Influence of slope aspect on the microbial properties of rhizospheric and non-rhizospheric soil on the Loess Plateau, China

Ze Min Ai [1,2,3], Jiao Yang Zhang [1,2,3], Hong Fei Liu [4], Sha Xue [1,2]*, Guo Bin Liu [1,2]

[1] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, 712100, People's Republic of China

[2] Institute of Soil and Water Conservation, Chinese Academy of Sciences & Ministry of Water Resources, Yangling, Shaanxi 712100, People's Republic of China

[3] University of Chinese Academy of Sciences, Beijing 100101, People's Republic of China

[4] College of Forestry, Northwest A&F University, Yangling, Shaanxi 712100, People's Republic of China

* Corresponding author.

E-mail address: xuesha100@163.com.

*Corresponding address: Xinong Rd. 26, Institute of Soil and Water Conservation, Northwest A&F University, Yangling, Shaanxi 712100, People's Republic of China.

Abstract. Slope aspect is an important topographic factor in the micro-ecosystemic environment, but its effect on the microbial properties of grassland rhizospheric soil (RS) and non-rhizospheric soil (NRS) remain unclear. A field experiment was conducted at the Ansai Research Station on the Loess Plateau in China to test the influence of slope aspects (south-facing, north-facing, and northeast-facing slopes, all with *Artemisia sacrorum* as the dominant species) on RS and NRS microbial biomass carbon (MBC) content, phospholipid fatty acid (PLFA) content, and the rhizospheric effect (RE) of various microbial indices. Soil samples were collected from the three slope aspects, including rhizospheric and non-rhizospheric region, and analyzed to determine the related various microbial indices. The results showed that MBC content differed significantly among the slope aspects in RS but not in NRS, and RE for MBC content in the south-facing slope was larger than that in the north-facing slope. RS total, bacterial, and gram-positive bacterial PLFA contents in the south-facing slope were significantly lower than those in the north- and northeast-facing slopes, and RS gram-negative bacterial (G⁻) and actinomycete PLFA contents in the south-facing slope were significantly lower than those in the north-facing slope. In contrast, NRS total, bacterial, and G⁻ PLFA contents in the north-facing slope were significantly higher than those in the south- and northeast-facing slopes, and NRS fungal and actinomycete PLFA contents in the north- and south-facing slopes were significantly higher than those in the northeast-facing slope. RE for all PLFA contents except fungal in the northeast-facing slope were higher than those in the south-facing slope. Slope aspect significantly but differentially affected the microbial properties in RS and NRS, and the variable influence was due to an evident RE for most microbial properties.

Keywords: topographic factor, rhizospheric effect, phospholipid fatty acid, fungi, bacteria, actinomycete

1   Introduction

As an important topographic factor, slope aspect can affect the amount of solar radiation received (Selvakumar et al., 2009), and solar radiation influences ecologically critical factors of local microclimates and determines soil temperature, evaporation capacity, and soil-moisture content (Carletti et al., 2009; Bennie et al., 2008). South-facing slopes in the Northern Hemisphere, which receive more solar radiation than north-facing slopes, are typically hot, dry, and subject to rapid changes in seasonal and diurnal microclimates. North-facing slopes have the opposite pattern and receive the least insolation, are cool, moist, and subject to slow changes in seasonal and daily microclimates (Sariyildiz et al., 2005). Slope aspect can therefore substantially affect soil-moisture content, water budget, and soil temperatures (Sidari et al., 2008; Carletti et al., 2009; Sariyildiz et al., 2005; Dearborn and Danby, 2017). The effect of slope aspect on basic soil properties (pH, bulk density, and texture), nutrient (carbon, nitrogen, and phosphorus) contents, microbial biomass, and enzymatic activities have been studied (Ai et al., 2017a; Ascher et al., 2012; Gilliam et al., 2014; Huang et al., 2015; Sidari et al., 2008; Qin et al., 2016; Bardelli et al., 2017; Liu et al., 2017). Previous research indicated that slope aspect markedly affects soil and microbiological properties in micro-ecosystemic environments. The results of studies on the impact of slope aspect on the microbiological properties, however, are not consistent. Some studies have shown that north-facing slopes have more microbial biomass carbon (MBC), bacteria, and actinomycetes than south-facing slopes (Ascher et al., 2012; Huang et al., 2015); in contrast, other studies have found that the MBC, fungal, and total phospholipid fatty acid (PLFA) contents in the south-facing slopes were significantly higher than those in

77 north-facing slopes (Huang et al., 2015; Sidari et al., 2008; Gilliam et al., 2014). Gilliam et al. (2014)
78 found that bacterial biomass did not vary with slope aspect. The influence of slope aspect on microbial
79 characteristics has obviously been variable in these studies, and the differences may be caused by the
80 differences in plant species (trees vs shrubs), soil properties, climatic conditions, and research methods.
81 Previous studies have also mainly focused on trees and shrubs, but the influence of slope aspect on
82 grassland soil microorganisms is still unclear, even though the grassland ecosystem is an important
83 component of terrestrial ecosystems.

84   The rhizosphere is commonly defined as the narrow zone of soil adjacent to and influenced by
85 plant roots (Chen et al., 2002). The rhizosphere contains root exudates, i.e. leaked and secreted
86 chemicals, sloughed root cells, and plant debris (Warembourg et al., 2003). Microbial activity is
87 therefore high in rhizospheric soil (RS) and clearly distinct from the activity in non-rhizospheric soil
88 (NRS) due to differences in nutrient availability, pH, and redox potential (Hinsinger et al., 2009).
89 Microbial content is higher in RS than NRS (Buyer et al., 2002; Marschner et al., 2002), which is
90 known as the rhizospheric effect (RE). The effect of slope aspect on RS and NRS microbial biomass
91 and community composition has not been extensively studied. Knowledge of the influence of slope
92 aspect on the differences between RS and NRS microbial communities could provide new insights into
93 topographical influences of RE on local micro-ecosystemic environments.

94   Soil microbial communities play important roles in soil quality and ecosystemic processes,
95 including nutrient cycling, decomposition of organic matter, bioremediation of structural formation,
96 and even plant interactions (Harris, 2009). These communities are closely associated with their
97 surroundings, rapidly responding to changes and environmental stresses. Soil microbes are thus
98 commonly used as sensitive indicators of change to soil quality under environmental stresses. Various
99 microbial PLFAs represent the different nutritional requirements of the microbial groups. Bacteria and
100 fungi form most of the microbial biomass and represent the main drivers of organic-matter turnover
101 (Bååth and Anderson, 2003). Moreover, different kinds of bacteria produce different PLFAs:
102 Gram-negative (G^-) and Gram-positive (G^+) bacterial PLFA contents are usually considered indicators
103 of chemolithotrophic and heterotrophic bacterial communities, respectively. G^- bacteria are mainly
104 associated with roots and thus decompose low-molecular-weight organic molecules (Griffiths et al.,
105 1999), whereas G^+ bacteria decompose more complex materials, such as organic matter and litter
106 (Kramer and Gleixner, 2006). Soil respiration is widely used for measuring microbial activity (e.g.
107 basal respiration) or determining the potential microbial activity in soil (e.g. substrate-induced
108 respiration) (Nannipieri et al., 1990; Wardle, 1995). These microbial indices are all sensitive
109 bio-indicators that can be used to estimate soil quality and the effect of slope aspect on RS and NRS
110 microbial communities. Soil ecologists have long been interested in the response of microbial
111 communities to environmental factors for understanding the underlying mechanisms determining the
112 content and composition of microbial biomass. Microbial communities have a close relationship with
113 pH, carbon (organic and water-soluble organic carbon), nitrogen (total nitrogen, ammonium and nitrate
114 nitrogen, and water-soluble ammonium and nitrate nitrogen), and phosphorus (total and available
115 phosphorus) (Bardelli et al., 2017; Huang et al., 2014; Nilsson et al., 2005; Ma et al., 2015). Under the
116 conditions of different slope aspects, the effect of the main soil nutrient factors on RS and NRS
117 microbial communities on local micro-ecosystemic environments, however, remains unclear.

118   The Chinese government introduced the Grain for Green Project in the 1990s to control soil
119 erosion and improve the ecological environment of the Loess Plateau by converting large areas of
120 sloping cropland to forest and grassland. *Artemisia sacrorum*, a perennial herb with multiple branches,

well-developed root suckers, and high seed production and fertility, is widely distributed on the plateau (Wang and Liu, 2002), especially in the converted grassland. *A. sacrorum* was selected as a typical grassland plant of this region to study the effect of slope aspect on the MBC, total, fungal, bacterial, and actinomycete PLFA contents in RS and NRS and the differences of their REs. The main RS and NRS environmental factors affecting microbial content and composition were also identified. Three slope aspects (south-facing, north-facing, and northeast-facing slopes) with the same rehabilitation age were tested on the Loess Plateau in China. The following hypotheses were tested: (1) slope aspect significantly but differentially affects the MBC, total, fungal, bacterial, and actinomycete PLFA contents and their REs; and (2) soil carbon (C) and nitrogen (N) are the main soil nutrient factors that affect RS and NRS microbial communities under different slope aspects.

