Original Research Article

*Puccinelliachinampoensis*Ohwishows highselectivityof K^+, Ca^{2+} and Mg^{2+} over Na^+ in the rhizosphere of sodicsoil

ABSTRACT

In order to examine the characteristics of *Puccinelliachinampoensis*Ohwi (*P. chinampoensis*), tolerant plant for sodic condition, uptake of metal macronutrients(K, Ca, Mg) and Na in the plant were measured. Sodic soil and alkaline soil were collected from Songnen Plain in Jilin Province in northeast China. In the first experiment, *P. chinampoensis*, *Festucaarundinacea*Schreb. (*F. arundinacea*) and *Dactylisglomerata* L.(*D. glomerata*) were grown in sodic soiland the sodicsoil mixed with vermiculite (artificial soil)in growth chamber under natural light. In the artificial soil, soil pH was similar to the sodic soil which was over 10. The soil CEC of the artificial soil was higher than the original sodic soil. The soil EC and exchangeable sodium percentage (ESP) of the artificial soil were lower than the original sodic soil. In the cultivation on the artificial soil, *P. chinampoensis*and the other plants showed better growth than those in the sodic soil. Furthermore, *P. chinampoensis*showed higher K content than the other plants and maintained low Na content in the shoot.*P. chinampoensis*had tremendously low Na/K, Na/Ca, and Na/Mg ratios. In the second experiment,*P. chinampoensis* and *Leimuschinensis*(*L. chinensis*) were grown on alkaline soil area,which was not affected by soil sodification, in the Songnen Plain. There were no significant differences of the content of Na, K, Ca and Mg in the shoot between *P. chinampoensis*and *L. chinensis*. Thus, it was concluded that *P. chinampoensis*had high selectivity of K^+, Ca^{2+} and Mg^{2+} over Na^+ in the rhizosphere when grown in sodic soil but the selectivity was not shown in alkaline soil rich in Ca. It seemed that high soil EC and high concentration of exchangeable Na^+ were more harmful than high soil pH for plant growth in sodic soil.

*Key words:sodic soil; alkaline soil; Songnen Plain; northeast China; Puccinelliachinampoensis*Ohwi*;sodium; potassium; soil EC*

1.INTRODUCTION

Desertification areacaused by accumulated salts is gradually spreading in arid or semi-arid areas in the world[1]. In cultivated lands in the world, about 23% are saline soils and another 37% are sodic soils[2, 3]. Saline soils contain much amount of neutral soluble salts enough to interfere with the growth of most plants. Saline soils, however, do not contain enough exchangeable Na^+ to alter soil characteristics appreciablyand pH value of the soils are usually less than 8.5 [4, 5,6]. On the other hand, sodic soils contain the excessive amount of exchangeable Na^+ which forms alkaline soluble salts such as Na_2CO_3 and $NaHCO_3$. Therefore, the pH of the sodic soils is raised toaround 10 [4,5,6].

Because of high pH and high concentration of exchangeable Na^+, sodic soils may interfere with the plant growth more than saline soils[7,8]. Especially, excessive Na^+ interfere with the transport of K^+, Ca^{2+}, and Mg^{2+} from the root to shoot [5, 6, 9,10,11]. Furthermore, in high pH conditions, the nutrient availability of Ca^{2+} and Mg^{2+} are extremely low[12]. Thus, the plants grown on the sodic soils may be suffered from the deficiency of metal macronutrients such as K^+, Ca^{2+}, Mg^{2+} more than those grown on saline soils.

In the Songnen Plain in northeast China, located between 42º30'-51º20'N and 121º40'-128º30'E, the expansion of the area covered with sodic soils has been serious problem since the middle of twentieth century[13], and approximately 70% of the natural grasslands are affected by soil salinization and sodification[6,14]. The causes of soil sodification in the Songnen Plain are natural factors such as parent materials of soil, topographic positions, arid/semi-arid climate and anthropogenic causes such as population pressure, overgrazing, and improper agricultural and economic policy [13, 15].

Before the expansion of the area covered with sodic soils, *Leimuschinensis*(*L.chinensis*) was dominant grass in the Songnen Plain and was ideal for forage because of its high palatability[16, 17,18]. The grasslands of the *L.chinensis*, however, have degraded due to the soil sodificationwith high pH around 10 [19,20,21,22]. Then, the dominance of the *L.chinensis*has been replaced depending on soil conditions by grasses which have sodic tolerance such as *Puccinelliachinampoensis*Ohwi[22]. The *Puccinelliachinampoensis*Ohwi(*P.chinampoensis*)has also high palatability and was ideal for animal grazing [23].Thus, Academy of Agriculture Science of Jilin Provinces in China has proceeded to the project for the utilization of the *P.chinampoensis* for recovering of revegetation in the Songnen Plain. There isa few study about the plant, but more research work is required [23, 24].There are also some genetic studies about the sodic tolerant plants such as *Puccinelliatenuiflora* or *Chlorisvirgate* [23, 25]. However, to our understanding, the research about mineral nutrients of sodic tolerant plants in the actual field is not sufficient for revealing the chalacteristicsin nutrient uptake.

