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Performance of High-Magnesium Cultivars of Three Cool-Season Grasses Grown in Nutrient Solution Culture

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ABSTRACT

Breeding for high magnesium (Mg) concentrations has been conducted for several forage species. Mgwell, Magnet, and HiMag are the first experimental strains, bred for increased Mg concentrations of orchardgrass, Italian ryegrass, and tall fescue, respectively. This experiment compared the performance and genetic variability of these high-Mg cultivars grown in solution culture with other cultivars in each species. Three mineral absorption experiments were carried out with one month aged seedlings. Seedlings were evaluated for shoot dry weight, uptake and concentration of Mg, calcium (Ca), and potassium (K), and also the

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density of these minerals in the shoot. The cultivars of different species behaved differently among the experiments even though the over all environmental condition was kept similar. The high-Mg cultivars showed higher Mg uptake per plant, but the differences were not so distinct. However, the trend in Mg concentration among the cultivars of different species was similar, and the difference between high-Mg cultivars and control cultivars was distinct. The Mg density in the shoot of these cultivars was significantly high. Also the high-Mg cultivars showed lower equivalent ratio, K/(Ca + Mg). Genotypic differences in high-Mg cultivars with others could be distinctly explained by differences in Mg concentration and Mg density in the shoot, which coupled with low K/(Ca + Mg) ratio. These common properties of high-Mg cultivars might be considered as a good parameter for screening.

Key Words: Grass tetany; High-Mg cultivar; Orchardgrass; Italian ryegrass; Tall fescue; Solution culture.

INTRODUCTION

Grass tetany is a non-infectious, complex magnesium deficiency of ruminants grazing cool season grasses, and causes extensive economic losses around the world. Annual losses due to grass tetany in the United States are estimated at $50 million to $150 million.[1] Tall fescue is one of the major cool-season grasses in American pastureland. Genetic variation of minerals associated with grass tetany was studied in tall fescue[2–5] and they reported that several mineral concentrations were under genetic control.

Plant breeders developing cultivars to minimize the hazards of grass tetany are concentrating largely on increasing herbage Mg concentrations in C_3 forage grasses as the heritability estimates are highest for Mg.[6] and the breeding program succeeded in producing "HiMag" tall fescue cultivar.[1] Grass tetany incidence in dairy and beef cattle also causes considerable loss in U.K.[7]

Italian ryegrass is one of the popular forage grasses in U.K., and "Magnet" Italian ryegrass was bred by Hides and Thomas.[8] The characteristics of "Magnet" Italian ryegrass have been studied.[9–11]

In northern Japan, orchardgrass is one of the major forage species and livestocks grazing on orchardgrass-dominated grassland suffer from grass tetany, especially in early spring and fall. Several studies were conducted in Japan to understand the genetic variability in orchardgrass[12,13] and the first experimental strain "Mgwell" orchardgrass was bred. Grass tetany is also common in other European countries, Australia, Argentina, and

New Zealand.[14] In addition to causing grass tetany, low levels of Mg in the diet can lead to inappetence and reduced dry matter intake by livestock.[10]

Understanding the characteristics of these high-Mg cultivars may provide information for screening individual plants with low grass tetany potential. From that standpoint, our objective is to investigate the performance of high-Mg cultivars of orchardgrass, Italian ryegrass, and tall fescue grown in nutrient solution culture. Information about the similarity among these selected plant genotypes of different species is significant for further progress to be made in developing high-Mg cultivars of other species as well as for the establishment of efficient screening method.

For this purpose cultivars of orchardgrass, Italian ryegrass, and tall fescue with high Mg content were used to provide a range of comparison among different species. This research evaluates the genetic differences in the Mg uptake and concentrations in high-Mg experimental cultivars of different species grown in nutrient solution culture, by comparing with other commercial cultivars. This may contribute to understand the consistent characteristic in the individual selection for high Mg concentrations among different species.

MATERIALS AND METHODS

Experiments involving cultivars of three species of cool-season forage grasses viz, orchardgrass (*Dactylis glomerata* L.), Italian ryegrass (*Lolium multiflorum* L.), and tall fescue (*Festuca arundinacea* Schreb.) were conducted thrice, namely Experiment 1 (Expt. 1), Experiment 2 (Expt. 2), and Experiment 3 (Expt. 3) in nutrient solution culture in the controlled environment growth chamber. The experimental materials were selected as one high-Mg cultivar and two other commercial cultivars from each species (Table 1). The high-Mg cultivars of orchardgrass, Italian ryegrass, and tall fescue were "Mgwell", "Magnet", and "HiMag", respectively. All experiments involving Italian ryegrass and tall fescue were conducted together while those of orchardgrass were conducted separately under similar conditions. "Fawn" was not included as a commercial cultivar of tall fescue in Expt. 1.

