Jpn. J. Crop Sci. 61(3): 439—446 (1992)

Dry Matter Production and Distribution of Mineral Ions in Different Parts of the Plant in Hexaploid Triticale under Salt Stress Conditions

Md. Abdul KARIM, Eiji NAWATA and Shoji SHIGENAGA
(*Faculty of Agriculture, Kyoto University, Sakyo-ku, Kyoto 606, Japan*)
Recieved September 12, 1991

Abstract: Effects of saline irrigation on the dry matter production and mineral ions distribution in different parts of the plant in two cultivars of hexaploid triticale, Welsh and Currency, were investigated in the glasshouse irrigated with sodium chloride solutions at concentrations of 0, 25, and 50 mM. Comparison of dry matter production in the grains between the two cultivars suggested that Currency was more salt-tolerant than Welsh. Reduction of dry matter in the leaves and culm of the treated plants was more or less similar in the two cultivars. Dry matter of husks in Welsh was reduced more than that in Currency although roots showed opposite result. Sodium and chloride concentrations in all parts of the treated plants were in general increased in both cultivars. The increasing tendency of these ions in all parts of the plant in Welsh was higher than in Currency, except in the roots. Roots in treated plants of Currency showed more or less similar concentration of sodium and higher concentration of chloride compare to those in Welsh. It is, therefore, suggested that quantitative accumulation of sodium and chloride in some parts of the plant is related to the salt tolerance of hexaploid triticale cultivars. Potassium accumulation was increased in all parts of the treated plants in both cultivars except in the culm, which showed a decreasing accumulation. The tendencies of calcium and magnesium accumulation were different between two cultivars and among different parts of the plant. Therefore, the roles of these three ions in relation to salt tolerance were not clear.
Key words: Growth, Hexaploid triticale, Mineral ion distribution, Salt tolerance.

塩分ストレス下における六倍体ライコムギの乾物生産と無機イオンの体内分布：KARIM, M.A.・縄田栄治・重永昌二（京都大学農学部）

要　旨：塩分濃度の異なる塩水かんがいが六倍体ライコムギの乾物生産と無機イオンの体内分布に及ぼす影響を解析し，それによって耐塩性機構を検討する目的で，遺伝的背景の異なる2品種，Welsh 及び Currency, を用いてガラス室内でポット栽培による比較試験を行った．塩水かんがい処理は，ポットに移植後3週間目の幼苗期から成熟期まで2～4日おきに1個体あたり200 ml の塩化ナトリウム水溶液を0，25，及び50 mM の濃度区に分けて行った．その結果，穀実収量の比較により Currency の方が Welsh よりも耐塩性が大であることが示唆された．塩水処理により，両品種とも茎葉の乾物重が低下した．塩水処理による穎の乾物重の低下は，Welsh の方が Currency より著しかったが，根の乾物重の低下は Currency の方が大であった．植物体各器官のナトリウム及び塩素の濃度は，一般に処理に用いた塩水の濃度が高くなるほど上昇した．この傾向は，根以外のすべての器官で Welsh の方が Currency よりも著しかった．根におけるナトリウム濃度は，各処理区で品種間差は認められなかったが，塩素濃度は Currency の方が高かった．このことから，六倍体ライコムギにおいては各器官のナトリウム及び塩素の蓄積が耐塩性に関与し，とくに根が地上部へのこれらイオンの輸送調整に関する重要な役割を果していることが示唆された．カリウム，カルシウム及びマグネシウムの濃度は，品種間及び器官間で一定の傾向が見られず，耐塩性に関するこれら3無機イオンの役割は明らかでなかった．
キーワード：生長，耐塩性，無機イオン分布，六倍体ライコムギ．

In arid and semi-arid regions, both salinity levels and saline areas are increasing with the expansion of irrigation facilities. Salinity decreases both growth and yield of glycophytes, and if the salt concentration in the root zone is high a plant cannot set seeds and under extreme conditions it dies [2,15]. All glycophytes, however, do not respond equally to salinity[13]. Moreover, variations in salt tolerance exist among the cultivars of a species, e. g. wheat, barley, triticale[15], rice[5] and soybean[12]. The variation in salt tolerance among the cultivars may be related to multiple physiological processes including a different pattern of uptake and transport of ions[8]. Bernstein et al[3]. suggested that variation in Cl ion transport from root to shoot may be responsible for the varietal difference in salt tolerance of grape vines. In general, the salt tolerant cultivars have a greater ability to exclude Na and Cl ions in the foliage or greater compartmentation capability of these toxic ions within the cells and organelles[16].

