INFLUENCE OF CALCIUM ON AVAILABILITY OF OTHER SOIL CATIONS[1]

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Investigation of the nutrient-cation status and needs of 20 of New Jersey's most important agricultural soils led to publication of the following tentative statement (1):

> For the ideal soil, it is suggested that 65 per cent of the exchange complex should be occupied by Ca, 10 per cent by Mg, 5 per cent by K, and 20 per cent by H.

This statement emphasizes the importance of Ca *per se*. It also infers that consideration must be given to the ratios between the amounts of the several exchange cations. Thus it suggests a Ca–Mg ratio[2] of 6.5:1, a Ca–K ratio of 13:1, a Ca-H ratio of 3.25:1, and a Mg-K ratio of 2:1. If a total exchange capacity of 10 m.e. is assumed, the plow depth of such a soil would contain about 2,600 pounds exchange Ca, 243 pounds exchange Mg, and 390 pounds exchange K.

Data from which the foregoing conclusion was reached were obtained in a series of studies that have been under way since 1940. Some of the results of these studies have been published. The purpose of this paper is to bring the findings up to date.

The first study was designed to determine what constituted an optimum Ca–K ratio for alfalfa when grown on Dutchess shale loam. In preparation for this work the exchangeable bases were removed from the soil and then restored in accordance with a definite plan. This called for uniform amounts of exchange H and Mg and variable amounts of exchange Ca and K. Hardistan alfalfa was then planted and grown through seven successive harvests.

It was found in this study (5) that the alfalfa plant could adjust itself to very wide Ca–K ratios in the soil, making good growth at ratios anywhere between 100:1 and 1:1. Ratios within the plant, however, were much narrower than those in the soil. With a Ca–K ratio of 32:1 in the soil the Ca–K ratio in the plant was only a little over 3:1. Thus the rate of absorption of K by the plant was 10 times that of Ca. Without further additions of Ca or K to the soil, the Ca–K ratios in the successive harvests increased to 3.9, 4.3, 7.4, 9.1, 10.0, and 11.1:1.

As soon as the Ca–K ratio in the alfalfa rose above 4:1 the yields dropped off, but K-deficiency symptoms were not apparent until the Ca–K ratio had risen to approximately 8:1. A Ca–K ratio of 4:1 in such alfalfa corresponded to a Ca content of about 2 per cent and a K content of about 1 per cent. Thus the con-

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[2] All the ratios mentioned in this paper are cation-equivalent ratios.

clusion was reached that the K content of alfalfa should not be allowed to fall below 1 per cent. This, therefore, was set as the critical level for this element in alfalfa. To date, not a single sample of K-deficient alfalfa, as evidenced by white spots around the edges of the leaves, has been found to contain more than 1 per cent K.

TABLE 1

Exchange-cation status and Ca-K and Ca-Mg ratios in original soils in comparison with "ideal" soil

