Ecological Engineering 64 (2014) 130–135

Contents lists available at ScienceDirect

Ecological Engineering

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

Impacts of *Ageratina adenophora* invasion on soil physical–chemical properties of *Eucalyptus* plantation and implications for constructing agro-forest ecosystem

Fu-ke Yu[a], Xin-hui Huang[b,*], Chang-qun Duan[a], Shu-zhuang He[a], Guo-sheng Zhang[a], Chang-e Liu[a], Deng-gao Fu[a], Hong-bo Shao[c,d,*]

[a] *Institute of Environmental Sciences and Ecological Restoration, School of Life Sciences, Yunnan University, Kunming 650091, PR 6 China*
[b] *College of Environmental Science and Engineering, Southwest Forestry University, Kunming 650224, PR 7 China*
[c] *Key Laboratory of Coastal Biology & Bioresources Utilization, Yantai Institute of Coastal Zone Research (YIC), Chinese Academy of Sciences (CAS), Yantai 264003, PR China*
[d] *Institute of Life Sciences, Qingdao University of Science & Technology, Qingdao 266042, PR China*

A R T I C L E   I N F O

Article history:
Received 19 November 2013
Received in revised form
19 December 2013
Accepted 24 December 2013
Available online 21 January 2014

Keywords:
Ageratina adenophora
Biological invasion
Eucalyptus plantation
Soil properties
Agro-forest ecosystem

A B S T R A C T

Eucalyptus tree–*Ageratina adenophora* compound system is considered as a new invasion in Yunnan, southwest China in recent years. In this paper, the impacts of *A. adenophora* invasion on the soil physical and chemical properties of *Eucalyptus* plantation were investigated, based on the exploration of its causes, the assessment of its risk and the prediction of its succession. The results showed that the invasion had a different impact on eight different physical–chemical indexes of soil in *Eucalyptus* plantation, characterized with a certain complexity. Its impact on soil water was featured with seasonal difference, namely, during the rainy season, the soil water concentration decreased significantly, while, in the dry season, the soil water concentration increased significantly (excluding the severely invasive sample on shadowy slope). Meanwhile, its impact on soil organic matters (SOM), soil nitrogen (TN, AN), soil phosphorus (TP, AP) and soil potassium (TK, AK) was related to seasons, exposure and invasive degrees of *A. adenophora*, but there was no unified rule for them, which should be studied further. It is expected to provide a theoretical basis for the sustainable operation and scientific management of *Eucalyptus* plantation under the condition of *A. adenophora* invasion for sustainable agro-forest ecosystems.

1. Introduction

Ageratina adenophora, an herbal plant, belongs to *Eupatorium* Genus of Compositae Family, originated from Mexico and Costa Rica in Central America, now it is a typical vicious invasive weed worldwide, which is widely distributed in more than 30 countries and regions in tropical and subtropical areas (Xie et al., 2001). In the 1940s, it was introduced into Lincang, a boundary county in Yunnan China, from Myanmar, now, it has been widely spread to Yunnan, Guizhou, Sichuan, Chongqing, Guangxi, even further to Taiwan of China (Xie et al., 2001), and it continues to spread further eastward and northward at an annual speed of 20 km (Wang and Wang, 2006). Its invasion could produce many ecological impacts, such as changes in soil quality (Kourtev et al., 2002; Niu et al., 2007), the exclusion of local species (Stinson et al., 2006; Mangla et al., 2008), damages to regional biodiversity (McGeoch et al., 2010; Pritekel et al., 2006), which has brought about enormous economic losses (Xu et al., 2006; Zhu et al., 2005). Meanwhile, due to the covertness of its invasive impacts on soil construction and quality, along with lack of in-depth researches and deficiency in the understanding of its occurrence mechanism and influential factors, there is a major technological challenge on the cause exploration and risk assessment of its invasion.

Recently, in parts of Yunnan China such as Kunming, Chuxiong, Pu'er, etc., it was found that in *Eucalyptus* plantation with rare local species, *A. adenophora* could not only survive but widely spread, thus *Eucalyptus* tree–*A. adenophora* compound system appeared (Yu et al., 2013). Behind such phenomenon lied some major scientific issues, e.g., what's the essential reason for such a compound system? What ecological impacts would it produce, and how would it go in succession? Based on its great significance, a series of studies had been done. In this paper, the impact of *A. adenophora* invasion on soil physical and chemical properties (including soil water, soil

* Corresponding authors. Tel.: +86 871 65090855; fax: +86 871 65090855.
E-mail addresses: ylyfk2005@aliyun.com (X.-h. Huang), shaohongbochu@126.com (H.-b. Shao).

0925-8574/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.12.050

organic matter, soil nitrogen, and soil phosphorus and soil potassium) of *Eucalyptus* plantation would be mainly explored.

2. Materials and methods

2.1. A brief introduction to the research area

Humashan Hill in Kunming, Yunnan was selected as the research site, with its geographical coordination of 25°06′76″ N and 102°76′51″ E and an altitude of about 1920 m above sea level. It goes from eastward to westward, characterized with obvious dry and wet seasons. From mid May to mid October, it's the rainy season, while from the late October to early May, the dry season, with an annual average temperature around 16 °C and 850–950 mm of annual rainfall. The soil in the research site is characterized with red earth, with *Eucalyptus globules* plantation as its main vegetation with the invasion of *A. adenophora*.