Clarification of the chalacteristics of nutrient uptake insodic tolerant plants such as *P.chinampoensis*and demonstration of the usefulness of the plantswouldmake meaningful contributions to improvement of the revegetation of sodic soil. Thus, we focused on the uptake of metal macronutrients such as K^{+}, Ca^{2+}, Mg^{2+} of *P.chinampoensis* in the rhizosphere of sodic soils. In fact, *P.chinampoensis* is widespread on sodic grasslands and forms communities in the Songnen Plain [23].Therefore, it is considered that *Puccinelliachinampoensis*Ohwimay have some superior ability for nutrients uptake to survive on sodic soils, though physiological activity have not been well investigated. Furthermore, there is no research about the characteristics of the nutrient uptake of *P.chinampoensis*in related with the difference of soil types such assodic soil and alkaline soil withoutsodification, as far as we know.

Thus, we studied the nutrition uptake ability of *P.chinampoensis*comparing with other grasses growing on the sodic soil or the alkaline soil. The aim of this study was to reveal the superior characteristics in mineral uptake of *P.chinampoensis* grown on the sodic soils and to show the usefulness of the plant for improving revegetationon the soils.

2.MATERIAL AND METHODS

2.1 Cultivation of *Puccinelliachinampoensis*Ohwi in sodic soil in growth chamber

Sodic soil was collected in the Songnen Plain:suburbs of Dàān, Jilin Prov., China. This area is suffered from soil sodificationseverely [15]. In the spot where soil was collected, there were severalgrasses which hadsodic tolerance such as *Puccinelliachinampoensis*Ohwi and *Chlorisvirgata*[3, 25]were surrounding there. The collected soil was air-dried and passed through a 2 mm sieve, then, chemical properties were measured (soil pH, soil EC, the cation exchangeable capacity, the amounts of exchangeable cations, and exchangeable sodium percentage). The pH and EC of soil suspension were measured (soil: deionized water = 1: 2.5 for pH, soil: deionized water = 1: 5 for EC) with a pH conductivity meter (D-54, Horiba Co., Tokyo). The amounts of exchangeable cations and cation exchange capacity (CEC) were measured by the semi-micro Schollenberger's method using an extracting solution (1 mol/L NH_4-acetate) at pH 7 [26]. The metals in the extracted solution were analyzed by flame atomic absorption spectrometry (AA-6200, Shimadzu, Kyoto). Exchangeable sodium percentage (ESP) was calculated by the values of exchangeable Na^{+} and CEC.

This experiment was conducted in a growth chamber undera sunlightwith the adjusted temperature (12 h daytime at +25°C and 12 h nighttime at +15°C) from December in 2009 to January in 2010. Each pot (200 ml) containing 200 g of the sodicsoil or 200 g of the sodic soilmixedwith vermiculite(v/v, 1: 1) was prepared.Vermiculilte was purchased from MiyakoCalcine Co. (Miyako). This soil mixed with vermiculite was denoted as “artificial soil”. The chemical properties of the artificial soil were also measured by the similar methods. The seeds of *Puccinelliachinampoensis*Ohwi(*P. chinampoensis*) were granted from the Academy of Agriculture Science of Jilin provinces in China. Then, the seeds of *P.chinampoensis*, *Festucaarundinacea*Schreb. (*F. arundinacea*; Tall fescue), or *Dactylisglomerata* L. (*D. glomerata*; Orchard grass) were sownin the pots, respectively. After the two months growth, the shoots of cultivated plants were harvested and dried at +80°C to a constant weight. Then, the dry weight of the shoots was measured. The shoots were digested with a mixture of HNO_3 and $HClO_4$ (v/v, 5: 1), and the contents of Na^+, K^+, Ca^{2+}, Mg^{2+} in the shoots weremeasured by the flame atomic absorption spectrometry (AA-6200, Shimadzu, Kyoto).

2.2Cultivation of *Puccinelliachinampoensis*Ohwion alkaline soil in Songnen Plain

This experiment was conducted from middle June to middle August in 2012 on alkaline soil in the experimental field, which was not suffered from sodification, of Jilin agricultural universityin the Songnen Plain. The area isunder the continental monsoon climate, and seasonal temperature varies from -34°C to +37°C. From middle April to early June, it is a clear drought period. The annual precipitation ranges from 300-600 mm, and it has rain mainly from June to September (from 70% to 80% of the total rain fall of one year) [15, 23].

The experimental site was prepared,and the soil samplein the site was collected. The soil was air-dried and passed through a 2 mm sieve, then, chemical properties (soil pH, soil EC, the cation exchangeable capacity, the amounts of exchangeable cations, and exchangeable sodium percentage) were measured. The pH and EC of soil suspension were measured (soil: deionized water = 1: 2.5 for pH, soil: deionized water = 1: 5 for EC) with a pH conductivity meter (D-54, Horiba Co., Tokyo). The amounts of exchangeable cations and cation exchange capacity (CEC) were measured by the semi-micro Schollenberger's method using an extracting solution (1 mol/L NH_4-acetate) at pH 7[26]. The metals in the extracted solution were analyzed by flame atomic absorption spectrometry (AA-6200, Shimadzu, Kyoto). Exchangeable Na percentage (ESP) was calculated by the values of exchangeable Na^+ and CEC.