Germinated seeds were grown in Hoagland and Arnon solution (one-fifth strength, pH 5.5) in a glasshouse at Iwate University. After 15 days, the plants of almost similar shoot and root length (3–5 leaves) were selected to make bunches, then allowed to grow for another 15 days, and used for mineral absorption tests. Thus plants were grown in the initial nutrient culture for 30 days. Bunches consisting of three seedlings (one month old) were transplanted into individual glass beakers containing 500 mL of Hoagland and Arnon solution (one-half strength, pH 5.5). There were five replications for each

Table 1. Dry weight of shoots of each cultivar (g $plant^{-1}$).[a]

Species	Cultivar	Expt. 1	Expt. 2	Expt. 3	Mean
Orchardgrass	Mgwell	0.38 a	0.32 a	0.10 a	0.26 a
	Akimidori	0.36 b	0.25 b	0.08 b	0.23 a
	Okamidori	0.40 a	0.27 ab	0.10 a	0.26 a
Italian ryegrass	Magnet	0.34 b	0.28 c	0.29 b	0.30 b
	Tachiwase	0.64 a	0.33 b	0.56 a	0.51 a
	Waseyutaka	0.72 a	0.35 a	0.52 a	0.53 a
Tall fescue	HiMag	0.31 a	0.18 a	0.24 a	0.24 a
	Fawn	NI	0.14 b	0.21 a	0.18 b
	Ky-31	0.20 b	0.13 b	0.20 a	0.18 b

[a]Values within column and species with the same letters are not significantly different at $P < 0.05$.
Key: NI, not included.

cultivar to minimize the effect of heterogeneity of individual plants. The glass beakers were kept in small cardboard boxes not to disturb normal root growth, and placed in a phytotron. The air temperature of the phytotron was maintained at 25°C day/15°C night, and the photoperiod was maintained at 14 h. Relative humidity was approximately 75% and the light intensity was 280-μmol photons $m^{-2} s^{-1}$. Solutions were aerated throughout the experiment. Solution volume was maintained by addition of deionized water on daily basis. The mineral absorption tests for orchardgrass were conducted during May 18–31, 2000 (Expt. 1), July 25–31, 2000 (Expt. 2), and January 18–27, 2001 (Expt. 3). Experiments using Italian ryegrass and tall fescue were conducted during June 3–12, 2000 (Expt. 1), November 25–31, 2000 (Expt. 2), and January 22–31, 2001 (Expt. 3).

At the end of each mineral absorption test, plant samples were separated into shoots and roots, then shoots were dried at 60°C for 48 hours in a forced-air oven, and weighted. Concentrations of Mg, calcium (Ca), and K were analyzed by the Atomic Absorption Spectrophotometer. The results were expressed as nutrient uptake per plant (mg $plant^{-1}$) and concentration (mg g^{-1} dry wt.) of each cultivar. The dried plant samples were ashed in crucibles at 600°C for three hours. Mineral density in the ashed shoot was determined by energy-dispersive X-ray (EDX) apparatus attached with scanning electron microscope as described by Saiga et al.[12] to investigate the mineral composition in plants. Analysis of variance (ANOVA) and Ryan-Einot-Gabriel-Welsch Multiple Range Test[15] was calculated using SAS computer programs as well as data for Mg concentration and density of each experiment were tested by analysis of contrasts between high-Mg and control cultivars (SAS Inst., Cary, NC). A probability level of 0.05 was considered to be statistically significant.

RESULTS

Plant Growth and Shoot Dry Weight

Experiments involving Italian ryegrass and tall fescue were conducted together while those of orchardgrass were conducted separately under similar experimental conditions. The dry weights of the cultivars of different species are shown in Table 1. In all the three experiments the shoot dry weight of Mgwell was significantly higher than Akimidori. There was no significant difference between Mgwell and Okamidori in Expt. 1 and Expt. 3. In the mean value of three experiments, there was no significant difference among orchardgrass cultivars. The shoot dry weight of Magnet was significantly lower than the other two cultivars of Italian ryegrass in the three experiments. Similar trends were obtained among cultivars of Italian ryegrass across the three experiments. HiMag tall fescue had the highest dry matter yield in all the experiments but this difference was not significant in Expt. 3.

