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Title: Animal manure functions as soil amendment for urban green space in the Loess Plateau

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Abstract

Urban green space could efficiently tackle surface water management issues in modern cities. To achieve this purpose, it is necessary to transform traditional urban infrastructure accordingly, especially the areas of soil that support plantation. Constrained by poor soil structure and limited but unevenly distributed precipitation, the Loess Plateau is characterized by a fragile ecological system. Organic amendments could improve soil structure and the concomitant water holding capacity by increasing soil organic matter and aggregation stability, in which soil microorganism could play a key role. Here, three typical agricultural organic materials, animal manure (AM), plant residue (PR) and mushroom residue (MR), were evaluated in soil amelioration in the Loess Plateau. In addition, a new kind of synthetic polymers, polyvinyl alcohol (PVA), and a widely used inorganic soil conditioner, volcanic pumice (VOP) were also included in the comparison. The results showed that AM imposed the greatest beneficial effect on soil water holding capacity, aggregate stability, and enzyme activities, as well as microbial diversity and community composition, followed by PR and MR. PVA and VOP imposed no obvious, if not negative, effect on soil properties. In conclusion, animal manure could be a good soil amendment in the arid area of the Loess Plateau or other regions with similar soil properties.

Key words: Urban green space; Loess Plateau; Soil amendment; Aggregate stability; Microbial community

Introduction

“Sponge City” is a term to define the novel urban operational concept that aims to convert a city to a more livable environment, with focus on tackling urban water management issues, such as purification of urban runoff, attenuation of peak and water conservation (Chan et al., 2018). As a core component of this concept, urban green space could efficiently tackle those problems coming with the rapid urbanization and industrialization, like air pollution (M. Chen, Dai, Yang, & Zhu, 2019), heat-island effect (Cai, Chen, & Tong, 2019), surface-water management (Chan et al., 2018). To achieve these purposes, it is necessary to transform the traditional urban conditions accordingly, especially the soil underneath the green space. Urbanization modifies natural or agricultural ecosystems to human-dominated systems. Soil in the urban environment tends to be very disturbed by human activities.
and is often characterized by contamination, compaction and soil sealing (G. Li, Sun, Ren, Luo, & Zhu, 2018). Regarding the soil amelioration in urban green spaces, related studies mainly focused on the remediation of the soils contaminated by heavy metals (Khan, Khan, Khan, & Alam, 2017) and organic pollutants (Gong, Tang, & Zhao, 2016), while ignored soils unpolluted but constrained by poor structure and fertility. But the truth is that the natural quality (physical, chemical and biological properties) of the soil affects directly and/or indirectly the health of urban plants and the concomitant ecological functions, including the environmental livability and urban landscape (Vienneau et al., 2017).

Loess, an aeolian deposit, is primarily composed of silt-sized particles (<2.0 mm). Such formations occur widely around the world with the most extensive distribution in China (Jimin Sun, 2002). Located in arid/semi-arid region and deep inside the Eurasia, the Loess Plateau in northern China occupies more than 6% of the country’s territory (Hua, Zhong, & Ke, 2016). Such regions are exposed to continental monsoons and heavy variation in rainfall precipitation. Take Guyuan, a typical small city located in the central of the Loess Plateau, for example. More than 50% of its annual precipitation falls during summer (between June and August), with most of which are heavy storms (Y. Zhang, Guo, Liu, & Jiang, 2014). In contrast, the rainfall from February to March only accounts for 3% ~ 6% of the total annual precipitation, which results to severe spring drought with surface cracking and soil layer spalling as characteristics (Y. Li et al., 2019). Apart from the limited but severely unevenly distributed precipitation, the poor soil structure and the corresponding limited soil water holding capacity further increase the risk of environmental disasters threatening the plant growth (Xu & Wang, 2016), inducing soil collapse. The latter is a major threat for the construction and maintenance of urban infrastructure in the Loess Plateau (Liu et al., 2015), i.e. green space, roads, buildings, reservoirs, etc.

