Influence of Soil Drought Stress on C, N and P Stoichiometry of *Tamarix Chinensis* Lour. in Yellow River Delta, China

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Abstract:

Taking the one-year-old *T. chinensis* (*Tamarix chinensis* Lour.) in Yellow River Delta as the study object, the variations of C, N and P stoichiometry in *T. chinensis* under drought stress was studied using pot experiments. The results showed that, carbon (C), nitrogen (N) and phosphorous (P) contents and their stoichiometric ratios in the root, stem and leaf of *T. chinensis* exhibited large variations. The variation of the root C content presented an increasing trend with the gradual intensification of the drought stress while that in leaf and stem revealed different degrees of decrease. Both N and P contents in leaf, stem and root reduced when *T. chinensis* was under slight drought stress and showed a trend of first increasing and later decreasing with the intensification of the stress. The values of C : N, C : P and N : P ratios represented the same variation trend when *T. chinensis* suffered drought stress. They increased slightly when the *T. chinensis* was under slight stress and showed a trend of first decreasing and later increasing with the intensification of the drought stress. Slight drought stress did not have significant influence on the growth of *T. chinensis. T. chinensis* took competitive and defensive life-history strategies when suffering moderate and severe drought stresses, respectively. Thus, from the standpoint of ecological stoichiometry, *T. chinensis* had strong drought tolerance. And a certain degree of drought stress could help for the growth of *T. chinensis.*

Keywords: ecological stoichiometry, drought stress, *Tamarix chinesis* Lour., Yellow River Delta

Introduction

Carbon (C), Nitrogen (N) and phosphorus (P) are the primary biological elements, which is critical to the structure and function of cells (Elser et al. 2000a). As the main component of living organisms, C, N and P play very important roles in plant growth and physiological metabolism (ÅOREN 1988, Elser et al. 2000b). Besides, they are also critical for the stability of each element in the biosphere (Hobbie and Colpaert 2004, Reich et al. 2006). At the same time, C, N and P contents and their stoichiometric ratios of plant organs were the main research objects of the ecological stoichiometry (Vrede et al. 2004, Kang et al. 2011). As the important research contents of the biogeochemistry, ecological stoichiometry can help reveal the nutrient distribution and limiting factor during the growth process of plants (Tessier and Raynal 2003, Güsewell 2004). Also, the relations between C : N : P stoichiometry and plant characteristics (i.e. individual growth, population development, community structure and ecosystem processes) are of great importance for the ecological research (Sterner and Elser 2002, Ptacnik et al. 2005, Chapin III et al. 2011). Specifically, C, N and P have close relation to the process of plant metabolism, which is greatly affected by the environment factors, such as soil water content (Hu et al. 2007). Due to the special physical and chemical properties, water plays an important role in the process of plant growth and development (Heidari and Karami 2014). To be specific, water is a good solvent for a variety of chemical substance. It can regulate temperature of plant body and be involved in photosynthesis. Also, water can affect the physiological change of plants, which includes assimilate translocation, antioxidant reactions and enzyme activity (Stagnari et al. 2014). Thus, water is one of the most important environmental factors to maintain plant survival. Soil water content has become a main limiting factor for plant growth in many areas. Since plant is very sensitive to soil water, it is of great importance to study the influence of drought stress on C, N and P Stoichiometry of a given species in a typical area.