2.2. Sample sites selecting

Different water and thermal condition of the sunny side and shadowy side of Humashan Hill and different invasive degrees of *A. adenophora* into *Eucalyptus* plantation were taken into consideration, thus 12 sample sites with an area of 10 m × 10 m with a similar altitude were selected in *Eucalyptus* plantation on the sunny and shadowy side of the Hill respectively. Among 12 sample sites on each side of the Hill, 3 of them were severely invasive samples (SIS, with an invasive coverage of 51–70%, served as treatment 1 (T1)) and were marked with SIS_1, SIS_2, SIS_3 (represented 3 repeats of treatment 1), respectively; 3 of them were moderately invasive samples (MIS, with an invasive coverage of 31–50%, served as treatment 2 (T2)) and were marked with MIS_1, MIS_2, MIS_3 (represented 3 repeats of treatment 2), respectively; 3 of them were lightly invasive samples (LIS, with an invasive coverage of 11–30%, served as treatment 3 (T3)) and were marked with LIS_1, LIS_2, LIS_3 (represented 3 repeats of treatment 3), respectively; and 3 of them were weakly invasive samples (WIS, with an invasive coverage below 10%, served as treatment control (CK)) and were marked with WIS_1, WIS_2, WIS_3 (represented 3 repeats of treatment control), respectively. All the sample sites were used for soil samples collecting.

2.3. Soil sample collecting and the test of its physical–chemical indexes

In September, 2012 (the rainy season) and April, 2013 (the dry season), soils (0–30 cm layer) in each sample site in *Eucalyptus* plantation were collected twice as samples for the test of physical and chemical indexes. The specific test indexes and methods were shown as below: water concentration was measured by the Oven Drying Method; the concentration of organic matter was measured by Oxidation–Reduction Titration; the concentration of total nitrogen (TN) was measured with Potassium Dichromate–Sulfuric Acid Digestion and Distillation; the concentration of alkali-hydrolyzale nitrogen (AN) was measured with NaOH–Hydrolyzation Diffusion; the concentration of total phosphorous (TP) was measured with Sulfuric Acid–Perchloric Acid Extraction and Molydenum-Antimony-D-iso-ascorbie-Acid-colorimetry (MADAC); the concentration of available phosphorus (AP) was measured by Ammonium Fluoride Extraction and MADAC; the concentration of total potassium (TK) was measured with Molten Sodium Hydroxide-Colorimetry; the concentration of available potassium (AK) was measured with Ammonium Acetate Extraction-Flame Photometry.

Table 1
Soil water of different invasive samples (%).

Invasive samples	Rainy season		Dry season	
	Sunny slope	Shadowy slope	Sunny slope	Shadowy slope
SIS (T1)	13.80 ± 2.74a	16.80 ± 3.62b	10.25 ± 2.14b	9.75 ± 1.91a
MIS (T2)	15.60 ± 3.13b	14.40 ± 3.28a	11.00 ± 2.22b	12.75 ± 2.33c
LIS (T3)	12.00 ± 2.59a	16.80 ± 3.46b	9.50 ± 1.86a	13.25 ± 2.54c
WIS (CK)	17.40 ± 3.55c	19.80 ± 3.85c	9.00 ± 1.82a	11.25 ± 2.07b

Note: Data are mean ± SE; different letters (same letters) stand for significant difference (no significant difference) when $p = 0.05$; it is same to Tables 2–4 and Figs. 1–4.

3. Results

3.1. The impact of A. adenophora invasion on soil water in Eucalyptus plantation

The impact of the invasion of *A. adenophora* on soil water in *Eucalyptus* plantation varied greatly with the change of seasons (Table 1). In the rainy season, it reduced the water concentration of the samples (compared to CK) (Table 1); on the contrary, in dry season, the invasion of *A. adenophora* raised the water concentration of the invasive samples (excluding the severely invasive sample in shadowy slope) (compared to CK) (Table 1). Such rule was possible related to the flexible water use characteristics of *A. adenophora* (Zu et al., 2005). However, the relation between soil water concentration in *Eucalyptus* plantation and invasion degree of *A. adenophora* is not linear.

3.2. The impact of A. adenophora invasion on soil organic matters in Eucalyptus plantation

The impact of the invasion of *A. adenophora* on soil organic matters in *Eucalyptus* plantation was related to seasons, exposure and the invasive degrees (Fig. 1).

During the rainy season, on the sunny slope, in SIS and LIS, soil organic matters increased significantly, by contrast, in MIS, soil organic matters decreased significantly (compared to CK) (Fig. 1(a)); while on the shadowy slope, in SIS and LIS, soil organic matters were characterized with no significant difference, by contrast, in MIS, soil organic matters increased significantly (compared to CK) (Fig. 1(a)).

During the dry season, on the sunny slope, soil organic matters increased significantly in all samples with the invasion of *A. adenophora* to a different extent (compared to CK), and it is the most significant that the soil organic matters increased in MIS (Fig. 1(b)); by contrast, on the shadowy slope, in SIS and LIS, though soil organic matters increased, there was no significant change, on the contrary, in MIS, soil organic matters decreased significantly (compared to CK) (Fig. 1(b)).

