European Journal of Soil Biology 56 (2013) 95–100

Contents lists available at SciVerse ScienceDirect

European Journal of Soil Biology

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

Original article

Impact of total water potential and varying contribution of matric and osmotic potential on carbon mineralization in saline soils

Raj Setia*[,1], Petra Marschner

School of Agriculture, Food and Wine, The Waite Research Institute, The University of Adelaide, Adelaide SA5005, Australia

ARTICLE INFO

Article history:
Received 12 July 2012
Received in revised form
11 February 2013
Accepted 19 February 2013
Available online 4 March 2013
Handling editor: Yakov Kuzyakov

Keywords:
Matric potential
Microbial biomass
Osmotic potential
Respiration
Salinity
Water potential

ABSTRACT

In saline soils, microbial activity may be reduced by low matric (low water content) and low osmotic potential (presence of salts) but little is known about the impact of the relative contribution of matric and osmotic potential to water potential (sum of matric and osmotic potential) on microbial activity and biomass. A laboratory incubation experiment was conducted using a non-saline sandy loam; different osmotic potentials (−0.30 to −3.24 MPa) were achieved by adding different amounts of NaCl. After pre-incubation for 14 days, subsamples of these treatments were dried to achieve different contributions of matric potential (8–73%) and osmotic potential (27–92%) to water potential which ranged between −0.57 and −4.57 MPa. All treatments were amended with 20 g kg^{-1} pea residues to increase nutrient supply; carbon dioxide (CO_2) emission was measured over 14 days. Microbial biomass C and K_2SO_4-extractable C were measured at the end of the experiment. Cumulative CO_2–C (mg g^{-1} soil) was significantly ($p < 0.05$) lower at water potential −4 MPa than at water potential −1.5 MPa. Above water potential −4 MPa, cumulative CO_2–C significantly decreased with increasing percentage contribution of osmotic potential to water potential, particularly if the contribution of osmotic potential was >50%. In contrast, K_2SO_4-extractable C and microbial biomass C were little affected by water potential above −4 MPa. Only at water potential −4 MPa, cumulative CO_2–C and microbial biomass C were affected by matric potential and its contribution to water potential; that is when the soils are very dry. Our results show that cumulative CO_2–C was more sensitive to decreasing water potential or the contributions of osmotic and matric potential than microbial biomass C. This suggests that not only water potential but also the contribution of osmotic and matric potential should be taken into account to understand microbial activity and growth in saline soils.

1. Introduction

Salinity and sodicity are major constraints for crop production in arid and semi-arid regions. Of the 20.8 billion hectares of arable land on earth, 19% is affected by salt [1] and of irrigated areas (about 250 million ha), about half are affected by salinity and water logging [2].

High concentrations of salts in the soil decrease the osmotic potential of the soil solution and therefore cause osmotic stress to plants and soil biota. Salinity can stress or even kill soil microorganisms, the drivers of nutrient cycling [8]. As a result, key ecological functions such as carbon (C) [3–7] or nitrogen transformation may be reduced or delayed [9–11]. Soil matric potential (soil moisture) also affects microbial activity in soils [12–14]. Decreasing matric potential decreases C mineralisation in soils by limiting substrate availability to microbes [15,16]. As the soil dries (decreasing matric potential), the water films around aggregates become thinner and consequently water is held tightly on to aggregate surfaces resulting in a lack of water for metabolic activity and diffusion of substrates to the microbes which limits their activity [17,18]. Microbes can respond to low water potential (either matric or osmotic stress) by producing osmolytes to counteract the low potential outside the cells [19–21]. However, synthesis of osmolytes is energy consuming and may therefore reduce the energy available for other processes such as growth.

In the studies mentioned above, the effects of osmotic and matric potential were studied separately as unrelated entities but little is known about their interaction on microbial activity in saline soils. Drying of saline soils (low matric potential) not only increases the salt concentration in the soil solution (low osmotic potential) but also limits diffusion of substrates to the microbes and thus potentially aggravates salt stress. Chowdhury et al. [22] showed for the first time that cumulative respiration decreased with decreasing water potential in saline soils but microbial activity was more

* Corresponding author. Tel.: +61 8 8313 7306; fax: +61 8 8303 6511.
E-mail address: setiark@gmail.com (R. Setia).
[1] Present address: CSIRO Land and Water, Canberra ACT 2601, Australia.

1164-5563/$ – see front matter © 2013 Elsevier Masson SAS. All rights reserved.
http://dx.doi.org/10.1016/j.ejsobi.2013.02.003

strongly decreased by decreasing osmotic potential at a given water content. However, in their study, the contribution of matric and osmotic potential to water potential varied with treatments and they could not clearly distinguish between the effect of low matric potential and that of low osmotic potential. The relative contribution of matric potential and osmotic potential to water potential may be important in understanding the effect of water potential on soil microbes, but this has not been studied in detail. To close this knowledge gap, an experiment was conducted to evaluate the effect of water potential and varying contributions of matric potential and osmotic potential on soil respiration and microbial biomass. Different water potentials and contributions of matric potential and osmotic potential were achieved by adding varying amounts salt to a non-saline soil and adjusting its water content to different levels. We hypothesised that at all water potentials, microbial activity and biomass will be mainly affected by the salt concentration in the soil solution (contribution of the osmotic potential), whereas the relative contribution of the matric potential is less important.