The experimental site was divided into two sites and the square measure of each site was 9.0 m^2 (3.0 m × 3.0 m). The seeds of *Leimuschinensis*(*L. chinensis*) or *Puccinelliachinampoensis*Ohwi(*P. chinampoensis*) were sown in two sites, respectively. The plants were grown by rainwater in the natural climate of the Songnen Plain. About two months later (from middle June to middle August), the shoot of cultivated plants were harvested and dried at +80°C to a constant weight. Three samples (five shoots of each plant per sample) were selected, and the dry weight of samples was measured. Those samples were digested with a mixture of HNO_3 and $HClO_4$ (v/v, 5: 1), and the contents of Na^+, K^+, Ca^{2+}, Mg^{2+} in the plant tissues were analyzed by the flame atomic absorption spectrometry (AA-6200, Shimadzu, Kyoto).

2.3Statistical Analyses

Experiments were conducted in triplicate. Data was subjected to an ANOVA using computer of "HP proLiant DL320 G6" in Iwate university, Japan [27]. Differences between means were evaluated using the Ryan-Einot-Gabriel-Welsch multiple range test ($p < 0.05$).

3.RESULTS

3.1 Cultivation of *Puccinelliachinampoensis*Ohwi in sodic soil in growth chamber

Table 1 shows the chemical properties of the soils used in this experiment. The soil pH of sodic soil or artificial soil was higher than 10. The soil EC and ESP of the artificial soil was lowered and CEC was raised by mixingwith vermiculite. Besides, the amount of exchangeable Na^+ was lowered, but that of K^+, Ca^{2+} and Mg^{2+} was elevated by mixingwith vermiculite. According to the definition of sodic soil by Bear [4], soils whose pH is higher than 8.5, EC is less than 4 and ESP value is higher than 15 is defined as sodic soil. Thus,both of the sodic soil obtained from Dàān, Jilin prov., China and the artificial soil were defined as sodic soils (Table 1) [4].

In the pots containingsodic soil, *F. arundinacea* and *D. glomerata* did not germinate. *P. chinampoensis*only, however, could germinate on the sodic soil but it could not grow enough for the dry weight and cation contents to be measured. Figure 1 shows the shoot dry weight of plants which were grown in the artificial soil. *F. arundinacea* showed the highest shoot dry weight, and *P. chinampoensis* showed the second highest. *D. glomerata*showed, however, the lowest shoot dry weight and it could hardly grow in the artificial soil. Figures 2a, 2b, 2c, and 2d show the content of Na, K, Ca and Mg per shoot dry weight of each plant. In Na content, *D. glomerata*showed the highest content of Na among the plants. Na content of the plants were tremendously high as compared with the other elements. *P. chinampoensis* had low Na content, and there were no significant difference between those of *P. chinampoensis*and *F. arundinacea*. In K content, *P. chinampoensis*showed the highest content among the plants. The K content of *P. chinampoensis*was more than double of those of theother plants. There were no significant difference between those of *F. arundinacea*and *D. glomerata*. In Ca content, *F. arundinacea* showed the lowest content among the plants. The Ca content of *F. arundinacea* was less than one-tenth of those of the other plants. There were no significant difference between those of *P. chinampoensis* and *D. glomerata*. In Mg content, there were no significant differences among the plants.

Figures 3a, 3b, and 3c show the cation content ratio of plants. *P. chinampoensis*showed thelowest value of Na/K, Na/Ca, and Na/Mg. *F. arundinacea* showed the highest value of Na/Ca, and the values of Na/K and Na/Mg were the second highest among the plants,*D. glomerata*showed the highest value of Na/K and Na/Mg, and that of Na/Ca was the second highest among the plants.

Table 1. Chemical properties of the sodic soil and the artificial soil

	sodic soil	artificial soil
pH	10.6	10.1
EC (dS/m)	2.76	1.77
CEC (cmol/kg)	20.9	41.3
ESP (%)	55.1	18.2
Exchangeable Na^{+} (cmol/kg)	11.5	7.52
Exchangeable K^{+} (cmol/kg)	0.14	0.17
Exchangeable Ca^{2+} (cmol/kg)	2.58	3.56
Exchangeable Mg^{2+} (cmol/kg)	0.10	0.29

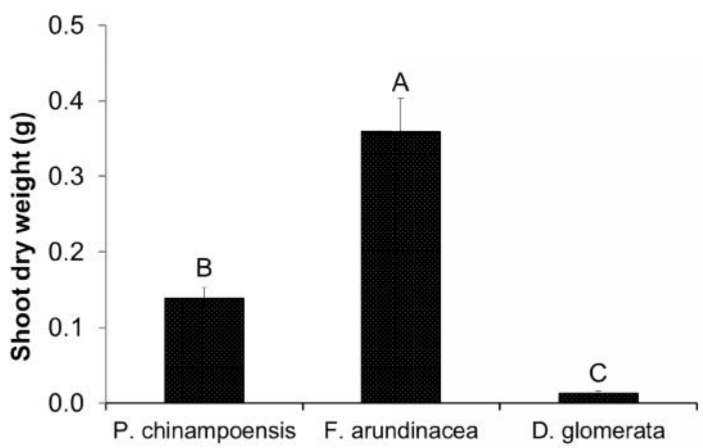

Fig. 1.Shoot dry weight of plants

Each value represents the mean ± SD (n = 3). Different letters at the top of each column indicate significant differences (p< 0.05) according to the Ryan-Einot-Gabriel-Welsch multiple range test.

