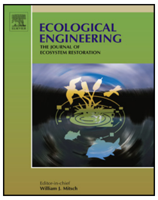
Ecological Engineering 87 (2016) 281–287

Contents lists available at ScienceDirect

Ecological Engineering

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



Effects of *Spartina alterniflora* invasion and exogenous nitrogen on soil nitrogen mineralization in the coastal salt marshes

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ARTICLE INFO

Article history:
Received 2 February 2015
Received in revised form 26 October 2015
Accepted 2 December 2015
Available online 21 December 2015

Keywords:
N mineralization
Nitrification
Spartina alterniflora invasion
Exogenous N
Coastal wetlands

ABSTRACT

The rapid expansion of *Spartina alterniflora*, exogenous nitrogen (N) input and climate change in the coastal wetlands in the east of China may interactively affect soil N mineralization in costal salt marshes. A laboratory incubation experiment was conducted with two exogenous N forms (NO_3^-—N and NH_4^+—N), six temperatures (5, 10, 15, 20, 25 and 30 °C) and three plant marshes (the invasive *S. alterniflora* and native *Suaeda salsa* and *Phragmites australis*) to investigate these interactive effects on soil net N mineralization rate and net nitrification rate in coastal wetlands. The averaged rates of net N mineralization and net nitrification over incubation temperature from 5 to 30 °C were significantly higher in the *S. alterniflora* marsh than in the *S. salsa* and *P. australis* marshes. The differences in N mineralization and nitrification among the tested soils were closely related with soil properties. With the addition of NO_3^-—N, net N mineralization and nitrification were increased in the studied soils by 16–29% and 34–54%, respectively, whereas with the addition of NH_4^+—N, they were increased by 58–69% and 65–94%, respectively. Net mineralization and nitrification in the tested soils increased with incubation temperature from 5 to 30 °C regardless of N addition. However, N addition (either NH_4^+—N or NO_3^-—N) not only dramatically raised the sensitivity of net N mineralization in the *S. alterniflora* marsh to temperature fluctuation, but also remarkably enhanced the percentage of net nitrification in net mineralization at incubation temperature from 15 to 25 °C, with peak values at 25 °C for all studied soils. These results suggest that under a changing climate, N supplying capacity of the *S. alterniflora* soil, as well as N pool, is notably great, which may shed light on the mechanism of rapid expansion of *S. alterniflora* in coastal China.

1. Introduction

The coastal wetland, a key transitional zone between land and ocean, is a complex and sensitive ecosystem with special environmental processes and functional values. N mineralization in coastal wetland, microbial conversion of organic to inorganic forms, is a bottleneck process of ecosystems that influences standing stocks of nutrients and nutrient availability to primary producers. Plant type (Henry and Twilley, 2013), primary production (Liao et al., 2007), temperature (David et al., 2014), exogenous N input (Gregory et al., 2013) have been identified as having important factors impacting on soil N mineralization in wetlands. Within a wetland where soil parent material and soil moisture are similar in, the spatial change of N mineralization is strongly linked to vegetation type and species composition (Henry and Twilley, 2013). Plants not only provide a large quantity of organic litter and root debris as carbon (C) source for the soil microbes, but also strongly compete for limited inorganic N with soil microbes in coastal marshes during growing period (Wang et al., 2007). Meanwhile, litter composition and chemistry exert an important influence on accessibility and net energetic value of organic matter (Knorr et al., 2005). Furthermore, wetland plants can release oxygen to the rhizosphere via their roots (Maricle and Lee, 2002), which is of great importance to the growth and reproduction of bacteria involved in the N mineralization.

Ongoing global environmental changes are also likely to influence the decomposition rate of organic N in coastal wetlands. For instance, temperature increase can enhance microbial activities to increase the rate of N mineralization (Lan et al., 2014). The increase in exogenous N (such as atmospheric N deposition

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http://dx.doi.org/10.1016/j.ecoleng.2015.12.003

or terrigenous N runoff) and changes in N form can affect litter decomposition and organic N mineralization through influencing soil chemistry, microbial activity, and the quantity and quality of substrate input (Gao et al., 2013; Hobbie, 2008). In fact, the impact of temperature change or N addition on N mineralization is complex and contradictory results are often reported. For example, N mineralization increases with temperature is not universally observed, as no responses of N mineralization to seasonality and experimental warming have also been found in coastal wetlands (Poungparn et al., 2009; Charles and Dukes, 2009). Moreover, it has been reported that exogenous N may have stimulatory, neutral, or negative effects on soil organic matter decomposition and N mineralization (Knorr et al., 2005). Thus, the effects of temperature or N addition and their interaction on N mineralization need to be further investigated for accurately predicting the sensitivity of coastal ecosystems to global change.

