TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2014) 38: 488-494

doi:10.3906/tar-1306-83

Macronutrient concentration and remobilization in spring wheat organs during grain filling

Murat TİRYAKİOĞLU[1,*], Mehmet YILDIRIM[2], Sema KARANLIK[3]

[1]Department of Field Crops, Faculty of Agriculture, Mustafa Kemal University, Hatay, Turkey
[2]Department of Field Crops, Faculty of Agriculture, Dicle University, Diyarbakır, Turkey
[3]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Mustafa Kemal University, Hatay, Turkey

Received: 27.06.2013 • **Accepted:** 12.12.2013 • **Published Online:** 27.05.2014 • **Printed:** 26.06.2014

Abstract: This study was conducted with 4 bread wheat genotypes to determine the macronutrient content in different plant organs during the grain filling period. Macronutrient contents such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined in lower stems, peduncles, lower leaves, flag leaves, rachises, florets, and grains. High genotype effects were found for all macronutrients and plant organs. N, P, K, and Mg decreased during grain filling in all plant parts except the grain. The rate of decrease varied depending on plant organs and nutrients. Grain nutrient concentration, except nitrogen content, increased up to physiological maturity. In contrast to the other nutrients, Ca content increased or remained stable depending on the plant organs. The macronutrient remobilization order from plant organs to grain was Mg < P < N < K ≤ Ca, and all nutrients were accepted as removable at grain development stages. Remobilization models of macronutrients in grains can be valuable for detecting high-capacity plants for nutrient accumulation in stressful environments. Relationships among macronutrients and their relationships with plant organs can be used, by way of indirect selection, in wheat breeding efforts.

Key words: Bread wheat, grain growth, nutrients, translocation, plant parts

1. Introduction

The grain filling process in cereals, especially in wheat, is well documented on the dry matter basis. Nutrient distribution in plant parts and remobilization during grain filling needs more explanation; this can be related to grain yield, quality, and stress tolerance. Although nitrogen (N) distribution among plant parts has been intensely investigated in wheat, there is limited information about other macronutrients, such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Nitrogen uptake or accumulation in the grain was positively associated with grain yield of winter wheat (Le Gouis et al., 2000), and plant N content at both anthesis and maturity was related to grain yield in wheat (Umar and Iqbal, 2007). The distribution of nutrients in plant parts can be affected by genotype, environment, and their interactions. Nutrient concentration and uptake by different plant genotypes or species are the most important criteria used in recent years for identifying the existing genetic specificity of plant mineral nutrition (Saric, 1987). Nutrient concentration in plant organs changes with growth and development of the plant and decreases with increasing plant age. Normally, as a plant ages, nutrient concentrations expressed per unit dry weight decrease.

Environmental factors such as moisture supply, temperature, and light affect nutrient concentrations in plants. Some nutrients affect the absorption and utilization of other nutrients. It is important to measure nutrient interaction at the basis of growth response. When interaction is positive, the combined effects of the nutrients and total growth are greater than the sum of their individual effects. When interaction is negative, the combined effects are lower than individual effects.

Wheat, as a determinate plant, allocates photosynthetic products first to vegetative growth and spike and then later to grain (Brown, 1984). Nutrient uptake by wheat was reported as 125 kg ha^{-1} N, 22 kg ha^{-1} P, 92 kg ha^{-1} K, 16 kg ha^{-1} Ca, 14 kg ha^{-1} Mg, and 14 kg ha^{-1} S when 8 t of dry matter was produced (Munson, 1982). Grain-to-straw ratios of these nutrients are 1.5, 2.1, 0.15, 0.23, 1.8, and 0.55, respectively. The objective of this study was to determine macronutrient concentration and distribution in wheat during the grain filling period.

2. Material and methods

The study was conducted at the experimental farm of the Mustafa Kemal University Faculty of Agriculture in the 2008/2009 and 2009/2010 wheat growing seasons

* Correspondence: mtiryaki@mku.edu.tr

(Hatay, Turkey; 36°15′N, 36°30′E; 43 m altitude). Four bread wheat (*Triticum aestivum*) cultivars (Seri-82, Panda, Adana-99, and Genç-99) that have similar anthesis times and grain filling periods were used to study macronutrient concentration.

Meteorological data of the first and the second growing seasons with long-term average data are given in Figure 1. In the first growing season, the rainfall for 30 days before sowing was 71.6 mm and total rainfall from sowing to physiological maturity was 390 mm. During the grain filling period, 50 mm of rainfall was recorded (Figure 2). Soil physical and chemical properties of the experimental area are presented in Tables 1 and 2 for both growing seasons. According to soil analyses, total N and organic matter levels were low, while P_2O_5 level was high.