2 Materials and methods

2.1 Study site

A field experiment was conducted at the Ansai Research Station (ARS) of the Chinese Academy of Sciences (36°51′30″N, 109°19′23″E; 1068–1309 m a.s.l.), northern Loess Plateau, China. The mean annual temperature of the study area is 8.8 °C, and the mean annual precipitation is approximately 505 mm, with >70% concentrated from July to September. Annual evaporation ranges from 1500 to 1800 mm. To control soil erosion and improve the ecological environment, the Chinese government has implemented the policy of converting sloping cropland to grassland in the region in 1990s. Synchronously, restoration of the local grassland mainly dependent on abandoned farmland. In order to study the effect of slope aspect on the soil microbial community in the restored grassland, three grassland areas abandoned in the same year were selected for the experiment. The main vegetation in the region includes woods such as *Robinia pseudoacacia* and *Platycladus orientalis*; shrubs such as *Caragana korshinskii*, *Hippophae rhamnoides*, *Syzygium aromaticum*, and *Ostryopsis davidiana*; and herbage such as *Artemisia sacrorum*, *Bothriochloa ischcemum*, *Setaria viridis*, *Artemisia giraldii*, and *Artemisia capillaris*. Details of the soil properties and map of sampling sites were described by Ai et al. (2017a).

2.2 Experimental design and soil sampling

The slopes of the three grassland areas were south-facing (S15°W), northeast-facing (N75°W), and north-facing (N57°E). The three study areas were selected in September 2014 after consultation with ARS researchers and reviewing relevant land documents. The basic characteristics are shown in Table 1.

Table 1. Characteristics of the sampling sites.

Slope aspect	Latitude (°N)	Longitude (°E)	Altitude (m)	Plant community
S15°W	36.85	109.31	1269	*A. sacrorum + Bothriochloa ischaemum*
N75°W	36.85	109.31	1275	*A. sacrorum + Phragmites australis*
N57°E	36.85	109.31	1278	*A. sacrorum + Artemisia capillaries*

Three replicate 10 × 10 m plots were established at each site (*A. sacrorum* was the dominant plant at each site). The distance between sampling plots within sampling site was not less than 20 m. Each plot was first surveyed for latitude, longitude, elevation, slope aspect, and slope gradient. Three 1 × 1 m quadrats were then randomly set in each plot to characterise the vegetation, e.g. plant species, coverage, and number. The plants were removed, and the soil strongly adhering to the roots, i.e. RS, was collected (0–20 cm soil layer). Soil was also sampled from the same layer at locations

158 approximately 15 cm from the plant roots (i.e. NRS). Each NRS sample was a composite of

159 subsamples collected at five points (the four corners and the centre of the plot). A total of 18 soil

160 samples (3 sites × 3 plots per site × 2 soil types) were collected, and each was divided into two

161 subsamples: one subsample was placed in a cool container, and the other was placed into a cloth bag.

162 The samples were then taken to the laboratory, and gravel and coarse fragments were removed. The

163 container samples were homogenised and sieved to 2 mm and were also divided into two subsamples:

164 one subsample was stored at -80 ℃, and the other was stored at 4 ℃ until analysis. The samples in the

165 cloth bags were air-dried and sieved to 0.25 and 1 mm prior to analysis.

166 **2.3 Laboratory analysis**

167 The samples stored at 4 ℃ were used for determining MBC content (mg kg^{-1}), basal respiration (BR)

168 (mg kg^{-1} h^{-1}), and substrate-induced respiration (SIR) (mg kg^{-1} h^{-1}). Microbial biomass was measured

169 by chloroform fumigation (Vance et al., 1987). The soil samples were fumigated for 24 h at 25.8 ℃

170 with CHCl$_3$ (ethanol free) after the fumigation or non-fumigation treatments and then were extracted

171 with 100 ml of 0.5 M K$_2$SO$_4$ by horizontal shaking for 1 h at 200 rpm and then filtered. The amount of

172 K$_2$SO$_4$-extracted organic C was determined by a liquiTOCII analyser (Elementar, Hanau, Germany),

173 and MBC content was calculated using a kEC factor of 0.38 (Vance et al., 1987). The soil BR was

174 estimated by measuring the CO$_2$ evolution from 10.0 g of field fresh soils. The homogenized soil

175 samples were first placed in a polyethylene bottle with rubber stopper (the soil water content was

176 adjusted to 50% of field water-holding capacity). The polyethylene bottle was then incubated at 28 ℃

177 for 2 h, and the CO2 evolution was measured by an infrared gas analyser (QGS-08B, Beijing, China)

178 (Hueso et al., 2011). Soil SIR was determined using the same method as for BR but with the addition of

179 0.06 g glucose to the soil, after the glucose and soil were fully compounded, they were then incubated

180 at 28 ℃ for 1 h.

181 The soil stored at -80 ℃ was used for the determination of PLFA contents. The structures of the

182 microbial communities were determined using a method (Bligh and Dyer, 1959) modified by Bardgett

183 et al. (1996). Briefly, fatty acids were extracted from 3.0 g of freeze-dried soil using a solution

184 containing citrate buffer, chloroform, and methanol. The PLFAs were separated from neutral and

185 glycolipid fatty acids by solid-phase-extraction chromatography. After mild alkaline methanolysis, the

186 PLFAs were analysed using a gas chromatograph (GC7890A, Agilent Technologies Inc., Wilmington,

187 USA) equipped with MIDI Sherlock software (Version 4.5; MIDI Inc., Newark, USA).

188 **Table 2.** Characterisation of the microbial phospholipid fatty acids.

Microbial group	Specific PLFA markers
Gram-positive bacteria	11:0 anteiso, 12:0 anteiso, 13:0 iso, 13:0 anteiso, 14:0 iso, 14:0 anteiso, 15:0 iso, 15:0 anteiso, 15:1 iso w6c, 15:1 iso w9c, 16:0 iso, 16:0 anteiso, 17:0 iso, 17:0 anteiso, 18:0 iso, 19:0 iso, 19:0 anteiso, 22:0 iso
Gram-negative bacteria	12:1 w4c, 12:1 w8c, 14:1 w5c, 14:1 w8c, 14:1 w9c, 15:1 w5c, 15:1 w7c, 15:1 w8c, 16:1 w7c DMA, 16:1 w7c, 16:1 w9c DMA, 17:0 cyclo w7c, 17:1 w5c, 17:1 w7c, 17:1 w8c, 18:1 w5c, 18:1 w6c, 18:1 w7c, 18:1 w8c, 18:1 w9c, 19:0 cyclo w6c, 19:0 cyclo w7c, 19:1 w6c, 19:1 w8c, 20:1 w6c, 20:1 w9c, 21:1 w3c, 21:1 w5c, 21:1 w6c, 22:1 w3c, 22:1 w5c, 22:1 w6c, 22:1 w8c, 22:1 w9c, 24:1 w9c, 19:0 cyclo 9,10 DMA
Fungi	16:1w5c, 18:2w6c
Actinomycetes	16:0 10-methyl, 17:0 10-methyl, 17:1 w7c 10-methyl, 18:0 10-methyl, 18:1 w7c 10-methyl, 19:1 w7c 10-methyl, 20:0 10-methyl

189   An external standard of 19:0 methyl ester was used for quantification (Frostegård et al., 1993),

190 and the amounts were expressed as nmol g^{-1} for dry soil. Zelles (1999) reported that specific PLFA

191 signatures could serve as indicators of specific microbial groups. Total PLFAs were obtained by

192 summing the contents of all fatty acids detected in each sample. The classification of the PLFAs are

193 shown in Table 2.

194   The concentrations of soil organic carbon (SOC), total nitrogen (TN), and total phosphorus at the

195 sites have been reported by Ai et al. (2017a). Soil pH and available phosphorus (SAP), ammonium N

196 (NH_4), nitrate N (NO_3), water-soluble organic C (WSOC), water-soluble NH_4 (WNH$_4$), and

197 water-soluble NO_3 (WNO$_3$) contents were measured as described by Ai et al (2017b). The soil moisture

198 contents of sampling sites during investigation were determined gravimetrically by drying the samples

199 to a constant weight at 105 ℃, and then the water content was expressed as a percentage of the soil dry

200 weight. The characteristics of the rhizospheric and non-rhizospheric soils are shown in Table 3.