As a core component of soil structure, soil aggregates are groups of soil particles that bind to each other more closely than to adjacent particles. The stability of soil aggregate is viewed as an estimating indicator for the formation, stabilization and degradation of the soil structure (Verchot, Dutaur, Shepherd, & Albrecht, 2011). High aggregate stability could improve soil fertility, minimize soil degradation when exposed to external forces such as water erosion, shrinking/swelling processes (S. Zhang, Wang, Yang, Sun, & Li, 2016). The pores between the aggregates provide with space for retention and exchange of air and water as well as nutrient recycling within the soil (Bronick & Lal, 2005). Hence, in those regions with limited but severely
concentrated precipitation good soil aggregates should have not only large porous (> 70 μm) to remain aerobic and allow rapid drainage during rainy periods, but also smaller ones (0.2 - 30 μm) to retain water for plant growth during dry seasons (Tisdall & Oades, 1982). In the Loess Plateau, due to the silt-dominated soil structure combined with rather low soil organic matter content (SOM) (Guo et al., 2019), soil aggregates are rather fragile and easily slake into smaller sub-units when rapidly wetted during heavy rains (Tisdall & Oades, 1982).

There are many soil amendments, both inorganic and organic, widely used to improve soil aggregation. Volcanic pumice (VOP), the product of volcanic eruption, is a widely-used naturally-suited soil conditioner with numerous beneficial for the soil properties (i.e. stimulated soil aggregation, enhancement of soil drainage capacity, promoted soil moisture and nutrients storage with more than 70 beneficial minerals through its tiny pores on its surface, etc (Cruz-Ruíz, Cruz-Ruíz, Vaca, Del Aguila, & Lugo, 2016; Noland, Spomer, & Williams, 1992; Temiz & Cayci, 2018)). Organic amendments, such as typical agricultural residues and the new mounting synthetic polymers, are also widely applied to improve soil aggregation by binding soil particles together through increased SOM (Youzhi Feng et al., 2015; Peregrina et al., 2012; Powlson, Prookes, & Christensen, 1987; K. Wang, Mao, & Li, 2018). In this process, soil microorganisms play a key role and they indeed could serve numerous important ecological functions. They break down pollutants, municipal waste/ingested food and they are the primary means by which nutrients in organic matter can be utilized by plants and other autotrophs (Bell, Newman, Silverman, Turner, & Lilley, 2005). Particularly, microorganisms drive the formation and transformation of humic substances which could increase the connectivity of soil particles and the turnover of mineral nutrient, and finally improve the soil structure and fertility (Verchot et al., 2011). When soil structure improves through aggregation the resulting pore space favors the retention and exchange of water and air, which in turn provides with a proper niche for the soil microbial community. For example, crop straw return in soil could increase the bacterial biomass carbon and total phospholipid fatty acid, typical indicators of the status of the microbial community (Z. Chen et al., 2017). After 2-4 years of organic manure application to soil, indigenous Bacillus asahii becomes the predominant population in soil and this organism plays a key role in the promotion of crop yield and soil fertility (Youzhi Feng et al., 2015). In urban green space, soil microbial community still follows the classic patterns of plant-microbe associations in the natural environment, but the continuous anthropogenic disturbance leads to a more...
diverse microbial community in soil (Hui et al., 2017). Microbial community with relatively high biodiversity generally tends to provide with more pronounced ecological functions than communities with unique, limited species. Thus, increased speciation is vital to the stability of the ecosystem (Bell et al., 2005).

In this study, we conducted an experiment to estimate the effect of different soil amendments (three organic agricultural materials, animal manure, plant residue, mushroom residue, a new kind of synthetic polymers, polyvinyl alcohol, and a widely used inorganic soil conditioner, volcanic pumice) on the physical and biological properties of the soils collected from arid areas. We have two hypotheses: 1) considering the rather low soil organic carbon in the Loess Plateau, organic amendments will improve the soil’s physical and biological properties compared to inorganic amendments; 2) with regards the degradability of organic substrate, easily degradable animal manure will promote microbial community composition and function to a larger extend, compared to the more recalcitrant plant and mushroom residues.