Although salinity decreases dry matter production in plants as a whole, all parts of the plant do not respond equally. Roots are usually less affected than aboveground parts of the plant. It is reported that leaf-stem ratio in alfalfa increased with an increase in salinity level[9]. Reduction in grain yield in rice and corn under saline conditions was more than for straw yield. On the contrary, barley, wheat and cotton showed opposite response[13]. The dissimilar responses of plant organs in the same cultivar under salt-stress conditions may have some relationship to their difference in the mechanism of ion absorption, and/or capability of toxic ions exclusion. Information is still insufficient on the distribution pattern of mineral ions in various parts of the plant, and the roles of these ions and the parts in the determination of salt tolerance in cereal crops. Furthermore, there are few pubblications addressing the topic of salt tolerance in triticale, although triticale is considered a promising crop for marginal environments[1] and there is a possibility of expanding its cultivation in areas, where there is salinity or the potential for it to develop.

This experiment was conducted to analyze the effect of NaCl on dry matter production in different parts of the plant, accumulation of different mineral ions in these parts, and their roles in determination of salt-tolerance in two cultivars of hexaploid triticale with varying levels of salt-tolerance.

Materials and methods

Seven-day-old seedlings of two cultivars of hexaploid triticale, Welsh (substitution type) and Currency (complete type), were transplanted into plastic pots, 14 cm in diameter and 13 cm in height, with one seedling per pot, in the third week of February, 1990. The pots were filled with washed sand, perlite, and organic manure at a ratio of 2 : 1 : 1 by volume. The organic manure contained 2.3% N, 1.8% K_2O, and 3.5% P_2O_5. The pH and EC values of the prepared soil were 6.7 and 0.5 dS/m, respectively. Two grams of compound fertilizer at a ratio of $N : P_2O_5 : K_2O$ as 14 : 12 : 14 were also applied before transplanting. The plants were grown until their maturity in a glasshouse. Fifteen plants were used in each treatment in this experiment.

Plants were irrigated with tap water for three weeks, after which NaCl solutions were applied every other day at an increment of 12. 5 mM until the respective final concentrations, 25 and 50 mM, were attained for each treatment. Depending on plant and soil conditions, 200 ml treatment solution was applied at intervals of 2-4 days until maturity. Plants in the control group were irrigated with tap water. The plants were harvested in mid-june, 1990. After harvesting, roots were separated from the plants and washed with tap water. The plants were oven-dried at 70°C to a constant weight. After drying, the plants were segmented into culm, leaves (leaf blade+sheath), husks, and grains. The culm, upper four leaves, husks, and grains from the main shoot and the whole root mass were finely ground for the determination of mineral ions concentration. The ground samples were dry-ashed at 500°C for eight hours and digested with concentrated hydrochloric acid. Sodium, potassium, calcium, and magnesium concentrations were determined by atomic absorption spectrophotometry (Shimadzu, Atomic absorption/Flame Spectrophotometer ; Model-AA 610 s). In order to obtain Cl measurement, the dry-ash was digested with boiling water, and after cooling, this was determined by means of an ion-selective electrode (Orion Research Ion Analyzer ; Model-407A). For ion analysis, four-replicated-plant samples were used in each treatment.

Results

1. Dry matter production

Results presented in Table 1 show that NaCl reduced in general the dry matter production in all parts of the plant in both cultivars. Difference in the reduction levels was observed between cultivars and among different parts of the plant. Grain production clearly indicated that Currency was more salt-tolerant than Welsh. For instance, at 25 and 50 mM NaCl concentrations, Welsh showed 65 and 26 percent in grain yield compared to the control, while Currency

Table 1. Effect of NaCl on the dry matter production (g/plant) in different parts of the plant in two cultivars of hexaploid triticale.