201 **Table 3.** Characteristics of the rhizospheric and non-rhizospheric soils.

	Slope aspect	pH	Water Content (100%)	SOC (g kg^{-1})	SAP (mg kg^{-1})	NO$_3$ (mg kg^{-1})	NH$_4$ (mg kg^{-1})	WSOC (mg kg^{-1})	WNO$_3$ (mg kg^{-1})	WNH$_4$ (mg kg^{-1})
Rhizospheric soil	South-facing	8.55	7.73	9.20	3.23	8.60	12.94	59.12	1.55	0.61
	North-facing	8.72	10.37	7.36	2.41	9.70	9.87	37.02	1.27	0.44
	Northeast-facing	8.63	10.60	5.21	1.98	7.33	9.05	45.32	1.77	0.53
Non-rhizospheric soil	South-facing	8.54	8.13	5.53	1.35	4.93	12.32	38.14	1.20	0.50
	North-facing	8.58	10.31	4.90	1.37	6.73	13.13	36.47	0.98	0.38
	Northeast-facing	8.58	10.45	4.27	1.68	6.27	12.42	40.39	1.38	0.45

202 **2.4 Calculations and statistical analysis**

203   The metabolic quotient (10^3 h^{-1}) was calculated as BR per unit MBC: metabolic

204 quotient=$10^3 \times$BR/MBC=$10^3 \times$(mg kg^{-1} h^{-1})/(mg kg^{-1}) (Anderson and Domsch, 1993). RE was

205 calculated as: RE=Rs/NRs, where Rs is a microbial property in RS, and NRs is a microbial property in

206 NRS (Mukhopadhyay et al., 2016). For example, the RE for MBC: RE=RS MBC/NRS MBC=(mg

207 kg^{-1})/(mg kg^{-1}). All data were analysed using one-way ANOVAs, followed by Duncan's tests at a

208 probability level of P<0.05 for multiple comparisons. All statistical analyses were performed using

209 SPSS 20.0 (SPSS Inc., Chicago, USA), and structural equation models (SEMs) were analysed using the

210 AMOS SPSS expansion pack. A redundancy analysis (RDA) was performed using CANOCO 5.0

211 (Biometris, Wageningen, the Netherlands). The graphs were plotted using SigmaPlot 12.5 (Systat

212 Software, San Jose, USA).

213 **3 Results**

214 **3.1 Impacts of slope aspect on MBC content, respiration, and BR/MBC**

215 RS MBC content did not differ significantly among the slope aspects, but NRS MBC content in the

216 north-facing slope was higher than those in the south- and northeast-facing slopes (Fig. 1A). The RE

217 for MBC in the south-facing slope was highest among the slope aspects (Fig. 2A). Slope aspect did not

218 affect BR, BR/MBC, or SIR in either RS or NRS (Fig. 1B and Table 4). The RE for BR did not differ

219 significantly among the slope aspects (Fig. 2A). The RE for SIR in the south-facing slope was higher

220 than that in the north-facing slope.

Table 4. Microbial respiratory quotients (BR/MBC), ratios of fungal PLFA content to bacteria PLFA content (F/B), and ratios of G^+ PLFA content to G^- PLFA content (G^+/G^-) in the rhizospheric and non-rhizospheric soils.

Slope aspect	Rhizospheric soil			Non-rhizospheric soil		
	BR/MBC (10^3 h^{-1})	F/B ratio	G^+/G^- ratio	BR/MBC (10^3 h^{-1})	F/B ratio	G^+/G^- ratio
South-facing	3.03±0.49a	0.07±0.00a	2.16±0.58a	2.47±0.52a	0.07±0.00a	1.45±0.23a
North-facing	2.67±0.41a	0.03±0.00b	1.55±0.29a	2.00±0.26a	0.04±0.00b	1.20±0.10a
Northeast-facing	2.77±0.23a	0.04±0.00b	1.54±0.16a	2.47±0.35a	0.05±0.00ab	1.33±0.06a

3.2 Impacts of slope aspect on microbial PLFA contents and composition

The microbial PLFA contents in RS differed significantly among the slope aspects. Total PLFA contents in the north- and northeast-facing slopes were 115 and 88% higher, respectively, than that in the south-facing slope (Fig. 3A). Fungal PLFA content did not differ significantly among the slope aspects (Fig. 3A). Bacterial PLFA content was similar to the trend for total PLFA content, with the lowest content in the south-facing slope (Fig. 3B). In contrast to total PLFA content, the ratio of fungal PLFA content to bacterial PLFA content (F/B ratio) in the south-facing slope was significantly higher than those in the north- and northeast-facing slopes (Table 4). Both G^+ and G^- PLFA contents had trends similar to that of the bacterial PLFA content, with the lowest contents in the south-facing slope (Fig. 3B). The ratio of G^+ PLFA content to G^- PLFA content (G^+/G^- ratio) did not differ significantly among the slope aspects (Table 4). Actinomycete PLFA content in the north-facing slope was 102% higher than that in the south-facing slope, similar to that of G^- PLFA content (Fig. 3A).

The composition of the NRS PLFA contents also differed significantly among the slope aspects. Total PLFA content in the north-facing slope was 50 and 62% higher than those in the south- and northeast-facing slopes, respectively (Fig. 3C). Bacterial PLFA content had a trend similar to that of total PLFA content, with the highest content in the north-facing slope (Fig. 3D). Fungal PLFA content in the south- and north-facing slopes was significantly higher than that in the northeast-facing slope (Fig. 3C). The F/B ratio in the south-facing was substantially higher than that in the north-facing slope (Table 4). G^- PLFA content had a trend similar to that of bacterial PLFA content, and G^+ PLFA content did not differ significantly among the slope aspects (Fig. 3D). The G^+/G^- ratio did not differ significantly among the slope aspects (Table 4). Actinomycete PLFA content had a trend similar to that of fungal PLFA content, with higher contents in the south- and north-facing slopes, which were 149 and 117% higher, respectively, than that in the northeast-facing slope (Fig. 3D).

The REs for total, bacterial, G^+, G^-, and actinomycete PLFA contents differed significantly among the slope aspects, but the RE for fungal PLFA content did not (Fig. 2B and C). The REs for total, G^+, G^-, bacterial, actinomycete PLFA contents in the northeast-facing slope were highest among the slope aspects.

3.3 Redundancy analysis (RDA)

The constrained RDAs indicated that environmental factors affected RS microbial characteristics (Fig. 4A). The total variation was 6.10, and the explanatory variables accounted for 96.8%. The first two axes (RDA1 and RDA2) explained 89.6% of the total variance, wherein 84.1% was attributed to RDA1 and 5.5% to RDA2. WSOC content was the most significant of the seven environmental factors and explained 63.6% (P=0.006) of the total variance. The slope aspect was the next most significant environmental variable and explained 62.8% (P=0.004), followed by NH$_4$ (58.6%, P=0.004), SAP

258   (45.7%, P=0.022), and WNH$_4$ (45.2%, P=0.032) contents.

259   The constrained RDAs indicated that environmental factors affected NRS microbial characteristics
260   (Fig. 4B). The total variation was 2.97, and the explanatory variables accounted for 94.2%. RDA1 and
261   RDA2 explained 81.6% of the total variance, 68.3% for RDA1 and 13.3% for RDA2. Among the seven
262   environmental factors, WNO3 content was the most significant and explained 34.7% (P=0.04) of the
263   total variance.

264   **3.4 Path analysis**

265   The final SEM based on all indices adequately fitted the data to describe the effects of the
266   environmental factors on RS microbial characteristics (x^2=0.506; P=0.918; RMSEA, P<0.001; Fig. 5A).
267   The final model accounted for 99% of the variation in RS WSOC content, with 71% of the variation in
268   bacterial PLFA content, 78% of the variation in G$^+$ PLFA content, and 72% of the variation in total
269   PLFA content. Slope aspect was positively correlated with WSOC content (P<0.001). WSOC content
270   was negatively correlated with bacterial PLFA (P<0.001), G$^+$ PLFA (P<0.001), and total PLFA
271   (P<0.001) contents.

272   All indices adequately fitted the data to describe the effects of the environmental factors on NRS
273   microbial characteristics (x^2=3.222; P=0.521; RMSEA, P<0.001; Fig. 5B). The model was able to
274   explain 59% of the variation in WNH$_4$ content, 58% of the variation in MBC content, 55% of the
275   variation in G$^-$ PLFA content, and 45% of variation in total PLFA content. Slope aspect was strongly
276   positively correlated with WNH$_4$ content (P<0.001). WNH$_4$ content was strongly negatively correlated
277   with MBC (P<0.001), G$^-$ PLFA (P<0.05), and total PLFA (P<0.05) contents.