Magnesium Uptake and Concentration

The Mg uptake per plant and concentration of the cultivars of different species varied among the experiments (Table 2). The amount of Mg uptake in Expt. 1 was higher than those in Expt. 2 and Expt. 3. High-Mg orchardgrass cultivar, Mgwell showed significantly higher amount of Mg uptake per plant than the commercial cultivars in Expt. 2 and Expt. 3. In Expt. 1, there was no significant difference between Mgwell and Okamidori. In the mean of three experiments Mgwell showed significantly higher Mg uptake per plant. Magnesium concentration was significantly higher in Mgwell than the other cultivars in all experiments and also in the mean. In case of Italian ryegrass, high-Mg cultivar Magnet, showed significantly higher value than the other two cultivars in Expt. 2. Although this trend was similar in the other two experiments there was no significant difference among cultivars of Italian ryegrass in Expt. 1 and Expt. 3. In the mean of experiments Magnet showed significantly higher Mg uptake per plant. Magnesium concentration was significantly higher in Magnet in three experiments, which was also consistent

Table 2. Magnesium uptake and concentration by cultivars across three experiments.[a]

Species	Cultivar	Uptake (mg plant^{-1})				Concentration (mg g^{-1} dry weight)			
		Expt. 1	Expt. 2	Expt. 3	Mean	Expt. 1	Expt. 2	Expt. 3	Mean
Orchardgrass	Mgwell	2.31 a	1.19 a	0.83 a	1.45 a	6.06 a	3.78 a	10.00 a	6.61 a
	Akimidori	1.86 b	0.51 c	0.77 b	1.05 b	5.28 b	2.06 b	8.81 b	5.38 b
	Okamidori	2.40 a	0.91 b	0.63 c	1.31 ab	5.96 ab	3.34 ab	6.33 b	5.21 b
Italian ryegrass	Magnet	3.15 a	0.73 a	1.23 a	1.70 a	9.16 a	2.61 a	3.58 a	5.12 a
	Tachiwase	2.73 a	0.60 ab	1.17 a	1.50 b	4.35 b	1.82 ab	2.02 b	2.73 b
	Waseyutaka	3.06 a	0.46 b	1.02 a	1.51 b	4.39 b	1.32 b	2.33 b	2.68 b
Tall fescue	HiMag	1.40 a	0.41 a	1.15 a	0.99 a	4.48 a	2.30 a	4.89 a	3.89 a
	Fawn	NI	0.31 b	0.77 b	0.54 b	NI	2.14 b	3.71 b	2.92 b
	Ky-31	0.56 b	0.28 b	0.65 b	0.49 b	2.71 b	2.25 ab	3.23 b	2.73 b

[a]Values within column and species with the same letters are not significantly different at $P < 0.05$.
Key: NI, not included.

in the mean. Among the cultivars of tall fescue, HiMag showed significantly higher Mg uptake per plant than Ky-31 and Fawn as well as significantly higher Mg concentration in three experiments. The trend among the cultivars of tall fescue was also similar in the mean of three experiments.

Calcium and Potassium Uptake and Concentration

Calcium and K uptake per plant and concentration of each cultivar is shown in Table 3. In case of orchardgrass, Mgwell showed highest amount of Ca uptake per plant as well as Ca concentration in all experiments. There was no consistent trend in the K uptake per plant among the cultivars of orchardgrass. In Expt. 1 and Expt. 3 significantly lowest amount of K concentration was obtained in Mgwell than the other two cultivars. The amount of Ca uptake per plant by Magnet Italian ryegrass was not significantly differ from the other cultivars while the K uptake per plant was significantly lower. The Ca concentration of Magnet was higher but the difference was not always statistically significant. There was no consistent trend among the cultivars of Italian ryegrass in K concentration among the experiments. In case of tall fescue, there was no significant difference among the cultivars in Ca and K uptake per plant and concentration both in Expt. 2 and Expt. 3, but HiMag tall fescue showed significantly higher values in case of Ca and K uptake per plant in Expt. 1.