2. Materials and methods

2.1. Experimental design

A non-saline sandy loam (sand 55%, clay 18%, silt 27%, pH 8.3, $EC_{1:5}$ 0.26 dS m^{-1}, water holding capacity 309 mg g^{-1} soil, bulk density 1.45 g cm^{-3}, organic carbon 15.6 mg g^{-1} and microbial biomass C 47 mg kg^{-1}) was collected from Monarto (35° 05′ S and 139° 06′ E), South Australia. The area has a dry Mediterranean climate, and the average temperature is 30.1 °C in summer and 15.9 °C in winter with a mean annual rainfall of 352 mm.

The soil was passed through a 2 mm sieve before determining the water retention curve using suction and pressure techniques [23]. Matric potential was estimated from the moisture retention curve using the following equation [24]: $\Psi = a\theta^{-b}$ where, Ψ = water potential; a, b = empirical constants; θ = water content. The osmotic potential of the soil solution was estimated using the equation given by Richards [25]:

$$O_s = -0.036\ EC_{meas}\left(\theta_{ref}/\theta_{act}\right)$$

where O_s is the soil osmotic potential (MPa) at the actual water content (θ_{act}, g g^{-1}) of the soil and EC_{meas} is the measured electrical conductivity (dS m^{-1}) of the extract at the reference water content (θ_{ref}, g g^{-1}). In our case this reference water content is that of the 1:5 soil/water mixture. Because the electrical conductivity of soil was measured in a 1:5 soil: water suspension after 1 h end-over-end shaking at 25 °C.

The soil (<2 mm) was amended with different rates of NaCl to achieve different osmotic potentials (−0.30 to −3.24 MPa); a control treatment which was the soil without added NaCl was also included (Table 1). The lowest osmotic potential (most negative) was selected based on the results of Chowdhury et al. [26] who found that cumulative respiration was reduced by about 50% at osmotic potential −3 MPa. To activate the soil microbes, the soils were pre-incubated for 14 days at a water content that was optimal for microbial activity (0.16 g water g^{-1} soil) (matric potential = −0.28 MPa). This water content was chosen based on Setia et al. [27] who determined the water content for maximal microbial activity in a range of soils with varying texture. Osmotic potential decreases with decreasing matric potential. Therefore at the end of the pre-incubation different levels of water potential (matric plus osmotic potential) were obtained by drying the soils in a fan-forced oven at 25 °C to different water contents. The dried soils were separated into three groups based on water potential: −1.5 MPa (water potential varied between −1.48 and −1.60 MPa), −2.5 MPa (water potential between −2.32 and −2.50 MPa) and −4 MPa (water potential between −4.07 and −4.57 MPa). Within the groups of dried soils, the contribution of matric and osmotic potential to water potential ranged from 15 to 73% for the matric potential and from 27 to 85% for the osmotic potential (Table 2). The soils at optimum water content were not grouped and treated as continuous data.

2.2. Incubation

In the unamended soil, respiration was low (data not shown) suggesting that most microorganisms are in an inactive state and may therefore not respond to changes in water potential. However in the field soil microbes may be activated by plant residues or root exudates and then have to adapt to given water potential. Therefore to increase nutrient supply, the soils were amended with ground and sieved pea residue (C:N ratio 26, particle size between 2 and 0.25 mm) at a rate of 20 g kg^{-1} soil and mixed thoroughly. Twenty five gram of pre-incubated soil with residues was filled to PVC cores with a radius of 1.85 cm and a nylon mesh base (0.75 μm, Australian Filter Specialist) and packed to a bulk density of 1.45 g cm^{-3} in which is equivalent to the bulk density in the field using the following formula:

$$\text{Bulk density} = m\Big/\left(\pi r^2 h\right)$$

where,

m = mass of soil (g)
r = radius (cm) of PVC core

Table 1
Electrical conductivity (EC), concentration of NaCl added to obtain the target $EC_{1:5}$, water content, matric, osmotic and water potential, percent contribution of matric and osmotic potential to water potential cumulative CO_2–C, K_2SO_4-extractable C and microbial biomass C after 14 days *in soils at optimum water content* (160 g kg^{-1} soil) and matric potential (−0.28 MPa). Different letters indicate significant differences between treatments (n = 3).

$EC_{1:5}$	NaCl added	Osmotic potential	Water potential	% Contribution to water potential		Cumulative CO_2–C	K_2SO_4-extractable C	Microbial biomass C
dS m^{-1}	g 100 g^{-1} soil	MPa		Matric potential	Osmotic potential	mg CO_2–C g^{-1} soil	mg kg^{-1} soil	
0.26	–	−0.30	−0.57	48	52	4.2 f	149 ab	657 a
0.54	0.08	−0.61	−0.88	31	69	4.1 ef	142 a	732 a
0.58	0.09	−0.65	−0.93	30	70	3.9 e	172 abcd	615 a
0.72	0.13	−0.81	−1.09	25	75	3.6 d	164 abc	664 a
0.98	0.21	−1.10	−1.38	20	80	3.4 cd	159 abc	692 a
1.18	0.27	−1.33	−1.60	17	83	3.2 bc	188 bcd	655 a
1.45	0.35	−1.63	−1.91	15	85	3.3 c	175 abcd	659 a
1.80	0.45	−2.03	−2.30	12	88	3.3 cd	193 bcd	678 a
2.08	0.53	−2.34	−2.62	11	89	3.0 ab	215 d	716 a
2.88	0.77	−3.24	−3.52	8	92	2.9 a	202 cd	714 a