278   **4 Discussion**

279   **4.1 MBC, respiration, and BR/MBC**

280   Soil microbial biomass is closely associated with soil-moisture content (Zhang et al., 2005; Drenovsky
281   et al., 2010; Ma et al., 2015). The north-facing slope contained more moisture than the south-facing
282   slope (Sariyildiz et al., 2005), so microbial activity in the north-facing slope was higher than that in the
283   south-facing slope. NRS MBC content in the north-facing slope was significantly higher than that in
284   the south-facing slope in our study, supporting our hypothesis 1 and in agreement with other studies
285   (Huang et al., 2015; Sidari et al., 2008). Carletti et al. (2009), however, reported an opposite trend: soil
286   MBC content was higher in a south-facing slope. This disparity may have been due to the differences in
287   plant species, soil type, and regional climate (Gilliam et al., 2014). NRS MBC content in the
288   northeast-facing slope was lower than that in the north-facing slope, inconsistent with Huang et al.
289   (2015), whose study area had the same soil and climatic conditions as ours. The different result may
290   mainly be due to the different plant species: the effect of shrubland plants (Huang et al., 2015) on NRS
291   may be different from the effect of grassland plants (our study). Plant shade can affect soil microbial
292   activity (Blok et al., 2010), so different shading can lead to different MBC contents.

293   Plant roots release a high amount of exudates, such as sugars, amino acids, organic acids,
294   hormones, and enzymes (Zhang et al., 2012; Grayston et al., 1997). In contrast, soil with a low amount
295   of shading is prone to desiccation (Wang et al., 2008), and the quantity of exudates released by plant
296   roots is low, which may lead to lower activities of the microorganisms. RS MBC content therefore
297   should be higher than NRS MBC content, consistent with our results. In our study, the RE for MBC
298   content in the south-facing slope was significantly higher than that in the north-facing slope. The light

299 in south-facing slopes would have a greater impact on the soil micro-environmental than that in
300 north-facing slopes, because south-facing slopes in the Northern Hemisphere receive more sunlight
301 than north-facing slopes, leading to a larger difference between RS and NRS in south-facing slopes.
302 The RDA and path analysis found that NRS WSOC, WNO$_3$, and WNH$_4$ contents were well correlated
303 with MBC content (Figs. 4B and 5B), supporting our hypothesis that soil C and N the main soil
304 nutrient factors that affect RS and NRS microbial communities, and in agreement with other studies
305 (Haynes, 2000; Huang et al., 2014).

306 Neither RS nor NRS BR, SIR, and BR/MBC differed significantly among the slope aspects,
307 indicating that the actual microbial activities, potential microbial activities, and bioenergetic status of
308 the microbial biomass (Nannipieri et al., 1990; Wardle, 1995; Sinha et al., 2009) were similar among
309 the slope aspects in the study area. The RE of SIR in the south-facing slope was 96% higher than that
310 in the north-facing slope, indicating that the effect of slope aspect on the RS and NRS SIRs was more
311 evident in the south-facing slope than that in the north-facing slope, even though the influence of slope
312 aspect on SIR was not significant either in RS or NRS.

313 **4.2 PLFA contents and composition**

314 **4.2.1 Fungal and bacterial PLFA contents and composition**

315 NRS fungal PLFA content in the northeast-facing slope was lower than those in the south- and
316 north-facing slopes, but RS fungal PLFA content did not differ significantly among the slope aspects.
317 Previous studies have reported different results: Huang et al. (2015) and Gilliam et al. (2014) found that
318 slope aspect significantly affected the fungal community, and fungal abundance was lower in
319 north-facing slope; Bardelli et al. (2017) found that fungal abundance did not differ significantly
320 between north- and south-facing slopes. These different results may be due to the differences in plant
321 species (e.g. herbs vs shrubs), soil conditions, climate, and research methods (Gilliam et al., 2014). The
322 different responses of RS and NRS fungal PLFA contents indicated that rhizospheres could form an
323 environment that negates the effect of slope aspect on fungal communities more than non-rhizospheric
324 zones. SOC and TN can supply the microbial biomass with enough C, N, and energy resources to
325 support microbial growth (Jia et al., 2005), so the solubility of SOC (WSOC) and nitrogen (WNO$_3$,
326 WNH$_4$) would be closely associated with the fungal community. The RDA found that NRS WSOC and
327 WNO$_3$ were well correlated with fungal PLFA content (Fig. 4B), supporting our hypothesis 2 and
328 agreeing with previous studies (Haynes, 2000; Nilsson et al., 2005; Huang et al., 2014).

329 The effect of slope aspect on PLFA content differed between bacteria and fungi. Both RS and NRS
330 bacterial PLFA contents in the south-facing slope were lower than those in the north-facing slope,
331 suggesting more soil moisture in the north-facing slope suitable for the growth of bacteria, in
332 agreement with some studies (Huang et al., 2015; Ascher et al., 2012) but not others (Gilliam et al.,
333 2014; Bardelli et al., 2017). The effect of slope aspect on the bacterial community would therefore
334 become significant due to the plant species, soil type, and climatic conditions. The RE for bacterial
335 PLFA content in the northeast-facing slope was significantly higher than that in the south-facing slope,
336 indicating that the environmental conditions of the rhizosphere helped the bacterial community to resist
337 environmental pressure. The RDA indicated that the RS WNH4, WSOC, and SAP contents were well
338 correlated with the bacterial PLFA content, and the NRS WNH$_4$ content was well correlated with the
339 bacterial PLFA content (Fig. 4A, B). The path analysis indicated that RS WSOC content was the main
340 factor influencing the bacterial PLFA content and mainly affected the G$^+$ PLFA content (Fig. 5A), in
341 agreement with another study (Fierer et al., 2003), but the NRS WNH$_4$ content mainly affected the G$^-$

342 PLFA content (Fig. 5B). These results indicated that the RS and NRS bacterial PLFA contents were
343 affected by different soil nutrient factors.

344   Soil moisture is an important environmental factor affecting the composition of microbial
345 communities, the higher amounts of soil moisture in north-facing slopes (Sariyildiz et al., 2005) can
346 lead to lower F/B ratios (Brockett et al., 2012; Drenovsky et al., 2010; Ma et al., 2015). The F/B ratio
347 in our study was highest in the south-facing slope and lowest in the north-facing slope for both RS and
348 NRS, consistent with previous studies (Huang et al., 2015; Gilliam et al., 2014). The higher amount of
349 soil moisture in the north-facing slope would reduce soil aeration, and lower oxygen levels would
350 create an environment favourable for facultative and obligate anaerobic bacteria (Drenovsky et al.,
351 2004). Drought stress in the south-facing slope would likely facilitate the survival of fungi, because soil
352 fungi rely on more aerobic conditions and are more tolerant of drought due to their filamentous nature
353 (Zhang et al., 2005). The significant difference in the RE for bacterial PLFA content was not obvious
354 for fungal PLFA content, so the RE was much weaker in the fungal than the bacterial community,
355 consistent with Buyer et al. (2002). These results indicated that RE had a large effect on the structures
356 of the fungal and bacterial communities.

357   Previous studies have found that wetter soils are more enriched in G^+ bacteria (Zhang et al., 2005;
358 Drenovsky et al., 2010; Ma et al., 2015), in agreement with the result of the RE G^+ PLFA content, but
359 not the NRE G^+ PLFA content. As RE was significantly affected by slope aspect for the G^+PLFA
360 content, this may be one of the reasons that caused the difference between RE and NRE G^+ PLFA
361 contents. Furthermore, the RDA indicated that the RS WSOC was well correlated with the RE G^+
362 PLFA content, and the NRS WNH_4 content was well correlated with the NRE G^+ PLFA content (Fig.
363 4A, B). Although drier soils tend to be more enriched in G^- bacteria (Zhang et al., 2005; Drenovsky et
364 al., 2010; Ma et al., 2015), both the higher RE and NRE G^- PLFA contents were recorded at the
365 north-facing slope. It has been shown that drier soils can lead to low root exudates, which may lead to
366 lower activities of the soil microorganisms (Zhang et al., 2015). The G^+/G^- ratio can indicate the
367 dominance of bacteria in soil microbial communities (Tscherko et al., 2004; Zhang et al., 2015).
368 Neither the RS nor the NRS G^+/G^- ratio was affected by slope aspect, indicating that slope aspect did
369 not significantly affect the dominant bacterial community in either RS or NRS.

