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Soil Cation Ratios for Crop Production

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For many years, soil testing has been used as a management tool to arrive at fertilizer recommendations that are essential for economic crop production. Two general concepts or philosophies of making fertilizer recommendations evolved as the use of soil testing techniques and procedures were refined and used more and more as a basis for making fertilizer recommendations.

The "sufficiency level" approach is built on the concept that there are certain levels of plant nutrients in soil that can be defined as optimum. Below some defined level, crops will respond to the application of a nutrient in question. Likewise, crops will not respond to the addition of the nutrient if the soil test levels are above a defined sufficient level.

The "basic cation saturation ratio" (BCSR) approach promotes the concept that maximum yields can only be achieved by creating an ideal ratio of calcium (Ca), magnesium (Mg) and potassium (K) in the soil system. This approach is not concerned with recommendations for nitrogen (N), phosphorus (P), sulfur (S), and the micronutrients.

Today, most public and private soil testing laboratories responsible for making fertilizer recommendations use the "sufficiency level" approach. Others adjust recommendations generated from the "sufficiency level" approach with a consideration for the "basic cation saturation ratios." A more detailed discussion of the BCSR and "sufficiency level" approaches to fertilizer recommendations is provided by Eckert (1987). Recommendations based on the "basic cation saturation ratio" concept are usually quite different from those based on the "sufficiency level" concept. This confuses the grower as well as those who advise the grower. Therefore, this publication addresses the history of the "basic cation saturation ratio" concept and examines its importance and relevancy for crop production. It is not written for the purpose of comparing fertilizer recommendations resulting from the use of either concept.

Introducing New Terms:

At this point, it's important to define some soil chemistry terms before discussing the cation ratio concept. A "cation" is a positively charged ion. The cations used in largest amounts by plants are calcium (Ca^{++}), potassium (K^{+}), and magnesium (Mg^{++}). The ionic forms of Ca and Mg have two positive electrical charges while K has one.

These three nutrients exist in the **soil solution** in the form of ions. The **soil solution** is described as the thin film of water around plant roots, root hairs, and soil particles (see **Figure 1**). Cations are absorbed from the **soil solution** by actively growing plants. The cations are also held on **exchange sites** in soils. These **exchange sites** are negative charges associated with clay sized particles and some of the soil organic matter. Cations at the **exchange sites** are in equilibrium with the cations in the soil solution (see **Figure 1**). The number of negative electrical charges can be measured analytically and is referred to as the **cation exchange capacity.**

History and Early Development:

The development of the "basic cation saturation ratio" concept was based on the work of Bear and co-workers in New Jersey (Bear et al., 1945; Bear and Toth, 1948; Hunter, 1949; Hunter et al., 1943; Prince et al., 1947). A bulletin authored by Bear, Prince, and Malcolm (1945) introduced the ideal ratios with the following statement. "For the 'ideal soil', it is suggested that 65 per cent of the exchange complex should be occupied by calcium, 10 per cent by magnesium, 5 per cent by potassium, and 20 per cent by hydrogen." These percentages calculate to 13 parts of Ca to 2 of Mg to 1 of K.

Graham (1959) relaxed the optimum specific ratios by proposing that 65 to 85 percent of the cation exchange complex should be occupied by Ca, 6 to 12 percent by Mg, and 2 to 5 percent by K. More recently, Baker and Amacher (1981) defined normal values for the exchangeable cations as 60 to 80% for Ca, 10 to 20% for Mg, and 2 to 5% for K. Both bulletins were a general description of soil testing theory and procedures and experimental data were not cited.

Cation Ratios in Soil:

Exchangeable Ca, Mg, and K are measured on a regular basis by many laboratories and the various ratios can be calculated from these measurements. Measurements from Wisconsin, for example, show a range of Ca:Mg ratios in soils from 8.1:1 to 1.0:1 (**Table 1**).