NaCl (mM)	Welsh					Currency				
	Plant parts					Plant parts				
	Grains	Husks	Leaves	Culm	Roots	Grains	Husks	Leaves	Culm	Roots
0	5.83 a (100)	2.32 a (100)	2.73 a (100)	3.60 a (100)	0.30 a (100)	6.47 a (100)	2.20 ab (100)	2.50 a (100)	3.63 a (100)	0.42 a (100)
25	3.79 b (65)C	2.27 a (98)A	2.20 b (81)B	2.36 b (66)C	0.31 a (103)A	4.74 b (73)C	2.30 a (105)A	1.95 b (78)C	2.38 b (66)D	0.38 ab (90)B
50	1.51 c (26)D	1.87 b (81)A	1.90 b (69)B	2.15 b (60)C	0.23 b (77)A	2.56 c (40)D	2.08 b (95)A	1.65 b (66)B	2.17 b (60)C	0.27 b (64)BC

Different small letters within each plant-part in a column indicate a significant difference at $p=0.05$. Values in parentheses in each column indicate percentage values to the control at the respective level of NaCl. Different capital letters superscribed to the percentage values in a row indicate a significant difference at $p=0.05$ at each level of NaCl. Lettering was made separately for each cultivar.

showed 73 and 40 percent, respectively. Dry matter production in leaves and in culm were more or less similar in the two cultivars when compared by percentage values. Husks in Welsh, however, showed a more depressed tendency than in Currency, although root mass in Currency reduced more than in Welsh (% to the control) under saline conditions.

At 25 mM, the growth depression among different parts of the plant was the most in grains followed in descending order by culm, leaves, husks, and roots in Welsh compared by percentage values, while in Currency that was the most in culm, followed by grains, leaves, roots, and husks. At 50 mM, however, the order changed to grains, culm, leaves, roots, and husks in Welsh, and to grains, culm, roots, leaves, and husks in Currency, respectively.

2. Chloride concentration

Chloride ion in all parts of the plant in both cultivars increased with increasing concentration of applied NaCl (Fig. 1). In NaCl treated plants, Welsh contained more Cl than Currency in all the aboveground parts, except in leaves. Leaves in both cultivars accumulated similar quantity of this ion at all NaCl levels. On the other hand, roots in Currency showed significantly higher concentration of Cl than in Welsh under saline conditions. Leaves in both cultivars were estimated as the major sink of Cl. Chloride distribution pattern to different parts of the plant was similar to each other in both cultivars and that was shown in decreasing order of leaves, culm, husks, roots, and grains.

3. Sodium concentration

Sodium distribution data presented in Fig. 1 shows that Na ion increased with the increasing concentration of applied NaCl in all parts of the plant in both cultivars. The concentration, however, varied between two cultivars and among different parts of the plant. Under saline conditions, Na accumulation in all parts of the plant in Welsh was higher than in Currency, except in roots. Roots in both cultivars accumulated a more or less similar amount of Na in all treatments. In treated plants, the culm in both cultivars accumulated the highest quantity of Na followed in decreasing order by leaves, husks, roots, and grains.

4. Potassium concentration

The accumulation of K ion decreased in the culm and increased in other parts of the plant with an increasing concentration of applied NaCl in both Welsh and Currency (Fig. 2). The accumulating tendency of K in leaves, however, was not clear. For instance, there was no significant difference in K accumulation among different salinity levels in Welsh, but in Currency the concentration was significantly higher at 25mM than at 0 and 50 mM, and the concentrations resulted from the latter two treatments were similar. It was observed that the decreasing tendency of K in the culm in treated plants of Welsh was more than in Currency. On the contrary, the increase in K accumulation in husks with increased in NaCl levels was more in Currency than in Welsh,