These vibrations of soil organic matters described above were possibly due to the change in the process of humification and mineralization of soil organic matters (Huang and Xu, 2010) under the condition of the invasion of *A. adenophora*. Besides, the result was similar to the study that showing soil organic carbon dynamics in a coastal wetland of Eastern China with short-term invasion by exotic plant *Spartina alterniflora* (Yang et al., 2013).

3.3. The impact of A. adenophora invasion on soil nitrogen in Eucalyptus plantation

The impact of the invasion of *A. adenophora* on soil nitrogen in *Eucalyptus* plantation was related to seasons, exposure, and invasive degrees (Table 2 and Fig. 2).

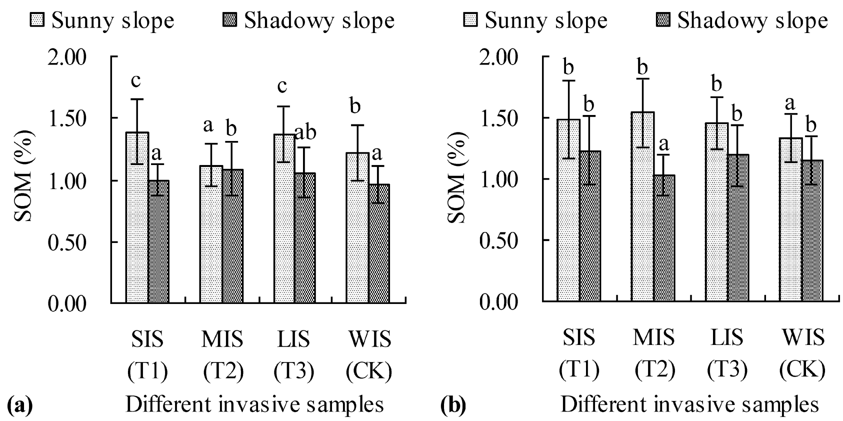

Fig. 1. Soil organic matter (SOM) of different invasive samples (%). *Note*: (a) Rainy season. (b) Dry season.

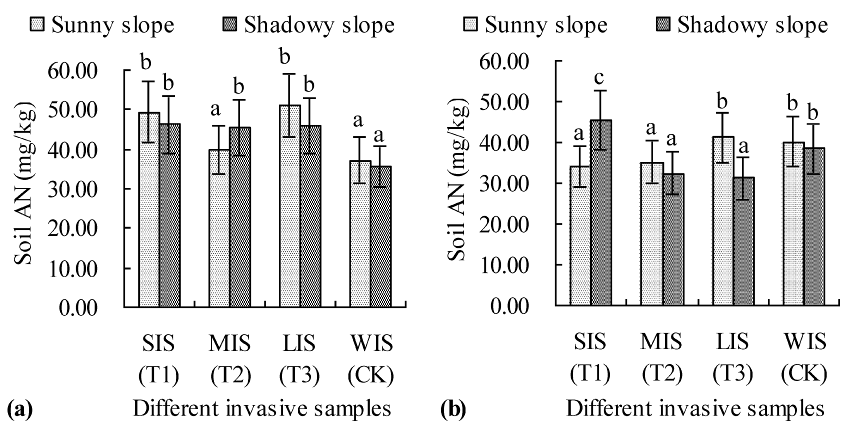

Fig. 2. Soil AP of different invasive samples (mg/kg). *Note*: (a) Rainy season. (b) Dry season.

Take soil TN for instance, during the rainy season, on the sunny side, in SIS and LIS, soil TN was characterized with significant increase, while in MIS, soil TN was characterized with significant decrease (compared to CK) (Table 2); on the shadowy side, in all samples, soil TN increase to a certain degree, while in MIS, soil TN was characterized with no significant increase (compared to CK) (Table 2). During the dry season, on the sunny slope, in MIS, the concentration of soil TN increased significantly, while the concentration of soil TN in SIS and LIS decreased significantly (compared to CK) (Table 2); by contrast, on the shadowy slope, in SIS, soil TN was characterized with no significant increase, while in MIS and LIS, soil TN was characterized with significant decrease (compared to CK) (Table 2).

Take soil AN for another instance, during the rainy season, on the sunny slope, in all samples, soil AN increased, while there was no significant increase in MIS (compared to CK) (Fig. 2(a)); by contrast, on the shadowy slope, in all samples, soil AN increased significantly (compared with CK), while there was no significant difference between SIS, MIS and LIS (Fig. 2(a)). During the dry season, in the sunny samples, the concentration of soil AN in SIS and MIS decreased significantly, while there was no significant change in LIS (compared to CK) (Fig. 2(b)); by contrast, in the shadowy samples, in SIS, soil AN increased significantly, while in MIS and LIS, soil AN decreased significant (compared to CK) (Fig. 2(b)).

3.4. The effect of *A. adenophora* invasion on soil phosphorus in *Eucalyptus* plantation

The effect of the invasion of *A. adenophora* on soil phosphorus in *Eucalyptus* plantation was related to seasons, exposure, and invasive degrees (Table 3 and Fig. 3).

As for soil TP, during the rainy season, on the sunny side, in all samples, soil TP increased significantly (compared to CK), in addition, in LIS and MIS, soil TP is significantly higher than in

Table 2
Soil TN of different invasive samples (g/kg).