SOIL TYPE	pH	CATION-EXCHANGE CAPACITY	PERCENTAGE SATURATION OF COMPLEX WITH				Ca:K	Ca:Mg
			H*	Ca	Mg	K		
		m.e.†						
Dutchess shale loam	7.2	14.8	0	103.3	23.6	4.7	21.8	4.4
Collington loam	4.7	15.9	60.6	28.3	8.1	3.0	9.3	3.4
Penn silt loam	4.5	19.8	88.0	2.0	8.0	2.0	1.0	0.2
Washington loam	4.6	11.3	67.7	14.1	16.8	1.4	9.5	0.8
Hoosic loam	6.9	11.4	18.3	71.0	8.7	1.2	57.4	8.1
Sassafras loam	4.5	7.5	86.4	5.3	5.3	3.0	1.7	1.0
Dover loam	7.3‡	14.0	0.0	68.5	25.0	1.5	43.2	2.7
Bermudian silt loam	6.1	13.2	24.6	48.4	25.7	1.3	35.5	1.9
Colts Neck sandy loam	4.2	9.9	92.2	2.0	3.0	1.2	2.4	0.7
Lansdale silt loam	4.6	13.0	60.8	25.0	11.5	2.7	9.2	2.2
Chester loam	5.8	10.6	75.0	14.1	9.3	1.6	8.6	1.4
Merrimac silt loam	4.4	10.2	81.1	2.9	14.7	1.3	0.2	0.0
Fox gravelly loam	7.4‡	8.5	0.0	71.7	40.7	2.0	34.8	1.9
Gloucester loam	5.4	11.9	79.8	14.2	5.0	1.0	14.8	2.8
Hagerstown loam	7.7‡	16.5	0.0	78.1	25.4	1.3	58.9	3.1
Whippany silty clay loam	5.2	8.7	44.5	36.7	17.2	1.6	22.2	2.1
Sassafras loamy sand	4.4	2.7	99.3	0.2	0.0	0.5	0.2	0.0
Sassafras sand	3.9	2.0	99.4	0.5	0.0	0.1	10.0	0.0
Papakating stony loam	5.6	9.0	44.3	44.4	7.7	3.6	12.1	5.8
Lakewood sand	4.4	2.8	93.7	3.0	3.0	0.3	11.7	1.0
"Ideal" soil	6.5	10.0	20.0	65.0	10.0	5.0	13.0	6.5

† Per 100 gm. soil.
* By difference.
‡ Free Ca- and Mg-carbonates present.

A second study (2) had to do with the application of these findings to 20 of the most important agricultural soils of New Jersey. Samples of the A-horizons of mostly virgin soils[3] were collected for this work and subjected to laboratory analysis. The data (table 1) reveal that not one of these soils contained exchange cations in ratios that even approached those of the suggested ideal soil. Thus the calcareous soils of the Dutchess, Dover, Fox, and Hagerstown series appeared to contain no exchange H, whereas the soils of the Penn, Colts Neck, Sassafras,

[3] The Dutchess, Hoosic, Hagerstown, and Fox soils were chosen from areas that had been under cultivation.

and Lakewood series contained exceedingly high percentages of it. All 20 soils showed a need for K, 15 of them for Ca, 11 for Mg, and 5 for H, if the exchange cation specifications for the ideal soil were to be met.

In preparing these soils for greenhouse studies it was decided to apply dolomitic limestone to pH 6.5, supply a liberal and uniform quantity of superphosphate, and add small amounts of the essential minor elements. K was then added as

TABLE 2

Ca-Mg and Ca-K ratios in limed and phosphated soils, yield of alfalfa on these soils with and without added K, and harvest at which K became < 1 per cent*

SOIL SERIES†	Ca:Mg IN SOIL AT START	Ca:K IN SOIL AT START		DRY MATTER PER POT		NUMBER OF HARVEST WHEN K CONTENT BECAME <1 PER CENT	
		No K	200 K	No K	200 K	No K	200 K
				gm.	gm.		
Dutchess	4.5	22	17	69	67	5th	7th
Collington	1.6	19	12	58	64	6th	7th
Penn	0.9	16	10	57	47	7th	8th
Washington	1.0	35	14	54	61	3rd	5th
Hoosic	8.5	61	23	52	63	2nd	5th
Sassafras (loam)	1.2	18	9	49	63	2nd	5th
Dover	2.9	46	18	45	50	2nd	5th
Bermudian	1.7	47	19	42	49	2nd	5th
Colts Neck	1.2	35	16	41	53	3rd	5th
Lansdale	1.5	26	15	41	53	2nd	5th
Chester	1.2	22	9	40	49	7th	8th
Merrimac	0.8	37	13	33	51	7th	5th
Fox	2.1	37	14	32	38	2nd	7th
Gloucester	1.5	35	11	29	47	3rd	5th
Hagerstown	3.1	61	28	27	50	1st	4th
Whippany	1.7	36	13	20	36	1st	5th
Sassafras (loamy sand)	1.3	36	7	17	29	1st	5th
Sassafras (sand)	1.6	1290	6	15	34	1st	5th
Papakating	2.9	18	10	13	35	2nd	5th
Lakewood	1.2	153	4	11	31	1st	5th

* Limed with dolomite to pH 6.5.

