EFFECTS OF A WASHING PROCESS OF CATTLE MANURE ASH ON ROOT AND SHOOT GROWTH OF KOMATSUNA (BRASSICA RAPA VAR. PERVIRIDIS) AT THE SEEDLING STAGE

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This study aims at testing the effects of a washing process on the germination of komatsuna (Brassica rapa var. perviridis) for three days. Cattle manure ash (CMA) was washed with deionized water to reduce electrical conductivity (EC). Not-washed ash (NWA) and washed ash (WA) were used in this experiment. Solutions extracted from NWA and WA (solid:water = 1:20) were diluted at different ratios and had EC values ranging from 0.6 to 28.4 deci-Siemens (dS) m⁻¹. Potassium (K) solutions (1, 2, 3, and 4 dS m⁻¹ as KCl) and phosphorus (P) solutions (5.2 and 2.5 mg P L⁻¹ as KH₂PO₄, adjusted to EC of 1 or 2 dS m⁻¹) were used for germination tests. Results showed that the washing process reduced EC and therefore enhanced shoot elongation. However, the washing process did not affect germination rates (p > 0.05). Stimulation of root and shoot elongation was seen at EC less than 3 dS m⁻¹ and K ranging from 3.5 to 16 mM. Potassium in NWA and WA was a stimulating factor for the elongation of roots and shoots for three days in the seedling stage, but K was reduced to 67% in the WA extract. Meanwhile, soluble P negligibly affected the growth of roots and shoots. In conclusion, K in both NWA and WA promoted the growth of roots and shoots. The washing process should be considered when EC is limited to less than 3 dS m⁻¹ by application rates.

Key words: Cattle manure ash, germination, not-washed ash, potassium, washed ash, washing process

1. INTRODUCTION

Thermal treatments are performed to reduce the volume of fresh manure and to produce ash because it is costly to transport fresh manure with high content of water and organic matter(12394). Recently, animal manure-derived ash has been applied as a potential P fertilizer for plants because it contains a high amount of phosphorus (P). For example, the P content is 30–42 g kg⁻¹ in cattle manure ash and 110–120 g kg⁻¹ in pig manure ash5. Moreover, manure-derived ash contains much potassium (K), which can be used as a fertilizer for plants5. However, the electrical conductivity (EC) of ash is high: for example, it is 27.5 dS m⁻¹ for poultry litter ash at a 1:2 ratio of ash to water6, and 29.5 dS m⁻¹ for broiler litter ash at a 1:10 ratio5. Yamamoto et al. (2008)7 reported that
EC of poultry litter ash burned at a temperature of 800°C is over 40 dS m⁻¹ at 1:5 ratio of ash to water. Application of ash with high EC values as P fertilizer can increase salinity, which inhibits plant growth. Germination is one of the most important stages of plant growth and affects the yield. Germination of seeds commences with the uptake of water and is completed with the elongation of embryonic roots through the seed coat. Stress caused by temperature and salinity affects seed germination rates and seedling growth. High salinity inhibits germination of seeds and causes dormancy. Al-Khateeb (2006) documented that a high level of salts results in a remarkable decline in shoot and root elongation and total dried weight of seedlings. Detrimental effects of salinity on germination of seeds were reported to be due to osmotic stress and ion toxicity. On the other hand, positive effects on seedling growth might be triggered by nutrients such as P and K. Drew (1975) observed that such nutrients cause localized promotion of lateral roots of barley (Hordeum vulgare cv. Proctor). The availability of P increases lateral root elongation of Arabidopsis thaliana. If cattle manure ash (CMA) has high levels of salts, the salinity should be reduced by washing or regulated by the amount of ash applied to farmland. The washing process is efficient to reduce salts, but would reduce nutrients such as K and P in ash. This study aims at evaluating the impacts of the washing of CMA on shoot and root growth in the seedling stage of komatsuna (Brassica rapa var. perviridis). Komatsuna was selected as a test crop because it has been often used for germination tests in Japan. Phosphorus and K solutions were used to identify the single effect of each nutrient on komatsuna seedlings.