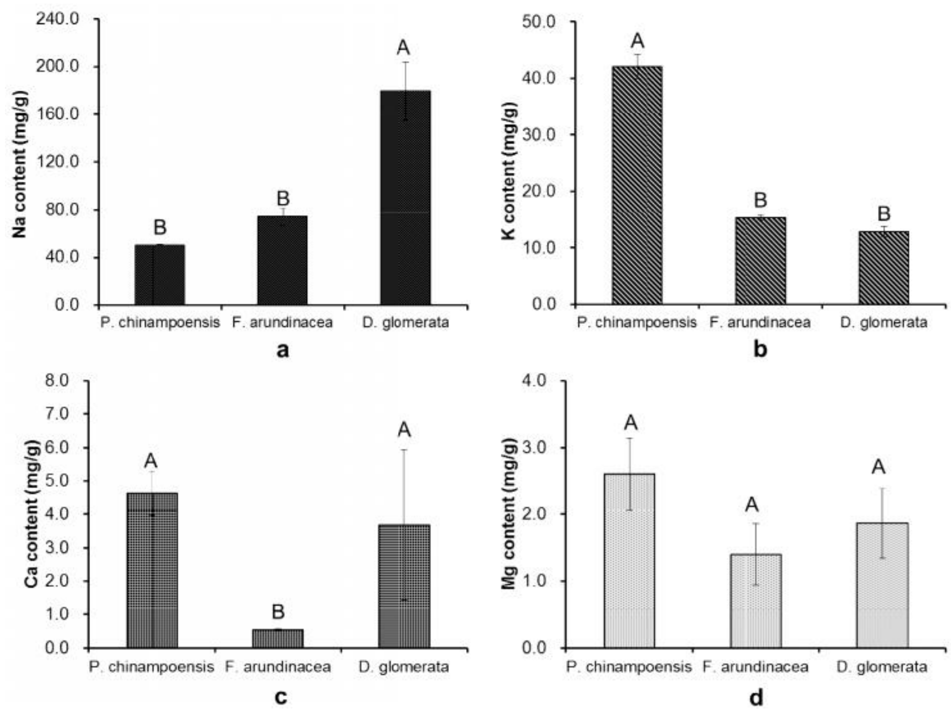

Fig.2.Cation contents of plants (a) Na content (mg/g), (b) K content (mg/g), (c)Ca content (mg/g) and (d) Mg content (mg/g)

Each value represents the mean ± SD (n = 3). Different letters at the top of each column indicate significant differences (p< 0.05) according to the Ryan-Einot-Gabriel-Welsch multiple range test.

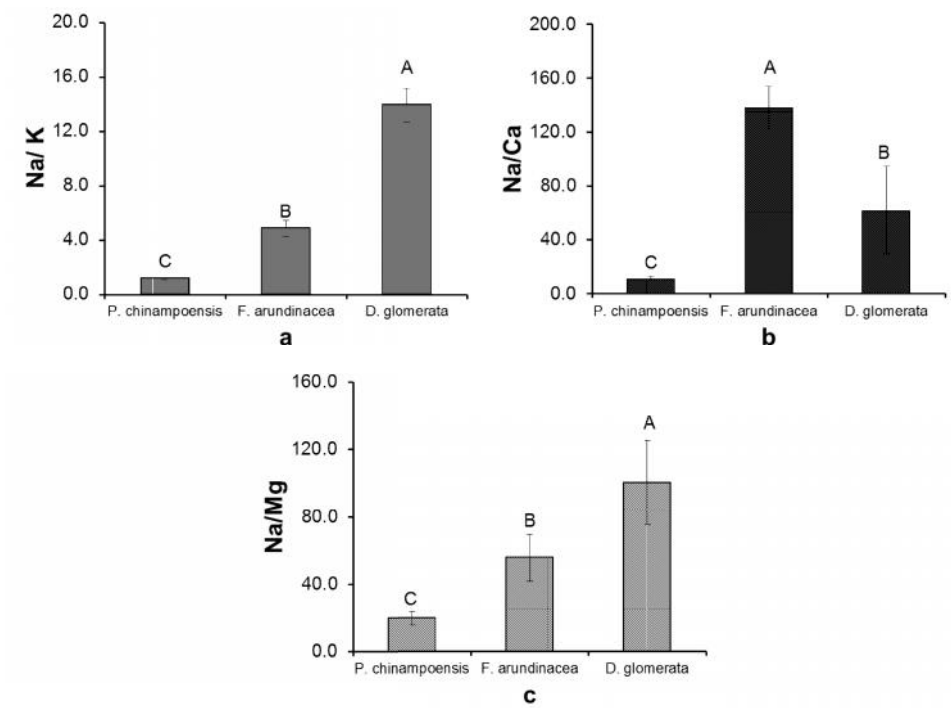

Fig.3.Cation content ratio of plants (a) Naand K ratio, (b) Na and Ca ratio, and (c)Na and Mg ratio

Each value represents the mean ± SD (n = 3). Different letters at the top of each column indicate significant differences (p< 0.05) according to the Ryan-Einot-Gabriel-Welsch multiple range test.

