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CATION-EQUIVALENT CONSTANCY IN ALFALFA[1]

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EVIDENCE presented in a previous paper (3)[3] indicated that, within certain critical limits, alfalfa will thrive on soils containing widely different ratios[4] of exchange Ca to exchange K. Under such conditions marked variations occur in the percentages of Ca and K and in the Ca-K ratios in the tissues of the plants. Thus, the Ca content of first-cutting Hardistan alfalfa increased from 0.77 to 1.82% and the K content decreased from 3.30 to 1.15% when the Ca-K ratio in the exchange complex of Dutchess shale loam on which the alfalfa was being grown was altered from 1:1 to 32:1. In conformity with these changes in percentages of Ca and K in the plant tissues, the Ca-K ratio was increased from 0.45 to 3.09. This adjustment was effected without sacrifice in yield.

The soil chemist interprets these facts as indicating that the analysis of alfalfa for total Ca and K provides a far more reliable index of the readily available supplies of these cations in the soil on which the plant has been grown than of the plant's critical need for each of them. The livestock man finds in such data substantiation for his belief that the mineral value of a crop produced on a soil of limestone origin is higher than that of the same crop when grown on a soil that has been derived from noncalcareous rocks. There are important practical reasons for considering the subject from both these points of view, and that is the purpose of this paper.

SOILS EMPLOYED AND THEIR CATION CONTENT

Further study of cation relationships in alfalfa was found possible in connection with an intensive investigation that is being made of the mineral qualities of 20 important New Jersey soils in which this plant is being used for indicator purposes. The soils were chosen to represent as wide differences in mineralogical, chemical, and textural composition as possible (Table 1). They belonged to 17 well-recognized series and to nine distinct classes, and differed markedly in their content of the several common nutrient elements. Thus, the Hagerstown loam, a soil of limestone origin, contained 0.72% Ca, whereas the Penn silt loam, derived from noncalcareous shale, contained only 0.09% of this element. Similarly, wide differences may be noted in the percentages of total K and Mg in the several soils.

For the purposes of this study it was deemed desirable to know, as definitely as possible, the amounts of "available" Ca, Mg, and K in the experimental soils at the time the alfalfa seed was sown. These were calculated by adding the quantities of these elements that had

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[3] Figures in parenthesis refer to "Literature Cited," p. 222.

[4] All cation ratios in this paper are expressed in terms of equivalents per unit weight of soils or plants.

been supplied in the form of lime and fertilizers[5] in preparation for seeding the alfalfa to the amounts contained in the exchange complexes of the original soils. The results of these calculations are shown in Table 2, in conjunction with the total yields of alfalfa and the cation situation in the soil at the end of the experiment.

TABLE 1.—*Chemical composition of A_1 horizons of 20 important New Jersey soils.*

Soils*	Total constituents, %						
	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	Ca	Mg	K
Collington loam	77.1	6.5	5.1	0.19	0.16	0.35	1.37
Washington loam	71.2	11.5	5.4	0.08	0.35	0.44	2.10
Penn silt loam	52.9	20.7	7.8	0.10	0.09	1.01	2.59
Lansdale silt loam	73.0	11.2	3.0	0.12	0.23	0.37	1.50
Dover loam	79.6	7.7	3.0	0.12	0.34	0.49	2.26
Dutchess shale loam†	66.1	12.6	4.6	0.20	0.47	0.89	1.41
Gloucester loam	69.5	13.0	4.5	0.21	0.80	0.52	2.26
Hoosic loam†	71.1	11.5	4.0	0.14	0.48	0.69	2.55
Sassafras loam	79.4	8.7	3.5	0.15	0.12	0.32	1.26
Merrimac silt loam	74.0	10.8	4.1	0.13	0.49	0.38	1.42
Whippany silt-clay loam	76.4	10.6	2.7	0.06	0.45	0.35	1.66
Hagerstown loam†	61.3	14.9	6.7	0.25	0.72	0.87	4.25
Bermudian silt loam	68.9	13.5	5.3	0.11	0.40	0.74	2.00
Fox gravelly loam†	73.5	10.4	3.5	0.18	1.06	1.17	2.54
Chester loam	65.9	15.2	5.3	0.12	0.25	0.29	3.00
Papakating stony loam	72.9	11.9	4.1	0.12	0.22	0.80	1.73
Sassafras loamy sand	86.1	7.3	2.4	0.04	0.11	0.13	1.27
Colts Neck sandy loam	82.2	4.9	5.7	0.14	0.14	0.37	0.70
Lakewood sand	96.1	1.6	0.7	0.01	0.03	0.02	0.07
Sassafras sand	97.2	1.8	0.1	0.02	0.00	0.09	0.35

*The soils are arranged in this and all succeeding tables in the order of their alfalfa-yielding capacity under standardized and experimentally controlled conditions in the greenhouse.

