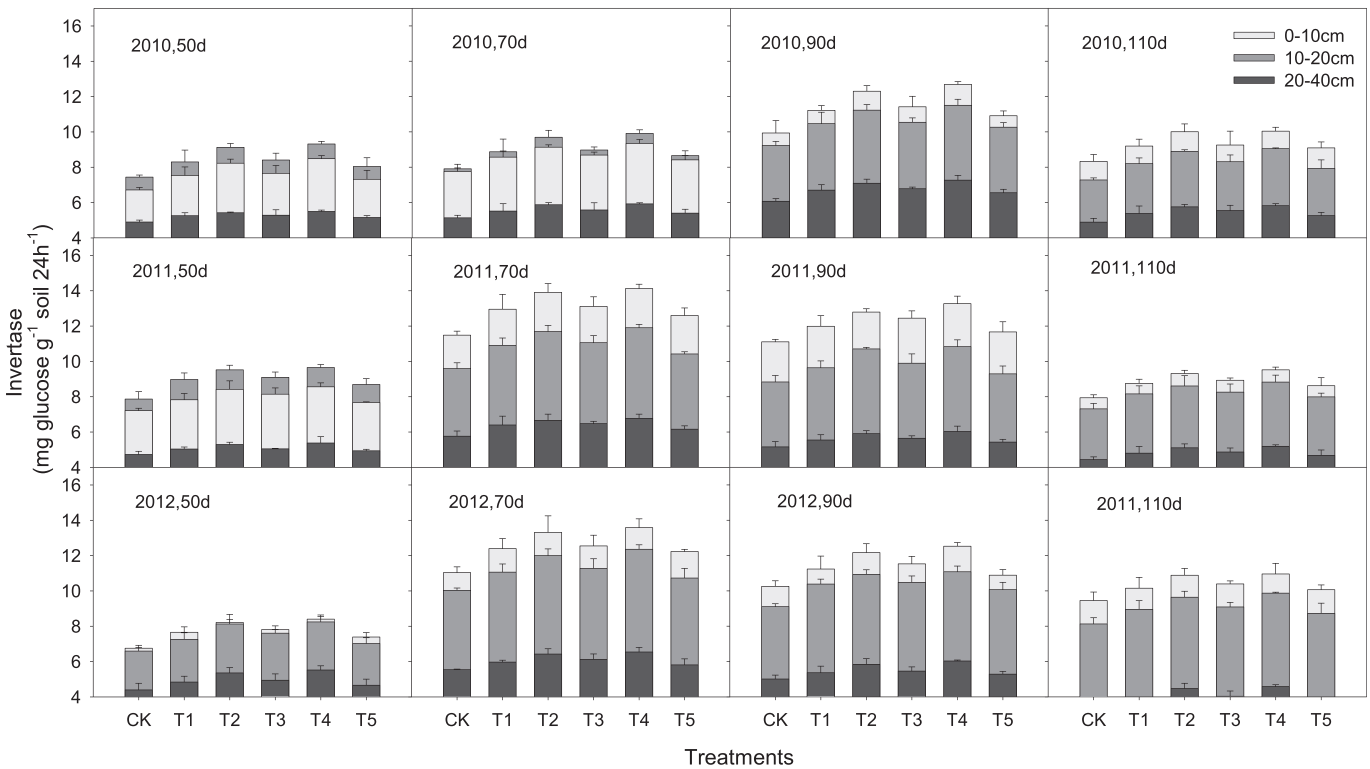

Fig. 3. Soil invertase activity with soil amendments in different soil layers and days after sowing in 2010, 2011 and 2012. Treatment code: CK, no amendment control; T1, PAA; T2, PAA + HA; T3, PAM; T4, PAM + HA; T5, HA. Small bar shows standard deviation. Previous results showed that soil amendments increased field water holding capacity by 0.7–17.7%, and improved soil moisture content respectively by 2.1–24.0% in 0–40 cm soil layer in the three years.

Table 2
Correlation among soil microbiological parameters.