† Same soils and in same order as those shown in table 1.

the chloride to one set of pots at a rate corresponding to 200 pounds of the element per 2 million pounds soil. The Ca-Mg and the Ca-K ratios of the exchange complexes of the soils to which no K and 200 pounds K, respectively, were added are shown in table 2. As a result of the use of dolomitic limestone, the Ca-Mg ratios are entirely out of line with that suggested for the ideal soil, but the Ca-K ratios of the 200-K set of soils approach the ideal fairly closely.

The yields of alfalfa (table 2) were materially increased in 18 of the 20 soils by adjusting the Ca-K ratios to a point approximating the ideal 13:1 ratio. The K content of the first crop of alfalfa was considerably higher than the critical 1 per cent. With the harvesting of successive crops, however, the time soon arrived with most of the soils when the K content of the crop fell below this level (table 2).

At this point it is necessary to digress for a moment to consider release of cations from the primary minerals in the soil. A further purpose of this study had been to determine the rate at which these soils would continue to yield K to alfalfa. In effect, the roots of the alfalfa plant were substituted for a laboratory extracting solution. The results showed that a number of the soils could supply considerable amounts of K more or less continuously.

In the growing of crop plants we are dealing with two sets of cation equilibria: those in the soil and those in the plant. Within limits, however, the equilibrium in the plant is the product of soil-plant interrelationships. Continued studies of plant cation values revealed that although the content of Ca, Mg, and K varied greatly, in relation both to the nature of the soil and to the number of successive crops harvested, the sum of their equivalents per 100 gm. dry matter for any one harvest was virtually constant for all soils (3). Although this fact had been pointed out by Liebig (4, pp. 64–65), it had been lost sight of until it was again demonstrated by Van Itallie (7) a century later.

Of these three basic cations, Ca is dominant in the soil, whereas K dominates in the plant. Thus only by maintenance of a relatively high Ca-K ratio in the soil can the K content of a plant being grown under conditions of high fertility be kept down where it belongs. Even so, it is difficult to maintain a high content of exchange K in farmed soils, most of them tending to become deficient in this element with continued cropping. The problem involved with K, therefore, is one of maintaining an adequate but not excessive supply in the soil.

If normal alfalfa plants can be grown at a K content of 1 per cent, it is false economy to apply large enough amounts of this element in fertilizer form to allow the plant to take it up to the extent of 3.5 per cent of its dry weight, as has been found possible (5). Ca is a relatively low-cost element, and the soil should be so well supplied with it that the plant roots will have an opportunity to absorb Ca up to the point of diminishing returns from its use. An exchange Ca–K ratio of 13:1 in the soil enables the plant to absorb a liberal margin of K in excess of its requirements and yet not so much as to be a serious waste of the element. Once the soil has been limed and fertilized with K to this point, the problem then resolves itself into one of supplying repeated moderate doses rather than infrequent heavy doses. This applies especially to soils with exchange capacities of less than 10 m.e. per 100 gm. The exchange Ca content of such soils is too low to permit of establishing suitable Ca–K ratios and, at the same time, of having enough K stored in the soil to meet the full-season requirements of the crop.

In connection with these studies it soon became apparent that the Mg-K ratio was even more important than the Ca–K ratio. This was found to apply especially to sandy soils of low exchange capacity and to soils that were being kept acid for the growing of such crops as potatoes. Thus the tendency of plants to take up K at the expense of adequate amounts of Mg was found to be very troublesome under such conditions.