Mineral Density

Table 4 showed the mineral density in the ashed shoot of different cultivars, where mineral density means relative percentage of each element among seven mineral nutrients, viz., Mg, Ca, K, phosphorus (P), sulfur (S), chloride (Cl), and silicon (Si). In all the experiments, the Mg density of Mgwell was significantly higher than that of Akimidori and Okamidori. In case of Italian ryegrass, shoot Mg density of Magnet was higher than the other two cultivars both in Expt. 1 and Expt. 2 while in Expt. 3 it was statistically insignificant. In case of tall fescue, HiMag showed significantly higher Mg densities in all the three experiments. However, in the mean of three experiments, the high-Mg cultivars of these three species showed significantly higher Mg density than the other cultivars (Fig. 1).

Calcium and K densities in the shoot of different cultivars are also shown in Table 4. The Ca density was significantly higher in Mgwell both in Expt. 2 and Expt. 3. Similar trend was observed in Expt.1 but the differences between

Table 3. Calcium and potassium uptake and concentration by cultivars across three experiments.[a]

		Ca			K		
Species	Cultivars	Expt. 1	Expt. 2	Expt. 3	Expt. 1	Expt. 2	Expt. 3
				Uptake (mg plant^{-1})			
Orchardgrass	Mgwell	4.10 a	1.46 a	0.90 a	22.6 a	16.9 a	7.0 b
	Akimidori	2.84 c	0.42 c	0.83 ab	20.2 b	11.4 b	7.4 a
	Okamidori	3.54 b	1.07 b	0.50 b	22.6 a	14.0 ab	7.6 a
Italian ryegrass	Magnet	6.76 a	1.40 a	2.07 a	17.0 b	12.1 b	12.4 b
	Tachiwase	6.49 a	1.50 a	3.47 a	21.8 a	16.0 a	20.7 a
	Waseyutaka	6.92 a	1.02 b	3.02 a	21.8 a	17.1 a	20.5 a
Tall fescue	HiMag	2.36 a	0.46 a	1.49 a	18.9 a	10.9 a	14.9 a
	Fawn	NI	0.50 a	1.24 a	NI	11.2 a	12.0 a
	Ky-31	1.24 b	0.41 a	0.86 a	13.6 b	10.7 a	12.2 a
				Concentration (mg g^{-1} dry weight)			
Orchardgrass	Mgwell	10.5 a	4.6 a	11.7 a	56.3 b	51.1 a	65.6 c
	Akimidori	7.9 b	1.7 c	7.8 ab	58.1 a	46.0 b	96.1 a
	Okamidori	9.0 ab	3.9 b	5.0 b	57.1 ab	53.5 a	76.3 b
Italian ryegrass	Magnet	20.2 a	4.5 a	7.1 a	30.4 b	38.9 b	42.8 a
	Tachiwase	10.4 b	4.5 a	5.9 a	35.2 b	47.9 a	36.8 a
	Waseyutaka	9.6 b	2.9 b	5.6 a	50.9 a	49.1 a	40.1 a
Tall fescue	HiMag	7.5 a	2.3 a	6.3 a	61.2 b	54.4 b	63.8 a
	Fawn	NI	3.5 a	6.1 a	NI	77.9 a	57.8 a
	Ky-31	5.9 a	3.3 a	4.4 a	67.4 a	84.0 a	64.7 a

[a]Values within column and species with the same letters are not significantly different at $P < 0.05$.
Key: NI, not included.

Table 4. Mineral density in the shoot of each cultivar (%).[a]

		Mg			Ca			K		
Species	Cultivars	Expt. 1	Expt. 2	Expt. 3	Expt. 1	Expt. 2	Expt. 3	Expt. 1	Expt. 2	Expt. 3
Orchardgrass	Mgwell	6.22 a	5.49 a	4.54 a	18.7 a	16.2 a	9.2 a	59.0 b	64.1 b	71.6 b
	Akimidori	4.59 b	4.46 b	3.98 b	15.7 b	13.3 b	7.5 b	64.7 a	67.7 a	72.9 ab
	Okamidori	4.51 b	4.46 b	3.54 c	18.1 a	13.6 b	7.4 b	60.5 ab	65.8 ab	74.8 a
Italian ryegrass	Magnet	8.74 a	5.72 a	5.37 a	25.3 a	11.0 a	17.1 a	52.6 b	63.6 b	61.8 c
	Tachiwase	6.93 c	3.87 b	5.23 a	22.5 b	7.8 b	15.1 b	55.8 a	72.7 a	65.4 b
	Waseyutaka	7.74 b	3.91 b	5.01 a	23.9 b	7.6 b	11.5 c	50.7 b	73.2 a	70.1 a
Tall fescue	HiMag	7.10 a	16.76 a	7.01 a	16.2 a	24.6 a	10.0 a	62.8 b	30.2 b	70.8 b
	Fawn	NI	13.80 b	6.01 b	NI	21.5 ab	9.2 b	NI	36.7 b	72.7 a
	Ky-31	4.90 b	11.86 c	6.07 b	10.9 b	16.7 b	8.6 c	70.6 a	47.1 a	72.8 a