The experiments were designed according to randomized completed block design with 4 replications. Doses of 8 kg ha^{-1} pure P_2O_5 (with sowing) and 150 kg ha^{-1} N (as NH_4NO_3; 50 kg ha^{-1} N at sowing and 100 kg ha^{-1} N at tillering) were applied. Sowing was performed with a Hege-80 sowing machine at 450 m^2 seed density. Plot size was 7.2 m^2 (6 rows, 20 cm apart). Phenological development was observed from emergence to physiological maturity according to the Zadoks growth scale (ZGS) (Zadoks et al., 1974). In the second year, there had not been enough rainfall in the grain filling period, so it was irrigated (20 mm) at the beginning of the linear period (ZGS 75). Macronutrient analysis was performed on 100 main shoots of plants, which were labeled at anthesis and measured at ZGS 65, 72, 80 (86 for second year), and 89. Twenty labeled plant shoots were cut at soil level for each measurement time and separated into 7 different plant organs: lower stems, peduncles, lower leaves, flag leaves, rachises, florets, and grains. Plant organs were washed first with tap water, then later rinsed out with distilled water. Plant organs were dried at 70 °C for 48 h and then ground. Macronutrient analysis of the grains was performed on first- and second-order grains of spikelets found on the middle parts of spikes (Figures 3a and 3b). All plant parts were grilled before chemical analysis. Total nitrogen was defined by the micro-Kjeldahl method. The P, K, Ca, and Mg concentrations in plant parts were determined by an inductively coupled plasma emission spectrometer. The data for each year were separately analyzed by analysis of variance using SPSS 16.

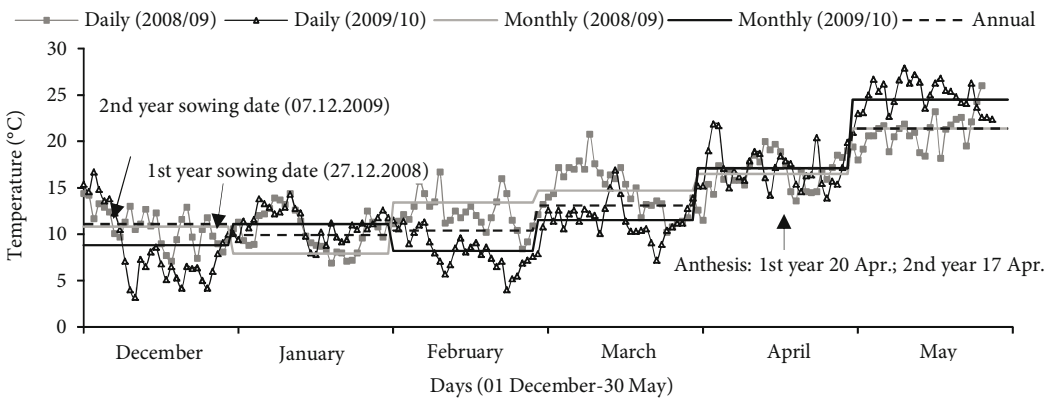

Figure 1. Daily, monthly, and annual long-term average temperatures at sowing (30 days before sowing) and physiological maturity during the 2008/09 and 2009/10 growing seasons in Antakya, Turkey.

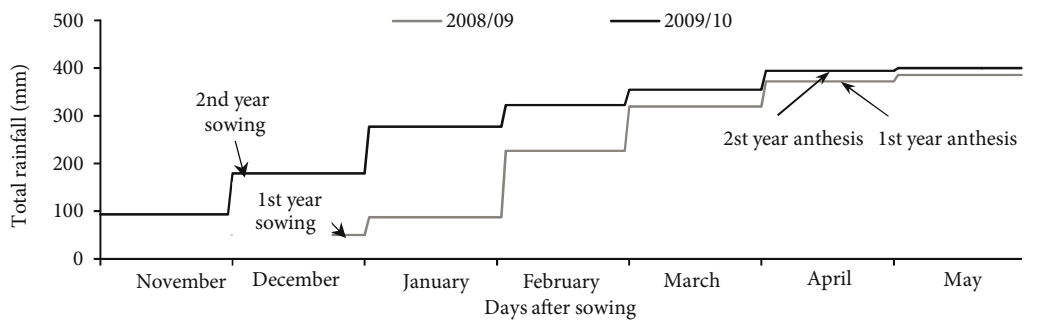

Figure 2. Rainfall between sowing (30 days before sowing) and physiological maturity during 2008/09 and 2009/10 growing seasons in Antakya, Turkey.

Table 1. Soil physical and chemical properties of experimental areas in 2008/09 and 2009/10.

