A FOLIAR DIAGNOSIS STUDY OF THE INFLUENCE OF CALCIUM FROM TWO SOURCES, LIME AND SUPERPHOSPHATE[1]

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INTRODUCTION

In the preceding paper of this series[2] the course of nutrition of maize plants (*Zea mays* L.) growing on eight plots of tier 1 of the Jordan fertility plots of this experiment station was described.

The treatments of these particular plots consisted of a single element, combinations of two elements, and a complete fertilizer containing all three elements, nitrogen, phosphorus, and potassium. The carrier of nitrogen was dried blood; of phosphorus, the superphosphate of commerce; and of potassium, the chloride or muriate.

Plot No. 1 (check) has never received any fertilizer or lime. But another plot (No. 23), not considered in the previous paper,[2] has received calcium in the form of lime, without any commercial fertilizer, every 4 years at the rate of 500 pounds per application to the ⅛-acre plot. Four of the plots, P (No. 3), NP (No. 5), PK (No. 7), and NPK (No. 9), received calcium in the form of ground bone black until 1917. Since then they have received superphosphate at such a rate as to provide 48 pounds of P_2O_5 to the acre, applied to the corn and wheat. Plot No. 23 accordingly received 3,000 pounds of calcium in the form of lime (CaO) up to 1936, and plots Nos. 3, 5, 7, and 9 received during the same 56-year period (1881–1936) approximately 400 pounds of calcium present in the superphosphate and ground bone black.

The object of the present investigation was to compare the foliar diagnosis of corn plants growing on a plot receiving lime only with that of corn plants on a check plot receiving no lime, and to determine the relationship of the foliar diagnosis of plants growing on plots receiving calcium in the form of superphosphate to that of plants on a plot receiving lime only. The results are reported herein.

EXPERIMENTAL PROCEDURE

The arrangement of the experimental plots has been described previously.[2]

The sampling of the leaves was carried out in the manner described in detail in an earlier paper.[3] The third leaf from the base of the stalk was taken periodically during the season from all of the plants lengthwise of each plot. Successive rows were sampled on each of the sampling dates indicated in table 1.

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[1] Received for publication August 29, 1938. Paper No. 857 in the Journal Series of the Pennsylvania Agricultural Experiment Station.

[2] THOMAS, WALTER, and MACK, WARREN B. FOLIAR DIAGNOSIS OF ZEA MAYS SUBJECTED TO DIFFERENTIAL FERTILIZER TREATMENTS. Jour. Agr. Research 58: pp. 477–499, illus. 1939.

[3] THOMAS, WALTER. FOLIAR DIAGNOSIS: PRINCIPLES AND PRACTICE. Plant Physiol. 12: 571–599, illus. 1937.

PRESENTATION AND DISCUSSION OF RESULTS

The composition of the third leaf expressed as percentages of N, P_2O_5, K_2O, CaO, and MgO in the dried foliage and the composition of the NPK unit [2] and yields of grain and stover of plants from plots No. 1 (check) and No. 23 (lime), are listed in table 1 and shown graphically in figures 1 to 3.

For purposes of orientation the derivation of the NPK unit represents the equilibrium between N, P_2O_5, and K_2O in the chosen leaf at the moment of sampling and is derived by converting the percentage composition for N, P_2O_5, and K_2O into milligram-equivalent values and then determining the proportion each of these bears to the milligram-equivalent total.[3]

COMPARISON OF THE FOLIAR DIAGNOSIS OF PLANTS ON THE LIME PLOT (NO. 23) WITH THAT OF PLANTS ON THE CHECK PLOT NO. 1

Indications Given by the Graphs Showing the Percentage of N, P_2O_5, K_2O, CaO, and MgO as Ordinates and Dates of Sampling as Abscissae

Table 1.—*Percentage composition expressed in terms of the dried foliage together with the composition of the NPK unit and yield of plots No. 1 (check) and No. 23 (lime)*

Date and plot	N	P_2O_5	K_2O	N+P_2O_5+K_2O (s)	CaO	MgO	Composition of the NPK unit (relative proportions of N, P_2O_5, K_2O)			Yield per plot	
							N	P_2O_5	K_2O	Grain	Stover
	Percent	*Percent*	*Percent*	*Precent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*
Check No. 1:											
July 6	2.960	0.307	2.387	5.654	2.308	0.934	76.804	4.719	18.477	165.4	117.1
July 21	2.210	.305	2.515	5.030	2.087	.966	70.361	5.753	23.886		
Aug. 8	1.800	.230	1.841	3.871	1.605	1.039	72.421	5.482	22.097		
Aug. 25	2.010	.316	1.608	3.936	1.999	1.216	75.087	6.993	17.920		
Lime No. 23:											
July 6	3.260	.582	.872	4.714	4.144	1.376	84.348	8.921	6,731	452.2	222.1
July 21	2.710	.568	.910	4.188	4.233	1.231	81.676	10.142	8.182		
Aug. 8	2.410	.474	.910	3.794	3.851	1.122	81.356	9.480	9.164		
Aug. 25	2.340	.524	.891	3.755	3.983	1.014	80.241	10.645	9.114		

In the following discussion it is necessary to refer continually to the content of, or the graph for, nitrogen, phosphoric acid, potash, lime, or magnesia of the selected leaf (third from the base) of plants growing on a particular plot. To avoid monotonous repetition and a cumbersome structure, the plot treatment or its symbol (check, N, P, lime, etc.), is used to refer to leaves from plants growing on the plot indicated.