Currently, there are a large number of studies upon C, N and P stoichiometry at global and regional scales (He et al. 2008, Kang et al. 2011, Wu et al. 2012). In particularly, researches upon the influence of environmental stresses on the ecological stoichiometry of a given species have been a hot topic within the research communities. Many of them have shown that environmental factors, such as soil nutrient, climate condition and soil moisture, can significantly affect the growth and development of the organism (Striebel et al. 2008, Xing et al. 2013). And these stresses could induce multiple responses of plants. Specifically, when environmental conditions change, plants often adjust the contents and stoichiometric ratios of nutrient elements to adapt to the changes of the environment, which can mitigate the effects of the change of external environment conditions. For example, C, N and P contents and their stoichiometric ratios in plants were significantly affected by the soil salt stress. Plants would change some physio-biochemical characteristics, such as photosynthesis and enzyme activity, to adapt to the stress (Rong et al. 2014). Although the influence of different environmental stress on plant growth has become a popular issue, studies about the ecological stoichiometry of the plants under soil drought stress in a typical area have rarely been reported. Lots of researchers investigated the water stress effects on the biochemical and physiological responses of plants (Shukla et al. 2012). Many of them have shown that drought stress can lead to physiological and metabolic disorder of plants. Because most of the plant physiological and metabolic characteristics are associated with the nutrient elements such as C, N and P (Aerts and Chapin III 1999), it is very important to investigate the influence of soil drought stress on C, N and P stoichiometry. Moreover, due to intensive human activities and climate change, the soil environments in the regions of big river delta have been greatly altered, leading to variations in soil water conditions. And those impacts are becoming extremely outstanding in China, particularly in Yellow River Delta. Due to its coastal morphology and complicated weather, Yellow River Delta is greatly being threatened by storm tide. Besides, because of the abundant underground brine and seawater resources, many chemical factories are sited in this area. Thus, plants in these areas are being obviously impacted by the changing environmental conditions and increasing human interventions, which are lack of studies. Also, the response mechanism of C, N and P stoichiometry of the plants under changing water condition and the impact that the change of soil water conditions has on the ecological stoichiometry of the plants in this area need to be further studied.

Therefore, through a series of pot experiments, the objective of this research is to reveal the change of C, N and P contents in the root, stem and leaf of *T. chinensis* under different degree of soil drought stress in the Yellow River Delta. Also, the stoichiometric ratios of these three elements were investigated. Thus, this research will help understand the adaptability and feedback of *T. chinensis* to the changes of soil water concentration from the perspective of ecological stoichiometry. It will also expand the results of the ecological stoichiometry studies on terrestrial plants, and especially can enrich ecological stoichiometry theory of plants in the regions of big river deltas.

Materials and methods

Study area

Drought stress experiments were carried out from May to June 2012, at the greenhouse of Shandong Key Laboratory of Eco-Environmental Science for the Yellow River Delta, Binzhou University in Shandong Province (37° 22′ 55.95″ N, 117° 58′ 58.29″ , 10 a.s.l.). It is located in the typical area of the Yellow River Delta in China. Yellow River Delta is one of the youngest but fast growing deltas in the world. It has a typical semi-humid continental monsoon climate with distinct seasonal changes. The annual average temperature in this area is 12.1 ℃. The annual average rainfall and evaporation are 552 mm and 1962 mm, respectively. And the frost-free period is 196 days (Ye et al. 2013). The dominant vegetations in the delta are *T. chinensis*, Suaeda salsa, and Phragmites australis. Generally, soil type in this delta mainly includes coastal saline alluvial soil and marsh soil (Cui et al. 2008).

Plant materials and experimental design

T. chinensis, belonging to the tamaricaceae, is a shrub or dungarunga, which is a typical kind of salt-tolerant and drought tolerant plant. Also, it can well adapt to the wetland habitat. Thus, it can grow in harsh environment, such as saline-alkaline land in desert in the northwest and coastal areas in the east of China. It plays an irreplaceable role in water conservation, wind resistance and sand fixation, as well as increasing biodiversity. Particularly, *T. chinensis* has become the dominant species in Yellow River Delta.

In this research, the typical sandy soil in the Yellow River delta was selected to conduct the experiment. The background values of each indicators of the soil were as follows, Soil Water Content: 16.68%, Soil Salt Content: 0.04%, Ammonia Nitrogen: 16.83mg kg^{-1}, Nitrate Nitrogen: 9.95 mg kg^{-1}, Available Phosphorus: 3.64 mg kg^{-1}. Before the experiments, urea and KH_2PO_4 were added to the soil to increase the soil available nitrogen and phosphorus to 0.15 g kg^{-1} and 0.044 g kg^{-1} (i.e. 0.1 g kg^{-1} P_2O_5).Then, the soil was put into the pots which were 55 cm in diameter × 31 cm in depth. And reasonable amount of Hoagland's nutrient solution was added to the soil to meet the needs of plants for other nutrient elements. After that, the one-year-old *T. chinensis* seedlings were planted in these pots. And they were watered every day until fully regrow.