Growth seasons	Volume weight	Clay	Silt	Sand	*CEP	$Ca^{++} + Mg^{++}$	K	Na	P	N	Organic matter
	($g\ cm^{-3}$)	(%)			(mEq/100 g)				($kg\ ha^{-1}$)		(%)
2008/09	1.30	56.3	21.7	24.4	42.3	40.2	0.64	1.52	46.6	3.7	1.17
2009/10	1.26	44.6	33.6	22.2	40.3	--	--	--	43.7	3.2	1.12

*: Cation exchange capacity.

Table 2. Soil clay, pH, and salt analysis values in first year experiment.

Soil level (cm)	$CaCO_3$ (%)	pH	Salt (%)
0–10	26.54	7.49	0.07
10–30	26.96	7.63	0.06
30–60	27.80	7.65	0.06
60–90	26.96	7.64	0.07

3. Results

Nitrogen content decreased continuously during the grain filling period for 6 plant organs, excluding the grain (Figure 4). A distinct decrease at the slope of the curve after ZGS 72 showed an acceleration in the rate of N remobilization among plant organs at the end of grain filling. The stability of N content at the grain also proved that nitrogen accumulation continued simultaneously with dry matter accumulation. The highest N content throughout all measuring times was found at the lower leaves and flag leaves, while the lowest N level was detected at the lower stems and peduncles.

P content of all plant organs, except the grain, decreased significantly throughout the measuring stages over 2 years, but the rate of decrease was very slow for lower stems in the second year (Figure 5). Grain P content showed an increase at the late grain filling period in both years. Genotypes showed similar curves for P changes.

K content after anthesis decreased gradually towards the end of the grain filling period for lower stems and leaves, flag leaves, and florets in both years (Figure 6).

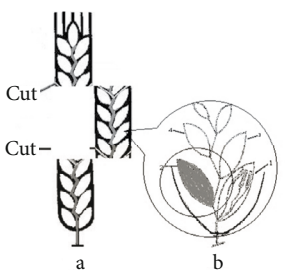

Figure 3. Grain: analyzed part of spike (a) and spikelet (b).

Grain K content increased significantly until grain maturity and final K ratios were similar for both years, although preliminary K content of the first year was 64% lower than that of the second year. Genotypic behavior for K accumulation or movement was similar for all investigated plant organs. The highest decrease from anthesis to grain maturity among plant organs was observed in stems, with the rates of 75% and 62% for the first and second years, respectively.

Ca content decreased slightly from anthesis onwards in lower stems and peduncles, while a constant satiation was observed in lower and flag leaves (Figure 7). However, Ca content in florets and rachises increased significantly from ZGS 72 to grain maturity. Ca concentrations in grains declined from ZGS 73 to ZGS 80–86 and later accumulation increased at grain maturity. Ca content in peduncles, flag leaves, and grains increased or decreased depending on genotypes during the grain filling period. Grain Ca content decreased between ZGS 72 and ZGS 80 or 86 for both years. Plant leaves had the highest Ca content among plant parts.

The curve of Mg content differed for each plant organ and sampling time, as well as for genotypic differences (Figure 8). Mg content decreased continuously for lower stems and peduncles, and the rate of decrease was very high between ZGS 65 and ZGS 72 in peduncles. The decrease of Mg content was very low for lower leaves; genotypic differences among flag leaves genotypic were also present. Both Mg content decreases and increases in florets were observed together with genotypic variations. Mg content at rachises rapidly increased between ZGS 65 and 72, then later decreased at the same rate between ZGS 72 and ZGS 80–86 and continued to decrease at a slow rate until ZGS 89. Mg content in grains increased until grain maturity, though with genotypic differences.

Final macroelement contents of grains were 2.55%, 0.25%, 0.16%, 0.13%, and 0.05% for N, P, K, Mg, and Ca, respectively (data not shown). Apart from the grain weight, the highest means of dry matter over 2 years were generally obtained at ZGS 72 for all organs. The content of macroelements dropped between ZGS 72 and maturity for most of the plant organs, apart from the grain weight. The exceptions to this decrease were peduncles and rachises