2. MATERIALS AND METHODS

2.1. Cattle manure ash

The ash was produced by incineration of composted cattle manure using a pilot-scale fluidized bed incinerator at temperatures of 850°C for 10 s. The composted cattle manure was collected at a composting facility located at Handa city in Aichi Prefecture, Japan. Before incineration, water content was reduced to 39%. The washing process was conducted by Oshita et al. (2016). The ash was washed with deionized water at a rate of 2 mL of deionized water to 1 g of ash to reduce salts in ash. The mixture was stirred at 300 rpm for 1 min. Subsequently, the solid and solution were separated by filtration through a 0.45-µm membrane filter. The ash solid was dried at 105°C for 24 h. Then, washed ash (WA) and not-washed ash (original ash, NWA) were used for the following germination tests. The properties of both types of ash are shown in Table 1. All parameters were measured in triplicates. Washed ash contained lower concentrations of Ca, K, and Na and higher concentrations of P, Ca, and Mg than NWA.

2.2. Germination test

Germination tests were conducted using the petridish method. A blotting seeding sheet was placed in an 85 x 13 mm petridish. Twenty-five komatsuna seeds were placed on the seeding sheet. The extracts were prepared according to Hase and Kawamura (2012). Not-washed ash and WA were extracted with boiled ultrapure water in a beaker at a ratio of 1 g to 20 mL. After being cooled to room temperature, each mixture was stirred for 1 h by a magnetic stirrer, then filtered using paper No.5C (Toyo Roshi Kaisha, Ltd.). Ten milliliters of each solution shown in Table 2 was poured into each petridish. Ash:water ratios were from 1:20 to 1:400. We chose high application rates of ash because ash is unevenly distributed in soil and close to seeds. For the control, ultrapure water was used. Each treatment was prepared in triplicate. All dishes were covered with an aluminum sheet to prevent evaporation, and then were kept in the dark at 25°C for 3 d. As mentioned earlier, P and K might affect growth of seedlings when CMA is applied as a P and K fertilizer. Moreover, Oshita et al. (2016) reported that K and Na formed with Cl in cattle manure ash was highly water soluble. Therefore, P, Na, and K solutions at different EC levels were prepared to evaluate the single effects of P, Na, and K in CMA. Concentrations of P solution and EC levels (1 and 2 dS m⁻¹) were similar to those in CMA extractions. Electrical conductivity was adjusted with NaCl in Na solutions and with KCl in K solutions to 1, 2, 3, and 4 dS m⁻¹.

| Element | NWA (mg kg⁻¹) | WA (mg kg⁻¹) |
|---------|---------------|---------------|
| C⁺ | 4,200 ± 700 | 5,300 ± 500 |
| H⁺ | 1,200 ± 0 | 1,600 ± 100 |
| N⁺ | 400 ± 0 | 470 ± 100 |
| Cl⁻ | 119,400 ± 1,400 | 16,800 ± 0.04 |
| K⁺ | 155,341 ± 6,500 | 53,500 ± 2,000 |
| Na⁺ | 30,700 ± 2,200 | 26,800 ± 390 |
| P | 42,500 ± 5,800 | 62,700 ± 1,600 |
| Ca | 79,300 ± 50,500 | 117,000 ± 72,700 |
| Mg | 31,400 ± 4,700 | 46,700 ± 1,200 |

Note: ¹CHN corder, ²X-Ray fluorescence spectroscopy, and ³Inductively coupled plasma-atomic emission spectrometry.
2.3. Plant parameters

The number of germinated seeds was recorded every 24 h. Seeds were considered to be germinated when radicles were visible. Three days after incubation, the length of shoots and main roots were measured by using a Vernier scale. The germination rate was calculated as the total number of germinated seeds divided by the total number of seeds \(^{10}\). The mean time to germination (MTG) was calculated as:

\[
MTG = \sum_{i=1}^{3} \left( \frac{m_i d_i}{N} \right)
\]

where \(n\) is the number of seeds germinated on day \(i\) (from 1 to 3), \(d\) is incubation time (day), and \(N\) is the total number of seeds \(^{24}\).