3.2Cultivation of *Puccinelliachinampoensis*Ohwi in alkaline soil in Songnen Plain

Table 2 shows the chemical properties of the soil of experimental field. The soil pH was higher than 8.5, and was lower than that of the sodic soil used in the experiment in the growth chamber. The soil EC and ESP were much lowerthan those of the sodic soil, but CEC was higher than that of the sodic soil. This soil had EC value 0.60 and ESP value 5.38, thus, this soil was not defined as saline or sodic soil [4, 5]. This soil contained extremely higher amount of exchangeable Ca^{2+} than that of sodic soil. The amount of exchangeable $Na^{+}$was muchlower than that of the sodic soil. The exchangeableK^{+} and Mg^{2+} were higher than those of the sodic soil. Thus, it seemed that this soil was rich in Ca andhad the characteristics offertile grassland soil such as chernozem [28].

Figure 4 shows the shoot dry weight of plants. The shoot dry weight of *L. chinensis* was significantly higher than that of *P. chinampoensis.* Figures5a, 5b, 5c and 5d show the contents of Na, K, Ca and Mg per shoot dry weight of each plant. Sodium contents of the plants were much lower than those of the plants grown on the artificial soil. Potassium content of *P. chinampoensis*was about 10 times lower than that grown on the artificial soil. There were no significant difference in the content of Na, K, Ca and Mg between *L. chinensis* and *P. chinampoensis.*

Figures 6a, 6b, and 6c show the cation content ratio of plants. There were no significant difference in the values of Na/K and Na/Ca between *L. chinensis* and *P. chinampoensis.*The Na/K ratio of *P. chinampoensis*was 0.6 comparing with that grown on the artificial soil, 1.2 (Fig. 3a). *P. chinampoensis*showed, however, significant higher value of Na/Mg than that of *L. chinensis*.

Table 2. Chemical properties of the soil in experiment field

	alkaline soil
pH	8.57
EC (dS/m)	0.60
CEC (cmol/kg)	28.3
ESP (%)	5.38
Exchangeable Na^{+} (cmol/kg)	1.52
Exchangeable K^{+} (cmol/kg)	0.40
Exchangeable Ca^{2+} (cmol/kg)	32.7
Exchangeable Mg^{2+} (cmol/kg)	1.24

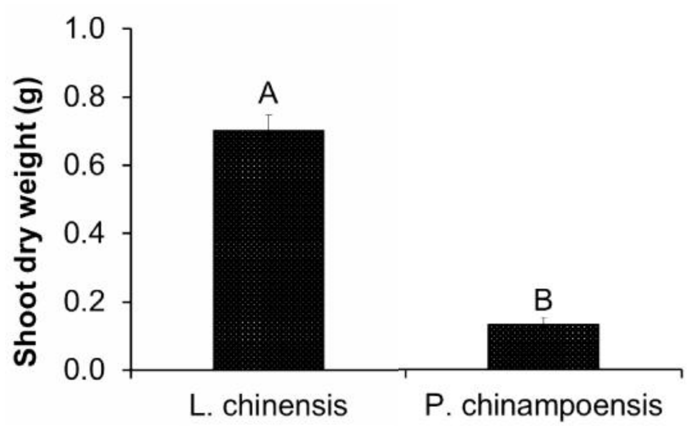

Fig. 4.Shoot dry weight of plants

Each value represents the mean ± SD (n = 3). Different letters at the top of each column indicate significant differences (p< 0.05) according to the Ryan-Einot-Gabriel-Welsch multiple range test.