370 **4.2.2 Actinomycete and total PLFA contents**

371 RS and NRS actinomycete PLFA contents were significantly affected by slope aspect, supporting our
372 hypothesis 1. Actinomycetes and G^+ bacteria have similar life habits, so wetter soils are more enriched
373 in actinomycetes (Zhang et al., 2005; Drenovsky et al., 2010; Ma et al., 2015). RS actinomycete PLFA
374 content in the north-facing slope was therefore higher than that in the south-facing slope, and the
375 northeast-facing slope had more moderate growth conditions for actinomycetes compared with the
376 north-facing and south-facing slopes. NRS actinomycete PLFA content, however, was lower in the
377 northeast-facing slope than those in the north-facing and south-facing slopes. This difference may have
378 been due to RE, because RE in the northeast-facing slope was significantly higher than those in the
379 other slopes. RE will affect soil nutrients more in RS than NRS (Zhang et al., 2012; Grayston et al.,
380 1997). The RDA indicated that the RS but not NRS actinomycete PLFA content was well correlated
381 with WSOC and WNH_4 contents, supporting our hypothesis 2 (Fig. 4A, B).

382   The G^+ and actinomycete PLFA contents accounted for more than 50% of total PLFA content in
383 both RS (57–59%) and NRS (54–58%), so the distribution of total PLFA content in our study area
384 depended mainly on the G^+ and actinomycete PLFA contents. Wetter soils tend to be more enriched in

385 G$^+$ bacteria and actinomycetes (Zhang et al., 2005; Drenovsky et al., 2010; Ma et al., 2015), so total
386 PLFA contents in both RS and NRS were highest in the north-facing slope. Total PLFA content,
387 however, was higher in the northeast-facing slope than that in the south-facing slope for RS and did not
388 differ significantly between the northeast-facing and south-facing slopes in NRS. These differences in
389 total PLFA content between RS and NRS may have been mostly due to RE. The shading by herbs in the
390 northeast-facing slope may make RS as suitable for microbial life as in the north-facing slope, whereas
391 NRS in the northeast-facing slope was not suitable for microbial life as in the south-facing slope
392 without plant shading. The path analysis indicated that WSOC content had a significant effect on RS
393 total PLFA content and that WNH$_4$ content had a significant effect on NRS total PLFA content (Fig. 5A,
394 B), as expected (Haynes, 2000; Huang et al., 2014; Nilsson et al., 2005). These results supported our
395 hypotheses 1and 2, but hypothesis 1 was inconsistent with the study by Huang et al. (2015) who found
396 a significantly higher total PLFA content in a south-facing slope than in other slopes. RE may have
397 been one of the main reasons, because shrub shading (Huang et al., 2015) clearly differs from herb
398 shading (our study), which could by caused a different RE (Blok et al., 2010).

399 **5 Conclusions**

400 This study provides experimental evidence that slope aspect can markedly but differentially affect
401 MBC and PLFA contents in RS and NRS that and the different influences can produce an evident RE;
402 the RE for most microbial properties was higher in the northeast-facing slope. WSOC content was well
403 correlated with RS microbial properties, and WNH$_4$ content was well correlated with NRS microbial
404 properties, likely due to RE. Studies of the influence of slope aspect on soil microbial communities
405 should therefore consider REs. This study provides new insights into the influences of topographic
406 factors affecting the mechanisms driving the structure of microbial communities in a
407 micro-ecosystemic environment. Further field investigation on different plant species, however, is
408 needed to determine the role of RE under the effect of slope aspect in micro-ecosystemic environments.

417 **References**

418 Ai, Z. M., He, L. R., Xin, Q., Yang, T., Liu, G. B., and Xue, S.: Slope aspect affects the non-structural
419   carbohydrates and C: N: P stoichiometry of *Artemisia sacrorum* on the Loess Plateau in China,
420   Catena, 152, 9-17, doi:10.1016/j.catena.2016.12.024, 2017a.
421 Ai, Z. M., Zhang, J. Y., Liu, H. F., Xin, Q., Xue, S., and Liu, G. B.: Soil nutrients influence the
422   photosynthesis and biomass in invasive *Panicum virgatum* on the Loess Plateau in China,

Plant Soil, 418, 153-164, doi:10.1007/s11104-017-3286-x, 2017b.

Anderson, T.-H., and Domsch, K.: The metabolic quotient for CO_2 (qCO_2) as a specific activity parameter to assess the effects of environmental conditions, such as pH, on the microbial biomass of forest soils, Soil Biol. Biochem., 25, 393-395, doi:10.1016/0038-0717(93)90140-7, 1993.

Ascher, J., Sartori, G., Graefe, U., Thornton, B., Ceccherini, M., Pietramellara, G., and Egli, M.: Are humus forms, mesofauna and microflora in subalpine forest soils sensitive to thermal conditions?, Biol. Fertility Soils, 48, 709-725, doi:10.1007/s00374-012-0670-9, 2012.

Bååth, E., and Anderson, T.-H.: Comparison of soil fungal/bacterial ratios in a pH gradient using physiological and PLFA-based techniques, Soil Biol. Biochem., 35, 955-963, doi:10.1016/S0038-0717(03)00154-8, 2003.

Bardelli, T., Gómez-Brandón, M., Ascher-Jenull, J., Fornasier, F., Arfaioli, P., Francioli, D., Egli, M., Sartori, G., Insam, H., and Pietramellara, G.: Effects of slope exposure on soil physico-chemical and microbiological properties along an altitudinal climosequence in the Italian Alps, Sci. Total Environ., 575, 1041-1055, doi:10.1016/j.scitotenv.2016.09.176, 2017.

Bardgett, R. D., Hobbs, P. J., and Frostegård, Å.: Changes in soil fungal: bacterial biomass ratios following reductions in the intensity of management of an upland grassland, Biol. Fertility Soils, 22, 261-264, doi:10.1007/BF00382522, 1996.

Bennie, J., Huntley, B., Wiltshire, A., Hill, M. O., and Baxter, R.: Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland, Ecol. Model., 216, 47-59, doi:10.1016/j.ecolmodel.2008.04.010, 2008.

Bligh, E. G., and Dyer, W. J.: A rapid method of total lipid extraction and purification, Canadian journal of biochemistry and physiology, 37, 911-917, doi:10.1139/y59-099, 1959.

Blok, D., Heijmans, M. M., Schaepman‐strub, G., Kononov, A., Maximov, T., and Berendse, F.: Shrub expansion may reduce summer permafrost thaw in Siberian tundra, Global Change Biol., 16, 1296-1305, doi:10.1111/j.1365-2486.2009.02110.x, 2010.

Brockett, B. F. T., Prescott, C. E., and Grayston, S. J.: Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in western Canada, Soil Biol. Biochem., 44, 9-20, doi:10.1016/j.soilbio.2011.09.003, 2012.

Buyer, J. S., Roberts, D. P., and Russek-Cohen, E.: Soil and plant effects on microbial community structure, Can. J. Microbiol., 48, 955-964, doi:10.1139/W02-095, 2002.

Carletti, P., Vendramin, E., Pizzeghello, D., Concheri, G., Zanella, A., Nardi, S., and Squartini, A.: Soil humic compounds and microbial communities in six spruce forests as function of parent material, slope aspect and stand age, Plant Soil, 315, 47-65, doi:10.1007/s11104-008-9732-z, 2009.

Chen, C., Condron, L., Davis, M., and Sherlock, R.: Phosphorus dynamics in the rhizosphere of perennial ryegrass (*Lolium perenne* L.) and radiata pine (*Pinus radiata* D. Don.), Soil Biol. Biochem., 34, 487-499, doi:10.1016/S0038-0717(01)00207-3, 2002.

Dearborn, K. D., and Danby, R. K.: Aspect and slope influence plant community composition more than elevation across forest–tundra ecotones in subarctic Canada, Journal of Vegetation Science, 28, 595-604, doi:10.1111/jvs.12521, 2017.

Drenovsky, R., Vo, D., Graham, K., and Scow, K.: Soil water content and organic carbon availability are major determinants of soil microbial community composition, Microb. Ecol., 48, 424-430, doi:10.1007/s00248-003-1063-2, 2004.