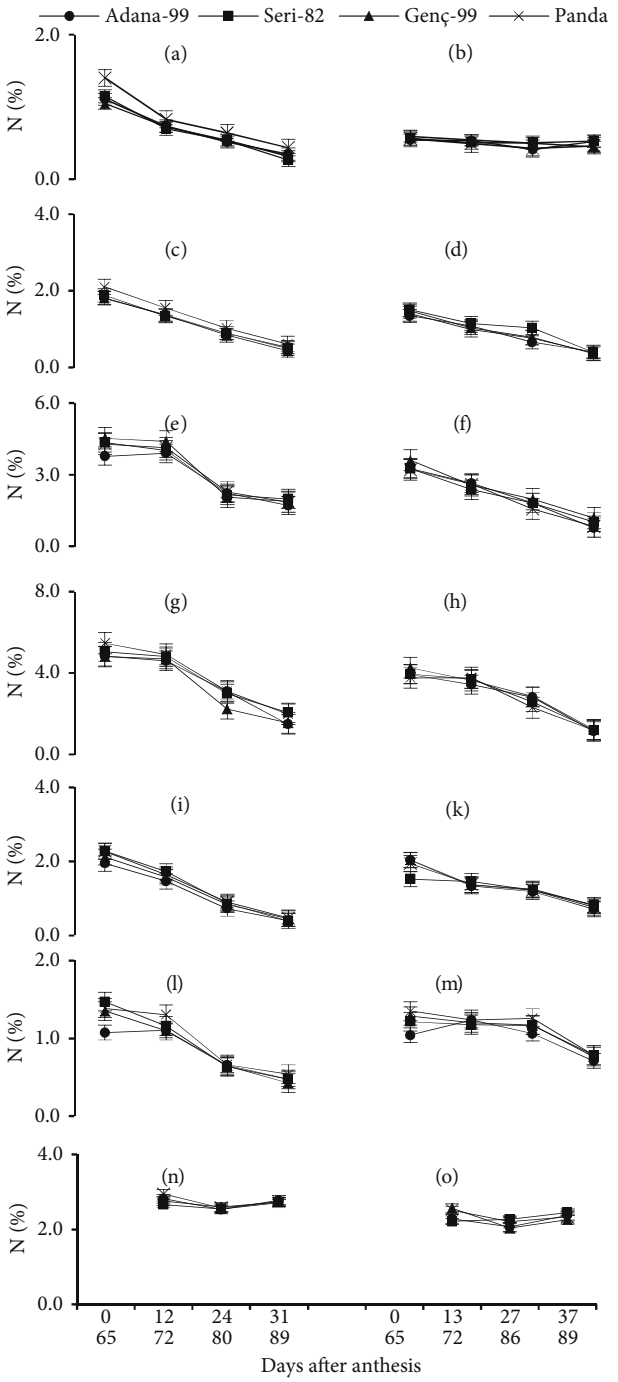

Figure 4. Changes in N content measured in different plant organs (a–b: lower stems, c–d: peduncle, e–f: lower leaves, g–h: flag leaf, i–j: rachis, k–l: florets, and m–n: grain) from anthesis to grain maturity for wheat genotypes in 2009 (left figures) and 2010 (right figures).