The germination index (GI) was also calculated from the relative seed germination and relative root elongation as follows \(^{25}\):

Relative seed germination (%):

\[
\text{Number of seeds germinated in ash extracts} \times 100
\]

Relative root growth (%):

\[
\text{Mean root length in ash extracts} \times 100
\]

Germination index (GI):

\[
\frac{\% \text{ relative seed germination} \times \% \text{ relative root growth}}{100}
\]

2.4. Statistical analysis

Data were shown as mean ± standard deviation. SPSS software 15.0 was used to analyze the data. One-way ANOVA tests were used to interpret effects of EC and nutrient elements on seed germination, shoot, and root elongation. The Tukey HSD test was implemented to determine the significant difference of parameters at \(p = 0.05\).

Table 2 Experimental designs and solution-making procedures

| Treatment | Procedures |
|-----------|------------|
| NWA       | The original extracts were diluted with ultrapure water at extract:water ratios of 5:95 (NWA5), 10:90 (NWA10), 20:80 (NWA20), 50:50 (NWA50), and 100:0 (NWA100). |
| WA        | The original extracts were diluted with ultrapure water at extract:water ratios of 5:95 (WA5), 10:90 (WA10), 20:80 (WA20), 50:50 (WA50), and 100:0 (WA100). |
| KH₂PO₄    | Solutions of 5.2 mg P L⁻¹ and 2.5 mg P L⁻¹ (equivalent to P concentration in the original extracts from NWA and WA, respectively) were diluted with ultrapure water at solution:water ratios of 5:95 and 10:90. EC was also adjusted to 1 or 2 dS m⁻¹ with NaCl. |
| NaCl      | 1, 2, 3, and 4 dS m⁻¹ EC values. |
| KCl       | 1, 2, 3, and 4 dS m⁻¹ EC values. |

3. RESULTS

3.1. Properties of ash extracts

The characteristics of both original extracts are listed in Table 3. Water-soluble K was 99% and 100% of total K in NWA and WA, respectively. Water-soluble Na accounted for 78% and 22% of total Na in NWA and WA, respectively. On the other hand, amounts of P, Ca, and Mg were less than 0.5% of their total amount in NWA and WA. The washing process reduced water-soluble P, K, Na, and Mg up to 52%, 67%, 75%, and 25%, respectively. Water-soluble Ca was unchangeable after washing. The EC value of the extract from NWA was much higher than that from WA (Table 4). This means that the washing process reduced the salinity of CMA to approximately one third. As a result, the decrease in EC value was mainly caused by the leaching of both K and Na. pH was unchanged by washing. Table 4 shows the EC and pH of the diluted solutions of NWA and WA. pH values were over 9 for NWA50 and WA50.

3.2. Germination rates

The final germination rate of komatsuna seeds was determined on day 3 (Table 5). Germination rates of all treatments were higher than 92% and did not show a significant difference among treatments \((p > 0.05)\), although higher EC levels were measured for both NWA and WA extracts compared to the CT. Hase and Kawamura (2012) \(^{23}\) also found approximately 100% komatsuna germination rates for different compost extracts on day 3 with EC ranging from 0.5 to 7.2 dS m⁻¹. Mean time to germination was not significantly different among treatments \((p > 0.05)\), except for NWA100 (Table 5). The greatest EC for NWA100 with 28.4 dS m⁻¹ delayed the germination of komatsuna to 1.6 days. Mean time to germination in other treatments was slightly longer than 1 day.