Spartina alterniflora (hereafter, *S. alterniflora*) was intentionally transplanted into the coastal marshes of China to stabilize the sediment in tidal marshes (Zhou et al., 2009). Currently, it has become one of the dominant salt marsh plants in the coastal wetlands due to its fast growth rate, covering a total area of about 112,000 ha. *S. alterniflora* invasions have both positive and negative effects on the coastal wetland of China (Li et al., 2009). Previous studies indicated that *S. alterniflora* invasions exerted a profound impact on ecosystem structure and function and soil organic carbon dynamics (Li et al., 2009; Zhang et al., 2010). However, the effect of plant invasions on native ecosystems soil N transformation remains inadequately understood. On the other hand, nitrogen loading to coastal environments has increased year by year due to the increase in the use of fertilizers and fossil fuel, and the intensive husbandry development. According to Wang et al. (2007), in the past fifty years, inorganic N concentration in tidal-flat overlying water has increased almost 8-fold in the Eastern China estuary caused by human activities. Furthermore, atmospheric N deposition in China was currently 13 kg N ha^{-1} year^{-1}, much higher than the 5 kg N ha^{-1} year^{-1} in the world (Lu and Tian, 2007; Galloway et al., 2004). Generally, N is an important growth-limiting nutrient in coastal wetlands, and hence N load could directly increase wetland plant production. Qing et al. (2011) confirmed that exogenous N input dramatically stimulated *S. alterniflora* expansion, which may replace the native species and alter the biodiversity in native ecosystems. Better understanding the impacts of N input on coastal soil dynamics is not only greatly important to predict changes in ecosystem functioning, but also has significance for the accurate predictions of future global N cycle and atmospheric N_2O levels. However, to date, there is little study on the interactive effects of plant invasion and exogenous N on soil N mineralization and nitrification.

In this study, it was hypothesized that N mineralization in coastal wetlands is affected by interactions among plant species, exogenous N and temperature, an incubation experiment was designed to investigate whether and how N mineralization potentials (14-d incubations) respond to *S. alterniflora* invasion, exogenous N level and form, and temperature.

2. Material and methods

2.1. Site description

We selected the core area of Yancheng National Nature Reserve (the Reserve, 32°36′51″ to 34°28′32″N, 119°51′25″ to 121°5′47″E) in China to collect soil samples. The climate here is the typical monsoon climate transition belt from warm-temperate zone to north subtropical zone, with annual precipitation of 1000 mm occurring primarily between June and September and annual solar radiation about 487–508 kJ cm^{-2}. The Reserve is characterized by typical alluvial mudflats controlled by standard semi-diurnal tides with a tidal range about 2.5–4.0 m. Water over the soil surface has a salinity of 30–34‰ on the average. The Reserve is the first and largest beach wetland reserve in China, and offers the world's largest winter habitat for the endangered *Grus japonensis* (Zhou et al., 2009).

Suaeda salsa (hereafter, *S. salsa*) and *Phragmites australis* (hereafter, *P. australis*) are the two primary native C_3 halophytes in coastal salt marsh ecosystem of the Reserve, and the former grows below survival elevation of the latter community. *S. alterniflora* was introduced to the Reserve in 1983, and it expanded rapidly bare flat in the intertidal zone during the next 30 years (Zhang et al., 2004). At present, it has become the dominant species in coastal salt marsh ecosystem of the Reserve.

2.2. Field sample collection

Field sampling was carried out in June 2012. Three parallel sample transects were selected from seaward to upland including the communities of the monospecific *S. alterniflora*, *S. salsa* and *P. australis*. Each sample transect was about 6 km long and with a distance of 50 m between them. Three locations within each transect were labeled from *S. alterniflora* to *S. salsa* to *P. australis*. In each location, five soil samples were randomly collected at top soil (0–20 cm) using a 10-cm diameter stainless steel soil cylinder and then all samples were carefully mixed to form a composite. All soil samples were immediately transported to laboratory for physical and chemical properties analysis.

The characteristics of the soils are summarized in Table 1. SOC concentrations were determined by the wet oxidation-redox titration method, and N concentrations determined using the micro-Kjeldahl method. Labile C and N were determined following the acid hydrolysis procedure described by Cheng et al. (2008). Microbial biomass C and N were determined by the chloroform fumigation-extraction method. The pH measurements were performed after shaking the soil with deionized water (1:2.5 mass ratio) for 30 min.

2.3. Soil incubation

In the laboratory, organic debris and plant roots were carefully removed from the soil samples by forceps and the soils were left to air dry at room temperature. then the soil samples were ground to pass a 2-mm sieve, mixed to ensure homogeneity of the soil, and stored at 4 °C. Soil moistures were measured to convert air-dry soil weight into oven-dry ones in incubation experiment.

Incubation experiments were carried out in the laboratory as described by Zhao et al. (2007). For each soil type (*S. alterniflora* soil, *S. salsa* soil and *P. australis* soil), a series of 150-mL conical flasks

Table 1
Soil physical and chemical properties (0–10 cm) in coastal salt marsh vegetated with different wetland plants.

Soil properties	*S. salsa* marsh	*P. australis* marsh	*S. alterniflora* marsh
Organic C (g kg^{-1})	2.38 ± 0.67a	3.56 ± 0.92b	5.46 ± 1.23c
Total N (g kg^{-1})	0.213 ± 0.078a	0.290 ± 0.097b	0.421 ± 0.011c
C:N ratio	11.2 ± 2.3a	12.0 ± 2.5b	13.1 ± 2.8c
Labile C (g kg^{-1})	1.14 ± 0.22a	1.50 ± 0.31ab	1.81 ± 0.43b
Labile N (g kg^{-1})	0.051 ± 0.012a	0.093 ± 0.021ab	0.184 ± 0.042b
Labile C:Labile N	22.8 ± 3.1a	16.4 ± 2.5b	9.8 ± 1.2c
pH	8.1 ± 0.3a	7.7 ± 0.4a	7.8 ± 0.2a
Bulk density (g cm^{-3})	1.41 ± 0.04a	1.38 ± 0.03a	1.37 ± 0.05a

Means with the standard errors ($n = 3$). Different letters within the same row indicate significant differences at $P < 0.05$.