Catena 157 (2017) 112–129

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Soluble ions dynamics in Mediterranean coastal pinewood forest soils interested by saline groundwater

A. Buscaroli*, D. Zannoni

[a] Biological, Geological and Environmental Sciences Department (BiGeA), University of Bologna, Operative Unit of Ravenna, Via S. Alberto, 163, 48123 Ravenna, Italy

ARTICLE INFO

Keywords:
Salinity
Entisols
Groundwater
Soluble ions
Sodium adsorption ratio

ABSTRACT

The aim of the study was to evaluate the dynamics of soluble ions in the soils of a pinewood forest of the Mediterranean coastal area in the Province of Ravenna, Italy. A one year monitoring was carried out in four *Entisols* of the San Vitale pinewood forest, a vulnerable natural area due to subsidence and salt water intrusion. Ionic soluble forms were examined in saturated paste extracts (SPEs) and compared to groundwater soluble forms. Due to the local thermo-pluviometric conditions, both the water table depth and groundwater electrical conductivity (ECw) varied widely ranging respectively from 0 to − 162 cm in depth and from 2 to 28 $dS \cdot m^{-1}$ in salinity content. As expected, this greatly influenced soluble ions concentrations in soil horizons, leading to variations in salt's speciation.

In soils with a deep water table (*Typic Ustipsamments*), superficial horizons showed a prevalence of Ca^{2+} and HCO_3^- ion forms during the whole year, while in the deep horizons, Na^+ and Cl^- were the dominant ions. During summertime in soils with a shallow water table (*Sodic Psammaquents*), superficial ions enrichment was detected with Na^+ and Cl^- ions being prevalent. Autumn and winter rainfall provoked the leaching of both Na^+ and especially of Cl^- ions, leaving HCO_3^- as the main anion. In the soils with intermediate water table depth and moderate salinity (*Aquic Ustipsamments)*, less relevant variations were observed. During winter the Ca^{2+} ion was the most present at the soil surface together with HCO_3^-. During summer Ca^{2+} and Cl^- were the most present ions at the soil surface. At deeper horizons Na^+ and Cl^- ions always prevailed. The sodium adsorption ratio (SAR) reached the greatest values (> 40) during summertime in *Sodic Psammaquents* superficial horizons and in *Typic Ustipsamments* deep horizons. On the basis of mixing curves, Na^+ and Cl^- displayed a conservative behavior and a likely sea origin. Both the Ca^{2+} and SO_4^{2-} ions appeared to be partially released from the solid soil fraction, while the Mg^{2+} ion seemed to be partially absorbed by the solid matrix. On the basis of the hydrochemical characterization of both groundwater and soil SPEs, it was possible to identify different refreshing and salinization processes along the soil profiles. The one year monitoring of both the whole soil profile and groundwater, never performed before, allows a better understanding of the presence of distinct plant species and disease symptoms.

1. Introduction

The Mediterranean basin has been identified as one of the world's most vulnerable regions in regards to climate and anthropogenic change (García-Ruiz et al., 2011; Milano et al., 2012). These changes create pressure on water resources which is expected to further increase in the future (Murray et al., 2012). In coastal areas, global warming plays a fundamental role in modifying sea levels, precipitation and temperature regimes. This provokes a deep modification of the environment, involving hundreds of millions of people living in these areas which are potentially vulnerable to these impacts (IPCC, 2014). As reported by Da Lio et al. (2015) due to relative sea level rise, decreasing precipitation and groundwater withdrawal, a significant saltwater intrusion occurs in shallow aquifers with low hydraulic gradients. This phenomenon has been recorded over the last decades along many worldwide coastal plains. For instance, from Maine to Florida along the Atlantic coast (Barlow, 2003), in the lower Burdekin delta, Australia (Narayan et al., 2003), in Jakarta, Indonesia (Abidin et al., 2011), in the Laizhou Bay, China (Qi and Qiu, 2011), in South Korea (Lee and Song, 2007) and also along the Ravenna coast, Italy (Giambastiani et al., 2007).