Invasive samples	Rainy season		Dry season	
	Sunny slope	Shadowy slope	Sunny slope	Shadowy slope
SIS (T1)	0.56 ± 0.15c	0.54 ± 0.16b	0.38 ± 0.10a	0.54 ± 0.15b
MIS (T2)	0.36 ± 0.10a	0.42 ± 0.12a	0.58 ± 0.16c	0.38 ± 0.12a
LIS (T3)	0.54 ± 0.14c	0.52 ± 0.14b	0.37 ± 0.12a	0.42 ± 0.13a
WIS (CK)	0.44 ± 0.12b	0.38 ± 0.10a	0.48 ± 0.13b	0.52 ± 0.14b

Table 3
Soil TP of different invasive samples (g/kg).

Invasive samples	Rainy season		Dry season	
	Sunny slope	Shadowy slope	Sunny slope	Shadowy slope
SIS (T1)	0.46 ± 0.13b	0.43 ± 0.11b	0.44 ± 0.10a	0.56 ± 0.11b
MIS (T2)	0.54 ± 0.10c	0.46 ± 0.10bc	0.48 ± 0.07a	0.42 ± 0.14a
LIS (T3)	0.58 ± 0.08c	0.55 ± 0.07c	0.46 ± 0.12a	0.51 ± 0.10b
WIS (CK)	0.39 ± 0.11a	0.36 ± 0.12a	0.43 ± 0.10a	0.41 ± 0.13a

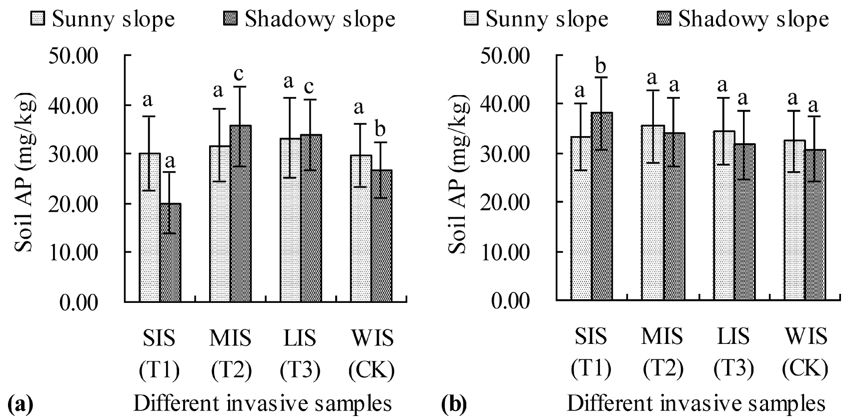

Fig. 3. Soil AK of different invasive samples (mg/kg). *Note*: (a) Rainy season. (b) Dry season.

SIS (Table 3); by contrast, on the shadowy side, in all samples, soil TP was characterized with significant increase (compared to CK), in addition, in LIS, soil TP is significantly higher than in MIS and SIS (Table 3). During the dry season, on the sunny side, in all samples, soil TP was characterized with no significant increase (compared to CK) (Table 3); by contrast, on the shadowy side, in SIS and LIS, soil TP increased significantly, while in MIS, soil TP was characterized with no significant change (compared to CK) (Table 3).

As for soil AP, during the rainy season, on the sunny side, in samples with different degrees of invasive *A. adenophora*, there was no significant change in soil AP (compared to CK) (Fig. 3(a)); while on the shadowy side, in SIS, soil AP decreased significantly, by contrast, in MIS and LIS, soil AP increased significantly (compared to CK) (Fig. 3(a)). During dry season, on the sunny side, in samples with different degrees of invasive *A. adenophora*, there was no significant change in soil AP (compared to CK) (Fig. 3(b)); while on the shadowy side, in SIS, soil AP increased significantly, by contrast, in MIS and LIS, there was no significant change in soil AP (compared to CK) (Fig. 3(b)).

3.5. *The effect of A. adenophora invasion on soil potassium (K) in Eucalyptus plantation*

The effect of the invasion of *A. adenophora* on soil potassium (K) in *Eucalyptus* plantation was also related to seasons, exposure, and invasive degrees (Table 4 and Fig. 4).

Take soil TK for instance, during the rainy season, on the sunny side, in SIS and LIS, soil TK was characterized with significant increase and no significant increase respectively, while in MIS, soil TK decreased significantly (compared to CK) (Table 4); by contrast, on the shadowy side, in all samples, soil TK was characterized with significant increase with the invasion (compared to CK) (Table 4). During the dry season, on the sunny side, in all samples, soil TK was characterized with significant decrease, with an order as follow: MIS > LIS > SIS (compared to CK) (Table 4); by contrast, on the shadowy side, in SIS and LIS, soil TK was characterized with significant increase, while in MIS, soil TK decreased significantly (compared to CK) (Table 4).

Take soil AK for another instance, during the rainy season, on the sunny side, soil AK increased significantly in all the samples (compared to CK), with the order as below: LIS < SIS < MIS (Fig. 4(a)); by contrast, on the shadowy side, soil AK also increased significantly in all the samples (compared to CK), with the order as below: LIS > SIS > MIS (Fig. 4(a)). During the dry season, on the sunny side, in SIS and MIS, soil AK increased significantly, while in LIS, there was no significant change in soil AK (compared to CK) (Fig. 4(b)); on the shadowy side, in SIS and LIS, soil AK decreased significantly, while there was no significant change in soil AK in MIS (compared to CK) (Fig. 4(b)).