	Catalase	Invertase	Urease	Phosphatase	MBC	MBN	MBP
Catalase	1						
Invertase	0.928***	1					
Urease	0.884***	0.916***	1				
Phosphatase	0.862***	0.841***	0.794***	1			
MBC	0.863***	0.931***	0.919***	0.818***	1		
MBN	0.318***	0.200***	0.168***	0.315***	0.075	1	
MBP	0.782***	0.831***	0.842***	0.828***	0.827***	0.262***	1

*** Significant at 0.001 probability levels. MBC, MBN and MBP refer to microbial biomass carbon, nitrogen and phosphorus respectively.

research where synthetic polymer improved soil microbial activity in a semi-arid soil [34,35]. The application of both synthetic polymer and natural amendments improved soil available water by absorbing and holding the limited rainfall [11,32,36]. Furthermore, it is indisputable that soil moisture is the main limiting factor for growth and metabolism of soil microorganisms in the arid and semi-arid areas [20,21]. Measurements of soil enzymatic activity may serve as a proxy for soil organic matter dynamics [37].

Previous reports indicate that soil microbial activity generally shows a decreasing trend with increasing soil depth in different soils in both forest and agriculture [38–42]. In this experiment, both soil enzymatic activity and microbial biomass were consistent with this trend. However an exception was 50 and 70 d after sowing in 2010 and 50 d in 2011 where there was an extreme weather condition (no precipitation) in the experiment field site early in the potato growing season [43]; the surface soil was exposed without any plant cover, and the evaporation was very high in this period which led to very dry surface soil [44].

Soil enzymatic activity can vary significantly with weather conditions and crop growth stage and vigour, and the highest values often coincide with the most favorable weather conditions (enough rainfall and suitable temperature) and the most active growth of plants [45–47]. Usually, in this experiment field site, the most favorable weather condition with adequate rainfall for potato growth occurred around 80 days after sowing. Moreover, the most active growth of potato was during this time period. Soil catalase, invertase, urease and phosphatase showed the highest activities in the 70 or 90 days after sowing (Fig. 3 and Supplementary Table 2–4). However, soil microbial biomass showed different variations with the potato growth. The plot of MBC and MBP against time exhibited a single peak was similar to soil enzymatic activity, and depended on the weather and plant growth conditions. However, MBN first trended downward reaching the minimum value at 70 d after sowing, and then trended upward later in the potato growing season. The initial application of N fertilizer and increasing temperature caused MBN to stay at a high level early in the growing season. MBN then decreased in the mid growing season (50–70 days after planting) because of the potato crop absorbs a great amount nitrogen for quick growth. Later with the potato crop absorbed less nitrogen (after 70 d) and the MBN showed an increasing tendency.

Our results showed combined amendment treatments are better than single amendment treatments. This might be due to more total amendment being applied as the rate of a particular amendment was the same whether applied as a single amendment, or in combination with another amendment. It might also be due to the interaction between synthetic and natural amendments on soil and crops. Synthetic amendments are beneficial for soil microorganisms by holding the limited precipitation in the dryland soil [7,36]. Simultaneously, natural amendments (humic acid) enhance soil microorganisms by involvement in the physiological and metabolic processes [48]. Both soil synthetic and natural amendments provide better soil conditions for soil microorganisms such as soil moisture and nutrients. Furthermore, all the soil microorganisms play an important role in the soil nutrient cycling [19,20]. Therefore, the combined treatments including synthetic and natural amendment might strengthen the effect on soil microorganisms which leads to better soil properties for plant growth [43]. The mechanism of the interaction between synthetic and natural soil amendments is not well understood and needs more research in the future.

5. Conclusion

The application of synthetic and natural soil amendments studied increased soil microbiological properties in a semi-arid region. Soil amendments had a highly significant effect ($P \leq 0.01$) on, and improved soil microbial biomass and soil enzyme activity. The combined addition of PAM and HA had the greatest effect of all of the amendment treatments on soil microbiological properties in different soil layers and days after sowing.

Our research over three years indicates that application of soil amendments provides an opportunity to improve soil biological properties; long-term research of soil amendments on soil properties is essential to provide a more complete understanding of the processes and relationships. The addition of these soil amendments may provide a sustainable strategy for potato production in a semi-arid area.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ejsobi.2016.04.002.

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