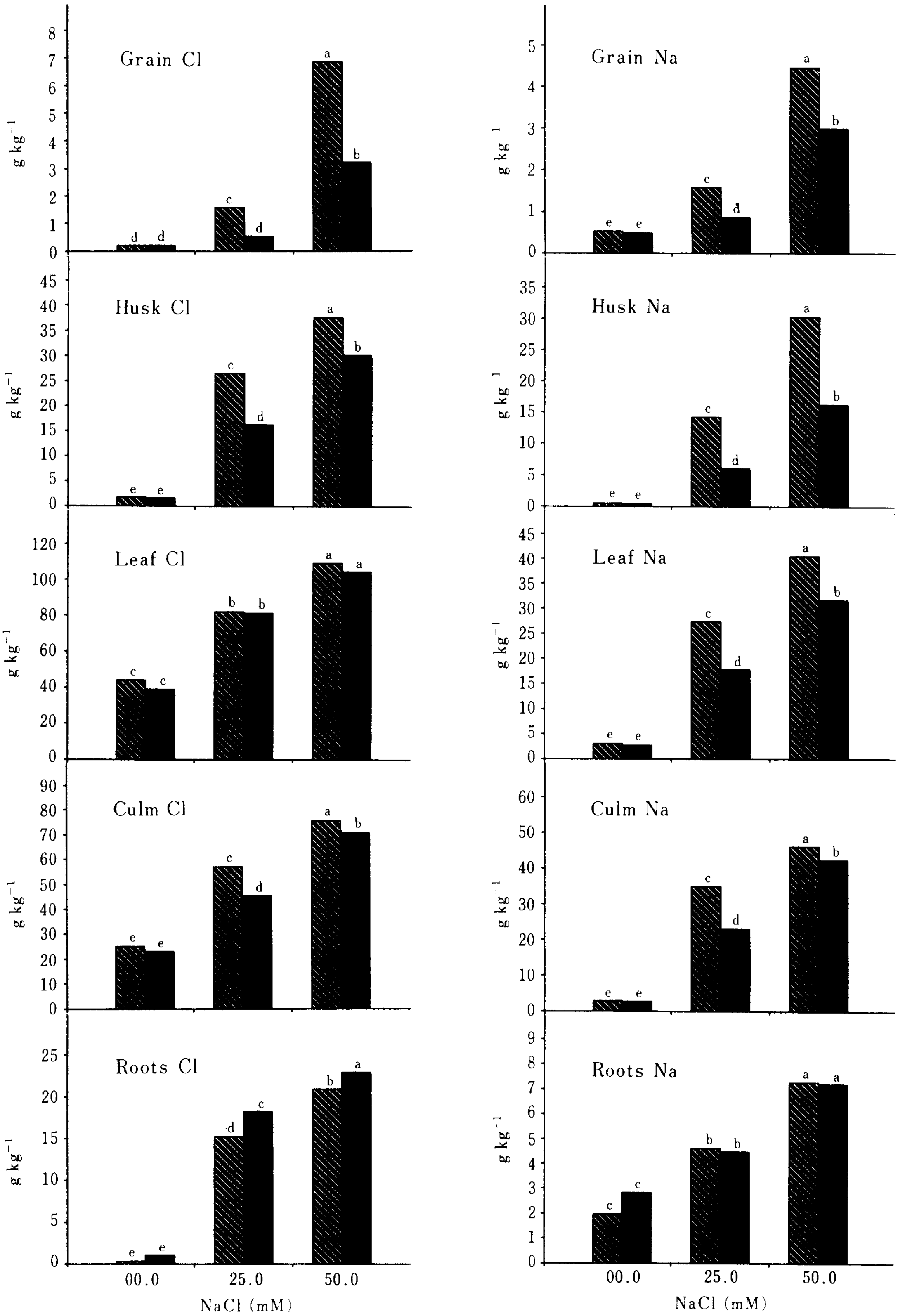

Fig. 1. Effect of NaCl on the distribution of Cl and Na ions in different parts of the plant in two cultivars of hexaploid triticale. The ion contents are expressed on a dry weight basis. ▨, Welsh ; ■, Currency. Different letters indicate a significant difference at $p=0.05$.