3.3. Root and shoot elongation

The final root length was significantly affected by the type and dilution of ash extracts \((p < 0.05)\) in Fig. 1a. Table 5 shows the stimulation and inhibition of root elongation of komatsuna by extracts from both types of CMA in comparison with the control. The root elongation in WA5, WA10,
WA20, and NWA5 treatments were stimulated compared with that in the control (Fig. 1). In addition, the stimulation occurred at EC values less than 3 dS m⁻¹. Both NWA and WA treatments did not cause a significant difference in root length in this range. Inhibition of root growth was found in the other treatments, in which NWA100 experienced maximum inhibition (97%). In addition, GI, the product of the relative germination rate and root length, is a sensitive parameter to assess the toxicity affecting germination and root growth. A GI value larger than 80 did not cause phytotoxicity in compost²⁵. However, the root length in NWA10 was retarded compared to the control while GI was 83. In this study, a GI larger than 100 implies the stimulation of seedling growth, for example in WA5, WA10, WA20, and NWA5 treatments. These results indicate that root elongation was more susceptible than the germination rate of seeds.

Final shoot lengths of komatsuna significantly decreased in all treatments when EC increased (p < 0.05). All WA treatments promoted the growth of shoots compared to the control treatment (Table 5). In NWA treatments, shoot lengths were increased by 70% and 32% in NWA5 and NWA10 as compared to the control, respectively, whereas those were inhibited in the other treatments of NWA, in particular up to 100% for NWA100. From the results, the washing process seems better to promote growth of shoots.

Figures 1a and 1b also show the effects of different EC levels due to NaCl and KCl on the shoot and root elongation of komatsuna. Root elongation in KCl solution was stimulated at EC values of 1 and 2 dS m⁻¹,
whereas that in NaCl solution was depressed at all EC levels compared to the control. In addition, stimulation of shoot and root elongation was seen in KCl treatments, while inhibition occurred in NaCl treatments at all EC levels. Therefore, water-soluble K in NWA and WA stimulated the growth of roots and shoots.

3.4. Germination on P solution

Seedling growth of komatsuna in P solutions is presented in Figs. 2a and 2b. A higher P concentration had not increased root and shoot lengths after 3 days. Root and shoot lengths in all P treatments (except for the data of root length in 20% dilution of 2.5 mg P L⁻¹) were not significantly longer than those in the control. Addition of P caused no stimulation of either root or shoot elongation. Therefore, the effect of P from CMA on germination and seedling growth was negligible.

4. DISCUSSION

The process of washing CMA reduced EC to one third. Undoubtedly, EC was an inhibiting factor for root and shoot growth, which is in agreement with previous studies. Bliss et al. (1984) documented that salts affect cell membranes of imbibing seeds and penetrate the membrane to the cytoplasm. According to Parida and Das (2005), excessive amounts of salts decrease osmotic potential and ion imbalance, and subsequently lead to initial growth reduction and limitation of plant productivity. With the increasing addition of ash, high EC inhibits seed germination and plant growth. Application of NWA probably increases the salinity at the seedling stage.