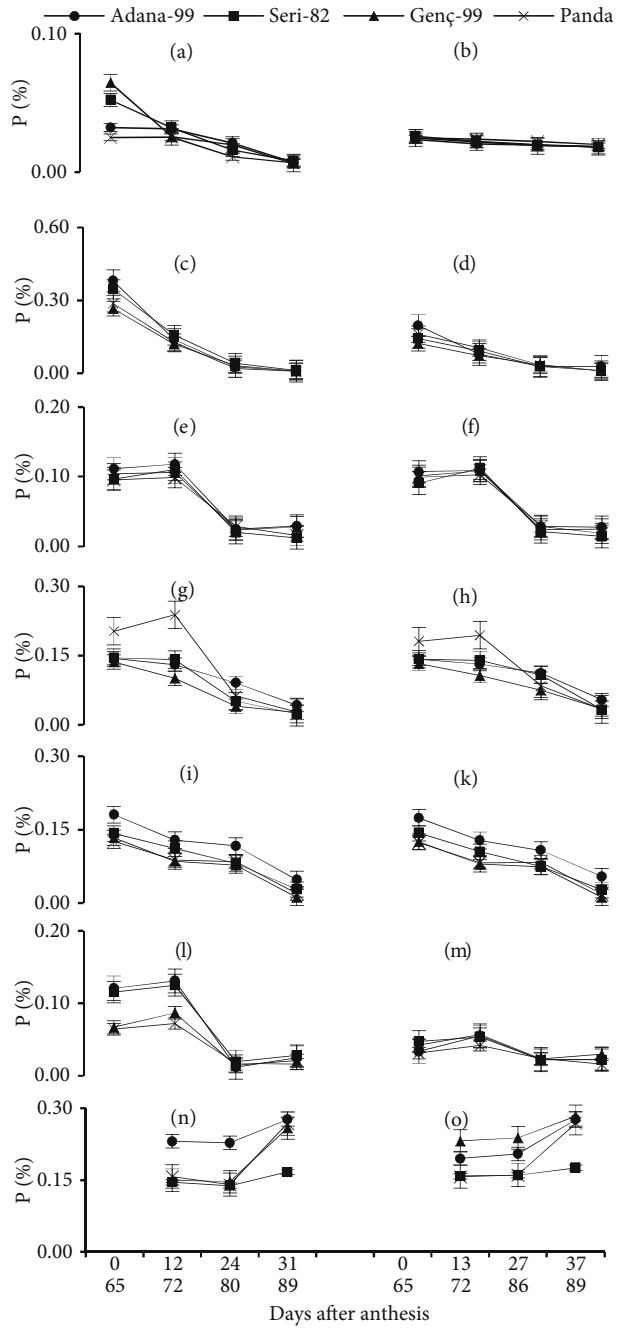

Figure 5. Changes in P content measured in different plant organs (a–b: lower stems, c–d: peduncle, e–f: lower leaves, g–h: flag leaf, i–j: rachis, k–l: florets, and m–n: grain) from anthesis to grain maturity for wheat genotypes in 2009 (left figures) and 2010 (right figures).

for K and peduncles, florets, and rachises for Ca. Genotype Seri-82 had the highest P, K, Ca, and Mg remobilization capacity from plant organs to grain, while Panda had the highest N remobilization (data not shown). However, the grain macronutrient content of Seri-82 was lower than that of the other genotypes. The correlation coefficient between final grain macronutrient contents and remobilization rate was significantly negative.

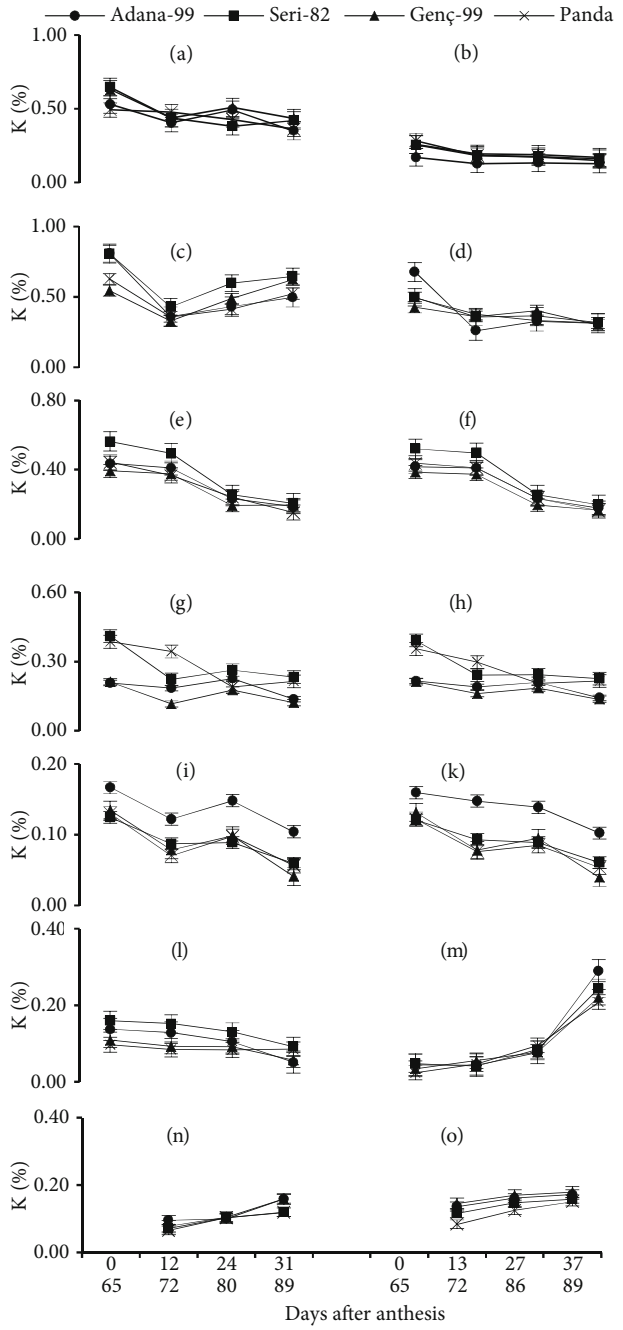

Figure 6. Changes in K content measured in different plant organs (a–b: lower stems, c–d: peduncle, e–f: lower leaves, g–h: flag leaf, i–j: rachis, k–l: florets, and m–n: grain) from anthesis to grain maturity for wheat genotypes in 2009 (left figures) and 2010 (right figures).