[a]Values within column and species with the same letters are not significantly different at $P < 0.05$.
Key: NI, not included.

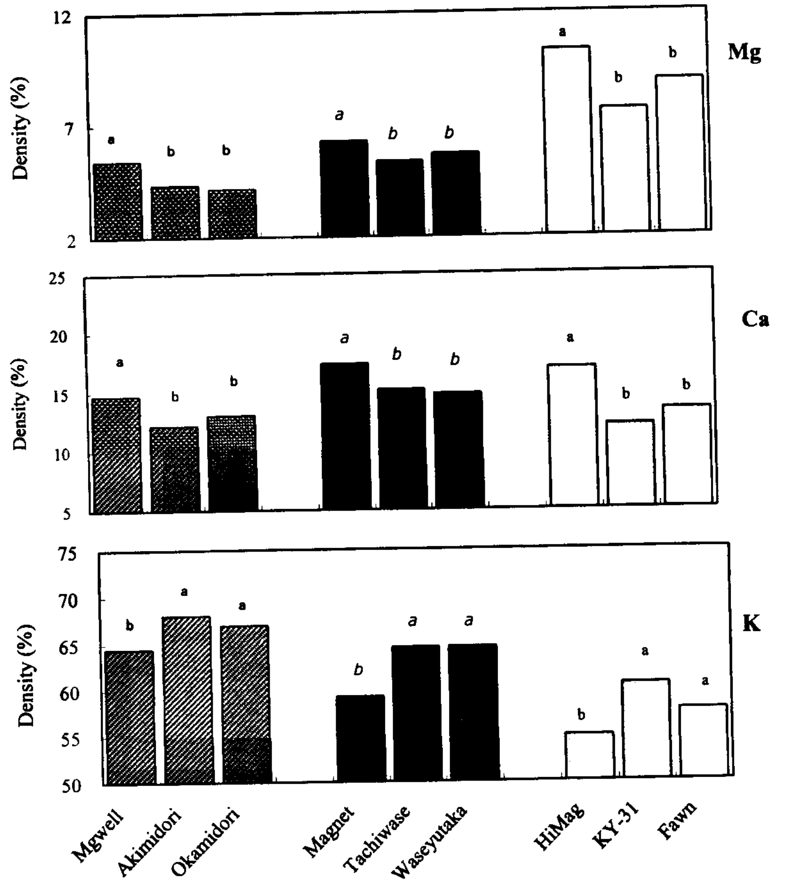

Figure 1. Mean mineral density in the ashed shoot of different cultivars. Bars within species with the same letters are not significantly different at $P < 0.05$.

Mgwell and Okamidori was not statistically significant. Shoot K density in the high-Mg cultivar of orchardgrass was significantly lower than the commercial cultivars. The shoot Ca density of Magnet Italian ryegrass was significantly higher than the other two cultivars. But the K density in the ashed shoot of Magnet was significantly lower in all the experiments. In case of tall fescue, HiMag contained higher amount of Ca than Ky-31 and Fawn. Potassium density in the shoot of HiMag was significantly lower in all experiments. In

mean results of three experiments, significantly higher values were obtained in high-Mg cultivars of all the three species for Ca density while lower values for K density (Fig. 1).

Equivalent Ratio K/(Ca + Mg)

The equivalent ratio, K/(Ca + Mg) of each cultivar across the experiments is shown in Table 5. The high-Mg cultivars of orchardgrass, Mgwell showed significantly lower equivalent ratio than the control cultivars across the experiments. In case of Italian ryegrass Magnet showed lower values in all experiments, but this difference was not significant in Expt. 2. HiMag tall fescue showed significantly lower equivalent ratio than the control cultivars but this was not consistent in Expt. 2.