Materials and Methods

Soil selection and experiments

The soil was collected at the roadsides of Guyuan City (35°14’-35°38’N, 105°20’-106°58’E), Ningxia Hui Autonomous Region, which lies in the Loess Plateau. Located in the arid area of northern China, Guyuan has a typical continental monsoon climate with a mean annual precipitation ranging between 250–820 mm and annual evaporation ranging from 1250 to 2000 mm (Chao, Lin, & Bingzhen, 2017). The soil was classified as Cambsoils (WRB, 2014), and its basic properties were as follows: pH 8.4, soil organic carbon (SOC) 4.7 g/kg, soil total nitrogen (TN) 0.053%, soil total phosphorus (TP) 0.045%, soil total potassium (TK) 1.09%, alkaline nitrogen (AN) 43 mg/kg, available phosphorus (AP) 7.5 mg/kg, available potassium (AK) 123 mg/kg (Jiao Sun et al., 2017).

The soil taken was homogenized using 2 mm sieve to discard gravel and plant residues. 80 g soil was load into the 60 ml tubes, and five different soil amendments were accordingly added into the soil: animal manure (AM), mushroom residues (MR), plant residues (PR), polyvinyl alcohol (PVA) and Volcanic pumice (VOP), and control with no amendment but only soil (initial soil). Thus, 6 treatments were prepared, each prepared in 3 replicates. After preparation each sample was weighed and then mixed thoroughly. All tubes with the sample were submerged into the water (80% of tube’s
height filled with water-sample mixture) for 12 hours to simulate a short intense rainfall. Initial weight of each tube was recorded after taking from water and standstill for 1-hour to simulate the drainage process. The samples were then positioned outside at the sunshine, the weight of the tubes was recorded daily. At the end of this experiment, with the upper surface layer removed, the soil was collected to measure enzyme activity, aggregate stability and microorganism diversity. Soil aggregate stability was measured following the method developed by Le Bissonnais (2016) and expressed as mean weight diameter (MWD). MWD values above 1.3 denoted stable soil structures (Le Bissonnais, 2016). Dehydrogenase and β-glucosidase activity were determined following the method of (Casida, Klein, & Santoro, 1964) and (Eivazi & Tabatabai, 1990), respectively.

**Soil bacterial community assays**

Soil total genomic DNA was extracted from 0.5 gram of soil using the FastDNA Spin Kit for Soil (MP Biomedicals, Santa Ana, USA) according manufacturer’s instructions. The soil bacterial community was assayed by high-throughput sequencing. For each DNA sample, the primer set 519F/907R (Imachi et al., 2008) was used to amplify approximately 390 bp of bacterial 16S rRNA gene fragments. Twenty-eight cycles (95°C for 45 s, 56°C for 45 s, and 72°C for 60 s) were performed with a final extension at 72°C for 7 min. The purified bar-coded PCR products from all samples were normalized equimolar amounts, then prepared using VAHTS™ Universal DNA Library Prep Kit (Vazyme Biotech, Nanjing, China) and sequenced using MiSeq Reagent Kit (300-cycles-PE) following the manufacturer's protocols on Illumina MiSeq platform.