Researchers at the University of Wisconsin have reported the effect of cropping on cation ratios (**Table 2**). Except for the Boone loamy fine sand, the Ca:Mg ratio remained the same or increased. In the case of the Boone loamy fine sand, the ratio decreased as a result of a lowering of the exchangeable Ca rather than an increase in exchangeable Mg (Shulte and Kelling 1985).

Figure 1. The relationships among soil particles, ions held by the exchange complex and ions in the soil solution. From R.D. Voss, Iowa State University.

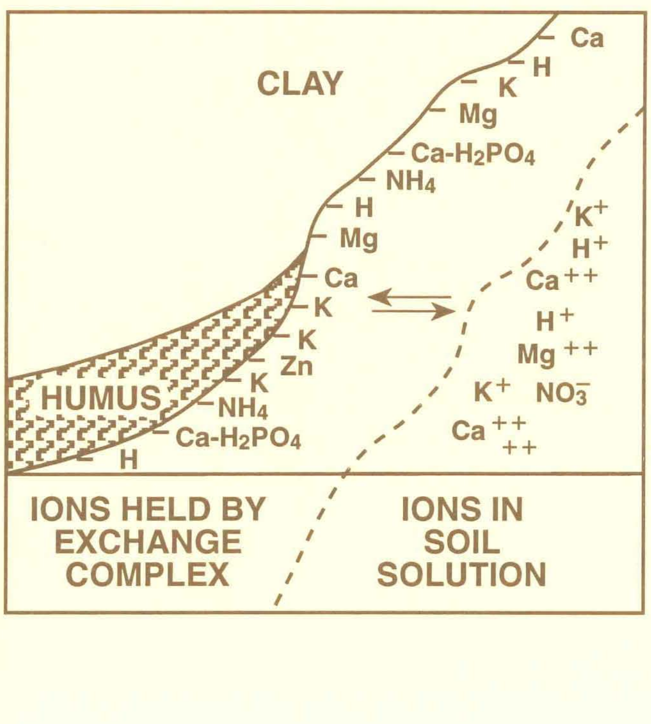

Table 1. Ratio of exchangeable calcium to exchangeable magnesium in some Wisconsin soils.[1]

Soil	Ca:Mg Ratio	Soil	Ca:Mg Ratio
Antigo	4.0:1	Morley	4.0:1
Almena	3.2:1	Norden	8.1:1
Boone	1.0:1	Onaway	6.7:1
Dubuque	4.0:1	Ontonagon	4.0:1
Gale	4.3:1	Pella	3.9:1
Freer	3.7:1	Plainfield	6.1:1
Kewaunee	3.1:1	Plano	3.3:1
Marathon	7.7:1	Poygan	4.3:1
		Withu	3.5:1

[1] *From Schulte and Kelling (1985)*

Table 2. Change in the ratio of exchangeable calcium to exchangeable magnesium with cropping.

Soil	Ca:Mg Ratio	
	Virgin	Cropped
Plainfield sand	7.9:1	8.7:1
Boone loamy sand	1.5:1	1:1
Gale silt loam	2.6:1	4.3:1
Ontonagon silt loam	3.9:1	4.2:1

From: Schulte and Kelling (1985)

Cation Ratios and Crop Production:

Although the concept of optimum cation ratios has been debated and promoted by agronomists over time, there is very little research evidence to show that these ratios have either a positive or negative effect on crop production. Liebhardt (1981) showed a direct relationship between soil pH and exchangeable Ca+Mg. The relationship of pH to crop growth was verified in greenhouse trials in Ohio (Eckert and McLean, 1981). It is reasonable to believe that increased growth reported by Bear and coworkers in their earlier research was a consequence of changes in soil pH rather than changes in cation ratios.

McLean and coworkers (1983) altered the Ca:Mg and Mg:K ratios of a silt loam soil in northern Ohio and measured crop response over a period of four years. The ratios were maintained with yearly additions of Ca, Mg, and K from various sources. Eighteen treatments were used. The ratios associated with the five highest yielding and 5 lowest yielding treatments for each year are listed in **Table 3**. Yields were

Table 3. Ranges in soil basic cation ratios for the five highest and five lowest yields for various crops.