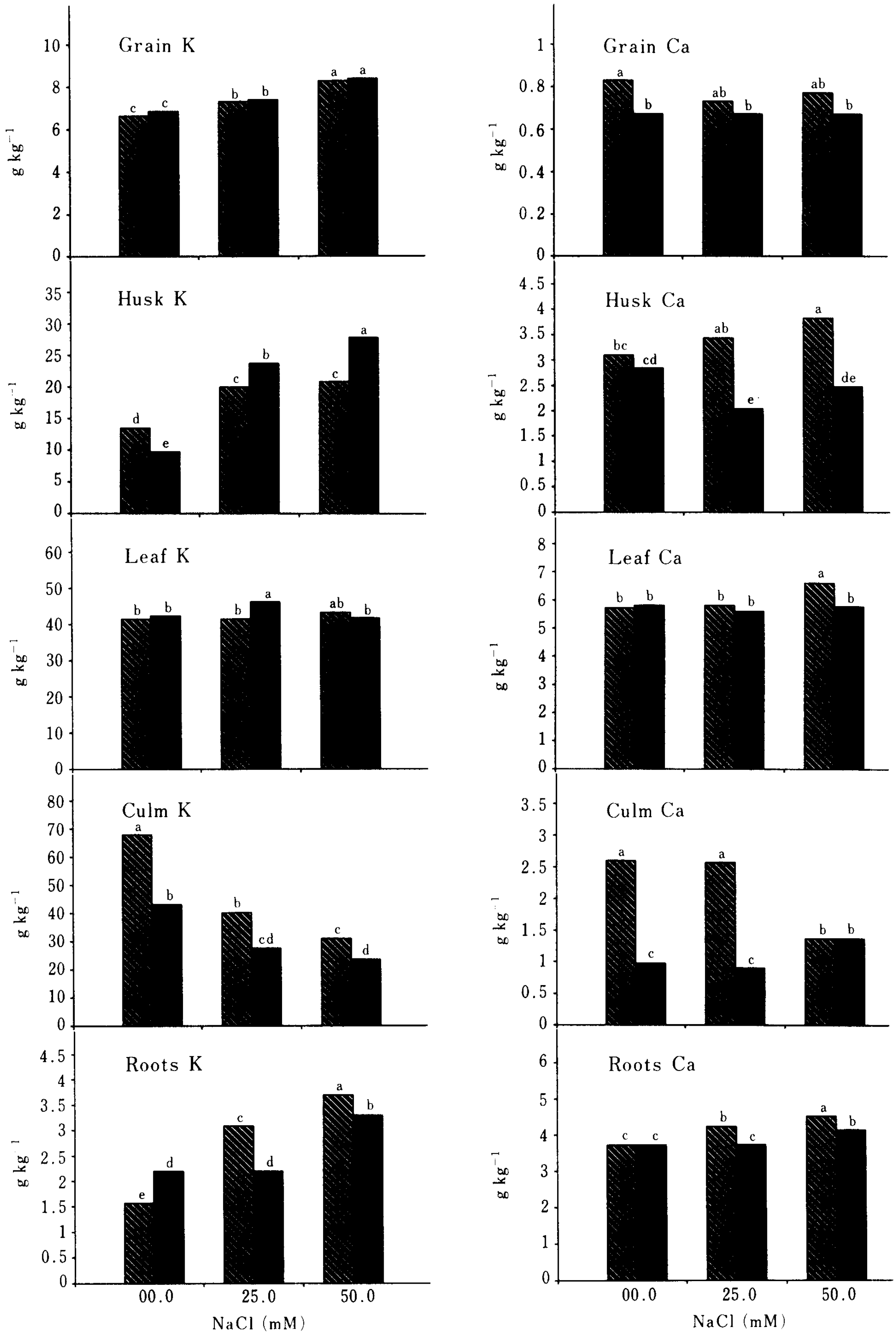

Fig. 2. Effect of NaCl on the distribution of K and Ca ions in different parts of the plant in two cultivars of hexaploid triticale. The ion contents are expressed on a dry weight basis. ▧, Welsh ; ■, Currency. Different letters indicate a significant difference at $p=0.05$.

