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**ORIGINAL PAPER**

# THE CONTENT OF CALCIUM AND MAGNESIUM AND THE Ca:Mg RATIO IN CULTIVATED PLANTS IN THE CONTEXT OF HUMAN AND ANIMAL DEMAND FOR NUTRIENTS*

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Abstract

Relationships between elements in biomass of plants which make up a food chain are related to the physiological role of each element. These relationships can be disturbed by different factors, particularly those related to the availability of individual elements to plants. Adverse effects of distorted relationships between the calcium and magnesium concentrations in biomass, which are caused by the low content of the two elements in soil and intensive fertilisation, mainly the application of nitrogen fertilisers, can manifest themselves as the occurrence of different human and animal diseases. The purpose of the study was to determine the Ca and Mg abundance in cereal grain (rye, wheat, oats, barley, maize), potatoes and staple vegetables, and in plants which are mainly used as animal feed (grasses, lucerne, clover, beet), in the aspect of human and animal nutrient demand, particularly in terms of the Ca:Mg ratio. The grain of cereal plants, which is the main ingredient of many food products, was found to be poor in Ca and Mg; moreover, the Mg content was higher than that of Ca, i.e. the Ca:Mg ratio was lower than 1, with the exception of maize, in which the Ca:Mg ratio was higher than 1. The plants used as feed were richer in the analysed elements; nevertheless, according to the literature data, their Ca and Mg content in a unit of weight does not meet the animals' demand for these components. The average content of both elements in average yields of different plant species cultivated on fertile soils established the Ca:Mg ratio at 1.1, whereas in plant yields from poor soils this ratio is 1.7.

**Keywords:** agricultural products, nitrogen, calcium, magnesium, Ca:Mg ratio, accumulation, relationships.

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## INTRODUCTION

Along with plant biomass, an ion flux enters the food chain. Each element has a specific share in this flux, resulting from its physiological role in the structure of biomass, and this is expressed in specific relationships among the elements. The disturbance of these relationships in the first link of a food chain, which can be caused by the factors influencing biomass production, mainly the availability of individual elements to plants, may be and is transferred to successive links of the chain.

The adverse effects of disturbed relationships between elements can be seen in the functioning of ecosystems and also individual organisms, including the occurrence of human and animal diseases (Durlach 1989, Ford, Mokdad 2003, Tam et al. 2003, Fanin et al. 2013, Ott et al. 2014, Van de Wall et al. 2014, Létourneau-Montminy et al. 2014, Rosanoff et al. 2015). For example, it has been found that an increasing N content in the aqueous environment and the related disturbed relationship between N and other elements cause the production of toxins by phytoplankton (Van de Wall et al. 2014) and distort the functioning of soil organisms (Mulder, Elser 2009). According to Xia and Wan (2008), the N content in the environment has increased by about 50% in recent years as a result of fertilisation and deposition. Many human and animal diseases are caused by inadequate relationships between Ca and Mg in food, which result from a deficit/surplus of one element with respect to the other. According to Durlach (1989), the Ca:Mg ratio in food recommended by nutrition specialists is 2. The human requirement for Ca and Mg is mainly related to age and gender, while the animal requirement depends on weight.

In order to maintain adequate relationships between elements in food, mineral compounds of Ca and/or Mg are supplemented, in particular in animal feed (Grunes, Welch 1989, Villegas et al. 2009, Schonewille 2013, Kleczkowski et al. 2014). With respect to humans, Mg is more frequently supplemented. According to Rosanoff (2013), Mg content in plant decreases with increasing yield stimulated by both intensification of agricultural production and use of high-yield cultivars. Some authors claim that elements contained in natural food products are more available than supplemented ones, whereas those supplemented as mineral compounds are available depending on the properties of the compound and an organism (Villegas et al. 2009).