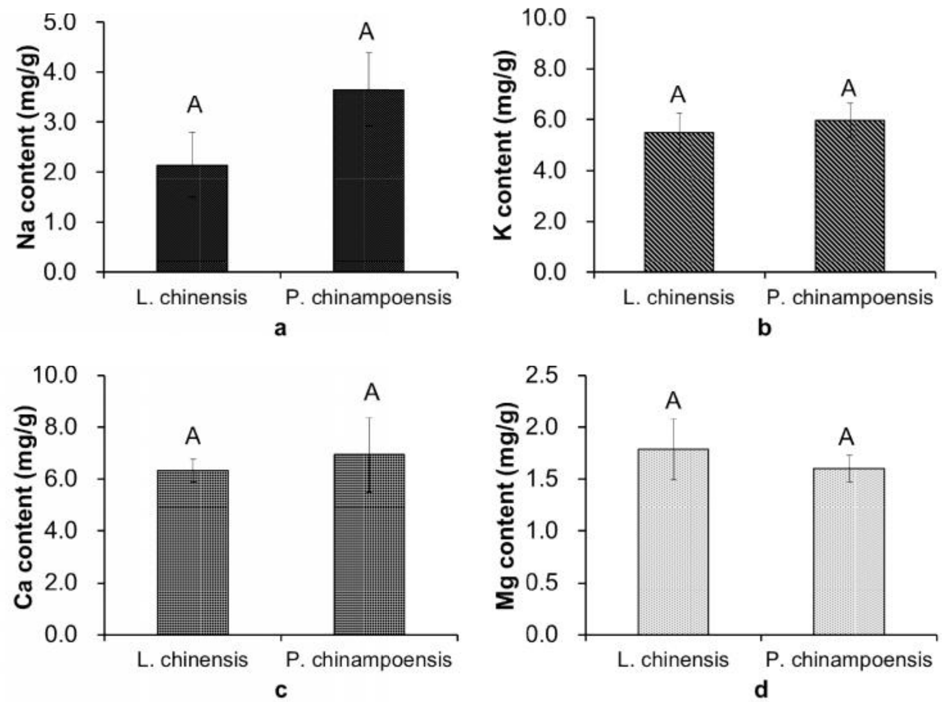

Fig.5.Cation contents of plants (a) Na content (mg/g), (b) K content (mg/g), (c)Ca content (mg/g) and (d) Mg content (mg/g)

Each value represents the mean ± SD (n = 3). Different letters at the top of each column indicate significant differences (p< 0.05) according to the Ryan-Einot-Gabriel-Welsch multiple range test.

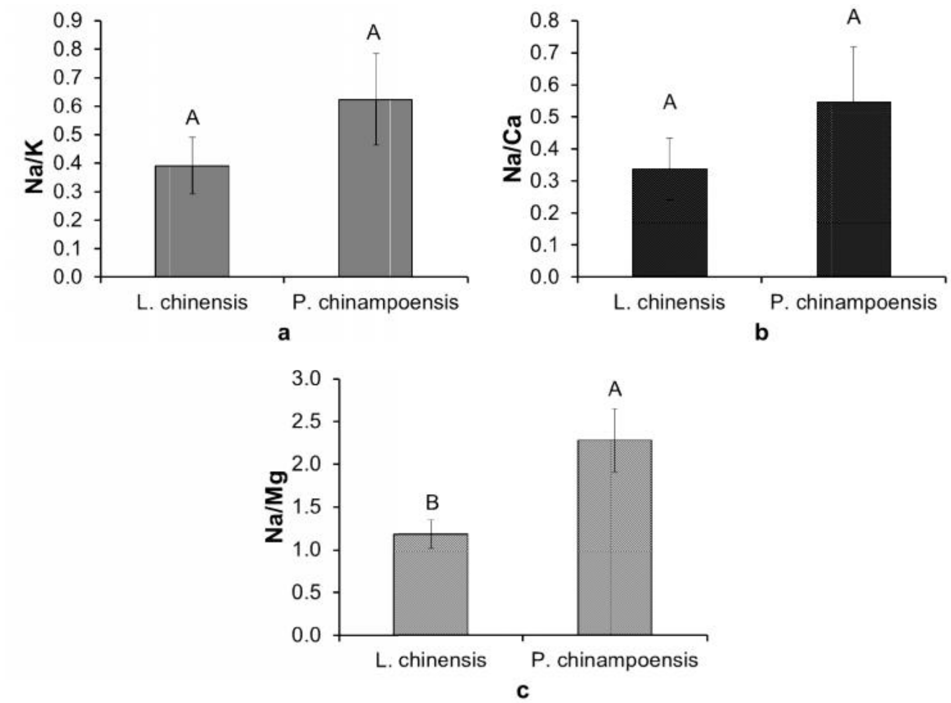

Fig.6.Cation content ratio of plants (a) Naand K ratio, (b) Na and Ca ratio, and (c)Na and Mg ratio

Each value represents the mean ± SD (*n* = 3). Different letters at the top of each column indicate significant differences (p< 0.05) according to the Ryan-Einot-Gabriel-Welsch multiple range test.

4.DISCUSSIONS

In the experiment withsodic soil in growth chamber, *P. chinampoensis*only could germinate in the sodic soil though it did not grow healthy. There are some reports about the superior germinationability of several plantsin salt or sodic conditions [8, 29, 30]. *P. chinampoensis*may also have superior ability of germination under the sodic conditions which may be advantageous to survive there. Further work is required to reveal it.