In the present study, K in CMA played an important role in the growth of roots and shoots of komatsuna. Potassium solution vigorously stimulated elongation of roots and shoots of komatsuna, especially at 1 to 2 dS m⁻¹ (Figs. 1a and 1b), while P solution did not (Figs. 2a and 2b). Similarly, K made root and shoot lengths longer than those in the control (p < 0.05, Table 6). According to Leigh and Wyn Jones (1984) and Votruba and Votruba (1986), K in the vacuole and cytoplasm of plant cells increases the osmotic potential and is therefore important in the generation of cell turgor. A positive relationship between dry matter weights of leaves and a primary root and K concentration was observed at the seedling stage of maize. A higher K concentration in a hydroponic solution enhanced shoot and root biomass of 15-day-old wheat seedlings. In addition, Li et al. (2010) showed that K improved root growth and the structure of cells of maize stalks, while deficient K caused a loose arrangement of root cells. The stimulation of root and shoot elongation was probably caused by greater K uptake in root cells. As mentioned above, 67% of K was removed by the washing process. Nevertheless, the stimulation of shoot and root elongation was stronger in WA treatments than in NWA treatments. This can be explained by the fact that 75% of Na, which causes salt stress and inhibition of root growth, was removed by the washing. In this study, both root and shoot lengths in all levels of Na solution were shorter in comparison with those in ultrapure water. The reduction of Na by washing leads to less damage to
the growth of seedlings. Moreover, the K left in WA seems to promote the elongation of both shoots and roots and competes with the uptake of Na. The results show that the optimal concentrations of K for seedling growth were from 3.5 to 16 mM, whereas inhibition of seedling growth was ascribed to K concentrations higher than 16 mM (Tables 5 and 6). Lin and Kao (1995) showed that K concentrations ranging from 0.1 to 10 mM suppress the inhibition of root growth of rice seedlings induced by NaCl due to the competition between K and Na ions to decrease levels of internal Na. The application of K increases seedling development of okra, cucumber, and Arabidopsis due to the increase in K/Na ratios and reduction of Na uptake by the plants.

Moreover, high Ca levels (5 and 10 mM) also ameliorate the deleterious influence of salinity on the seedling growth of rice during the germination stage. Leigh and Wyn Jones (1984) reported that in the absence or deficiency of K, the accumulation of Ca and Mg increases if they are available and compete with Na uptake. In contrast, Mg salts also cause abnormalities in seedlings of Haloxylon ammodendron, but the effects were completely alleviated by Ca salts ranging from 1 to 25 mM. In this study, because Ca concentrations in ash extracts were only equal or less than 0.5 mM, which were lower than that in previous studies, the effects of Ca were minor. However, the effects of the washing process on the amount of water-soluble Ca and Mg were negligible.

5. CONCLUSIONS

This study clarified the effects of the washing of CMA on the germination stage of komatsuna. The stimulation of both roots and shoots in the ash extracts with EC less than 3 dS m⁻¹ was greater compared to that in ultrapure water due to the water-soluble K in NWA and WA. The growth of roots and shoots was better in WA treatments than in NWA treatments. However, water-soluble K was reduced up to 67% in WA. Finally, the washing step should be performed when EC is greater than 3 dS m⁻¹; otherwise, NWA can be directly applied to retain K and save the cost and labor. Future studies are required to investigate effects of micronutrients and toxic compounds in CMA.