Hsiao’s moisture gradient design method is used in the experiments. Accordingly, three drought stress gradients (i.e. slight, moderate and severe stress) were set up as follows: pots kept at 50% - 60% of water holding capacity (WHC), 40% - 50% of WHC and 20% - 25% of WHC. And 80% of WHC was set up as the control group. Thus, *T. chinensis* seedlings in 12 pots, which have similar characteristics of growth and development, were selected to conduct the drought stress experiments. They were randomly divided into four groups with three replicates. The control of soil water contents were imposed starting after the plant regrowth. The soil water content was constantly monitored by soil moisture sensors. To maintain the initial water content, the pots were manually re-watered with tap water every day at 17:00. After a month, all the *T. chinensis* were reaped and the roots, stems and leaves were separated.

Determinations of physiological traits

C, N and P measurement were conducted for the leaf, stem and root samples of *T. chinensis*. All the plant samples were oven-dried at 60 ℃ to a constant weight. After grinded by a jet mill, they were saved in a dryer for the determination of total carbon (TC), total nitrogen (TN), and total phosphorus (TP). TC and TN were examined using an elemental analyzer. At the same time, TP was measured through the molybdate/stannous chloride method after pretreatment of H_2SO_4–H_2O_2 digestion. Leaf C, N and P data were expressed on dry mass basis.

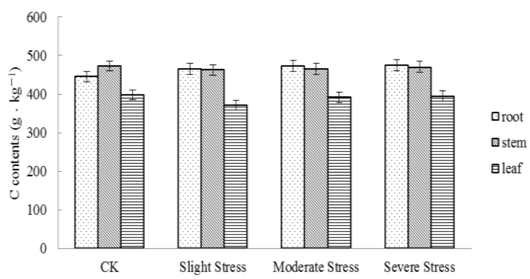
Statistical analysis

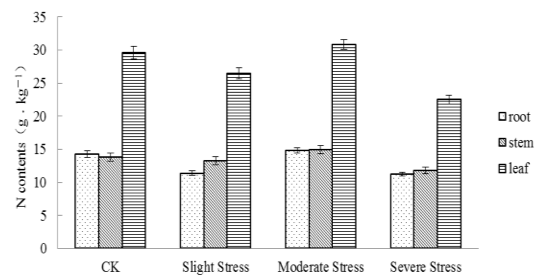
Microsoft Excel 2007 and SPSS19.0 were used for data processing and analysis. The variations in C, N and P stoichiometry of *T. chinensis* under different treatments were analyzed by one-way analysis of variance (ANOVA). Fisher Least-Significant Difference (LSD) was used for multiple comparisons among the data.

Results

The influence of soil drought stress on the total C, N and P contents in root, stem and leaf of *T. chinensis*

Various degrees of soil drought stress could have significant impact on the total C, N and P contents in the root, stem and leaf of *T. chinensis* (figure 1). Specifically, the total C content in the root went up when the degree of soil drought stress gradually increased. Compared to the control groups, the total C contents in the root increased by 4.39%, 6.09% and 6.37% respectively, when the *T. chinensis* was under slight, moderate and severe soil drought stress. However, the total C contents in the stem and leaf were observed varying degrees of decrease when the *T. chinensis* was under different soil drought stress. Also, with the drought stress turning severe, the total C contents had a tendency of increase. In particularly, compared to the control groups, the total C contents in the stem fell 2.31%, 1.76% and 2.31% respectively when the *T. chinensis* under slight, moderate and severe soil drought stress. And those in the leaf decreased by 6.83%, 1.69%, 0.78% respectively. Variations in total N contents in the root, stem and leaf of *T. chinensis* were similar to those in total P contents. Compared to the control groups, both the total N and P contents in the root, stem and leaf reduced when *T. chinensis* was affected by slight soil drought stress. Specifically, the N contents in the root, stem and leaf decreased by 20.01%, 3.95% and 10.54%, respectively. And the total P contents reduced 39.45%, 7.16% and 13.58%, respectively. With the stress turning severe, when the *T. chinensis* was under moderate stress, the N and P contents were obviously higher. They increased by 3.95%, 8.17%, 4.19% and 48.13%, 55.80%, 25.20% respectively in the root, stem and leaf of *T. chinensis.* However, when the stress reached severe degree, the N and P contents significantly reduced. Thus, when the soil drought stress turned severe, the total N and P contents in the root, stem and leaf revealed a trend of increasing first and decreasing then, with a shape of parabola.