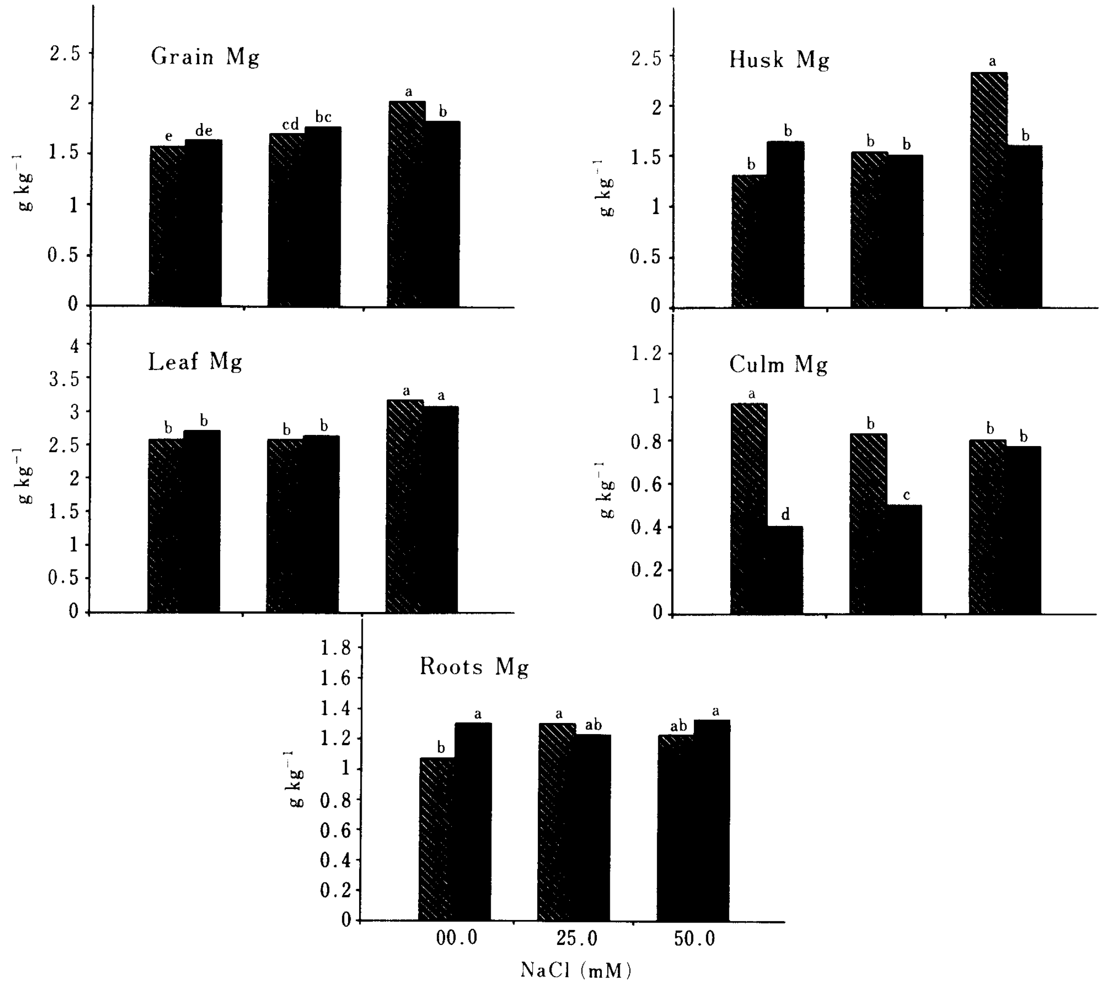

Fig. 3. Effect of NaCl on the distribution of Mg ion in different parts of the plant in two cultivars of hexaploid triticale. The ion contents are expressed on a dry weight basis. ▨, Welsh ; ■, Currency. Different letters indicate a significant difference at p=0.05.

though the tendency in roots was opposite to that in husks. Grains in both cultivars showed a similar and increasing tendency in K accumulation with increase in salinity level.