Our earlier research indicated that the relationships among elements were more diversified within a given species than between species. The main cause of the disturbance was an excess of N in the environment with respect to other elements (Ostrowska, Porębska 2002, 2009). The aim of this study was to determine the Ca and Mg content in different crop plant species, which are basic sources of food and feed, in the aspect of human and animal nutrient requirement, particularly in terms of the Ca:Mg ratio and the effect of N accumulation on the accumulation of Ca and Mg.

## MATERIAL AND METHODS

This paper is based on the results of nutrient content in plants cultivated in Poland (Czuba 1976-1981, unpublished data). At that time, extensive research concerning the effect of the soil quality and fertilisation on crop yields was carried out at the Institute of Soil Science and Plant Cultivation. The study on plant chemistry was conducted in over 600 farms in various regions of Poland, the farms being representative of a given region. The farms varied in soil quality and climatic conditions while the fertilisation level was fairly similar. Aerial parts of plants were harvested at full maturity or as green mass and the mineral composition of dry mass was determined by the standard methods.

In the present work, the content of N, Ca and Mg in grain and aerial parts of cereals (rye, wheat, oats, barley, maize), potato tubers, staple vegetables and plants directly used as animal feed (grasses, lucerne, clover, beet) from about 200 farms located in northern, southern, western and central parts of Poland were considered. We also took into consideration other studies on these elements (Ostrowska, Porębska 2002).

In the plants listed above, the N, Ca and Mg mean content and the mutual relationships were calculated. Additionally, examples of plants from the individual farms with the maximum and minimum N content were selected. The effect of the N content on Ca and Mg accumulation in plants was determined.

Subsequently, taking into account the fact that food/feed consumed is mostly a mixture of different products, the average Ca and Mg content in different plant species cultivated in rotation on fertile and poor soils was assessed. The results were considered in terms of human/animal nutrient requirement, mainly with respect to the relationships between Ca and Mg.

## RESULTS AND DISCUSSION

The Ca content in cereal grain (rye, wheat, oats, barley, maize) both in selected several farms and as its average value from many farms are mostly lower than 1 g $kg^{-1}$, except for maize grain where it varies between 2 and 4 g $kg^{-1}$. In turn, in most cases, the Mg content is higher than 1 g $kg^{-1}$. Thus, the Ca:Mg ratio is less than 1, except for maize grain where it varies between 1.3 and 3.4 (Table 1).

The analysis of the relationships between the N content and the Ca and Mg content in the plants showed low correlation coefficients: 0.22 and 0.21 ($P < 0.05$), respectively. At the same time, higher Ca values were found in cereal grain and potato tubers with the lowest N content, except for wheat grain, than in the case where the N content was high; thus, the Ca:Mg ratios for the low N content were higher than for its high content (Table 2).

Table 1

The mean content of N, Ca and Mg in the selected crop plant species (g $kg^{-1}$ d.m.) growing in various regions in Poland and in individual farms, and the ratios between the elements (the coefficient of variation is given in brackets) (elaborated on the basis of Czuba unpublished data and Ostrowska and Porębska 2002, 2009)