Table 4
Soil TK of different invasive samples (g/kg).

Invasive samples	Rainy season		Dry season	
	Shadowy slope	Sunny slope	Shadowy slope	Sunny slope
SIS (T1)	5.93 ± 1.32c	6.81 ± 1.31c	4.51 ± 1.03ab	6.52 ± 1.26c
MIS (T2)	4.37 ± 0.85a	6.42 ± 1.08bc	4.02 ± 0.75a	5.05 ± 0.73a
LIS (T3)	5.25 ± 1.10b	6.10 ± 0.91b	4.35 ± 0.93a	6.38 ± 1.19c
WIS (CK)	5.11 ± 0.96b	5.35 ± 0.77a	5.28 ± 1.25c	5.73 ± 0.88b

4. Discussion

At present, biological invasion throughout the world has greatly affected and changed the ecological environment which is of great significance for human existence, and threat to its health and stable and sustainable development as well (Wang et al., 2013; McGeoch et al., 2010; Celesti-Grapow et al., 2010; Wan et al., 2009; Reaser et al., 2007; Matthews, 2005; Matthews and Brand, 2004). Thus, scholars and governments worldwide have paid high attention to the global issue (Walpole et al., 2009; Barnard and Waage, 2004; CAB International, 2004; Mooney, 1999) and made great efforts in some relative fields such as researches on biological invasive mechanism (Wang et al., 2011; Feng et al., 2009; Handley et al., 2008; Funk and Vitousek, 2007; Callaway et al., 2004; Torchin et al., 2003; Kennedy et al., 2002; Callaway and Aschehoug, 2000), investigation on eco-environmental impacts (Zhang et al., 2013; Yang et al., 2013; Li et al., 2013a,b; Chen et al., 2012; Cui et al., 2011; Zhou et al., 2009; Mangla et al., 2008; Niu et al., 2007; Stinson et al., 2006; Pritekel et al., 2006; Pimentel et al., 2005) and socio-economic impacts (Emerton and Howard, 2008; Colautti et al., 2006; Xu et al., 2006; Pimentel et al., 2005), improvement of management strategies and practices (Chang et al., 2013; Shine, 2008; Wan et al., 2008a,b; CAB International, 2004; Commission SAUSoAB-N, 2000), and technologies exploration on prevention and control of invasive species (Alday et al., 2013; Wan et al., 2008a,b; Macdonald et al., 2003; Pallewatta et al., 2003; Shine et al., 2002). However, compared with the spreading range and developing speed of the invasive species and their damages as well, the width (depth) and developing speed of human recognition and counter measures towards its invasion and spread have lagged far behind its development. By taking *A. adenophora* in this paper as an example, its invasion began around

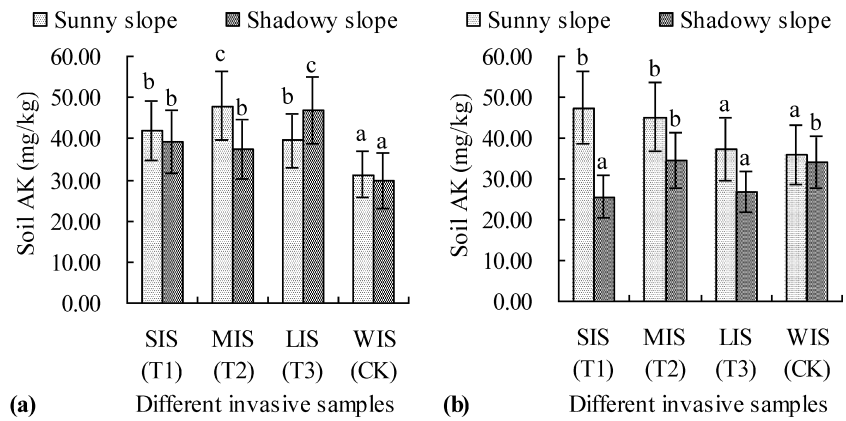

Fig. 4. Soil AN of different invasive samples (mg/kg). *Note*: (a) Rainy season. (b) Dry season.

80 years ago, but the research on its prevention and control just began 30 years ago, up to till now, there was no effective way to deal with it (Wan et al., 2010). Therefore, 2 problems will be mainly discussed further in combination with the above result of this paper.

4.1. Monitoring the evolution of invaded soil environment quality

It's well known that soil is a rather stable environmental media; its reaction towards the abrupt change of external nature is characterized with a certain buffer (Huang and Xu, 2010). In this study, the impact of the invasion of *A. adenophora* on the soil chemical index of *Eucalyptus* plantation is characterized with irregular changes, which is possibly due to the buffer effect of the invaded soil. However, whether such kind of irregular changes is a universal effect on the soil of *Eucalyptus* plantation due to the long term invasion of *A. adenophora* or not is not yet decided with sufficient evidence, which should be monitored and studied further in the future. In addition, the impact of *A. adenophora* invasion on biological characteristics of soil in *Eucalyptus* plantation should be explored, since it is helpful for a comprehensive understanding of soil environment effects of invasive species. Therefore, a long-term and systematic monitoring on the evolution of invaded soil environment quality should be strengthened in the near future.