Contrasts Between High-Magnesium and Control Cultivar for Magnesium

Table 6 showed the contrasts between high-Mg cultivar and control cultivars for Mg concentration and density. The high-Mg cultivar of

Table 5. The equivalent ratio K/(Ca + Mg)[a] of each cultivar across three experiments.[b]

Species	Cultivars	Expt. 1	Expt. 2	Expt. 3	Mean
Orchardgrass	Mgwell	1.40 b	2.01 b	1.89 b	1.77 b
	Akimidori	1.79 a	2.65 a	2.20 a	2.21 a
	Okamidori	1.76 a	2.41 ab	2.53 a	2.23 a
Italian ryegrass	Magnet	1.65 b	2.05 a	1.94 b	1.88 b
	Tachiwase	2.08 a	2.30 a	2.36 a	2.25 a
	Waseyutaka	2.16 a	2.09 a	2.27 a	2.17 a
Tall fescue	HiMag	2.05 b	1.93 a	1.95 b	1.98 b
	Fawn	NI	2.21 a	2.25 a	2.23 a
	Ky-31	2.69 a	2.33 a	2.25 a	2.42 a

[a]Calculated on an equivalent per kilogram basis.
[b]Values within column and species with the same letters are not significantly different at $P < 0.05$.
Key: NI, not included.

Table 6. Contrasts between high-Mg and control cultivars for Mg concentration and density.[a]

		Concentration ($mg\ g^{-1}$ dry weight)				Density (%)			
Species	Cultivar	Expt. 1	Expt. 2	Expt. 3	Mean	Expt. 1	Expt. 2	Expt. 3	Mean
Orchardgrass	High-Mg	2.07 a	1.26 a	3.28 a	2.20 a	6.22 a	5.49 a	4.54 a	5.42 a
	Control	1.86 a	0.91 b	2.66 a	1.81 b	4.55 b	4.46 b	3.80 b	4.27 b
Italian ryegrass	High-Mg	9.16 a	2.01 a	3.58 a	4.92 a	8.75 a	5.72 a	5.37 a	6.61 a
	Control	4.37 b	1.47 a	2.18 b	2.67 b	7.84 a	3.89 b	5.12 a	5.62 b
Tall fescue	High-Mg	4.48 a	2.45 a	4.89 a	3.94 a	7.11 a	16.76 a	7.01 a	10.29 a
	Control	2.71 b	1.85 a	3.47 b	2.68 b	4.90 b	12.83 b	6.04 b	7.92 b

[a]Values within column and species with the same letters are not significantly different at $P < 0.05$.

orchardgrass showed higher Mg concentration as well as density than control cultivars, but this difference was not always significant in case of Mg concentration. The high-Mg cultivar of both Italian ryegrass and tall fescue showed higher Mg concentrations across the experiments, but this was not significant in Expt. 2. The Mg densities of the high-Mg cultivar of Italian ryegrass were not significantly higher than the control cultivars in Expt. 1 and Expt. 3. In case of tall fescue the high-Mg cultivar showed significantly higher Mg densities across the experiments.

DISCUSSION

In the present study, high-Mg cultivars showed higher Mg uptake per plant but the differences were not so distinct (Table 2). The cultivars of different species behaved differently among the experiments even though the over all environmental condition was kept similar. In case of Italian ryegrass and tall fescue, plant growth was most vigorous in Expt. 1, followed by Expt. 3 and lowest in Expt. 2. But the growth of orchardgrass was highest in Expt. 1 and lowest in Expt. 3. Vigorous plant growth may influence the mineral uptake per plant among the experiments. According to Hovin et al.,[16] mineral concentrations have been found to be associated with dry matter yield. We did not observe consistent trend in initial plant growth among the high-Mg cultivars of different species. Generally, shoot dry weight of high-Mg cultivar of orchardgrass was not significantly differ from the control cultivars. Magnet Italian ryegrass showed lower dry weight than the other cultivars, while in case of HiMag tall fescue the opposite trend was observed (Table 1). It is frequently the case, in herbage breeding, that improvement of specific nutritional characteristics may be accompanied by a penalty in yield.[11] Saiga and co-workers (unpublished data) observed that Akimidori, orchardgrass is high yielding cultivar even though it showed low initial growth in solution culture. They concluded that initial growth of orchardgrass cultivars in nutrient culture was not related with the yield under field condition and there was a possibility of high-Mg cultivars to be related with low productivity.