| Sample | N | Ca | Mg | N/Ca | N/Mg | Ca/Mg |
|---|---|---|---|---|---|---|
| Rye, grain, *n* = 215* | 16.4 (10) | 0.7 (50) | 1.2 (50) | 23.4 | 13.7 | 0.6 |
| Rye, grain + straw, *n* = 215* | 10.2 | 1.6 | 1.0 | 6.4 | 10.2 | 1.6 |
| Rye, grain, individual farms | 14.1 | 0.5 | 0.9 | 28.2 | 15.7 | 0.6 |
| | 15.7 | 0.7 | 1.1 | 22.4 | 14.3 | 0.6 |
| | 16.0 | 0.6 | 1.0 | 26.7 | 16.0 | 0.6 |
| | 19.8 | 0.6 | 1.4 | 33.0 | 14.1 | 0.4 |
| | 14.4 | 0.8 | 1.3 | 18.0 | 11.1 | 0.6 |
| | 14.7 | 0.5 | 1.1 | 29.4 | 13.4 | 0.5 |
| | 14.5 | 0.7 | 0.9 | 20.7 | 11.1 | 0.8 |
| Oat, grain, *n* = 92* | 19.1 (11) | 0.10 (50) | 0.14 (30) | 19.1 | 13.6 | 0.7 |
| Oat, grain + straw, *n* = 92* | 12.1 | 2.2 | 1.0 | 5.5 | 12.1 | 2.2 |
| Oat, grain, individual farms | 17.3 | 1.0 | 1.8 | 17.3 | 9.6 | 0.6 |
| | 18.7 | 0.9 | 1.3 | 20.8 | 14.4 | 0.7 |
| | 16.8 | 0.9 | 0.9 | 18.7 | 18.7 | 1.0 |
| | 21.2 | 1.1 | 1.4 | 19.3 | 15.1 | 0.8 |
| | 22.7 | 1.0 | 1.3 | 22.7 | 17.5 | 0.8 |
| | 18.5 | 1.0 | 1.3 | 18.5 | 14.2 | 0.8 |
| Wheat, grain, *n* = 236* | 19.8 (22) | 0.7 (34) | 1.3 (44) | 28.3 | 15.2 | 0.5 |
| Wheat, grain + straw, *n* = 236* | 12.6 | 1.7 | 1.2 | 7.4 | 10.5 | 1.4 |
| Wheat, grain, individual farms | 19.7 | 0.6 | 1.3 | 32.8 | 15.2 | 0.5 |
| | 20.1 | 0.6 | 1.3 | 33.5 | 15.5 | 0.5 |
| | 30.9 | 0.7 | 1.2 | 44.1 | 25.8 | 0.6 |
| | 18.8 | 0.7 | 1.2 | 26.9 | 15.7 | 0.6 |
| | 20.1 | 0.8 | 2.3 | 25.1 | 8.7 | 0.3 |
| | 22.3 | 0.8 | 1.2 | 27.9 | 18.6 | 0.7 |
| | 37.0 | 0.7 | 1.2 | 52.9 | 30.8 | 0.6 |
| Barley, grain, *n* = 222* | 18.6 (10) | 0.7 (50) | 1.2 (50) | 26.6 | 15.5 | 0.6 |
| Barley, grain + straw, *n* = 222* | 10.2 | 2.4 | 1.3 | 4.3 | 7.8 | 1.8 |
| Barley, grain, individual farms | 17.0 | 0.5 | 1.1 | 34.0 | 15.5 | 0.5 |
| | 19.1 | 0.7 | 1.4 | 27.3 | 13.6 | 0.5 |
| | 19.1 | 0.5 | 1.2 | 38.2 | 15.9 | 0.4 |
| | 18.3 | 0.7 | 1.5 | 26.1 | 12.2 | 0.5 |
| | 23.6 | 0.9 | 1.5 | 26.2 | 15.7 | 0.6 |
| | 17.9 | 0.7 | 1.2 | 25.6 | 14.9 | 0.6 |
| | 15.0 | 1.9 | 1.1 | 7.9 | 13.6 | 1.7 |
| Maize, grain, *n* = 47* | 18.7 (16) | 2.9 (50) | 1.7 (30) | 6.4 | 11.0 | 1.7 |
| Maize, grain, individual farms | 14.9 | 2.3 | 1.8 | 6.5 | 8.3 | 1.3 |
| | 15.6 | 2.9 | 1.3 | 5.4 | 12.0 | 2.2 |
| | 13.6 | 3.1 | 1.4 | 4.4 | 9.7 | 2.2 |
| | 15.9 | 4.1 | 1.2 | 3.9 | 13.3 | 3.4 |
| Rape, grain, *n* = 38* | 33.2 | 3.4 | 3.3 | 9.8 | 10.1 | 1.0 |
| Fodder beet, leaves + roots, *n* = 95* | 18.1 (26) | 5.6 (50) | 2.6 (50) | 3.2 | 6.9 | 2.2 |
| Potatoes (tuber), *n* = 290* | 14.7 | 1.0 | 0.8 | 14.7 | 18.4 | 1.3 |
| Grass, hay, *n* = 199* | 22.1 (26) | 6.1 (46) | 2.1 (38) | 3.6 | 10.5 | 2.9 |
| Lucerne, green mass, *n* = 31* | 31.8 | 13.9 | 2.7 | 2.3 | 11.8 | 5.0 |
| Clover, green mass, *n* = 85* | 24.8 | 12.2 | 2.7 | 2.0 | 9.2 | 4.5 |
| Pasture, green mass, *n* = 159* | 24.2 | 6.4 | 2.5 | 3.8 | 9.7 | 2.6 |
| Maize, green mass, *n* = 32* | 20.6 | 5.1 | 1.9 | 4.0 | 10.8 | 2.7 |
| Cabbage | n.d. | 31.7 | 2.8 | n.d. | n.d. | 11.3 |
| Tomatoes | n.d. | 1.5 | 1.4 | n.d. | n.d. | 1.1 |
| Pepper | n.d. | 2.0 | 2.0 | n.d. | n.d. | 1.0 |
| Carrot | n.d. | 3.4 | 1.8 | n.d. | n.d. | 1.9 |
| Pea, grain | n.d. | 7.7 | 5.4 | n.d. | n.d. | 1.4 |