467 Drenovsky, R. E., Steenwerth, K. L., Jackson, L. E., and Scow, K. M.: Land use and climatic factors
468   structure regional patterns in soil microbial communities, Global Ecol. Biogeogr., 19, 27-39,
469   doi:10.1111 / j.1466-8238.2009.00486.x, 2010.
470 Fierer, N., Schimel, J. P., and Holden, P. A.: Variations in microbial community composition through
471   two   soil   depth   profiles,   Soil   Biol.   Biochem.,   35,   167-176,
472   doi:10.1016/S0038-0717(02)00251-1, 2003.
473 Frostegård, Å., Tunlid, A., and Bååth, E.: Phospholipid fatty acid composition, biomass, and activity of
474   microbial communities from two soil types experimentally exposed to different heavy metals,
475   Appl. Environ. Microbiol., 59, 3605-3617, doi:0099-2240/93/113605-13$02.00/0, 1993.
476 Gilliam, F. S., Hédl, R., Chudomelová, M., McCulley, R. L., and Nelson, J. A.: Variation in vegetation
477   and microbial linkages with slope aspect in a montane temperate hardwood forest, Ecosphere,
478   5, 1-17, doi:10.1890 / ES13-00379.1 2014.
479 Grayston, S., Vaughan, D., and Jones, D.: Rhizosphere carbon flow in trees, in comparison with annual
480   plants: the importance of root exudation and its impact on microbial activity and nutrient
481   availability, Appl Soil Ecol, 5, 29-56, doi:10.1016/S0929-1393(96)00126-6, 1997.
482 Griffiths, B. S., Bonkowski, M., Dobson, G., and Caul, S.: Changes in soil microbial community
483   structure in the presence of microbial-feeding nematodes and protozoa, Pedobiologia, 43,
484   297-304, 1999.
485 Harris, J.: Soil microbial communities and restoration ecology: facilitators or followers?, Science, 325,
486   573-574, doi:10.1126/science.1172975 2009.
487 Haynes, R.: Labile organic matter as an indicator of organic matter quality in arable and pastoral soils
488   in New Zealand, Soil Biol. Biochem., 32, 211-219, doi:10.1016/S0038-0717(99)00148-0,
489   2000.
490 Hinsinger, P., Bengough, A. G., Vetterlein, D., and Young, I. M.: Rhizosphere: biophysics,
491   biogeochemistry   and   ecological   relevance,   Plant   Soil,   321,   117-152,
492   doi:10.1007/s11104-008-9885-9, 2009.
493 Huang, X., Liu, S., Wang, H., Hu, Z., Li, Z., and You, Y.: Changes of soil microbial biomass carbon
494   and community composition through mixing nitrogen-fixing species with Eucalyptus
495   urophylla   in   subtropical   China,   Soil   Biol.   Biochem.,   73,   42-48,
496   doi:10.1016/j.soilbio.2014.01.021, 2014.
497 Huang, Y.-M., Liu, D., and An, S.-S.: Effects of slope aspect on soil nitrogen and microbial properties
498   in the Chinese Loess region, Catena, 125, 135-145, doi:10.1016/j.catena.2014.09.010, 2015.
499 Hueso, S., Hernández, T., and García, C.: Resistance and resilience of the soil microbial biomass to
500   severe drought in semiarid soils: The importance of organic amendments, Appl Soil Ecol, 50,
501   27-36, doi:10.1016/j.apsoil.2011.07.014, 2011.
502 Jia, G. M., Cao, J., Wang, C. Y., and Wang, G.: Microbial biomass and nutrients in soil at the different
503   stages of secondary forest succession in Ziwulin, northwest China, For. Ecol. Manage., 217,
504   117-125, doi:10.1016/j.foreco.2005.05.055, 2005.
505 Kramer, C., and Gleixner, G.: Variable use of plant-and soil-derived carbon by microorganisms in
506   agricultural soils, Soil Biol. Biochem., 38, 3267-3278, doi:10.1016/j.soilbio.2006.04.006,
507   2006.
508 Liu, M., Zheng, R., Bai, S., and Wang, J.: Slope aspect influences arbuscular mycorrhizal fungus
509   communities in arid ecosystems of the Daqingshan Mountains, Inner Mongolia, North China,
510   Mycorrhiza, 27, 189-200, doi:10.1007/s00572-016-0739-7 2017.

Ma, L. N., Guo, C. Y., Lü, X. T., Yuan, S., and Wang, R. Z.: Soil moisture and land use are major determinants of soil microbial community composition and biomass at a regional scale in northeastern China, Biogeosciences, 12, 2585-2596, doi:10.5194/bg-12-2585-2015, 2015.

Marschner, P., Marino, W., and Lieberei, R.: Seasonal effects on microorganisms in the rhizosphere of two tropical plants in a polyculture agroforestry system in Central Amazonia, Brazil, Biol. Fertility Soils, 35, 68-71, doi:10.1007 / s00374-001-0435-3, 2002.

Mukhopadhyay, S., Masto, R. E., Cerdà, A., and Ram, L. C.: Rhizosphere soil indicators for carbon sequestration in a reclaimed coal mine spoil, Catena, 141, 100-108, doi:10.1016/j.catena.2016.02.023, 2016.

Nannipieri, P., Grego, S., and Ceccanti, B.: Ecological significance of the biological activity in soil, Soil Biochemistry, 6, 293-355, doi:10.1201/9780203739389-7, 1990.

Nilsson, L. O., Giesler, R., Bååth, E., and Wallander, H.: Growth and biomass of mycorrhizal mycelia in coniferous forests along short natural nutrient gradients, New Phytol., 165, 613-622, doi:10.1111 / j.1469-8137.2004.01223.x 2005.

Qin, Y. Y., Feng, Q., Holden, N. M., and Cao, J. J.: Variation in soil organic carbon by slope aspect in the middle of the Qilian Mountains in the upper Heihe River Basin, China, Catena, 147, 308-314, doi:10.1016/j.catena.2016.07.025, 2016.

Sariyildiz, T., Anderson, J., and Kucuk, M.: Effects of tree species and topography on soil chemistry, litter quality, and decomposition in Northeast Turkey, Soil Biol. Biochem., 37, 1695-1706, doi:10.1016/j.soilbio.2005.02.004, 2005.

Selvakumar, G., Joshi, P., Mishra, P. K., Bisht, J. K., and Gupta, H. S.: Mountain aspect influences the genetic clustering of psychrotolerant phosphate solubilizing Pseudomonads in the Uttarakhand Himalayas, Curr. Microbiol., 59, 432-438, doi:10.1007/s00284-009-9456-1, 2009.

Sidari, M., Ronzello, G., Vecchio, G., and Muscolo, A.: Influence of slope aspects on soil chemical and biochemical properties in a Pinus laricio forest ecosystem of Aspromonte (Southern Italy), Eur J Soil Biol, 44, 364-372, doi:10.1016/j.ejsobi.2008.05.001, 2008.

Sinha, S., Masto, R., Ram, L., Selvi, V., Srivastava, N., Tripathi, R., and George, J.: Rhizosphere soil microbial index of tree species in a coal mining ecosystem, Soil Biol. Biochem., 41, 1824-1832, doi:10.1016/j.soilbio.2008.11.022, 2009.

Tscherko, D., Hammesfahr, U., Marx, M.-C., and Kandeler, E.: Shifts in rhizosphere microbial communities and enzyme activity of Poa alpina across an alpine chronosequence, Soil Biol. Biochem., 36, 1685-1698, doi:10.1016/j.soilbio.2004.07.004, 2004.

Vance, E. D., Brookes, P. C., and Jenkinson, D. S.: An extraction method for measuring soil microbial biomass C, Soil Biol. Biochem., 19, 703-707, doi:10.1016/0038-0717(87)90052-6, 1987.

Wang, G. L., and Liu, G. B.: Study on the interspecific association of the *artemisia sacrorum* community in Loess Hilly Region, Grassland of China, doi:10.3969/j.issn.1673-5021.2002.03.001, 2002.

Wang, L., Wang, Q., Wei, S., Shao, M. a., and Li, Y.: Soil desiccation for Loess soils on natural and regrown areas, For. Ecol. Manage., 255, 2467-2477, doi:10.1016/j.foreco.2008.01.006, 2008.

Wardle, D. A.: Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices, Adv. Ecol. Res., 26, 105-185, doi:10.1016/S0065-2504(08)60065-3, 1995.

Warembourg, F., Roumet, C., and Lafont, F.: Differences in rhizosphere carbon-partitioning among plant species of different families, Plant Soil, 256, 347-357, doi:10.1023/A:1026147622800,

2003.

Zelles, L.: Fatty acid patterns of phospholipids and lipopolysaccharides in the characterisation of microbial communities in soil: a review, Biol. Fertility Soils, 29, 111-129, doi:10.1007/s003740050533, 1999.

Zhang, C., Liu, G. B., Xue, S., and Zhang, C. S.: Rhizosphere soil microbial properties on abandoned croplands in the Loess Plateau, China during vegetation succession, Eur J Soil Biol, 50, 127-136, 2012.