†These soils were known to have been farmed and, therefore, the samples represent A_p rather than A_1 horizons.

The 10 most productive soils (Table 2) tended to have higher exchange capacities and higher contents of available Ca than the equal number of soils making up the lower half of the list on the production scale. Thus, the exchange capacities of these two groups of soils averaged 13.0 and 8.4 M.E., respectively, and their contents of available Ca averaged 11.1 and 6.3 M.E. at the start of the test. By the end of the test, however, the supplies of all three cations had fallen markedly, the amount of available K having been reduced to such a low level in 15 of the soils as to make its lack a seriously limiting factor in plant growth.

PLANT-GROWING PROCEDURES AND RESULTS

The same plant-growing procedures were employed as in a previous study (1), the essential features being that 2-gallon quantities of each

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[5] The fertilizer, consisting of a mixture of $CaH_4(PO4)2.H_2O$, KCl, and $MgSO_4.7H_2O$, all C. P. salts, was formulated and used in such amounts as were required to supply the equivalent of 200 pounds P_2O_5, 200 pounds K_2O, and 80 pounds MgO per 2 million pounds of soil. To simulate superphosphate, $CaSO_4$ was used in approximately the same quantities as the $CaH_4 (PO_4)_2$. Small amounts of the several trace elements were also added to each soil.

soil, after its pH value had been adjusted to approximately 7.0 by the use of $CaCO_3$, were given standard applications of fertilizer, brought to optimum moisture conditions, and seeded to the Atlantic variety of alfalfa. Eight successive cuttings were harvested from each soil, the produce of triplicate pots being combined for analysis.

TABLE 2.—*Yield of alfalfa in relation to exchange capacities of soils* and to their content of available† cations at start and exchange cations at end of test.*

Soils	Dry weight of alfalfa, grams		Exchange capacity of soils, M.E.	Available cations in soil at start, M.E.			Exchange cations in soil at end, M.E.		
	Tops	Roots		Ca	Mg	K	Ca	Mg	K‡
Collington	68.0	31.7	15.9	12.4	1.5	0.74	9.8	0.9	0.15
Washington	60.8	46.3	11.3	8.9	2.1	0.42	6.7	0.5	0.07
Penn	60.1	35.0	19.8	12.1	1.8	0.65	10.5	0.3	0.18
Lansdale	59.9	28.7	13.0	13.0	1.7	0.63	8.5	0.6	0.21
Dover	58.0	21.3	14.0	10.1	3.7	0.47	8.3	3.0	0.10
Dutchess	56.8	36.3	14.8	15.8	3.7	0.95	12.2	1.2	0.19
Gloucester	55.6	23.7	11.9	7.1	0.8	0.35	7.0	0.6	0.05
Hoosic	52.3	28.7	11.4	15.6	1.2	0.37	9.4	0.9	0.11
Sassafras loam	51.3	24.7	7.5	6.3	0.6	0.45	4.8	0.3	0.08
Merrimac	48.9	34.0	10.2	8.4	1.7	0.37	7.0	0.4	0.06
Whippany	48.6	19.3	8.7	7.7	1.7	0.41	8.8	2.5	0.09
Hagerstown	47.1	23.0	16.5	13.4	4.5	0.48	12.7	4.1	0.13
Bermudian	44.4	23.3	13.2	9.9	3.6	0.45	7.9	1.7	0.05
Fox	44.4	19.7	8.5	6.6	3.3	0.41	6.9	3.4	0.10
Chester	42.3	20.0	10.6	4.8	1.3	0.42	6.5	2.0	0.20
Papakating	42.0	25.7	9.0	7.7	0.9	0.57	6.2	0.4	0.10
Sassafras loamy sand	37.5	30.3	2.7	3.0	0.2	0.29	2.0	0.1	0.04
Colts Neck	37.1	21.7	9.9	5.8	0.5	0.36	5.1	0.2	0.08
Lakewood	26.6	23.7	2.8	1.6	0.3	0.22	1.1	0.2	0.003
Sassafras sand	12.4	7.0	2.0	1.4	0.2	0.22	1.1	0.2	0.04

*In M.E. per 100 grams air-dry soil.