n.d. – not detected; * mean from various regions of Poland

Table 2

The effect of the N content* on the Ca and Mg (g kg$^{-1}$ d.m.) and their relationships in different plant species (elaborated on the basis of Czuba unpublished data and Ostrowska and Porębska 2002)

| Plant | N | Ca | Mg | N:Ca | N:Mg | Ca:Mg |
|---|---|---|---|---|---|---|
| | (g kg$^{-1}$ d.m.) | | | | | |
| Rye, grain | 11.0 | 1.9 | 1.0 | 5.8 | 11.0 | 1.9 |
| | 22.4 | 0.2 | 1.6 | 112 | 14.0 | 0.1 |
| Oat, grain | 15.2 | 1.6 | 1.4 | 9.5 | 10.9 | 1.1 |
| | 23.8 | 1.0 | 1.4 | 23.8 | 17.0 | 0.7 |
| Wheat, grain | 18.8 | 0.7 | 1.2 | 26.9 | 15.7 | 0.6 |
| | 37.0 | 0.7 | 1.2 | 52.9 | 30.8 | 0.6 |
| Barley, grain | 15.0 | 1.9 | 1.1 | 7.9 | 13.6 | 1.7 |
| | 23.6 | 0.9 | 1.5 | 26.2 | 15.7 | 0.6 |
| Potatoes, tuber | 12.9 | 0.9 | 1.1 | 14.3 | 11.7 | 0.8 |
| | 21.2 | 0.3 | 0.4 | 70.7 | 53.0 | 0.8 |

* results selected from all data with minimum and maximum N content

An effect of N on the Mg accumulation was also found, but it was less strong than for Ca (Table 2). It can be added that the Ca and Mg content in the grain from the selected farms varied about the average value from many farms (Table 1).

In the plants used directly as animal feed, the Ca and Mg concentrations were much higher than in cereal grain, while the Ca:Mg ratios varied from 2.6 to 5.0 (Table 1).

During the growth and development of plants, the accumulated elements are diluted in the biomass produced and translocated between the individual parts. In wheat, the N content decreased by 60%, that of Ca by 43% and that of Mg by 21% between the tillering and stem elongation stages, while at the subsequent stages it was mainly the Ca content that decreased. At the full maturity stage, there was distinct retranslocation of the elements. The N in grain remained at a similar level from the stem elongation stage and decreased in straw by about 50% relative to its content in grain. Compared with the tillering stage, the Ca and Mg content in wheat grain was lower by factors of seven and two, respectively (Table 3).