Ratio	Yield Level	Ranges in BCSR			
		Corn (75)	Corn (76)	Soybeans (77)	Soybeans (78)
Ca:Mg	Highest Five	5.7-26.8	5.7-14.3	5.7-14.0	5.7-26.8
Ca:Mg	Lowest Five	5.8-21.5	5.0-16.1	2.3-16.1	6.8-21.5
Mg:K	Highest Five	0.6-3.0	1.3-3.1	1.0-3.0	1.1-3.1
Mg:K	Lowest Five	1.1-2.1	0.7-2.1	0.7-3.6	0.7-2.1

not related to a specific ratio and, as might be expected, no ideal ratio was identified. After completing the project, the researchers stated, "The results strongly suggest that for maximum crop yield, emphasis should be placed on providing sufficient, but nonexcessive levels of each basic cation rather than attempting to attain a favorable BCSR which evidently does not exist."

Field trials have been conducted in Wisconsin to evaluate the effect of the ratio of Ca:Mg in soils on alfalfa production (Simson et al., 1979). The ratio was varied by adding either gypsum ($CaSO_4$) and/or Epsom salts ($MgSO_4$) to two soils. Adequate amounts of other essential nutrients were applied. The results of this study are presented in **Table 4.**

Although the Ca:Mg ratio varied from 2.28 to 8.3, there was no impact on alfalfa yield. This is additional evidence that common field crops tolerate a wide range of cation ratios with no effect on yield. The added Ca and Mg did, however, change the percent saturation on the exchange sites. At all sites, the quantities of Ca and Mg in the soil were above the defined deficiency range when the sufficiency concept was used.

While a majority of the discussion revolving around cation ratios has focused on the relationship between Ca and Mg, some research in Nebraska examined the potential relationship between K and Mg for corn production (Rehm and Sorensen, 1985). Several rates of K and Mg were

Table 4. Effect of varying the Ca:Mg ratios on the yield of alfalfa.

Ca:Mg Ratio	Exchange Sites Saturated With Ca	Mg	Yield
	- - - % - - -		ton/acre
Theresa silt loam:			
2.28	34	35	3.31
3.40	45	22	3.31
4.06	46	19	3.40
4.76	49	17	3.40
5.25	52	16	3.50
8.44	62	12	3.22
Plainfield loamy sand:			
2.64	32	20	4.14
2.92	35	20	4.28
3.48	38	18	4.35
4.81	43	15	4.12
7.58	65	13	4.30
8.13	68	15	4.35

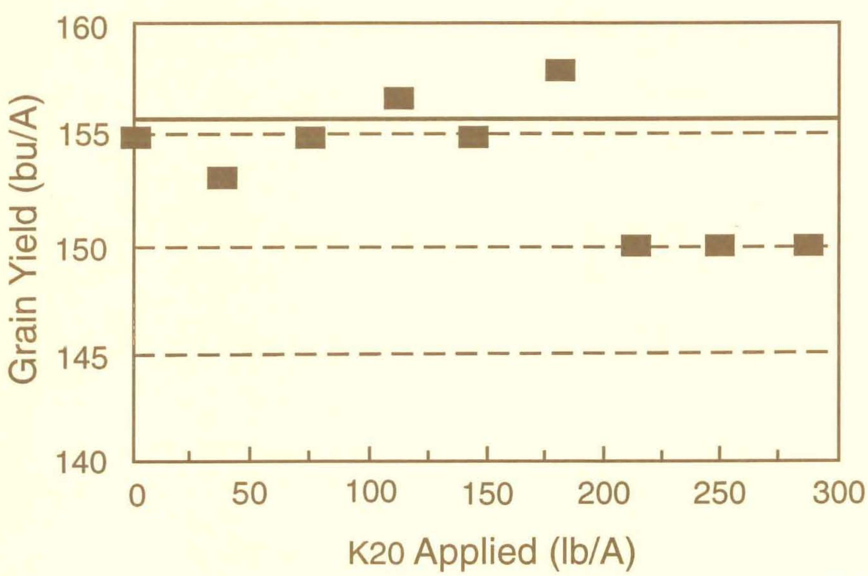

Figure 2. The effect rate of potash fertilizer on yield of corn (5-year average) grown on an irrigated sandy soil.