4.2. The ideological and methodological transition of the prevention and control towards invasive species

In the past decades, invasive species were considered as harmful species to agriculture and forestry, thus more attention was paid to its prevention and control. While at present, continuous major findings related to the benefits of some invasive species worth developing have been observed. For instance, the typical aquatic plant *Eichhornia crassipes*, which invaded into Asia, can be used to engineer soil nutrient availability in a low-land rain-fed rice farming system of north-east India (Balasubramanian et al., 2013), as well as the function of the powder of its root as absorbing and eliminating water heavy metal pollutants (Li et al., 2013a,b); *S. alterniflora*, a typical invasive species in China has the potential as biofuels, besides, it also has strong carbon sequestration capabilities (Lu and Zhang, 2013); and the list can go on. Such cases have provided significant enlightenment for environment protectionists – invasive species should be treated as raw materials to be developed further to control its development rather than directly preventing and controlling it in vain. Therefore, scientific outlook and technological methods to the prevention and control of invasive species should be adjusted and changed as well. *A. adenophora*, for example, its negative ecological environment effect is universally recognized, but it cannot only be used to produce forage, methane, active carbon, and biomass, and can also be treated as composting material or an ecological recovery species for a certain phrase in extremely environment, which indicated that it is of a certain recycling value. It can be forecast that in the way of recycling and consuming its biomass, the effective prevention and control over *A. adenophora* population can be realized eventually.

5. Conclusions

The impacts of the invasion of *A. adenophora* on eight different physical-chemical indexes of soil in *Eucalyptus* plantation were characterized with great differences and a certain complexity as well. Its impact on soil water was featured with seasonal difference, namely, in the rainy season, soil water concentration decreased significantly, while in the dry season, soil water concentration increased significantly (excluding the severely invasive sample in shadowy slope). Its impact on soil organic matters (SOM), soil nitrogen (TN, AN), soil phosphorus (TP, AP) and soil potassium (TK, AK) was related to seasons, exposure and invasive degrees of *A. adenophora*, whereas, there was no unified rule suitable for all of them, thus its influential mechanism required for further study.

Acknowledgement

The authors would like to acknowledge National Natural Science Foundation of China (Nos. 31160155 and 31270751), Applied Basic Research Program of Yunnan Province, China (No. 2007C022M) and Scientific Researching Project of Southwest Forestry University, Kunming, China (No. 110714) for financial support of this work.

References

Alday, J.G., Cox, E.S., Pakeman, R.J., Harris, M.P.K., Le Duc, M.G., Marrs, R.H., 2013. Effectiveness of *Calluna*-heathland restoration methods after invasive plant control. Ecol. Eng. 54, 218–226.

Balasubramanian, D., Arunachalam, K., Arunachalam, A., Das, A.K., 2013. Water hyacinth [*Eichhornia crassipes* (Mart.) Solms.] engineered soil nutrient availability in a low-land rain-fed rice farming system of north-east India. Ecol. Eng. 58, 3–12.

Barnard, P., Waage, J.K., 2004. Tackling Species Invasion Around the World: Regional Responses to the Invasive Alien Species Threat. The Global Invasive Species Programme (GISP), Cape Town, South Africa.

CAB International,2004. Prevention and management of invasive alien species: forging cooperation throughout West Africa. In: Proceedings of a Regional Workshop. The Global Invasive Species Programme (GISP), Accra, Ghana.

Callaway, R.M., Aschehoug, E.T., 2000. Invasive plants versus their new and old neighbors: a mechanism for exotic invasion. Science 290 (5491), 521–523.

Callaway, R.M., Thelen, G.C., Rodriguez, A., Holben, W.E., 2004. Soil biota and exotic plant invasion. Nature 427 (6976), 731–733.

Celesti-Grapow, L., Alessandrini, A., Arrigoni, P.V., Assini, S., Banfi, E., Barni, E., Bovio, M., Brundu, G., Cagiotti, M.R., Camarda, I., Carli, E., Conti, F., Del Guacchio, E., Domina, G., Fascetti, S., Galasso, G., Gubellini, L., Lucchese, F., Medagli, P., Passalacqua, N.G., Peccenini, S., Poldini, L., Pretto, F., Prosser, F., Vidali, M., Viegi, L., Villani, M.C., Wilhalm, T., Blasi, C., 2010. Non-native flora of Italy: species distribution and threats. Plant Biosyst. 144 (1), 12–28.

Chang, Y.H., Wu, B.Y., Lu, H.L., 2013. A study on the use of ecological fences for protection against *Polypedates megacephalus*. Ecol. Eng. 61 (Part A), 161–165.

Chen, J.H., Wang, L., Li, Y.L., Zhang, W.Q., Fu, X.H., Le, Y.Q., 2013. Effect of *Spartina alterniflora* invasion and its controlling technologies on soil microbial respiration of a tidal wetland in Chongming Dongtan, China. Ecol. Eng. 41, 52–59.

Colautti, R.I., Bailey, S.A., van Overdijk, C.D.A., Amundsen, K., MacIsaac, H.J., 2013. Characterised and projected costs of nonindigenous species in Canada. Biol. Invasions 8, 45–59.