Understanding the mixing between salt/fresh surficial water and groundwater in coastlands is an issue of paramount importance considering the ecological, cultural, and socio-economic relevance of

* Corresponding author.
E-mail address: alessandro.buscaroli@unibo.it (A. Buscaroli).

http://dx.doi.org/10.1016/j.catena.2017.05.014
Received 14 October 2016; Received in revised form 29 April 2017; Accepted 15 May 2017
Available online 23 May 2017

the coastal plains (Da Lio et al., 2015). In fact, in many regions, groundwater is the key source of water for some vegetation species, and its availability and dynamics can define vegetation composition and distribution (Orellana et al., 2012) especially in regards of phreatophytes, defined as plants that have roots that can penetrate the capillary fringe and the saturated zone (Naumburg et al., 2005).

Groundwater/plant species interaction generally occurs in the soil, which represents the medium for plant growth. Several studies have focused their attention on soil salinity in coastal environments and its influence on agriculture and vegetation composition and distribution both worldwide (Lee and Song, 2007; Radimy et al., 2017; Sun et al., 2012; Yao et al., 2013) and also in the Mediterranean basin (Álvarez-Rogel et al., 2007; González-Alcaraz et al., 2014; Kotb et al., 2000; Molina et al., 2003). Sometimes studies have been conducted only at a given time (e.g., Álvarez-Rogel et al., 2007; Yao et al., 2013) without considering the evolution over time of the salinization process. Sometimes groundwater or irrigation water salinity has been assessed instead of that of soil, because they are easier to measure (e.g., Lee and Song, 2007). Also pedotransfer functions have largely been developed (e.g., Radimy et al., 2017) to assess different aspects related to soil salinity but the challenge, in this case, is to fit the models to the different fields, crops and soils. In some cases soil salinity has been properly monitored in saturated past extracts (SPEs) but at fixed depths (e.g., Benyamini et al., 2005) thus loosing information related to the natural and distinctive soil horizons, or only at the soil surface (e.g. González-Alcaraz et al., 2014; Ortiz et al., 1995) because of the presence of grasses and shrubs.

Also soluble ions in the SPEs have been monitored (e.g. Álvarez-Rogel et al., 1997; González-Alcaraz et al., 2014) even if, in these studies, observations where limited to the uppermost 20 cm of soil. The soluble ions determination in SPE appears to be the most appropriate technique especially in cases in which a comparison is made with soluble ions content in groundwater. In fact, the SPE allows the assessment of the maximum salt content which is brought in solution in a possible soil saturation condition, obtaining the concentration of soluble salts similar to those in real soil situations (Sonmez et al., 2008). The extracts with soil to water suspension ratios above the saturation threshold (e.g. soil: water equal to 1:1; 1:2.5; 1:5) are more easily achievable, but less correlated with the real saline composition in soils at field conditions. Moreover, experimental errors (i.e. by dispersion, hydrolysis, cation exchange and mineral dissolution) increase as the ratio of the soil to water amount in the suspension decreases (Mandal et al., 2015). The electrical conductivity measured in SPE (ECe) is recommended as a general parameter for estimating soil salinity in relation to plant growth (Rhoades et al., 1989) thus permitting to define the salinity tolerance thresholds for many species (Maas and Grattan, 1999). The electrical conductivity of the SPE is a parameter required by both the World Reference Base (IUSS Working Group WRB, 2006) and the USDA Soil Taxonomy (SSS, 2006) for the *salic* horizon identification. Furthermore, while the former classification considers only the presence of some degree of ECe at some time during the year, the latter requires the verification of the excess of ECe for 90 consecutive days, thus requiring a monitoring of the soil salinity.

To the best of our knowledge, a year-long monthly monitoring of whole soil profiles and groundwater in a coastal pinewood forest, focused on soil salinity and related parameters, has never been performed before.

Based on the experience presented by Buscaroli and Zannoni (2010) in the San Vitale Pinewood forest, in north Italy, this paper presents and discusses the soluble ions dynamics, not limited only to the soil surface, or to groundwater, but also comprising the vadose zone in which forest plant species develop their roots.