5. Calcium concentration

Calcium accumulation pattern in different parts of the plant differed between cultivars (Fig. 2). In Welsh, concentration of Ca ion in the culm was lower in the 50 mM treatment than in the control and 25 mM treatment. In Currency, however, the concentration was higher at 50 mM than at other salinity levels. Leaves in Welsh showed high quantity of Ca at 50 mM NaCl, whereas in Currency it did not show such a response. Husks in Welsh accumulated a significantly higher amount of Ca in the plants treated with 50 mM NaCl than in control plant, while in Currency the husks accumulated less Ca at 25 mM NaCl than in the control treatment. Salinity did not affect the concentration of Ca ion in grains in either cultivar. In roots, however, Ca was increased under saline conditions in both Welsh and Currency but the concentration was higher in Welsh than in Currency.

6. Magnesium concentration

Similar to Ca, pattern of Mg ion distribution did not show any clear-cut tendency to salinity (Fig. 3). It seemed that NaCl treatment generally increased Mg concentration in the plant. Culm in Welsh, however, showed a tendency for decreasing Mg accumulation under saline conditions. Magnesium in leaves and grains in both cultivars seemed to have a tendency to increase with the increasing concentration of NaCl. Husks and roots in Welsh also showed more or less a tendency of increasing Mg accumulation under NaCl saline conditions.

In Currency, however, Mg concentration in those parts of the plant was not affected by salinity.

Discussion

Under salt-stress conditions plants uptake mineral ions from the growth media for osmotic adjustment. So far, different kinds of osmotica including inorganic mineral ions like Na, K, and Cl, and metabolites such as proline, glycinebetaine, and various organic acids have been identified in salt-affected plants. Among the osmotica, the increased amount of Na and Cl creates a toxic effect on plant growth[4]. In general, resistant varieties maintain a smaller amount of Na and Cl in their shoots than susceptible ones, e.g. in barley[7], rice[5], and wheat[6]. Kingsbury et al. [11], however, did not observe a different content of these ions in wheat varieties differing in salt-tolerance.

In this experiment, it was obvious that Welsh, which showed more depressive growth under NaCl-treatment conditions, accumulated more Na and Cl in the aboveground parts of the plant than Currency. Consequently, it is supposed that Welsh was affected more with toxicity of Na and Cl ions than Currency. The three ions, K, Ca, and Mg, did not follow a similar accumulating tendency to Na and Cl in different parts of the plant in either of the cultivars tested. It is, therefore, possible to conclude that difference in tolerance level between Welsh and Currency is due to the difference in quantitative accumulation of Na and Cl ions in the shoots of these two cultivars.

Under saline conditions, K, Ca, and Mg play a similar role in protecting the plant cells from osmotic shock. They can be substituted for one another as well as by other cations during stress conditions. Accordingly, with the increase in Na concentration under saline conditions, K, Ca, and Mg ions may be decreased, especially in the shoot[14]. In this experiment these three ions showed a different response in different parts of the plant. Potassium concentrations decreased only in the culm and in other parts either increased or were not affected by increasing concentration of applied NaCl in both cultivars. A different mode in accumulation of Ca and Mg was observed between the cultivars and among different parts of the plant. Consequently, the roles of these three ions are not clear in determining salt-tolerance levels in hexaploid triticale cultivars. The results, however, suggest that the relatively high concentration of negative Cl ion in the culm and leaves in both cultivars was primarily balanced by positive Na and K ions[10].

The dissimilar growth response in different parts of the plant under NaCl-stress conditions may be related to the toxic effect of accumulated ions of Na in particular. In both cultivars the growth depression pattern among the parts of the shoot exactly followed their Na accumulation pattern, in which culm accumulated the most followed in descending order by leaves and husks. However, the much more reduction in grain production, although it accumulated a smaller amount of Na and Cl ions than other parts of the plant, suggests that grain development is greatly affected in the presence of Na and Cl ions, even though the quantity of these ions are small.