Commission SAUSoAB-N, 2000. Best Management Practices for Preventing and Controlling Invasive Alien Species: Symposium on Policies and Implementation. South Africa/United States of America Bi-National Commission, Kirstenbosch Botanical Gardens, Cape Town, South Africa.

Cui, B.S., He, Q., An, Y., 2011. *Spartina alterniflora* invasions and effects on crab communities in a western Pacific estuary. Ecol. Eng. 37 (11), 1920–1924.

Emerton, L., Howard, G., 2008. A Toolkit for the Economic Analysis of Invasive Species. The Global Invasive Species Programme (GISP), Nairobi, Kenya.

Feng, Y.L., Lei, Y.B., Wang, R.F., Callaway, R.M., Valiente-Banuet, A., Inderjit, Li, Y.P., Zheng, Y.L., 2009. Evolutionary tradeoffs for nitrogen allocation to photosynthesis versus cell walls in an invasive plant. Proc. Natl. Acad. Sci. U. S. A. 106 (6), 1853–1856.

Funk, J.L., Vitousek, P.M., 2007. Resource use efficiency and plant invasion in low-resource system. Nature 446 (5719), 1079–1081.

Handley, R.J., Steinger, T., Treier, U.A., Muller-Scharer, H., 2008. Testing the evolution of increased competitive ability (EICA) hypothesis in a novel framework. Ecology 89 (2), 407–417.

Huang, C.Y., Xu, J.M., 2010. Soil Sciences, 3rd ed. China Agriculture Press, Beijing.

Kennedy, T.A., Naeem, S., Howe, K.M., Johannes, M.H.K., Tilman, D., Reich, P.B., 2002. Biodiversity as a barrier to ecological invasion. Nature 417, 636–638.

Kourtev, P.S., Ehrenfeld, J.G., Häggblom, M., 2002. Exotic plant species alter the microbial community structure and function in the soil. Ecology 83 (11), 3152–3166.

Li, H., Shao, J.J., Qiu, S.Y., Li, B., 2013a. Native *Phragmites* dieback reduced its dominance in the salt marshes invaded by exotic *Spartina* in the Yangtze River estuary, China. Ecol. Eng. 57, 236–241.

Li, X.S., Liu, S.L., Na, Z.Y., Lu, D.N., Liu, Z., 2013b. Adsorption, concentration, and recovery of aqueous heavy metal ions with the root powder of *Eichhornia crassipes*. Ecol. Eng. 60, 160–166.

Lu, J.B., Zhang, Y., 2013. Spatial distribution of an invasive plant *Spartina alterniflora* and its potential as biofuels in China. Ecol. Eng. 52, 175–181.

Mangla, S., Inderjit, Callaway, R.M., 2008. Exotic invasive plant accumulates native soil pathogens which inhibit native plants. J. Ecol. 96 (1), 58–67.

Matthews, S., Brand, K., 2004. Africa Invaded: The Growing Danger of Invasive Alien Species. The Global Invasive Species Programme (GISP), Cape Town, South Africa.

Matthews, S., 2005. South America Invaded. The Global Invasive Species Programme (GISP), Cape Town, South Africa.

Macdonald, I.A.W., Reaser, J.K., Bright, C., Neville, L.E., Howard, G.W., Murphy, S.J., Preston, G., 2003. Invasive Alien Species in Southern Africa: National Reports & Directory of Resources. The Global Invasive Species Programme (GISP), Cape Town, South Africa.

McGeoch, M.A., Butchart, S.H.M., Spear, D., Marais, E., Kleynhans, E.J., Symes, A., Chanson, J., Hoffmann, M., 2010. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Divers. Distrib. 16 (1), 95–108.

Mooney, H., 1999. The global invasive species program. Biol. Invasions 1, 97–98.

Niu, H.B., Liu, W.X., Wan, F.H., Liu, B., 2007. An invasive aster (*Ageratina adenophora*) invades and dominates forest understories in China: altered soil microbial communities facilitate the invader and inhibit natives. Plant Soil 294 (1/2), 73–85.

Pallewatta, N., Reaser, J.K., Gutierrez, A.T., 2003. Invasive Alien Species in South-Southeast Asia: National Reports & Directory of Resources. The Global Invasive Species Programme (GISP), Cape Town, South Africa.

Pimentel, D., Zuniga, R., Morrison, D., 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol. Econ. 52 (4), 1088–1091.

Pritekel, C., Whittemore-Olson, A., Snow, N., Moore, J.C., 2006. Impacts from invasive plant species and their control on the plant community and belowground ecosystem at Rocky Mountain National Park, USA. Appl. Soil Ecol. 32 (1), 132–141.

Reaser, J.K., Meyerson, L.A., Cronk, Q., De Poorter, M., Eldrege, L.G., Green, E., Kairo, M., Latas, P., Mack, R.N., Mauremootoo, J., O'Dowd, D., Orapa, W., Sastroutomo, S., Saunders, A., Shine, C., Thrainsson, S., Vaiutu, L., 2007. Ecological and socioeconomic impacts of invasive alien species in island ecosystems. Environ. Conserv. 32 (2), 98–111.

Shine, C., 2008. A Toolkit for Developing Legal and Institutional Frameworks for Invasive Alien Species. The Global Invasive Species Programme (GISP), Nairobi, Kenya.