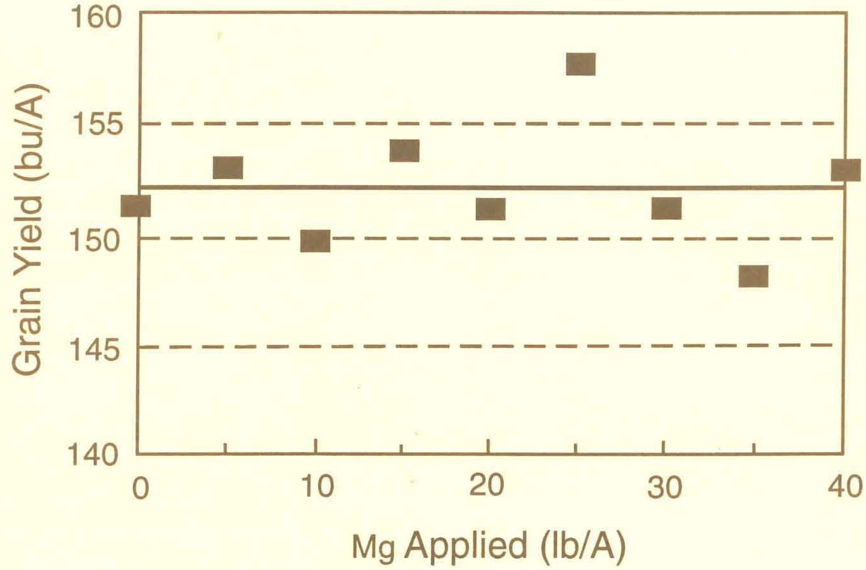

Figure 3. The effect of rate of applied magnesium on yield of corn (5-year average) grown on an irrigated sandy soil.

applied to an irrigated sandy soil with an initial Ca:Mg:K ratio of 10.3:2.5:1. The treatments were repeated annually from 1979 through 1982.

Throughout the study, there was no response to either the applied K or Mg. The average grain yields are shown in **Figures 2** and **3**. The results of this study show that the soil was able to supply ample K and Mg for corn production. When adequate amounts of nutrients are present in the soil system, additions of those nutrients to a fertilizer program are not needed.

Some Concerns:

The optimum cation ratio concept has one major disadvantage in that even if the ratio of cations in the soil is considered to be optimum, a nutrient deficiency might still exist. For example, the total amount of exchangeable cations is small for sandy soils with a low organic matter content. In these situations, it is possible to have a deficiency of K and/or Mg even though the ratios might be in the stated ideal range. On the other hand, while the ratios of the cations may be considered to be less than ideal for some fine-textured soils, these soils may have adequate amounts for crop production and additional applications are not necessary.

McLean (1976) concluded that the sufficiency level for K should vary with cation exchange capacity. For example, an ideal ratio of 13 parts of Ca to 1 of K on an exchange basis could provide an adequate supply of K for plants in a soil containing 600 lb. of exchangeable K per acre. This same ratio would not provide an adequate supply of K if the soil contained only 60 lb. of exchangeable K per acre.

SUMMARY

The optimum soil cation ratio concept, developed about 50 years ago, has been incorporated into some fertilizer recommendation philosophies in various ways. Recent field evaluations of this concept, however, show that the ratio of cations has no impact on the response of crops to Ca, Mg, and K in fertilizer programs. The optimum cation ratio concept has a major disadvantage in that even if the ratio of cations in the soil is considered to be optimum, a nutrient deficiency may still exist. A sufficient supply of available cations in the root zone is the most important consideration in making economic fertilizer recommendations.

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