*P. chinampoensis*and *F. arundinacea*grew in the artificial soil. *P. chinampoensis*and *F. arundinacea* showed higher shoot dry weight as compared with *D. glomerata*(Fig. 1), and *F. arundinacea* showed the highest shoot dry weight. It seemed that not only *P. chinampoensis*but also *F. arundinacea*hadsodictolerance and *F. arundinacea* may also be useful for revegetation of sodic soils. Further study about the usefulness of *F. arundinacea* for revegetation of sodic soil is also required. In the artificial soil, the soil EC and exchangeable Na^+were loweredthough the high soil pH was maintained even after the addition of vermiculite at higher than 10. Plant growth was improved by the addition of vermiculite. It was shown that plants grown on sodic soils were suffered both alkaline stress and salt stress [7, 8, 27, 30, 31]. This result indicated that excessive Na content was more harmful than high soil pH to the growth of sodic tolerant plants. Thus, it is considered that reduction ofexchangeable $Na^+$and EC value would be essential procedure for the revegetation of the sodicsoil. In addition, elevation of exchangeable Ca^{2+} and Mg^{2+} without increase of EC value in the soil may be also effective to improve plant growth.

P. chinampoensis showed the lowest Na content and highest K, Ca, Mg contentsin the shoot as compared with the other plants (Fig. 2a, 2b, 2c, and 2d). This result showed that *P. chinampoensis* had high selectivity of K^+, Ca^{2+}, Mg^{2+} over Na^+ in rhizosphere of sodic soils. Thus, this activity would be advantageous for *P. chinampoensis*to survive insodic conditions. *P. chinampoensis* is widespread and forms communities on sodic grasslands where *L. chinensis*cannot grow on the sodic soil with pH 10 in the Songnen Plain.Furthermore, *P. chinampoensis*showed the lowest values of cation content ratio of Na/K, Na/Ca, and Na/Mg as compared with other plants (Fig. 3a, 3b and 3c). These results also indicated the high cation selectivity of *P. chinampoensis*.*F. arundinacea*also showed low Na contentsimilarly to *P. chinampoensis* (Fig. 2a), and this may be one of the reason why *F. arundinacea*had high shoot dry weight (Fig. 1). *F. arundinacea* showed, however, the lower uptake of K and Ca which were different tendency of those of *P. chinampoensis* (Fig. 2b and 2c). It is shownthat*F. arundinacea* grows on calcareous soils in Rocking mountains area of north America [32], which contain much amount of Ca and high pH values up to 8.5.This plant has tolerance to survivethere. Thus, the plant may have ability to repress the Ca uptake. It isalso reported that the plant have high tolerance for many environmental harm [32]. Therefore, *F. arundinacea* mayhave somefunctions to repress the Na uptake but may not have similar selectivity of K^+ over Na^+ to*P. chinampoensis* (Fig. 2a, 2b and 3a).*D. glomerata*showed the lowest shoot dry weight (Fig. 1). Therefore, *D. glomerata*didnot have tolerance tosodic conditions. In fact, *D. glomerata*showed the highest Na content (Fig. 2a), and this plant may not have similar selectivity of K^+ over Na^+ to*P. chinampoensis*. Actually, it had the low K content (Fig. 2b). The highest Ca content of the plant shoots may be resulted from the high amount of exchangeable Ca^{2+} in the soil (Table 1). It seemed that Mg^{2+} selectivity of *P. chinampoensis* and *F. arundinacea* in the sodic soil may be similar, which is different fromselectivity of K and Ca;because there were no significant differences of Mg content among the plants (Fig. 2d).*P. chinampoensis*, however, showed the lowest value of Na/Mg (Fig. 3c). Therefore, it was shown that*P. chinampoensis* also had selectivity of Mg^{2+} over Na^+ similarly to that of K^+ and Ca^{2+}.

In the experiment in alkaline soil field in the Songnen Plain,*L. chinensis* grew faster than *P. chinampoensis* and showed higher shoot dry weight (Fig. 4). Furthermore, there were no significant differences among the Na, K, Ca and Mg contents between two plants (Fig. 5a, 5b, 5c, and 5d). Growth of *L. chinensis* was faster than that of *P. chinampoensis*. It would be advantageous for *L. chinensis*to have faster growth rate in alkaline conditions. Presumably, this is the reason whydominant plant in the area of alkaline soil was not *P. chinampoensis* but *L. chinensis* in the area of the Songnen Plain with low exchangeable Na^+ and pH 8.5 [16, 17, 18]. In the experimental field, thealkalinesoil contained much amount of exchangeable Ca^{2+} and lower amounts of exchangeable Na^+ and K^+ than sodic soil (Table 2). It seemed that the K^+ selectivity over Na^+ in *P. chinampoensis* was not shown in the growth on the alkaline soil. It is in the condition of the sodic soil that the advantage of cation selectivity of *P. chinampoensis*was shown. Thus, it was indicated that *P. chinampoensis* was well adapted to the condition ofsodic soils, and *P. chinampoensis* can be the dominant plant only on sodic soils.It seemed that K^+ selectivity over Na^+ was specifically shown under Na rich condition. Additionally, *L. chinensis* showed the significantly higher value of Na/Mg than that of *P. chinampoensis* in the alkaline soil (Fig. 6c). *L. chinensis* may have a little higher cation selectivity of Mg^{2+} over Na^+ than *P. chinampoensis* under the alkaline condition with pH 8.5. Therefore,*L. chinensis*would be more adapted to the condition of pH 8.5, Ca rich condition, but it does not have tolerance for high alkaline stress with pH 10, Na rich condition. This may be the reason that *L. chinensis*cannot be the dominant plant in the sodic soil

In order to survive on the sodic soil, tolerance for both salt stress and alkaline stress may be essential [7, 8, 27, 30, 31]. It is indispensable to have the cation selectivity under high pH conditions more than 10. *P. chinampoensis* did not show the superior cation selectivity in the alkaline soil, pH 8.5. The plant, however, showed the noticeable cation selectivity in the sodic soil, pH around 10. This result was noteworthy and important information for revealing characteristics of plants grown in the sodic soil.