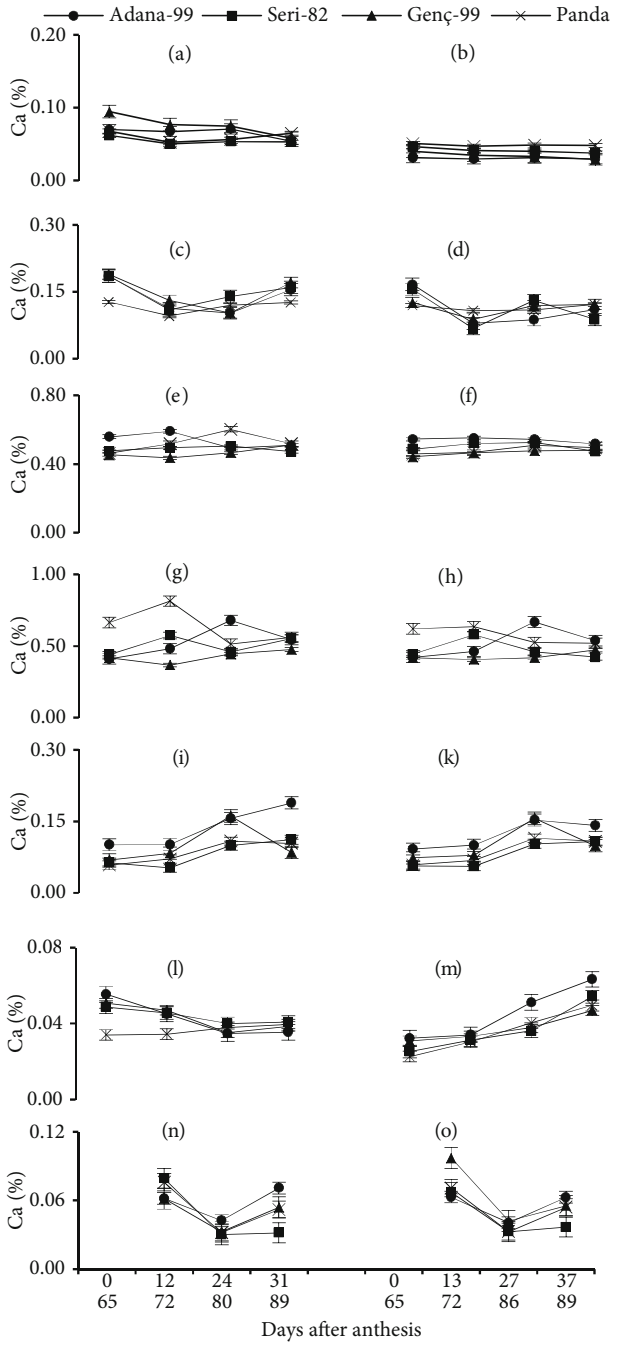

Figure 7. Changes in Ca content measured in different plant organs (a–b: lower stems, c–d: peduncle, e–f: lower leaves, g–h: flag leaf, i–j: rachis, k–l: florets, and m–n: grain) from anthesis to grain maturity for wheat genotypes in 2009 (left figures) and 2010 (right figures).

4. Discussion

Nutrient concentrations in plants are affected by several factors, including species, cultivar, plant age, interaction with other nutrients, and environmental factors such as moisture supply and humidity. According to our results, year, genotype, and plant stage played significant roles in the macronutrient content of bread wheat genotypes. The effects of the other factors were different in different plant organs and with different remobilization capacities.