The sequencing data were processed using the Quantitative Insights Into Microbial Ecology (QIIME) 1.9.0-dev pipeline (Caporaso et al., 2010) using default parameters unless otherwise noted. In brief, after discarding those of length < 200bp and score < 25, the qualified sequences were binned into OTUs with a 97% identity threshold, and the most abundant sequence from each OTU was selected as a representative sequence. Chimera were removed using USEARCH with the UCHIME algorithm (Edgar, Haas, Clemente, Quince, & Knight, 2011). Taxonomy was assigned using the QIIME-compatible SILVA 123 database (www.arb-silva.de/download/archive/qiime/). OTU representative sequences were aligned using PyNAST (Caporaso et al., 2009). A phylogenetic tree was then constructed using FastTree2 (Price, Dehal, & Arkin, 2010) to support the phylogenetic diversity.
Total 347,556 sequences of bacterial 16S rRNA gene with a range of 8,018 and 36,503 sequences per sample were obtained. Alpha and beta diversity based on Bray-Curtis dissimilarity were calculated using 8,000 reads per sample (nearly closed to minimum number of sequences required to normalize the differences in sampling effort) with multiple indices (observed species (hereafter Richness), Shannon-Winner index (hereafter Shannon), and phylogenetic diversity using Faith’s index (hereafter PD)); the Bray-Curtis distance between samples visualized using non-metric multidimensional scaling (NMDS) plots.

**Statistical analysis**

Mean separation was conducted based on Tukey’s *t.test*, which was conducted using ‘*compare_means*’ function in R package ‘*ggpubr*’. The heatmap of the bacterial community composition at a phylum level was realized using R package ‘*pheatmap*’.

**Result**

1. **Alteration of soil chemical and physical properties**

   Important soil fertility indices such as pH and SOC, as well as soil aggregate stability were quantified (Fig. 1). Soil pH was slightly alkaline and not affected by the different amendments. Compared to the initial soil format (control), AM amendment significantly increased the SOC content and soil aggregate stability (*p* < 0.05). PR also significantly increased the soil aggregate stability (*p* < 0.05). The rest of the amendments showed no significant effect on the soil properties compared to un-amended soil. The results showed that animal manure and plant residue could efficiently bind soil particles together very likely due to the increased SOC content. However, MWD for all treatments was less than 1.3, close to the threshold which differentiates a stable from an unstable soil (Le Bissonnais, 2016). This indicates that improved soil structures in such soil-eroded areas are in scarcity and it would require prolonged periods of time to be formed.
Figure 1. Comparison of soil pH, SOC content and aggregate stability (MWD, mean weight diameter) among treatments. The asterisk (*) above bars in each plot denotes the significant difference ($p < 0.05$) compared to initial soil (Ctrl treatment in plots).

We further present the alteration of soil water holding capacity among the different amendments (Fig. 2); the results show very similar dynamics with those observed for soil aggregate stability and SOC content (Fig. 1). Except the VOP, the other four carbon-source amendments (AM, PR, MR, and PVA) increased the soil water storage capacity. AM, had the most positive effect compared to all other amendments used, specifically it could store 9% and 7% more water compared to the initial soil during peak rainfall and after 28 experimental days, respectively. MR (mushroom residue), PR (plant residue) and PVA (polyvinyl alcohol) had a similar, almost negligible beneficial effect.

Figure 2. Changes of soil water holding capacity among different amendments. Two peaks represent heavy rainfall simulated by submerging the tubes with 80% of its height beneath the water.

2. Effects of soil amendments on bacterial diversity
The microbial communities developed at different soil amendment conditions were investigated. A dataset of 347,556 quality sequences were produced from all soil samples, with almost all classified to the kingdom of bacteria. The total number of OTUs was 2,640 defined by 97% sequence similarity. Both AM and PR amendments significantly increased the bacterial Richness, Shannon and PD values ($p < 0.05$), with AM having the largest increase in diversification among all treatments compared to un-amended soil. MR imposed no significant impact on bacterial community at taxonomic level (Richness and Shannon) ($p > 0.05$), while VOP negatively decreased the bacterial diversity at both taxonomic (Richness and Shannon) and phylogenetic levels (PD) ($p < 0.05$).