It was shown that *P. chinampoensis* had high selectivity of K^+, Ca^{2+}, Mg^{2+} over Na^+ in rhizosphere of sodic soils as compared with the other grasses. Additionally, *P. chinampoensis*would havesuperiorgermination ability in sodic soil. Therefore, these results indicated that *P. chinampoensis*was adapted to the sodic soil and would be useful for improving revegetation of the sodic soil. It was suggested that the selection activity of cations might be induced under the condition with high Na content in soil. At present, there are several studies about Natolerant mechanisms of sodic tolerant grasses. For example, it is known that *Puccinelliatenuiflora*(in *Puccinellia* genus) and *Chlorisvirgata*, which aresodic tolerant plants, can absorb K^+preferentially to Na^+[27, 33, 34]. It was also shown that *P.tenuiflora*had the plasma membrane localized Na^+/K^+antiporter (*PtSOS1*) which could function in preferential absorption of K^+ and exclusion of Na^+ and a high-affinity K^+ transporter (*PutHKT2;1*) [35, 36]. Furthermore, it was suggested that *P.tenuiflora*had the casparian bands of the endodermis as an apoplastic barrier and this barrier leads to the high levels of K^+ in the shoot and a large Na^+ gradient between the root and the shoot [37]. *P. chinampoensis*alsomay have some abilities to select K^+ over Na^+ in the rhizosphere of sodic soils similarly to*P.tenuiflora*. The selectivity of Ca^{2+} and Mg^{2+} of *Puccinellia* genus, however,has not been documented except for our result which was about *P. chinampoensis*, as far as we know. It is also suggested, however, that there are some different physiological characteristics between *P. chinampoensis*and *P. tenuiflora* [23]. Thus, further work is required for revealing the mechanisms of *P. chinampoensis* for adaptationtosodicconditions.

Under the high alkaline condition with pH around 10, metal micronutrients such as Fe, Cu, Mn, Zn and other cations are precipitated. Therefore, absorption of the metals by plants may be repressed. Especially, Fe is precipitated as $Fe(OH)_3$ in alkaline soils, and the total concentration of inorganic Fe species in the soil solution is around 10^{-10}mol L^{-1}[5]. Therefore, Fe deficiency is one of the inhibitory factors in plant growth on alkaline soils [38]. Thus, Fe acquisition ability is also important in the rhizosphere of sodic soils. There are possibilities that sodic tolerant plants such as *P. chinampoensis* have superior mechanisms to acquire metal micronutrients. Further works are also required to reveal the mechanism to uptake not only metal macronutrients but also metal micronutrients.

Preventing land from degradation by soil sodification is an important global issue for food production in the 21st century. Therefore, clarification of the properties of plants growing on sodic soils and utilization of the plantsto recover revegetation of the soils are essential. Thus, further work is required to investigate the mechanism of the sodic tolerant plants such as *P. chinampoensis*in the future.

5 CONCLUSIONS

The uptake of metal macronutrients (K, Ca, Mg) and Na of *Puccinelliachinampoensis*Ohwi (*P. chinampoensis*), one of the sodic tolerant plants, in the rhizosphere of sodic soil were examined. *P. chinampoensis*showed higher shoot content of K, Ca, Mg and lower Na as compared with *Festucaarundinacea*Schreb.and*Dactylisglomerata* L.when grown in the sodic soil mixed with vermiculite. Thus, it was indicated that *P. chinampoensis* had high selectivity of K^+, Ca^{2+} and Mg^{2+} over Na^+ in the rhizosphere of sodic soil. This ability would be advantageous to survive on the sodic soil.*P. chinampoensis,* however,did not show superior uptake ability in alkaline soil with pH 8.5 in the Songnen Plain in northeast China as compared with *Leimuschinensis.* Thus, the superior cation uptake ability of *P. chinampoensis* may be shown only in sodic soil and the plant is well adapted to survivie in the sodic soil.

In the growth on the sodic soil mixed with vermiculite, *P. chinampoensis*and other plants showed better growth thanin sodic soil. In the sodic soil mixed with vermiculite, soil pH was similar to sodicsoil which was higher than 10. However, the soil CEC was increased, and the soil EC and exchangeable sodium percentage (ESP) were decreased. Thus, it seemed that high soil EC and high exchangeable Na^+were harmful factors but high soil pH around 10 was not the inhibitory factor for the growth of the plant in sodic soils.

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