To study this point in detail, the same set of 20 soils was again employed. In this case, however, pure $CaCO_3$ was used to raise the pH values to pH 6.5, and Mg was added only as the sulfate. The report on this work (6) showed that, when the Mg content of the exchange complex fell below the ideal 10 per cent saturation, marked response was obtained from use of this element in soluble form. The evidence indicated that this might be more nearly a critical than an optimum value for exchange Mg. Thus alfalfa yields were considerably higher on the whole where much larger amounts of Mg had been added, as in the case where dolomitic limestone was used to correct soil acidity, than when this element was supplied only in controlled and relatively limited amounts by the use of $MgSO_4$.

Although adequate amounts of Mg can be supplied in the form of liming materials, it is not safe to assume that they will be. This method of supplying Mg often fails on sandy soils and for acid-soil crops. It also fails where oyster shells and calcitic forms of lime are used on Mg-deficient soils. So important has this problem become in the New Jersey Coastal Plain area, where large amounts of K are being applied to the soil, that most fertilizer manufacturers now include a soluble form of Mg in the fertilizer mixtures that are offered for sale in these areas.

More recently we have been impressed with the fact that Ca can have a negative as well as a positive value, especially when it comes to occupy too large a percentage of the exchange complex at the expense of H. Thus even though the Ca-Mg, Ca-K, and Mg-K ratios may have been adjusted to supposedly correct values, the Ca-H value still remains to be considered. In the enthusiasm for liming acid soils, the concept has developed that such soils cannot be overlimed, particularly if pulverized limestone is employed. But so many cases of Mn deficiency have been brought to our attention during the last few years that this problem can no longer be ignored. Once the soil has been limed and relimed to the point that few zones of low pH remain and the whole volume of soil has a pH level beyond 6.5, the problem of deficiencies of Mn and certain other minor elements comes into play. In other words, the exchange-H values in soils of the humid areas are as important as those of the exchange Ca, K, and Mg. Thus a Ca-H ratio of 3.25:1, which is normally obtained at about pH 6.5, has been set as the tentative upper limit for crops, other than those belonging to the perennial deep-rooted group, until such time as the Mn studies that are now under way can be brought to a conclusion.

SUMMARY AND CONCLUSIONS

An 8-year study on 20 important agricultural soils of New Jersey, in which use was made of the roots of alfalfa plants as cation-extracting agents, has led to the following conclusions:

Conditions approach the optimum for the cation nutrition of alfalfa when 65 per cent of the exchange complex of the soil is occupied by Ca, 10 per cent by Mg, 5 per cent by K, and 20 per cent by H.

The ratios of the basic nutrient cations in the alfalfa plant bear little resemblance to those in the exchange complex of the soil on which it was grown.

Ca is the dominant cation in the soil and K in the alfalfa plant. The plant tends to take up more K than it needs unless the Ca content of the soil is maintained at a relatively high level.

When the Ca-K ratio in alfalfa tops exceeds 4:1, or when the K content of the tops falls below 1 per cent, marked response to applications of soluble K will normally be obtained.

When any one of the nutrient cations is deficient in the soil, more of the others move into the alfalfa, but the sum of the cation equivalents in the plant per unit weight of dry tissue tends to be a constant.

The tendency of alfalfa to absorb more K than it requires makes it necessary to consider how this can be avoided. K is a much more expensive element than the Ca which it replaces. Furthermore K is of much less importance, quantitatively, than Ca in the nutrition of animals. In soils of low exchange capacity, or in those that are maintained at low pH values for the benefit of acid-soil crops, it would be desirable to apply moderate amounts of K from time to time during the crop season rather than a large amount at the time of planting only. Otherwise the crop will contain an unduly large amount of K.

Mg deficiency tends to be widespread on sandy and acid soils because the liberal applications of K that are normally used under such conditions enable the plant to absorb an excess of K in place of part of the needed Mg.

Liming acid soils to the point where virtually all the exchange H in the entire volume of plowed soil has been replaced by Ca tends to cause a deficiency of Mn in crops other than the deep-rooted perennials, and an increasing number of crop failures are resulting from this practice. This principle also applies to other members of the minor-element group.

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