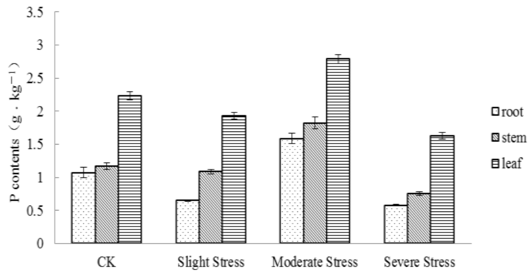


Figure 1. Total C, N and P contents in root, stem and leaf of *T. chinensis* under different soil drought stress.

The influence of soil drought stress on the C, N and P stoichiometric ratios in root, stem and leaf of *T. chinensis*

With the influence of different degrees of soil drought stress, C : N, C : P and N : P ratios represented the similar variation trends (figure 2). The values of C : N, C : P and N : P ratios increased when the *T. chinensis* was under the slight stress. Compared to the control groups, C : N ratios in the root, stem and leaf increased by 30.63%, 1.71% and 4.14%. The data of C : P and N : P ratios were 72.41%, 5.22%, 7.81% and 31.99%, 3.46%, 3.52%. With the aggravation of drought stress, C : N, C : P and N : P ratios revealed a trend of decreasing first and increasing later, with a shape of "inverted parabola".

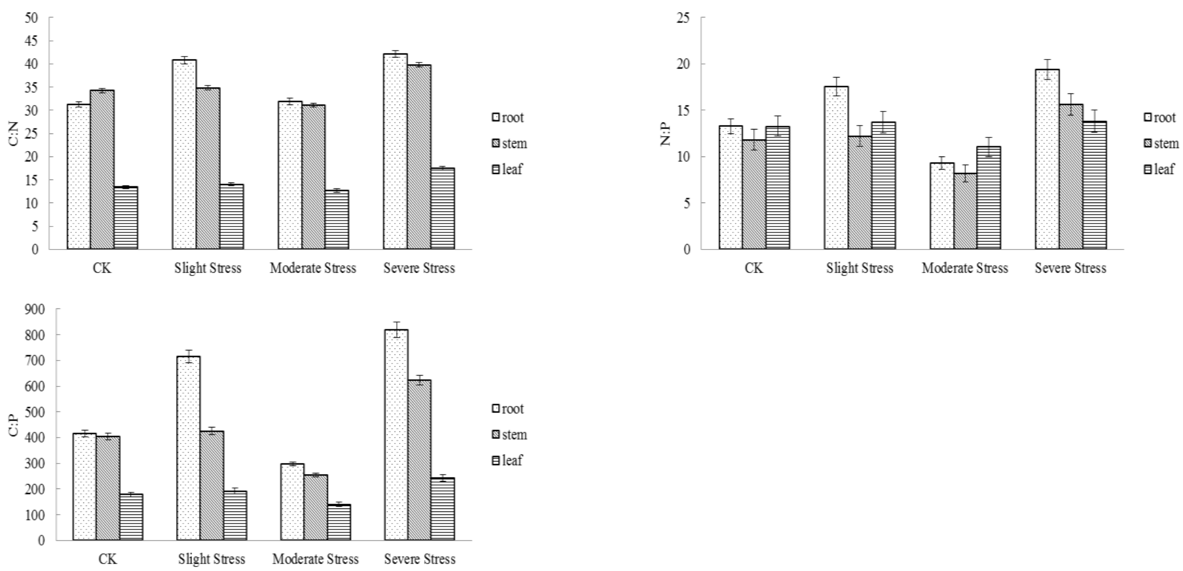


Figure 2. Stoichiometric ratios of C, N and P in root, stem and leaf of *T. chinensis* under different soil drought stress.

Discussion

The growth, development, behavior and reproduction of plants could be significantly affected by soil drought stress (Bloch and Hoffmann 2004, de Abreu and Mazzafera 2005, Li et al. 2011). When plants were under drought stress, they usually adjusted the growth and physiological characteristics, such as changing the growth rate, reducing the leaf area and improving the protective enzyme activity, to adapt to the external environment (Guerfel et al. 2009, Kannan and Kulandaivelu 2011). Relevant studies have shown that soil drought stress could significantly affect the absorption and distribution of plant nutrient elements (Oktem 2008). At the same time, the decrease of soil water availability reduced the root's absorption rate of water, which increased the resistance of plants to absorb nutrient and further affected their contents and distribution in plants (Sardans et al. 2013). Since the growth rate of plant roots and their nutrient absorption ability were two important factors affecting the nutrient contents in plant (Jones et al. 2005), soil drought stress usually affected the absorption of nutrients of plants by reducing the root system activity, leading to the reduction of assimilation and accumulation in inorganic nutrients (Fernandez et al. 2006). In addition, C, N and P in plants played an important role in the physiological and biochemical processes. Thus, physiological metabolism disorder and assimilative capacity reduction in plants under drought stress could also result in the decrease of the nutrient element contents in plants (Kannan and Kulandaivelu 2011).