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REFERENCES

1. Sweeten J. M., Annamalai K., Thien B. and McDonald L. A.: Co-firing of coal and cattle feedlot biomass (FB) fuels. Part I. Feedlot biomass (cattle manure) fuel quality and characteristics, Fuel, Vol. 82, pp. 1167-1182, 2003.
2. Buckley J. and Schwarz P.: Renewable energy from gasification of manure: An innovative technology in search of fertile policy, Environmental Monitoring and Assessment, Vol. 84, pp. 111-127, 2003.
3. Kuligowski K., Poulsen T. G., Stoholm P., Pind N. and Laursen J.: Nutrients and heavy metals distribution in thermally treated pig manure, Waste Management & Research, Vol. 26, pp. 347-354, 2008.
4. Kuligowski K., Poulsen T. G., Rubæk G. H. and Sørensen P.: Plant-availability to barley of phosphorus in ash from thermally treated animal manure in comparison to other manure based materials and commercial fertilizer, European Journal of Agronomy, Vol. 33, pp. 293-303, 2010.
5. Komiya T., Kobayashi A. and Yahagi M.: The chemical characteristics of ashes from cattle, swine and poultry manure, Journal of Material Cycles and Waste Management, Vol. 15, pp. 106-110, 2013.
6. Codling E. E., Chaney R. L. and Sherwell J.: Poultry litter ash as a potential phosphorus source for agricultural crops, Journal of Environmental Quality, Vol. 31, pp. 954-961, 2002.
7. Yamamoto S., Irshad M., Uchiyama T. and Honna T.: Phosphorus fractionation in chicken and duck litter burned at different temperatures, Soil Science, Vol. 173, pp. 287-295, 2008.
8. Ahmad M. S. A. and Ashraf M.: Essential roles and hazardous effects of nickel in plants, in: Whitacre MD, editor. Reviews of Environmental Contamination and Toxicology, New York, NY, Springer New York; 2011, pp 125-167.
9. Nonogaki H., Basseil G. W. and Bewley J. D.: Germination - Still a mystery, Plant Science, Vol. 179, pp. 574-581, 2010.
10. Sanchez P. L., Chen M., Pessarakli M., Hill H. J., Gore M. A. and Jenks M. A.: Effects of temperature and salinity on germination of non-pelleted and pelleted gauyle (Parthenium argentatum A. Gray) seeds, Industrial Crops and Products, Vol. 55, pp. 90-96, 2014.
11. Steinmaus S. J., Prather T. S. and Holt J. S.: Estimation of base temperatures for nine weed species, Journal of Experimental Botany, Vol. 51, pp. 275-286, 2000.
12. Khan M. A., Gul B. and Weber D.: Influence of salinity and temperature on the germination of Kochia scoparia, Wetlands Ecology and Management, Vol. 9, pp. 483-489, 2001.
13. Iqbal M., Ashraf M., Jamil A. and Ur-Rehman S.: Does seed priming induce changes in the levels of some endogenous plant hormones in hexaploid wheat plants under salt stress?, Journal of Integrative Plant Biology, Vol. 48, pp. 181-189, 2006.
14. Woodell S.: Salinity and seed germination patterns in coastal plants, Plant Ecology, Vol. 61, pp. 223-229, 1985.
15. Kubota H., Hirai M. F. and Satoshi M.: Effects of compost maturity on growth of komatsuna (Brassica Rapa var. pervidis) in neubauer's pot, Soil Science and Plant Nutrition, Vol. 29, pp. 251-259, 1983.
16. Gulzar S. and Khan M. A.: Seed germination of a halophytic grass Aeluropus lagopoides, Aquatic Botany, Vol. 87, pp. 319-324, 2001.
17. Al-Khateeb S. A.: Effect of salinity and temperature on germination, growth and ion relations of Panicum turgidum Forsk, Bioresource Technology, Vol. 97, pp. 292-298, 2006.
18. Wellemsa G. E., Tissouati T. and Bradford K. J.: Water relations of seed development and germination in muskmelon (Cucumis melo L.) III. Sensitivity of germination to water potential and abscisic acid during development, Plant Physiology, Vol. 92, pp. 1029-1037, 1990.
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19) Drew M. C.: Comparison of the effects of a localised supply of phosphate, nitrate, ammonium and potassium on the growth of the seminal root system, and the shoot, in barley, New Phytologist, Vol. 75, pp. 479-490, 1975.

20) Pérez-Torres C.-A., López-Bucio J., Cruz-Ramírez A., Ibarra-Laclette E., Dharmasiri S., Estelle M. and Herrera-Estrella L.: Phosphate availability alters lateral root development in Arabidopsis by modulating auxin sensitivity via a mechanism involving the TIR1 auxin receptor, Plant Cell, Vol. 20, pp. 3258-3272, 2008.

21) Oshita K., Kawaguchi K., Takaoka M., Matsukawa K., Fujimori T. and Fujiwara T.: Emission and control of nitrous oxide and composition of ash derived from cattle manure combustion using a pilot-scale fluidized bed incinerator, Environmental Technology, Vol. 37, pp. 439-445, 2015.