Zhang, C., Liu, G. B., Xue, S., and Wang, G. L.: Changes in rhizospheric microbial community structure and function during the natural recovery of abandoned cropland on the Loess Plateau, China, Ecol. Eng., 75, 161-171, doi:10.1016/j.ecoleng.2014.11.059, 2015.

Zhang, W., Parker, K., Luo, Y., Wan, S., Wallace, L., and Hu, S.: Soil microbial responses to experimental warming and clipping in a tallgrass prairie, Global Change Biol., 11, 266-277, doi:10.1111/j.1365-2486.2005.00902.x, 2005.

599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
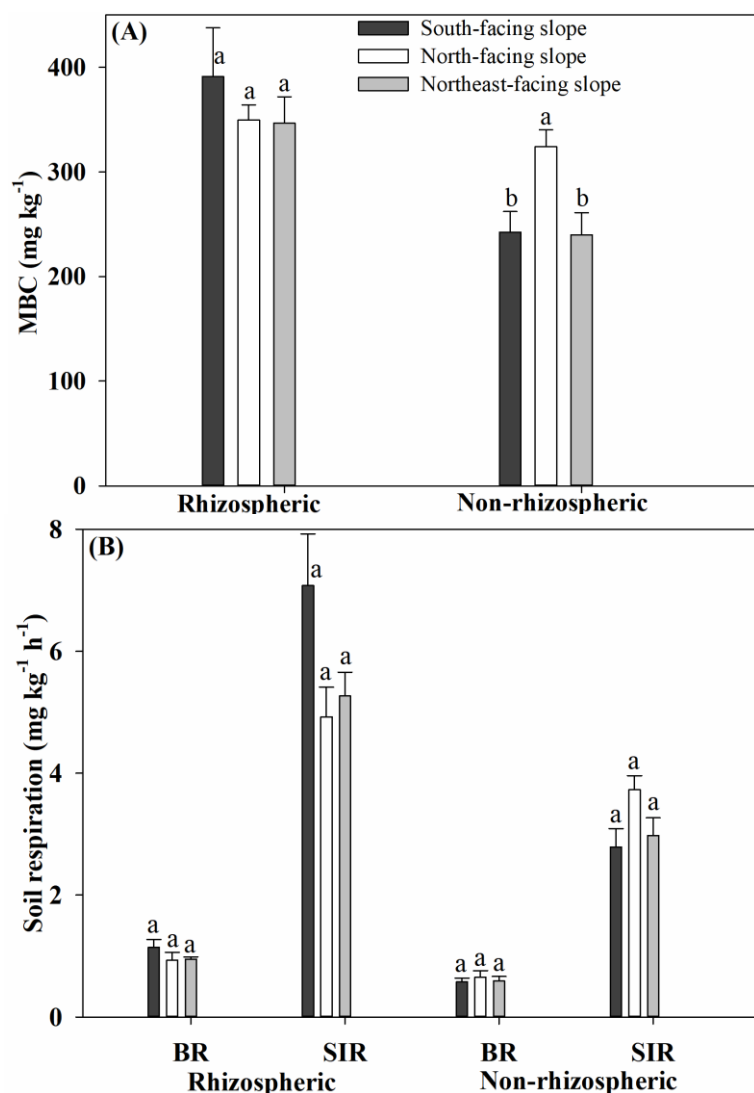630
631
632
633
634
635
636
637
638
639
640
641
642

Fig. 1 Microbial biomass carbon (MBC) content, basal respiration (BR), and substrate-induced respiration (SIR) in the rhizospheric and non-rhizospheric soils. Error bars are standard errors (n=3). Different letters above the bars indicate significant differences at P=0.05.

643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
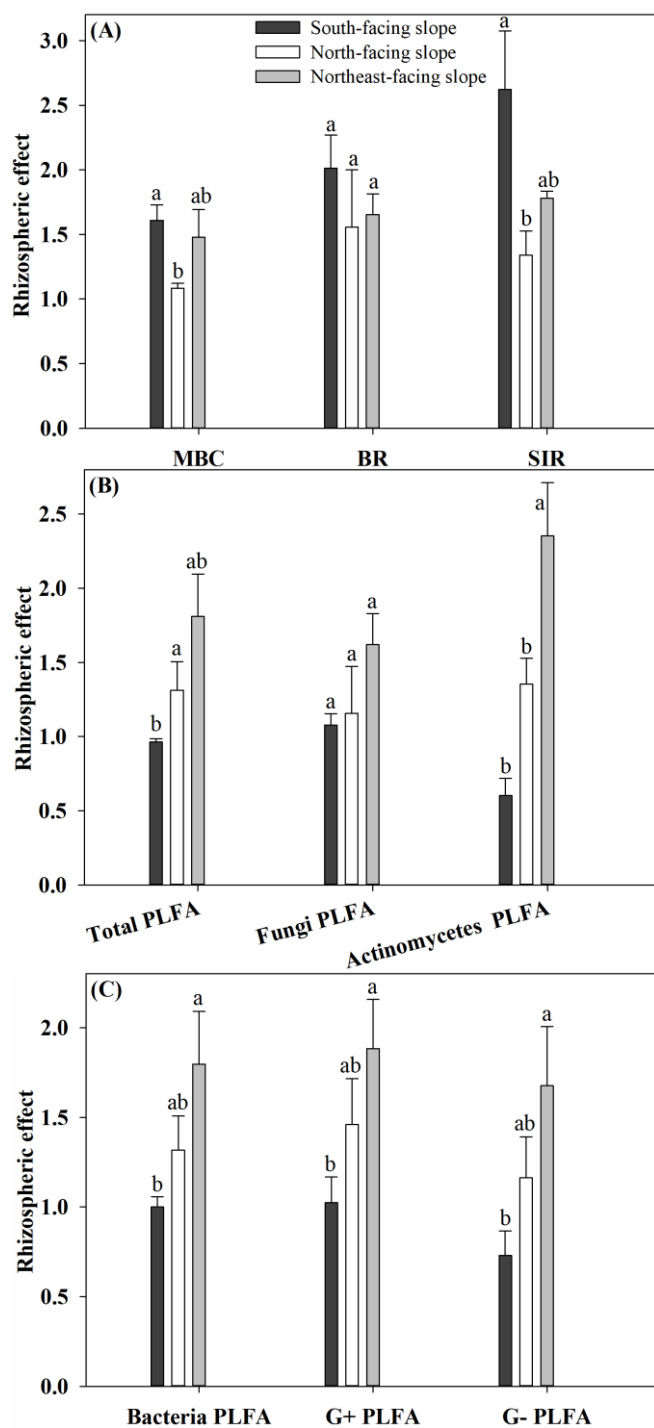
Fig. 2 The rhizospheric effects of MBC, BR, SIR, and PLFA contents. Error bars are standard errors (n=3). Different letters above the bars indicate significant differences at P=0.05.

687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
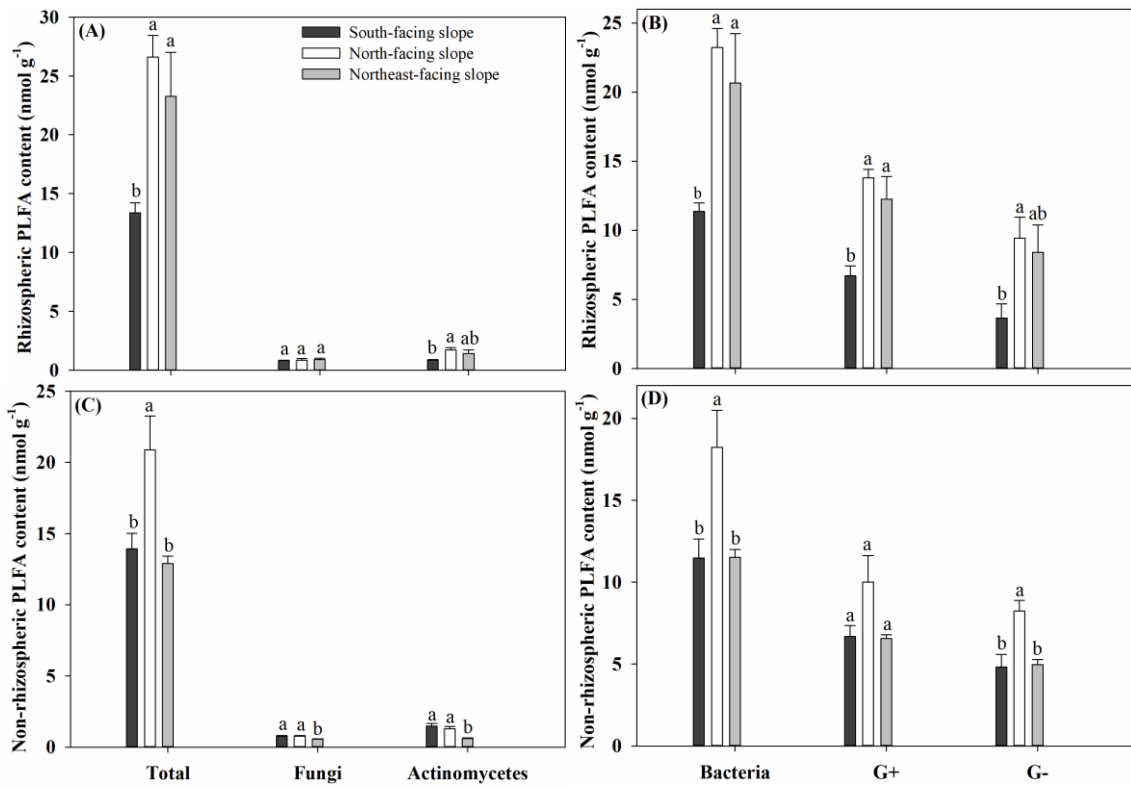
Fig. 3 Effects of slope aspect on PLFA contents in rhizospheric and non-rhizospheric soils. Error bars are standard errors (n=3). Different letters above the bars indicate significant differences at P=0.05.