Shine, C., Reaser, J.K., Gutierrez, A.T., 2002. Invasive Alien Species in the Austral Pacific Region: National Reports & Directory of Resources. The Global Invasive Species Programme (GISP), Honolulu, Hawaii.

Stinson, K.A., Campbell, S.A., Powell, J.R., Wolfe, B.E., Callaway, R.M., Thelen, G.C., Hallett, S.G., Prati, D., Klironomos, J.N., 2006. Invasive plant suppresses the growth of native tree seedlings by disrupting belowground mutualisms. PLoS Biol. 4 (5), e140.

Torchin, M.E., Lafferty, K.D., Dobson, A.P., Mckenzie, V.J., Kuris, A.M., 2003. Introduced species and their missing parasites. Nature 421, 628–630.

Walpole, M., Almond, R.E.A., Besancon, C., Butchart, S.H.M., Campbell-Lendrum, D., Carr, G.M., Collen, B., Collette, L., Davidson, N.C., Dulloo, E., Fazel, A.M., Galloway, J.N., Gill, M., Goverse, T., Hockings, M., Leaman, D.J., Morgan, D.H.W., Revenga, C., Rickwood, C.J., Schutyser, F., Simons, S., Stattersfield, A.J., Tyrrell, T.D., Vie, J.C., Zimsky, M., 2009. Tracking progress toward the 2010 biodiversity target and beyond. Science 325 (5947), 1503–1504.

Wan, F.H., Guo, J.Y., Zhang, F., et al., 2009. Research on Biological Invasion in China. Science Press, Beijing.

Wan, F.H., Li, B.P., Guo, J.Y., et al., 2008a. Biological Invasion: Biological Control Theory and Practice. Science Press, Beijing.

Wan, F.H., Liu, W.X., Guo, J.Y., Qiang, S., Li, B.P., Wang, J.J., Yang, G.Q., Niu, H.B., Gui, F.R., Huang, W.K., Jiang, Z.L., Wang, W.Q., 2010. Invasive mechanism and control strategy of *Ageratina adenophora* (Sprengel). Sci. China Life Sci. 53 (11), 1291–1298.

Wan, F.H., Xie, B.Y., Chu, D., et al., 2008b. Biological Invasions: Legislations and Management Strategies. Science Press, Beijing.

Wang, R., Wang, J.F., Qiu, Z.J., Meng, B., Wan, F.H., Wang, Y.Z., 2011. Multiple mechanisms underlie rapid expansion of an invasive alien plant. New Phytol. 191 (3), 828–839.

Wang, R., Wang, Y.Z., 2006. Invasion dynamics and potential spread of the invasive alien plant species *Ageratina adenophora* (Asteraceae) in China. Divers. Distrib. 12 (4), 397–408.

Wang, X.L., Wang, Y.Q., Wang, Y.J., 2013. Use of exotic species during ecological restoration can produce effects that resemble vegetation invasions and other unintended consequences. Ecol. Eng. 52, 247–251.

Xie, Y., Li, Z.Y., Gregg, W.P., Li, D.M., 2001. Invasive species in China – an overview. Biodivers. Conserv. 10 (8), 1317–1341.

Xu, H.G., Ding, H., Li, M.Y., Qiang, S., Guo, J.Y., Han, Z.M., Huang, Z.M., Sun, H.Y., He, S.P., Wu, H.R., Wan, F.H., 2006. The distribution and economic losses of alien species invasion to China. Biol. Invasions 8 (7), 1495–1500.

Yang, W., Zhao, H., Chen, X.L., Yin, S.L., Cheng, X.L., An, S.Q., 2013. Consequences of short-term C_4 plant *Spartina alterniflora* invasions for soil organic carbon dynamics in a coastal wetland of Eastern China. Ecol. Eng. 61, 50–57.

Yu, F.K., Huang, X.H., Duan, C.Q., Zhang, G.S., Lu, S.G., Liu, C.E., Fu, D.G., Shao, H.B., 2013. *Eucalyptus* trees–*Ageratina adenophora* complex system: a new eco-environmental protection model. Clean Soil Air Water, http://dx.doi.org/10.1002/clen.201200642.

Zhang, Y.H., Wang, L., Xie, X.J., Huang, L.D., Wu, Y.H., 2013. Effects of invasion of *Spartina alterniflora* and exogenous N deposition on N_2O emissions in a coastal salt marsh. Ecol. Eng. 58, 77–83.

Zhou, C.F., An, S.Q., Deng, Z.F., Yin, D.Q., Zhi, Y.B., Sun, Z.Y., Zhao, H., Zhou, L.X., Fang, C., Qian, C., 2009. Sulfur storage changed by exotic *Spartina alterniflora* in coastal saltmarshes of China. Ecol. Eng. 35 (4), 536–543.

Zhu, P., Tang, X.Q., Xu, H.G., 2005. Model study on loss assessment of invasion species. World J. Model Simul. 1 (1), 19–26.

Zu, Y.G., Wang, W.J., Yang, F.J., Zhao, Z.H., Cao, J.G., 2005. Stomatal regulation on the gas exchange of *Eupatorium adenophorum*: implication on its invasive ability. Scinetia Silvae Sinicae 14 (3), 25–35.