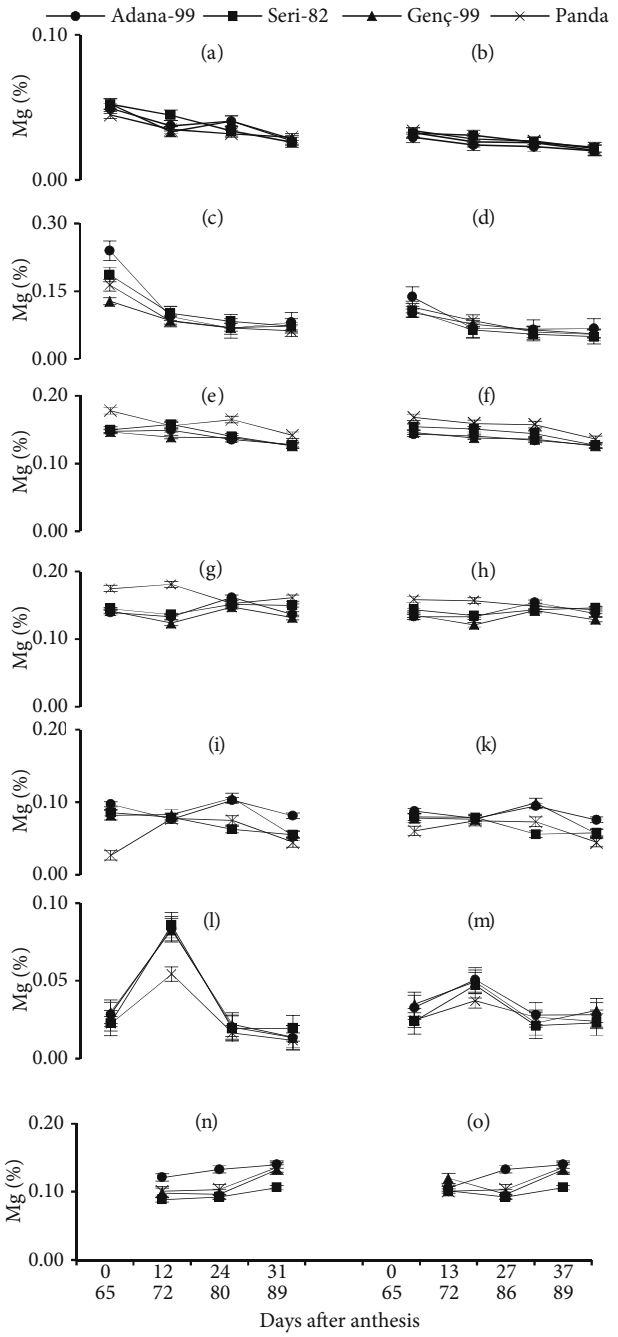

Figure 8. Changes in Mg content measured in different plant organs (a–b: lower stems, c–d: peduncle, e–f: lower leaves, g–h: flag leaf, i–j: rachis, k–l: florets, and m–n: grain) from anthesis to grain maturity for wheat genotypes in 2009 (left figures) and 2010 (right figures).

The rate of genotypic effects in total variation changed among macroelements and plant organs (data not shown). Genotypic effects for grain were 4%, 25%, 16%, 7%, and 21% for the macroelements of N, P, K, Ca, and Mg, respectively. Genotypic effects were reported as 7% and 21% for Ca and Mg, respectively (Saric, 1987). The same calculations for flag leaf were 20%, 9%, 43%, 12%, and 30% for N, P, K, Ca, and Mg, respectively. However, the reports of Saric (1987) for leaves were 9%, 6%, 18%, 16%, and 57% for the same elements. During grain filling, N content of nongrain tissue generally decreased while grain N content increased. Similar results were reported by Fageria (2004). Decreases in leaf and stem macronutrient content after flowering were not generally related to remobilization of macronutrients from the leaves and stem to the spike from flowering to maturity, because the total decrease was higher than the increase at the spike. Concentrations of macronutrients in most organs of wheat plants decreased with increasing plant age, except the grain (Figures 4–8). This may occur with increasing plant age, since the production of dry matter dilutes the concentration of accumulated nutrients (Fageria, 2009). The decrease was faster for N and P (Figures 4 and 5). This is supported by the findings of Maier et al. (2002), who demonstrated that mobile nutrients such as N, P, and K usually show a decline in concentration with the advancement of plant age in potato.

Soil moisture has an important role in the movement of nutrients to roots and to other plant parts. Although the temperature in the second year of the study was warmer and rainfall was lower than in the first year, this stress was eliminated by supplementary irrigation during the grain filling period. Hence, the macronutrient concentration was generally similar throughout the grain filling, except in lower shoots. However, most of the macronutrients had higher concentrations at anthesis in the first year than the second year, but this was compensated until grain maturity in both years. N, P, and K concentrations of leaves at anthesis were 41.5, 1.2, and 3.73 g kg^{-1}, respectively (data not shown). These values were high for N, adequate for P, and deficient for K according to approximate nutrient concentrations predicted by Reuter (1986) for wheat leaf. The P and Mg concentrations in flag leaves (0.3 and 1.5 g kg^{-1}, respectively) and grains (2.5 and 1.3 g kg^{-1}, respectively) measured at maturity confirm the findings of Merah's (2001) work with durum wheat, while our K concentration was much lower in leaves and grains (1.8 and 1.5 g kg^{-1}, respectively) than Merah's values. Final grain nutrient rates in total plant nutrients were similar for N, but at least 2 times higher than in the report of Fageria (1990). Grains had over 65% of the N, P, and Mg content of the whole plant, as well as 23%–37% of Ca and K content. These results were similar with the finding of Hocking (1994) for N and P, and higher than those for K, Ca, and Mg.