Between the tillering stage and full maturity of barley, the N content in the whole plant decreased by about, 40%, that of Ca by about 18% and that of Mg by 25%. After the retranslocation of the elements, the Ca content in the grain decreased by about 80% compared to its content in the whole plant, whereas the Mg content remained at approximately the same level as in that in the earlier growth stages (Table 3). During the growth and development of wheat and barley plants, the Mg content was lower than that of the Ca con-

Table 3

The N, Ca and Mg content in wheat and barley and the relationships between the elements depending on the development stage of the plant (elaborated on the basis of Ostrowska and Porębska 2002)

| Plant/development stage | N | Ca | Mg | N:Ca | N:Mg | Ca:Mg |
|---|---|---|---|---|---|---|
| | g kg$^{-1}$ d.m. | | | | | |
| Wheat tillering | 53.4 | 3.7 | 1.9 | 14.4 | 28.1 | 1.9 |
| stem elongation | 21.6 | 2.1 | 1.5 | 10.3 | 14.4 | 1.4 |
| booting | 21.0 | 1.5 | 1.4 | 14.0 | 15.0 | 1.1 |
| grain | 20.7 | 0.5 | 0.8 | 41.4 | 25.9 | 0.6 |
| straw | 11.0 | 4.3 | 1.3 | 2.6 | 8.5 | 3.3 |
| Barley tillering | 24.6 | 4.0 | 1.6 | 6.2 | 15.4 | 2.5 |
| stem elongation | 15.6 | 3.3 | 1.2 | 4.7 | 13.0 | 2.8 |
| full maturity aboveground parts | 14.3 | 3.3 | 1.2 | 4.3 | 11.9 | 2.8 |
| grain | 19.7 | 0.7 | 1.3 | 28.1 | 15.2 | 0.5 |
| straw | 9.0 | 5.1 | 0.9 | 1.8 | 10.0 | 5.7 |

tent and therefore the Ca:Mg ratios were higher than 1, whereas an inverse proportion was found in their grain.

The food consumed and the feed applied in so-called daily doses constitute a mixture of different products, with different Ca and Mg content and different mutual relationships. The average content of both elements in average yields of different plant species cultivated on fertile soils establish the Ca:Mg ratio of 1.1, whereas in the plant yields from poor soils this ratio is 1.7 (Table 4). The N:Ca ratios in yields from poor and rich soils are similar, whereas the N:Mg ratio in yields from poor soils is almost twice as high as in yields from rich soils. The relationships between the elements indicate that yields of plants are poor in Ca and Mg in relation to the N content. This is connected with the acidification of arable soils and mineral fertilisation, without Ca and Mg (GUS 2015). Rosanoff (2013) stated that the intensification of agricultural production caused a decrease of Mg content in cereal

Table 4

The average amounts of the elements in the yields (dry mass) of different plant species cultivated in rotation on soils of high and low fertility (elaborated on the basis of Czuba unpublished data and Ostrowska and Porębska 2002)

| Fertility | Crop | N | Ca | Mg | N:Ca | N:Mg | Ca:Mg |
|---|---|---|---|---|---|---|---|
| | (t ha$^{-1}$ yr$^{-1}$) | (kg ha$^{-1}$ yr$^{-1}$) | | | | | |
| High* | 9.7 | 171 | 34 | 31 | 5.0 | 5.5 | 1.1 |
| Low** | 6.4 | 89 | 17 | 10 | 5.2 | 8.9 | 1.7 |

* – fodder beet, potatoes, corn, rape, lucerne, clover, hay, wheat
** – rye, oats, potatoes, grassland, barley

grains. According to Gerendás and Führs (2013), the ratio of Ca:Mg is an indicator of Mg deficiency in plant crop and an imbalanced Ca:Mg ratio often negatively affects product quality.

The human and animal requirement for Ca and Mg is determined as the concentration of each of these elements per unit of weight or in different parts of the organism, i.e. blood, plasma, skin and hair, as well as daily doses of a diet or feed (Martin-Tereso, Martens 2014, Kleczkowski et al. 2014). According to Durlach (1989), most nutrition specialists recommend a Ca:Mg ratio of 2:1.