In this study, significant influence was observed for the total C, N and P contents in root, stem and leaf when *T. chinensis* was under different degrees of soil drought stress. *T. chinensis*, on the whole, distributed more C to the root system when affected by soil drought stress. And the C contents in the stem and leaf were relatively low. This revealed that, when soil water content turned lower, most C element, assimilated by photosynthesis, was transferred to the root system. Through strengthening the growth of root system to increase the absorption of moisture, *T. chinensis* reduced the effect of soil drought stress on its growth. At the same time, total N and P contents in the root, stem and leaf represented a trend of increasing first and decreasing then with the intensification of drought stress. Also, total N and P contents were highest in the leaf and minimum in the root. Thus, when *T. chinensis* was under slight and moderate drought stress, it decreased the influence of soil water stress by increasing the leaf N and P contents to facilitate the synthesis of osmotic regulation substances, which was necessary for its survival in the adverse environmental conditions. However, when the stress reached the severe level, physiological metabolism became disordered and root activity significantly decreased, leading to the reduction of N, P nutrient absorption and assimilation. Thus, N and P contents decreased in body of *T. chinensis*.

Based on the Growth Rate Hypothesis (GHR), high growth rate of organism was commonly company with the low C : P and N : P ratios (Main et al. 1997, Sterner and Elser 2002). Also, C : N and C : P ratios could reflect the changes of plant life-history strategies. Specifically, when these two ratios were relatively low in the plant body, the plants showed competitive life-history strategies. On the contrary, when C : N and C : P ratios were relatively high, the plants showed defensive life-history strategies (Wright et al. 2004, Poorter and Bongers 2006, Shipley et al. 2006). The results of this study showed that, when *T. chinensis* was under slight soil drought stress, root C : N, C : P and N : P ratios significantly went up, compared with the control groups. Also, these three ratios in the leaf and stem slightly increased, but the difference was not significant. With the stress turning intensive, the three ratios in *T. chinensis* represented a trend of first decreasing and later increasing. This revealed that slight soil drought stress did not have the significant influence on the growth of *T. chinensis*. When affected by moderate soil drought stress, *T. chinensis* showed a competitive life-history strategy, which could illustrated that a certain degree of drought stress was conducive to the growth of *T. chinensis.* When the stress reached the severe level, *T. chinensis* changed to the defensive life-history strategy because of the poor external experiment. Thus, from the perspective of ecological stoichiometry, *T. chinensis* had a strong ability of drought tolerance. Soil drought stress did not have great impact on *T. chinensis* during its growing process.

Conclusion

It is critical to identify the variation in the C, N and P stoichiometry when the plants were under soil drought stress. In this research, *T. chinensis* in Yellow River Delta was selected as study object and the C, N and P contents, as well as their stoichiometric ratios was investigated based on a series of pot experiments. Various degrees of soil drought stress could have significant impact on the total C, N and P contents in the root, stem and leaf of *T. chinensis.* C, N and P represented different variation trend with the stress turning intensive. On the contrary, C : N, C : P and N : P ratios were observed a similar variation trend. They increased slightly when the *T. chinensis* was under light stress and showed a trend of first decreasing and later increasing with the intensification of the drought stress. Slight drought stress did not have significant influence on the growth of *T. chinensis. T. chinensis* took competitive and defensive life-history strategies when suffering moderate and severe drought stresses, respectively. Thus, from the standpoint of ecological stoichiometry, *T. chinensis* had strong drought tolerance. And a certain degree of drought stress can help for the growth of *T. chinensis.* The results of this research could facilitate understand C, N and P stoichiometry of the plant in the areas of big river delta and the response of plant C, N and P stoichiometry to environmental stresses, which can further enrich the ecological stoichiometry studies.

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