731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
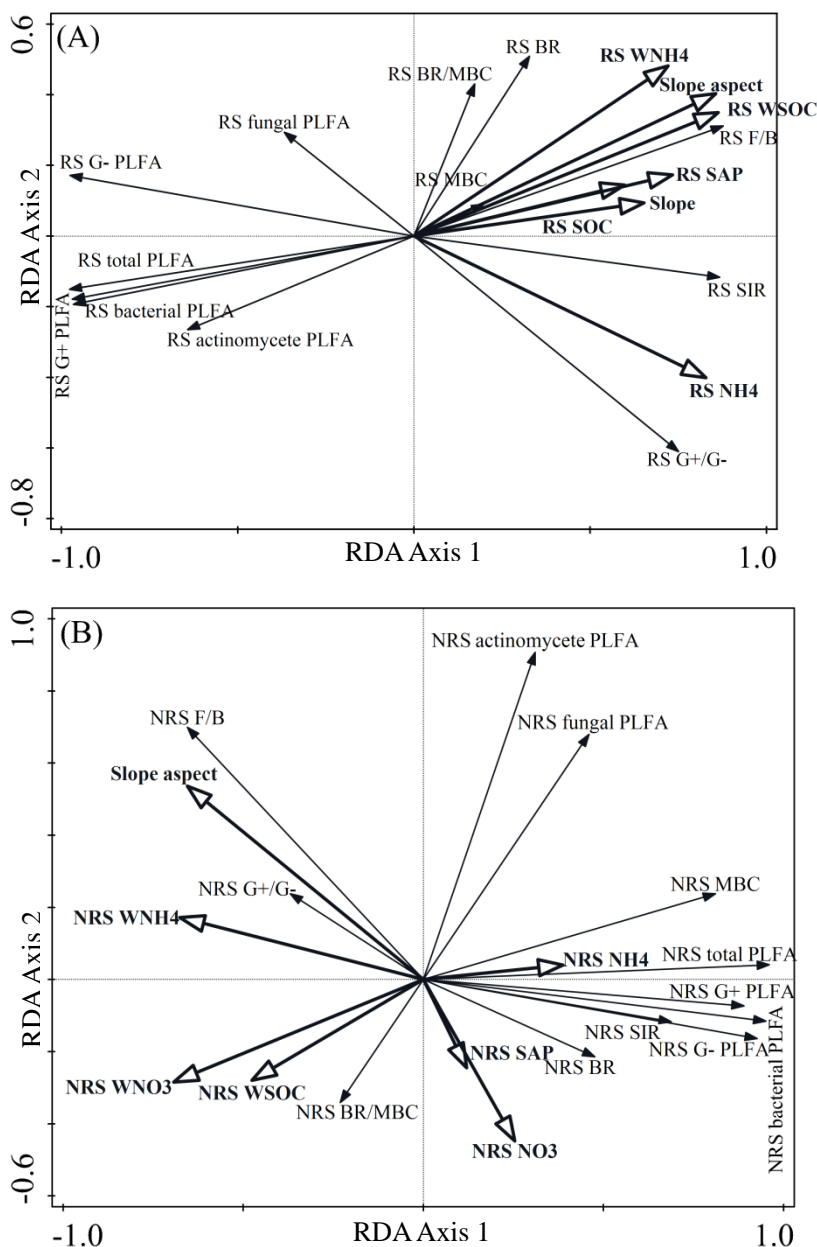766
767
768
769
770
771
772
773
774

Fig. 4 Bidimensional graph for a redundancy analysis of the relationships between microbial properties and environmental factors in the rhizospheric (A) and non-rhizospheric (B) soils.

Note: RS, rhizospheric soil; NRS, non-rhizospheric soil; MBC, microbial biomass carbon; BR, basal respiration; SIR, substrate-induced respiration; F/B, the ratio of fungal PLFA content to bacterial PLFA content; G+/G−, the ratio of G+ PLFA content to G− PLFA content; SAP, available phosphorus; SOC, soil organic carbon; NH4, ammonium nitrogen; NO3, nitrate nitrogen; WSOC, water-soluble organic carbon; WNH4, water-soluble ammonium nitrogen; WNO3, water-soluble nitrate nitrogen .
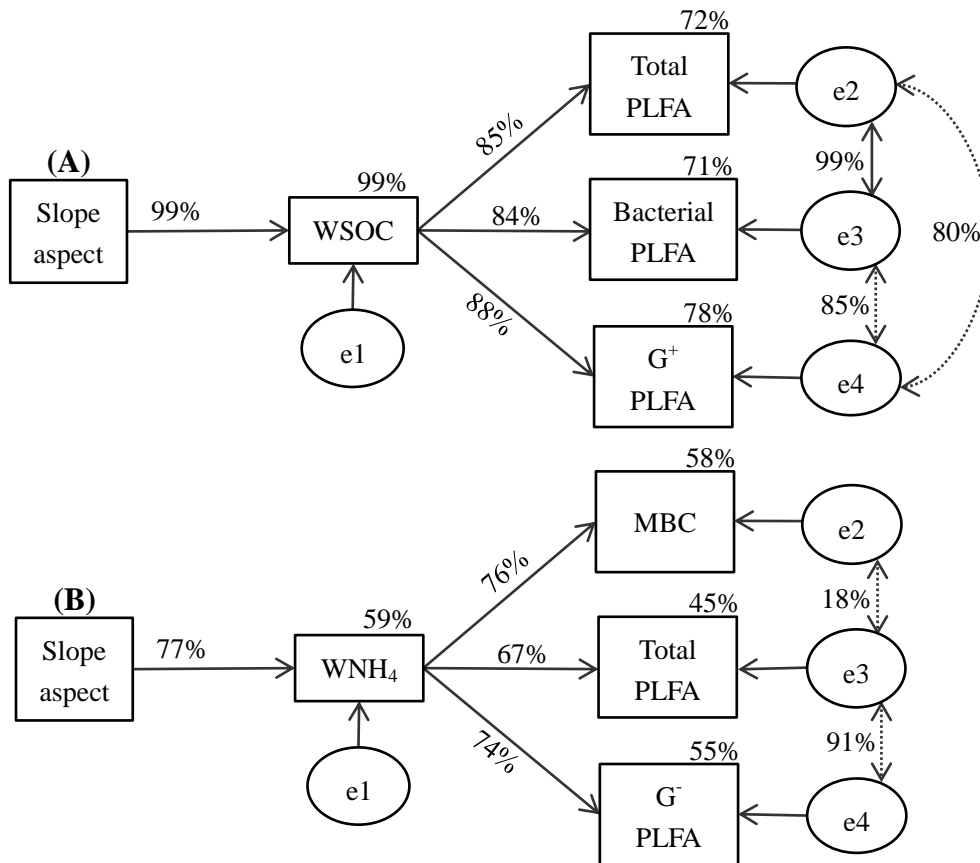
Fig. 5 Structural equation models of the effect of slope aspect on microbial properties in the rhizospheric (A) and non-rhizospheric (B) soils. Numbers on the arrows are standardised path coefficients (equivalent to correlation coefficients). Solid lines indicate significant standardised path coefficients (P <0.05). Circles indicate error terms (e1–e4). Percentages near the endogenous variables indicate the variance explained by the model.