Our results indicated that in basic cereal products, except for maize grain, the Ca:Mg ratio was less than 1. Similarly, other authors (Nogalska et al. 2012, Wojtkowiak et al. 2014) found the Mg content higher than that of Ca in cereal grain and consequently the Ca:Mg ratios were lower than 1. In turn, the Ca:Mg ratio in vegetables was equal to or higher than 1.

Satisfying quantitative and qualitative nutrient demand for both elements mostly depends on the nutritional preferences in terms of the structure of a diet (Ford, Mokdad 2003), i.e. shares of the particular input products with different Ca and Mg content. In general, the authors found that there was too little Mg in the diets applied to maintain the correct relationships between Ca and Mg, but Kumssa et al. (2015) stated that the risk of dietary My deficiency was low. The agricultural products investigated in this study, which are basic sources of food, are particularly poor in Ca and this can cause real or supposed Ca deficits in a diet, which was also pointed out by Sapek (2003). The direct causes of the low Ca content in plants are soil acidification and often the use of nitrogen fertilisers only, without applying other elements into soils. Nitrogen present in excess in the plant growth environment with respect to other elements reduces their intake, particularly Ca and Mg, as the current and earlier research has found (Ostrowska, Porębska 2009).

Different diseases identified in animal organisms were found to result from a deficit/surplus of Ca and Mg in feed; moreover, particularly adverse effects occur in a situation of a deficit/surplus of one element with respect to the other, i.e. when incorrect relationships between them exist (Radwińska, Żarczyńska 2014, Kleczkowski et al. 2014, Martin-Tereso, Martens 2014). Our results indicated that the Ca and Mg content was higher in the plants which are directly used as animal feed than in cereal grain, potatoes and most vegetables, while the proportions between the Ca and Mg content varied within the limits of 2-5:1.

The Ca (5-14 g $kg^{-1}$ dry mass) and Mg (2-3 g $kg^{-1}$ d.m.) content in the fodder plants was similar to obtained by other authors (Grunes, Welch 1989, Kleczkowski et al. 2014, Wyłupek et al. 2014). Both food and animal feed are mixtures of different agricultural products with different Ca and Mg content. A comparison of the average N, Ca and Mg content in the average yields of different plant species cultivated in rotation, except for permanent grassland, on fertile and poor soils, indicated that on fertile soils the Ca content in plants was 3.5 g $kg^{-1}$ dry mass and that of Mg was 3.2 g $kg^{-1}$ dry mass, whereas on poor soils they were 2.6 and 1.6 g $kg^{-1}$ d.m., respectively.

The fodder plants investigated in this study contain on average 2-3 times less Ca and Mg than the feed supplementation with Ca up to a quantity of 12.6 g $kg^{-1}$ and with Mg up to 7.8 g $kg^{-1}$ of feed, as proposed by Kleczkowski et al. (2014). More often than not, the supplementation of mineral compounds may not correspond to the human and animal nutrient demand, since the availability of elements depends on the properties of the compound in which an element is used. Thus, the supplementation of Ca and Mg even in a 2:1 proportion may pose a risk that an adverse relationship between the two elements will increase the risk of illness. Indeed, the availability of Ca or Mg from the compounds in a dietary supplement has been too poorly recognised.

## CONCLUSIONS

1. Rye, oats, wheat and barley grain contains smaller concentrations (dry weight) of Ca than Mg; therefore, the Ca:Mg ratios are lower than 1. In turn, the Ca:Mg ratios in maize, potatoes, vegetables and fodder crops are higher than 1.

2. High N content in plants limits the accumulation of other elements, especially Ca, an event which may occur with an intensive nitrogen fertilisation of acid soil. Therefore the Ca:Mg ratio in plants cultivated on acid soils, for example in the grain of rye, can be as low as 0.1.

3. Most of forage plants contain more Ca and Mg than cereals, and a higher content of Ca than Mg results a Ca:Mg ratio between 1 and 5.

4. An assessment of the human and animal nutrient demand for Ca and Mg and the need to supplement a diet and feed with these elements require further research on amounts of Ca and Mg and their relationships in food products, as well as on their availability from supplements.

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