†For any given cation the term "available" represents the quantity in exchange form plus that added in the form of lime and fertilizer salts.

‡The critical lower limit in the soil's supply of K for alfalfa is believed to lie between 0.15 and 0.20 M.E. of the element per 100 grams air-dry soil.

With repeated harvesting of the successive crops, the Ca and Mg contents of the alfalfa tended to increase whereas the content of K decreased (Table 3). Thus, the average Ca, Mg, and K contents of the first crop were 88, 27, and 55 M.E., respectively, per 100 grams dry weight of tops, whereas the eighth crop contained 123, 40, and 25 M. E. of these elements. The reverse of this tendency was found only in the second crop, indicating a higher degree of availability of the soil K to the alfalfa during that period of its growth.

It will be noted in Table 3 that the sums of the equivalents of Ca, Mg, and K contained in any given harvest tended toward a constant. Thus, the mean of these sums for the first crop harvested from the 20 soils was 170, and the departure from this mean did not exceed 10 points in 15 of the soils. Similarly, the mean for the eighth crop was 187 and the sum of the cation equivalents of 14 of the soils lay within a 10-point range around that value. The harvesting of each crop was performed on the same day on all soils, notwithstanding the fact that the plants varied somewhat in their degree of maturity. If all the plants could have been brought to the same stage of development by each harvest date, it seems probable that the sums of the equivalents of Ca, Mg, and K in the produce of any given harvest would have been practically a constant for all these soils. This tendency toward cation-equivalent constancy in legumes has been noted by other workers (3, 5).

TABLE 3.—*Milliequivalents* of Ca, Mg, and K in first, second, and eighth crops alfalfa.*

Soils	First crop				Second crop†				Eighth crop			
	Ca	Mg	K	Total	Ca	Mg	K	Total	Ca	Mg	K‡	Total
Collington	90	31	60	181	72	23	72	167	111	37	30	178
Washington	94	29	52	175	76	20	58	154	141	36	19	196
Penn	126	19	53	198	84	16	58	158	134	23	31	188
Lansdale	93	21	59	173	68	17	60	145	123	26	30	178
Dover	81	34	60	175	73	27	63	163	115	57	19	191
Dutchess	95	25	51	171	76	18	63	157	117	39	29	185
Gloucester	81	36	57	174	78	23	61	162	113	40	24	177
Hoosic	86	21	57	164	72	21	62	155	132	39	23	194
Sassafras loam	93	25	49	167	69	20	61	150	131	28	18	177
Merrimac	101	20	55	176	79	20	63	162	161	23	19	203
Whippany	101	24	38	163	75	31	44	150	105	60	13	178
Hagerstown	71	35	51	157	75	30	47	152	116	70	20	206
Bermudian	101	28	52	181	64	28	61	163	127	52	22	201
Fox	66	40	57	163	65	33	63	161	109	69	21	200
Chester	78	28	59	165	54	24	72	150	101	43	40	184
Papakating	93	26	44	163	78	23	53	154	144	39	18	201
Sassafras loamy sand	94	23	56	173	71	18	62	151	134	24	24	182
Colts Neck	91	16	50	157	69	22	57	148	144	27	24	195
Lakewood	59	28	74	161	74	36	77	187	93	32	24	149
Sassafras sand	72	33	61	166	65	26	70	161	107	33	46	186
Mean	88	27	55	170	72	24	61	157	123	40	25	187

*Per 100 grams dry weight of tops.

†The Na content of the second crop of alfalfa from each soil was also determined, but the quantities found were small, averaging 0.82 M.E. per 100 grams dry matter. The produce of the Whippany silt loam contained 2.04 M.E. Na, the only case in which it exceeded 1 M.E. per 100 grams of produce.

†The critical lower limit for K in the harvested portion of the alfalfa plant is believed to be about 25 M.E. K per 100 grams of dry matter.

The individual equivalent values for Ca, Mg, and K in the plant tissues of any given harvest of alfalfa varied greatly from soil to soil, but in no apparent relationship to yield until the K content of the soil had fallen to less than 0.15 to 0.20 M.E. per 100 grams on the air-dry basis. When this occurred the K content of the plant tissues fell below 25 M.E. per 100 grams dry matter, the Ca-K ratio in the crops rose above 4:1, and the Ca-K ratio in the soils themselves reached levels approaching 100:1, the three critical values previously arrived at (3).[6]

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[6] Nothing in these studies to date permits of setting critical values for Ca and Mg in the tissues of the alfalfa plant or in the soil on which it is being grown.