The forests growing on the ancient and the more recent dunes of the Po plain, in the Province of Ravenna, known as "Pinewoods", represent a complex ecosystem where both the water table oscillations and the micro-topography play a fundamental role in soils and landscape development. The sandy nature of Holocenic sediments (Amorosi et al., 1999; Marchesini et al., 2000) characterizes these areas as points of aquifer recharge. The intense exploitation of artesian and methane wells has led to a subsidence of the area by 1 m during the 20th century (Teatini et al., 2005), nowadays diminished to around 0–5 mm per year (ARPA – Regione Emilia-Romagna, 2013). However, this phenomenon has increased the need for mechanical drainage of surrounding agricultural soils in order to prevent submersion. These anthropic local factors, together with the decrease of rainfall due to climate change, have led to the reduction of the fresh water hydraulic charge of the phreatic coastal aquifer, favoring sea water intrusion and aquifer salinization (Giambastiani et al., 2007). In these areas at the hydrological level, both the superficial water table and the phreatic aquifer salinization were monitored and modelled (Antonellini et al., 2008; Giambastiani et al., 2007; Laghi et al., 2010). The geochemical characterization of the phreatic aquifer has permitted the evaluation of the water type and the provenance of chemical species (Mollema et al., 2013; Petrini et al., 2009). In respect to soils, the very first study in the San Vitale Pinewood forest, addressed the problem of salinization (Sandri, 1974). Some decades later a general pedological characterization was conducted by the Emilia-Romagna (1994), while Buscaroli et al. (2009, 2010), Buscaroli and Zannoni (2010) and Ferronato et al. (2016) contributed to the knowledge of the pinewood soils.

The year-long monitoring study conducted by Buscaroli and Zannoni (2010) highlighted how significant variations in ECe arose in soils profiles and how these were strongly influenced by the thermo-pluviometric regime and the depth and salinity of the water table. Soil salinity variations and plant diffusion, in relation to micro-topography and thermo-pluviometric regimes, were also studied in dune soils and brackish marshland in Mediterranean littoral environments by Ortiz et al. (1995) and by Álvarez-Rogel et al. (1997, 2001, 2007). Also in the pinewoods of Ravenna, the studies concerning phytosociological association (Piccoli et al., 1991, 1999) showed how vegetation distribution was strictly related to the water table depth and its salinity (Antonellini and Mollema, 2010). The influence of groundwater and soil salinity on nutrition and growth of forest plants were also studied for the main species growing in Ravenna pinewoods. In particular some authors (Alaoui-Sossé et al., 1998; Blaylock, 1994; Ganatsas and Tsakaldimi, 2007; Khaldi et al., 2011; Loustau et al., 1995; Qin et al., 2009; Sixto et al., 2005) found the salinity tolerance levels for many distinct species of plant.

On this basis, our current work aimed at: i) focusing on soluble ions movement and SAR assessment in soil profiles, in order to comprehend where salinity and sodicization conditions arise over a year-long study and to what extent they are influenced by water table characteristics and the thermo-pluviometric regime; ii) studying the soluble ions concentration with the mixing curves obtained starting from sea water, in order to evaluate the degree of interaction with the solid soil matrix; iii) classifying the ground waters and the soil horizons SPEs at a hydrochemical level, in order to establish possible relations to thermo-pluviometric trends, as well as to observe freshening and salinization phenomena along soil profiles; iv) comparing ECe values of the soil thickness penetrated by the roots of the typical plants of the pinewood forest with their salinity tolerance levels reported in the literature, in order to verify possible stress.

2. Material and methods

2.1. Sites description

The San Vitale pinewood forest (Fig. 1) covers an area of about 1312 ha and represents an ecosystem which is highly affected by both subsidence and salinization processes. The substrata is characterized by medium and fine sands of beach ridge and aeolic dune deposits, formed between the 10th and the 15th century by the deposition of sediments from an ancient branch of the Po river (Bondesan et al., 1995; Veggiani,