It can be noted that all parts of the plant except roots in Currency accumulated less amount of Na and Cl ions than in Welsh. Roots in Currency accumulated similar amount of Na and more amount of Cl compared to those in Welsh at both 25 and 50 mM NaCl levels. This dissimilar response of roots to other parts of the plant in Currency is supposed to be on a par with the idea that the function of differential regulation of transporting Na and Cl ions from the growth media to the aboveground parts is located on the roots[12], and roots in tolerant cultivar possess higher regulating capacity than in susceptible cultivar.

References

1. Anonymous 1985. Triticale-A crop for marginal environments. In Research Highlights CIMMYT, 72—87.
2. Ayers, A.D. and H.E. Hayward 1948. A method for measuring the effects of soil salinity on seed germination with observations on several crop plants. Soil Sci. Soc. Am. Proc. 13 : 224—226.
3. Bernstein, L., C.F. Ehlig and R.A. Clark 1969. Effect of grape root stocks on chloride accumulation in leaves. J. Am. Soc. Hort. Sci. 94 : 584—590.
4. Blum, A. 1988. Salinity resistance. In Plant Breeding for Stress Environments. CRC Press. Florida. 163—179.

5. Flowers, T.J. and A.R. Yeo 1981. Variability in the resistance of sodium chloride salinity within rice (*Oryza sativa* L.) varieties. New Phytol. 88 : 363—373.
6. Francois, L.E.,Maas, E.V., T.J. Donovan and V. L. Yongs 1986. Effect of salinity on grain yield and quality, vegetative growth, and germination of semi-dwarf and durum wheat. Agron. J. 78 : 1053—1058.
7. Greenway, H. 1965. Plant response to saline substrates. VII. Growth and ion uptake throughout plant development in two varieties of *Hordeum vulgare*. Aust. J. Biol. Sci. 18 : 763—779.
8. ——— 1973. Salinity, plant growth, and metabolism. J. Aust. Inst. Agric. Sci. 39 : 24—34.
9. Hoffman, G.J., E.V. Maas and S.L. Rawlins 1975. Salinity-Ozone interactive effects on alfalfa yield and water relations. J. Env. Quality 4 : 326—331.
10. Jeffrey, R.S. and C. Chritchley 1985. Effects of salt stress on the growth, ion content, stomatal behaviour and photosynthetic capacity of a salt-sensitive species, *Phaseolus vulgaris* L. Planta. 164 : 151—162.
11. Kingsbury, R.W., E. Epstein and R.W. Pearcy 1984. Physiological responses to salinity in selected lines of wheat. Plant Physiol. 74 : 417—427.
12. Lauchli, A. and J. Wieneke 1979. Studies on growth and distribution of Na^+, K^+ and Cl^- in soybean varieties differing in salt tolerance. Z. Pflanzenernaehr. Bodenkd. 142 : 3—13.
13. Maas, E.V. and G.J. Hoffman 1977. Crop salt tolerance-current assessment. J. Irrig. Drain. Div. Am. Soc. Civ. Eng. 103 : 115—134.
14. Rabie, R.K. and K. Kumazawa 1988. Effect of NaCl salinity on growth and distribution of sodium and some macronutrient elements in soybean plant. Soil Sci. Plant Nutr. 34 : 375—384.
15. Richards, R.A., C.W. Dennett, C.O. Qualset, E. Epstein, J.D. Norlyn and M.D. Winslow 1987. Variation in yield of grain and biomass in wheat, barley, and triticale in a salt affected field. Field Crops Res. 15 : 277—287.
16. Steveninck, R.F.M.V., M.E.V. Steveninck, R. Stelzer and A. Lauchli 1982. Studies on the distribution of Na and Cl in two species of lupin (*Lupinus luteus* and *Lupinus angustifolius*) differing in salt tolerance. Physiol. Plant. 56 : 465—473.