![Figure 3](image.jpg)

**Figure 3.** Comparisons of bacterial community diversity among different treatments.

### 3. Effects of soil amendments on bacterial community composition

Six phyla including *Firmicutes*, *Bacteroidetes*, *Proteobacteria*, *Actinobacteria* and *Acidobacteria* were the most dominant groups and accounted for nearly 99% of the overall sequences (Fig. 4). Specifically, *Firmicutes* was most dominant phylum ranging from 20.97% to 63.10% depending on the soil treatment. Among the predominant phyla *Proteobacteria*, *Alphaproteobacteria* and *Gammaproteobacteria* were the dominant subgroups. VOP amendment significantly increased the abundance of *Firmicutes* while decreased *Gammaproteobacteria*, *Alphaproteobacteria*, *Betaproteobacteria* compared to what was observed at the control soil ($P < 0.05$). The relative abundance of *Gammaproteobacteria* was significantly decreased in AM and PR treatment compared to the control soil ($P < 0.05$). Additionally, AM increased the relative abundance of those rare species present in the bacterial community (the ‘Other’ part in Fig. 4).
Figure 4. Bacterial community composition among treatments. ‘Other’ accounts for those rare species with relative abundances lower than 0.1% in all samples.

A phyla heatmap plot showed that AM amendment enriched more bacterial phyla, especially those that appeared in lower abundancies at the other treatments resulting in a relatively independent cluster. This indicated that animal manure amendment could promote diversity and subsequently balance the bacterial community structure (Fig 5) as later discussed. This observation is further supported by its greatest Shannon Index (Fig 3) compared to the indices observed at the other treatments. Additionally, VOP resulted to a very similar bacterial composition (at phylum level) compared to the control soil, with the main difference being that the VOP was richer in Firmicutes and Proteobacteria (also shown on Fig. 4).

Figure 5. The bacterial community composition among treatments at phylum level.
The heatmap indicates the profile of bacterial phyla with z-scored transformed relative abundance.

4. Effects of soil amendments on soil enzyme activities

The dehydrogenase and β-glucosidase were used to estimate the influence of the amendments on soil redox characteristics to indicate the soil’s degradation of organic matter as well as its nutrient turnover capacities (Schröder, Elleuche, Blank, & Antranikian, 2014). Compared to the un-amended soil, AM, MR, and PR all significantly increased the soil dehydrogenase and β-glucosidase activities \( (p < 0.05) \), while PVA and VOP imposed no evident, if not negative, impact \( (p > 0.05) \). AM imposed the greatest positive impact on the two important soil enzymes (nearly 10 times increase); this indicated that animal manure could efficiently increase soil biogeochemical activity. This observation was consistent with the significant increase in SOC content (Fig. 1).

Figure 6. The effects of different soil amendments on soil enzyme activities.

Discussion

1. Organic amendments improve soil physical and chemical properties

Soil is a complex material with strong buffer capacity and soil pH is a relatively stable property when exposed to potential disturbances (Youzhi Feng et al., 2014). The results showed that none of the soil amendments could alter soil pH during experimentation (Fig. 1), while it is uncertain whether changes could have appeared if the experimental period was longer. This however, is unlikely at normal conditions since environmental conditions at such soils formations do vary (as also described in methodology). Soil aggregate is another key property indicating the soil’s natural
fertility that can be enhanced via addition of appropriate amendments that can
strengthen the connectivity between soil particles (Boyle, Frankenberger, & Stolzy,
1989; Celik, Gunal, Budak, & Akpinar, 2010). Overall, organic amendments
significantly improved SOC content and soil aggregate stability at different extents;
on the other hand, inorganic amendments didn’t impose any beneficial effect (Figs. 1-
2). This confirmed the first hypothesis of the study. These results are consistent with
previous studies where organic carbon residues (manure, straw, fermentation, etc.)
were used as soil additive to improve soil texture (i.e., increase soil porosity, and
aggregate stability, but decrease bulk density) and fertility (i.e., increase SOC and
nutrient availability) (Bao et al., 2019; Garccia-Orenes et al., 2005; J. Li et al., 2014;
Peregrina et al., 2012).