The remobilization rate to grain from ZGS 72 to maturity was 65.2%, 39.8%, 100.0%, 100.0%, and 38.9% for N, P, K, Ca, and Mg, respectively. Based on these results,

all macronutrients would be accepted as phloem-mobile. K and Ca seemed to be more mobile than the others. Our N-remobilization rate was at the lower limits of the reports of Smith and Whitfield (1990) and Palta and Fillery (1995). Efficiency of macronutrient remobilization is an important mechanism for increasing grain yield, grain N content, and quality. Additionally, total N, P, and Mg concentrations in plants showed an increase from ZGS 72 to grain maturity. These increases may be more valuable when emphasized as cultivar-based. Umar and Iqbal (2007) reported significant differences among wheat genotypes in N losses and gains from anthesis to maturity; the genotypes that had high N accumulation after anthesis had high harvest indexes and N-use efficiency. Significant relations among micronutrients may be valuable tools when direct selection for any high nutrient concentration is difficult due to high genotype × environment interactions (Oury et al., 2006). In this case, if efforts are focused on the nutrient that has low genotype × environment interactions, indirect selection success for the other nutrients can be obtained. Significant relations among the P and K and Mg contents of grain can be manipulated by wheat breeders for different aims, like nutritional quality, yield relations, and healthy plant development.

Nutrient concentrations in all plant parts of wheat decreased during grain filling, except for Ca content. The capacity of wheat to redistribute nutrients to the grain will be a critical trait when nutrient uptake is severely restricted by biotic stress in the grain filling period. In the current study, the genotypes that have high remobilization capacities can be evaluated in breeding programs as genitor sources. Information about nutrient concentration at grain filling would be important for improving yield and micronutrient concentrations.

References

Brown RH (1984). Growth of the green plant. In: Tesar MB, editor. Physiological Basis of Crop Growth and Development. Madison, WI, USA: ASA and CSSA, pp. 153–174.

Fageria NK (1990). Response of wheat to phosphorus fertilization on an Oxisol. Pesqui Agropecu Bras 25: 530–537.

Fageria NK (2004). Dry matter yield and shoot nutrient concentrations of upland rice, common bean, corn, and soybean in rotation on an Oxisol. Commun Soil Sci Plan 35: 961–974.

Fageria NK (2009). The use of nutrients in crop plants. Cereal Res Commun 37: 149–150.

Hocking PJ (1994). Dry-matter production, mineral nutrient concentrations, and nutrient distribution and redistribution in irrigated spring wheat. J Plant Nutr 17: 1289–1308.

Le Gouis J, Beghin D, Heumez E, Pluchard P (2000). Genetic differences for nitrogen uptake and nitrogen utilization efficiencies in winter wheat. Eur J Agron 12: 163–173.

Maier NA, McLaughlin MJ, Heap M, Butt M, Smart MK (2002). Effect of current season application of calcitic lime and phosphorus fertilization on potato tuber phosphorus concentration and leaf chemical composition. Commun Soil Sci Plan 33: 2167–2188.

Merah O (2001). Carbon isotope discrimination and mineral composition of three organs in durum wheat genotypes grown under Mediterranean conditions. Life Sci 324: 355–363.

Munson RD (1982). Potassium, Calcium, and Magnesium in the Tropics and Subtropics. Technical Bulletin T-23. Muscle Shoals, TN, USA: International Fertilizer Development Center.

Oury FX, Leenhardt F, Remesy C, Chanliaud E, Duperrier B, Balfourier F, Charmet G (2006). Genetic variability and stability of grain magnesium, zinc and iron concentrations in bread wheat. Eur J Agron 25: 177–185.

Palta JA, Fillery IRP (1995). Nitrogen application enhances remobilization and reduces losses of preanthesis N in wheat grown on a duplex soil. Aust J Agr Res 46: 519–531.

Reuter DJ (1986). Temperate and sub-tropical crops. In: Reuter DJ, Robinson JB, editors. Plant Analysis: An Interpretation Manual. Melbourne, Australia: Inkata Press, pp. 38–99.

Saric MR (1987). Progress since the first international symposium: "Genetic aspects of plant mineral nutrition", Beograd, 1982, and perspectives of future research. Plant Soil 99: 197–209.

Smith CJ, Whitfield DM (1990). Nitrogen accumulation and redistribution of late applications of ^{15}N-labelled fertilizer by wheat. Field Crop Res 24: 211–226.

Umar AS, Iqbal M (2007). Identification of characteristics affecting nitrogen utilization efficiencies in wheat cultivars. Arch Aceker Pfl Boden 53: 459–472.

Zadoks JC, Chang TT, Konzak CF (1974). A decimal code for the growth stages of cereals. Weed Res 14: 415–412.