Mineral concentration was determined to ignore the effect of vigorous plant growth and to find the actual amount of mineral uptake by each unit of dry weight. In general, the trend in Mg concentration among the cultivars of different species was similar, and the difference between high-Mg cultivars and control cultivars was distinct (Table 2). The Mg density of high-Mg cultivars of all the three species was significantly higher which coupled with higher Ca and lower K densities (Table 4). The reason may be plants with high Mg concentration usually selected during the process of breeding, as the objective of individual selection is to increase the Mg concentration in the shoot.[10,17,18] Although our results obtained under controlled environments they are generally consistent with the findings concerning the magnesium content of these studies under natural conditions.

The equivalent ratio, K/(Ca + Mg) is used to estimate the grass tetany potential of a forage because of the interactions of Mg, Ca, and K in grass tetany. This ratio should be 2.2 or less for forage to be safe in terms of its potential for inducing grass tetany.[19] In the present study, the high-Mg cultivars of three species showed equivalent ratio less than 2.2 (Table 5). Besides, the high-Mg cultivars of these three cool season grasses showed higher Mg concentrations and densities than the control cultivars (Table 6). This indicates that the high-Mg cultivars are less potential for inducing grass tetany than the control cultivars.

Information about the similarity among these selected plant genotypes of different species is significant for further progress to be made in developing high-Mg cultivars of other species as well as for the establishment of efficient screening method. In the present study, we observed distinct and consistent trend in Mg concentration, and Mg density among the high-Mg cultivars of different species. These common properties of high-Mg cultivars might be considered as good parameter for screening. Evaluation of Mg density by EDX is more efficient and less time consuming than Mg concentration. Individual plant needs not to grow separately in solution culture for evaluating Mg density by EDX. For this reason it is possible to evaluate a large number of plants by EDX within short time. While investigating Mg concentration, plants should grow separately, and require individual determination of dry weight and Mg uptake for each entry. Saiga et al.[20] reported that EDX of plant organ was effective when screening orchardgrass seedlings and young plants for reduced risk-potential of grass tetany.

Interrelationships of various mineral concentrations are important when selecting for altered mineral concentrations. Hannaway et al.[21] using solution culture found that increasing levels of K in solution decreased the shoot concentration of Mg. Correlations between Mg and K in tall fescue were generally low and nonsignificant.[6] In the present study, Mg and Ca densities of high-Mg cultivars were high while that of K was low (Fig. 1). This indicates that the accumulation of Mg and Ca in the shoot depressed the accumulation of K. Marschner[22] stated that cation such as K^+, which are rapidly transported across plasma membrane, may depress the uptake rate of Mg^+ and Ca^+. Unfortunately, the mechanism of Mg uptake and translocation are not fully understood, but the results of the present study gives some beneficial information for investigating the factors responsible for genetic variability of Mg concentration in the high-Mg cultivars of different species. According to Ohno and Grunes,[23] after Mg enters the plant roots, it must be translocated to plant shoot to be effective. Both K and Ca appear to restrict Mg translocation to plant shoots. The effect of Mg in decreasing the Ca concentration of the shoot was greater than that of K in decreasing the Ca concentration of the shoot. Barber[24] stated that the nutrient uptake is governed by the interplay of the nutrient supplying power of a soil with the nutrient demand exerted by the plant root. It may be necessary to evaluate the performance of the selected high-Mg cultivars under different nutrient levels for better understanding of interrelationships of nutrients.

The main objective of present study was to investigate the genotypic variability in the performance of high-Mg cultivars, which may provide information for screening forage plant individuals. In this study, the high-Mg cultivar of all species showed significantly higher Mg uptake per plant and Mg concentration. Other consistent properties among the observed characteristics of high-Mg cultivars of these three cool season grasses were high Mg and Ca densities while low K densities in the shoot. Genotypic differences in high-Mg cultivars of this experiment could be distinctly explained by differences in Mg concentration and Mg density. The reason of differences in mineral densities may be due to lower functional requirement of K per unit dry weight in high-Mg cultivars. These high-Mg cultivars also showed lower equivalent ratio, K/(Ca + Mg), which indicates reduced risk of potential for inducing grass tetany. By understanding the mechanism of Mg absorption by high-Mg cultivars, it may be possible to find out whether any genetic factor is responsible for high Mg concentration. For that purpose, importance of studying the mechanism of Mg uptake and translocation by high-Mg cultivars needed to be considered.

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