Among all amendments, AM increased soil organic carbon content and
concomitant aggregate stability (Fig. 1) as well as soil water holding capacity (Fig. 2)
to the largest extend, followed by PR and MR. This is relevant to manure’s nature as it
is primarily composted labile fractions (Z. Wang et al., 2019; Xing, Li, Yang, Huang,
& Lu, 2012) as a result of the intestinal digestion. In comparison, plant residue (straw)
and mushroom residue are more recalcitrant due to their higher fractions of lignin and
cellulose (Bao et al., 2019; Z. Wang et al., 2019). These results then confirmed the
second hypothesis of this study. Similar studies showed that amendments of organic
materials from ex situ farmlands (animal manure, and other residues) could also
promote soil quality more efficiently compared to in situ similar additives (Long et
al., 2015). On the contrary, there are also reports that question the beneficial effect of
organic additives on soil structure. Specifically, Guo et al. (2019) showed that long-
term application of animal manure in semi-arid region could deteriorate soil structure
due to accumulation of Na\(^+\) in the soil. Peregrina et al. (2012) reported that mushroom
residue could not increase soil aggregation but increased the inorganic nitrogen
concentrations in the surface soil, which then became a potential risk for N leaching.
Such contradicting observations may be a result of different soil properties,
atmospheric conditions and various management regimes (Guo et al., 2019). For
green open space reserves (i.e. vegetated lands in open area) that don’t need
excessively fertile soil as for farmlands, organic amendments can be adjusted to
eliminate the likelihood for potentially negative effects that may occur with
oversaturation of harmful elements. Further work in carbon-dosing optimization (i.e.
concentration of carbon per kg or cubic meter of soil) may be useful to detect the
saturation level of these amendments.
VOP and PVA imposed no significant effect on soil’s physical properties (Figs. 1 and 2, \( p > 0.05 \)). PVA (polyvinyl alcohol) is a type of uncharged synthetic organic polymer used as soil conditioner (Blavia, Moldenhauer, & Law, 1971). With plausible interaction between the polymers and the clay surface of the soil via hydrogen binding, PVA could efficiently protect the soil surface from water ingress (Stefanson, 1973). However, these characteristics were dependent on the carbon content and the humidity of the soil (Moayedi, Asadi, Moayedi, & Huat, 2011), both of which are rarely available in arid areas where the poor soil quality (silt-dominated, but not clay) and limited precipitation are the two major threats. Additionally, PVA can rapidly dissolve and/or become easily degradable, meaning that it would just impose an intense but transient effect to the soil (Wiśniewska, 2010). VOA is a prospering naturally-suited, hardly degradable soil conditioner with numerous beneficial for the soil properties (Noland et al., 1992). However, in this study, VOP appeared to impose no positive effect on the soil’s physical and/or biochemical properties (Figs. 1 and 2). Similar phenomena were also reported by Temiz and Cayci (2018) who found that plant residue increases soil aggregation to a higher degree than pumice mulch. Given the fact that evaporation is often larger than precipitation in arid areas (Chao et al., 2017), plausible high salt content in volcanic pumice amendments could even deteriorate via increased soil salinity (unfavorable conditions for both the microbial community and the soil properties (Meester, 1970)). In addition, the main limiting factor in Loess Plateau region was the rather low soil organic carbon content (Guo et al., 2019), issue that volcanic pumice could offer nothing to increase soil carbon (Fig. 1). Hence, PVA and VOA alone were inappropriate for the improvement of the soil structure in arid areas.

2. Organic amendments improve soil biological properties

Soil quality is strongly defined by several interactions between chemical and biological components, including soil organic matter and microbial community structure, which both play key roles on soil fertility (Faissal et al., 2017). It has been documented that soil bacterial community could be altered, directly or indirectly, by various environmental factors, such as soil pH (Youzhi Feng et al., 2014), moisture (Van Horn et al., 2014), host plants (Kiers et al., 2011), and other environmental changes (Y. Feng et al., 2013; J. Zhang, Tang, Zhu, Lin, & Feng, 2019). After addition of different amendments, vast changes in bacterial diversity (Fig. 3), community composition (Figs. 4-5) and soil enzyme activities (Fig. 6) occurred. These changes
confirmed that the effect of the exogenous amendments on the soil microbial community depend more on the nature, rather than the type, of the substrate. Specifically, easily degradable substances impose an intense but transient effect on aggregate stability while more recalcitrant ones, such as lignin and cellulose, usually have lower but longer-lasting effects (Diacono & Montemurro, 2010).