It is particularly important to note that the alfalfa tended to accumulate K far beyond its critical need for the element, as is especially apparent in the data for the second crop (Table 3). Because of this tendency, it is difficult in practice to maintain an adequate supply of this element in the soil, and the likelihood of its falling below the critical lower level in the plant presents a problem that has constantly to be reckoned with.

Taken as a whole, the evidence strongly suggests that Ca, Mg, and K may each have not only a specific function that cannot be fulfilled by any other cation, but certain general functions of the type that can be performed by any one of these cations. Once the supply of any given cation has become adequate to meet its specific functional need, any additional quantity of it that may be absorbed by the plant is used only in these more general cation functions. To that extent, substitution of one cation for the other can be effected without detriment to the yield until a point is reached at which the content of the other is reduced below the critical value necessary for the specific function it performs. The tendency of the plant to absorb K in excess of the amount needed to fulfill its specific function is greater than for either of the other two cations, as might be expected from its position in the electromotive series and the properties of the element associated therewith (2).

When the evidence is viewed in relation to both economy of production and feeding value of alfalfa, it would appear that Ca and K should be differently used, the Ca in liberal amounts in advance of seeding and the K as needed, part at seeding time and the remainder year by year during the life-history of the plant. These regularly repeated applications of K should be sufficiently liberal to maintain the K content of the plant at not less than the critical lower limit of 1%, or around 25 M.E. per 100 grams dry matter.

During this study this question arose as to the Na content of the alfalfa. Accordingly, the second crop was analyzed for this element. The data indicate that Na plays a very minor role in the cation economy of this plant when grown on New Jersey soils. The average Na content of the produce from the 20 soils was 0.82 M.E. per 100 grams dry matter. The extremes were 0.34 M.E. in the alfalfa from the Hoosic soil and 2.04 M.E. for that of the Whippany soil, the only one in which the Na content exceeded 1 M.E. per 100 grams.

SUMMARY AND CONCLUSIONS

Consideration has been given to the cation content of alfalfa plants that were grown on 20 very different New Jersey soils under as nearly optimum conditions as our knowledge of these soils at the outset of the study permitted.

The data indicate that high yielding-capacity of these soils for alfalfa over a period of sufficient duration to permit of eight cuttings was associated with a high content of available Ca in the soil at the start of the test.

Under conditions in which all the fertilizer was applied before seeding, the alfalfa accumulated large amounts of K in the first few crops with the result that most of the soils were rapidly depleted of this element.

This tendency toward excessive absorption of K by plants might be expected from the position of this element in the electromotive series.

The equivalents of K per 100 grams dry weight of alfalfa tended to decrease from the second to the eighth crop, whereas those of Ca and Mg tended to increase.

The sum of the equivalents of Ca, Mg, and K per unit of plant material tended to be a constant for the produce of any given harvest, this constant having a value approaching 170 M.E. per 100 grams dry matter in the first crop and 187 M.E. in the eighth.

The evidence supports the belief that each of these cations has at least two functions in the plant, one specific and the other or others of the type that can be performed interchangeably by all three cations. Once the supply of each cation is adequate to meet the specific need for it, there can be a wide range in ratios in the remaining quantities that are absorbed by the plant to meet its total cation needs.

Whether the problem of growing alfalfa is considered from the point of view of economy in its production or that of its mineral value to the animal to which it is fed, it would appear that the soil on which it is to be grown should be fortified with an abundance of Ca and Mg in preparation for seeding, but that the K applications should be governed by the specific annual needs of the plant, a suitable application being made at seeding time and additional quantities being supplied each year the crop is allowed to continue on the same land.

Because of alfalfa's tendency to accumulate K in excess of its critical need for it, difficulty is experienced in maintaining an adequate supply of this element in the soil. The annual application of K must be sufficient to maintain the K content of the plant at not less than 1%, but it should not be so large as to effect a substitution of K for Ca and Mg in the functions that are common to all three cations in the plant.

The Na content of the alfalfa was too small to be of any significance in connection with the conclusions reached in this paper, the largest amount found being 2.04 M.E. per 100 grams dry matter in the produce of the Whippany silt loam soil.

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