22) Oshita K., Sun X., Kawaguchi K., Shiota K., Takaoka M., Matsukawa K. and Fujiwara T.: Aqueous leaching of cattle manure incineration ash to produce a phosphate enriched fertilizer, Journal of Material Cycles and Waste Management, Vol. 18, pp. 608-617, 2016.

23) Hase T. and Kawamura K.: Germination test on Komatsuna (Brassica rapa var. peruviridis) seed using water extract from compost for evaluating compost maturity: evaluating criteria for germination and effects of cultivars on germination rate, Journal of Material Cycles and Waste Management, Vol. 14, pp. 334-340, 2012.

24) Giménez Luque E., Delgado Fernández I. C. and Gomez Mercado F.: Effect of salinity and temperature on seed germination in Limonium cossonianum, Botany, Vol. 91, pp. 12-16, 2013.

25) Tiquia S. M.: Reduction of compost phytotoxicity during the process of decomposition, Chemosphere, Vol. 79, pp. 506-512, 2010.

26) Mohammad M., Shibli R., Ajlouni M. and Nimri L.: Tomato root and shoot responses to salt stress under different levels of phosphorus nutrition, Journal of Plant Nutrition, Vol. 21, pp. 1667-1680, 1998.

27) Bliss R., Platt-Aloia K. and Thomson W.: Effects of salt on cell membranes of germinating seeds, California Agriculture, Vol. 38, pp. 24-25, 1984.

28) Parida A. K. and Das A. B.: Salt tolerance and salinity effects on plants: a review, Ecotoxicology and Environmental Safety, Vol. 60, pp. 324-349, 2005.

29) Lau S. S. S. and Wong J. W. C.: Toxicity evaluation of weathered coal fly ash amended manure compost, Water, Air, and Soil Pollution, Vol. 128, pp. 243-254, 2001.

30) Leigh R. A. and Wyn Jones R. G.: A hypothesis relating critical potassium concentrations for growth to the distribution and functions of this ion in the plant cell, New Phytologist, Vol. 97, pp. 1-13, 1984.

31) Votrubová O. and Votrub M.: The influence of IAA on the uptake of potassium, calcium, magnesium, water absorption and growth in young maize seedlings, Biologia Plantarum, Vol. 28, pp. 460-464, 1986.

32) Wei J., Li C., Li Y., Jiang G., Cheng G. and Zheng Y.: Effects of external potassium (K) supply on drought tolerances of two contrasting winter wheat cultivars, Plos One, Vol. 8, pp. e69737, 2013.

33) Li W., He P. and Jin J.: Effect of potassium on ultrastructure of maize stalk pith and young root and their relation to stalk rot resistance, Agricultural Sciences in China, Vol. 9, pp. 1467-1474, 2010.

34) Lin C. C. and Kao C. H.: NaCl stress in rice seedlings: the influence of calcium on root growth, Botanical Bulletin Academia Sinica, Vol. 36, pp. 41-45, 1995.

35) Paksoy M., Türkmen Ö. and Dursun A.: Effects of potassium and humic acid on emergence, growth and nutrient contents of okra (Abelmoschus esculentus L.) seedling under saline soil conditions, African Journal of Biotechnology, Vol. 9, pp. 5343-5346, 2013.

36) Türkmen Ö., Şensoy S. and Erdal I.: Effect of potassium on emergence and seedling growth of cucumber grown in saline conditions, University Journal of Agricultural Sciences, Vol. 10, pp. 113-117, 2000.

37) Yang L., Zu Y.-G. and Tang Z.-H.: Ethylene improves Arabidopsis salt tolerance mainly via retaining K+ in shoots and roots rather than decreasing tissue Na+ content, Environmental and Experimental Botany, Vol. 86, pp. 60-69, 2013.

38) Tobe K., Li X. and Omasa K.: Effects of five different salts on seed germination and seedling growth of Haloxylon ammodendron (Chenopodiaceae), Seed Science Research, Vol. 14, pp. 345-353, 2007.

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