Animal manure (AM) imposed the most significantly beneficial effect on the bacterial community, followed by plant residue (PR) and mushroom residue (MR), findings that confirmed the second hypothesis. As mentioned above, animal manure is more degradable compared to plant residue and mushroom residue (Z. Wang et al., 2019). Mushroom substrate has also been used as a soil amendment due to its high organic matter content as well as its increased content in other nutrients, however, it usually takes up to 4 years to have a steadily beneficial effect on soil quality due to its recalcitrant nature (Peregrina et al., 2012). Specifically, animal manure significantly increased the bacterial alpha-diversity indices (Fig. 3) as well as the relative abundances of the rare species (Figs. 4-5). This would help the soil to sustain a more diverse and balanced soil bacterial community. Microbial communities with increased diversity could transform carbon from organic debris into biomass at accelerated rates and at higher conversion efficiency (Maeder et al., 2002; Patsch, van Vliet, Marcantini, & Johnson, 2018). Indeed, the findings presented the significant increase of soil dehydrogenase and β-glucosidase activities (Fig. 6) as well as soil aggregate stability (Fig. 1) under organic amendments, with the highest improvement found in animal manure, followed by plant residue and mushroom residue. Our results were consistent with other reported studies. For example, Maeder, et al. (2002) found that organic manure supports a diverse and active biotic community which could decompose more carbon than the ones present in conventional soil. In addition, manure amendments could also inhibit the pathogenic microbes in soil; thus, reduce plant diseases (i.e. scab and wilt incidence) (Conn & Lazarovits, 1999). However, we should bear in mind that animal manure should be processed in harmless treatment to avoid negative effects such as the contamination of soil with antibiotics (Peng, Wang, Zhou, & Lin, 2015) and heavy metals (Ji et al., 2012). Composted manure after batch fermentation, to a large degree, could overcome such problems (Peng et al., 2015).

VOP and PVA amendments decreased bacterial alpha diversities (Fig. 3) while altered the microbial community composition. VOP is the product of volcanic activity and it is primarily compost of Si, Al, K, Na, and Fe oxides etc. but lacks of carbon content (Cruz-Ruíz et al., 2016). Specifically, VOP amendment significantly increased
the relative abundance of *Firmicutes* at the phylum level (Fig. 4). This is partly because VOP amendments could accelerate soil organic carbon metabolism due to the improved soil porosity that could promote aeration as well as improve soil nutrient-microbes contact (Noland et al., 1992). Soil organic carbon was the main source for the metabolism of the soil microorganisms. Considering the main limiting factor in Loess Plateau region was the ‘poor’ soil with rather low SOM content (Guo et al., 2019), VOP could offer nothing to improve, if not worsen the status of soil functioning as a carbon sink (Fig. 1). PVA can be rapidly dissolved and be easily degradable highlighting its short effect on soil the microorganisms (Wiśniewska, 2010). Thus, VOP and PVA amendments alone could not impose long-last beneficial effects on the soil’s bacterial community.

**Conclusions**

Application of exogenous amendments can affect the soil structure and bacterial community in soils from the arid area of the Loess Plateau. Compared with the widely used non-plant soil amendments (i.e. polyvinyl alcohol and volcanic pumice), plant-sourced organic amendments (animal manure, plant residue and mushroom residue) significantly increased soil water holding capacity, aggregate stability, enzyme activities, and can influence beneficially soil bacterial community. Overall, animal manure imposed the greatest beneficial effect to the soil properties, followed by plant residue and mushroom residue. Animal manure could function as soil amendment for urban green space in the Loess Plateau and other regions with similar soil properties.

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