NITROGEN

The graphs for nitrogen are unlike both in form and position; the graph of lime (No. 23) is higher than that of the check (No. 1) throughout the whole period. At the third sampling the difference is as great as 0.61 percent.

PHOSPHORIC ACID

The graphs for phosphoric acid are similar in form but not in position. The graph of lime (No. 23) is much above that of the check (No. 1) throughout the whole period, an indication that inhibition of

[2] Thomas, Walter. See footnote 3, page 685.
[3] Thomas, Walter, and Mack, Warren B. See footnote 2, page 685.

the absorption of P_2O_5 resulting from the medium (soil) has been removed by liming. The mechanism of this phenomenon has been described.[4]

POTASH

The graphs of potash are unlike both in form and position. The graph of lime (No. 23) is always much below that of the check (No. 1). During the early period the K_2O content of the selected leaf from plants on plot receiving lime (No. 23) is less than one-half that of the

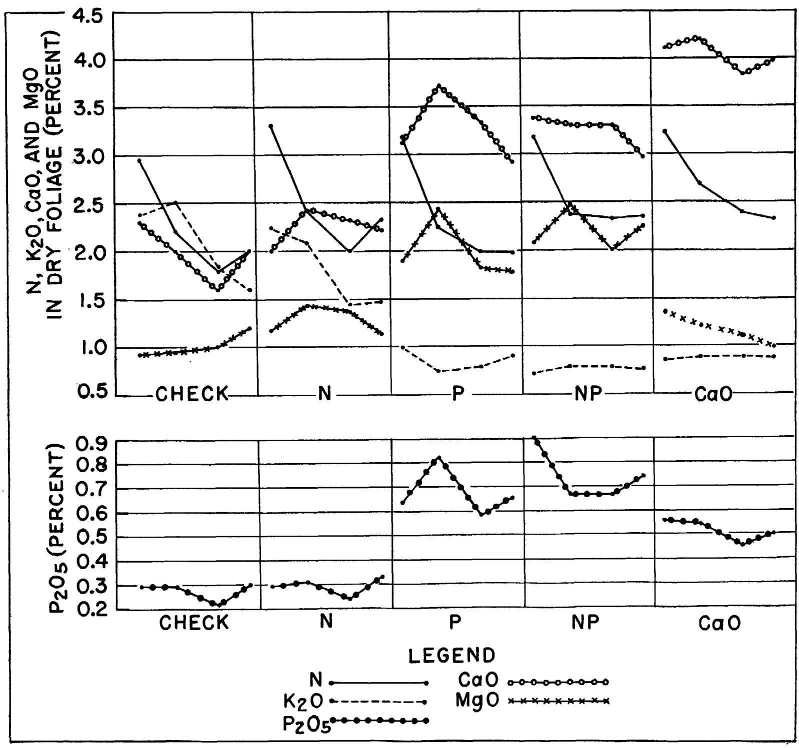

FIGURE 1.—The nitrogen, phosphoric acid, potash, lime, and magnesia content of the third leaf plotted as ordinates, and dates of sampling as abscissae. (The dates of sampling are July 6, July 21, August 8, and August 25, and are indicated by the four dots in each curve.)

selected leaf from plants on check plot (No. 1). Lime, consequently, has reduced the absorption of potassium by the plant, and the seat of this inhibition lies in the soil and not in the plant.

LIME

The graphs of lime differ in form and position. The graph of lime (No. 23) is very much higher than that of the check (No. 1) throughout the whole period, a reflection of the fact that certain functions of potassium can be performed by calcium when the former is deficient.[5]

[4] THOMAS, WALTER. PROPERTIES OF THE HYDROXYL GROUPS OF CLAY AS A BASIS FOR CHARACTERIZING A MINERAL SOIL. Soil Sci. 42: 243–259, illus. 1936.

[5] THOMAS, WALTER. MATHEMATICAL EXPRESSION OF EQUILIBRIUM BETWEEN LIME, MAGNESIA, AND POTASH IN PLANTS. Science 88: 222–223, illus. 1938.

MAGNESIUM

The graph of the check (No. 1) rises progressively, whereas that of lime (No. 23) falls progressively with the advancing age of the leaf. Such relative differences between import of Mg into the leaf and export from it are an indication that the demand by the plants on the former plot is always less, and on the latter always greater than the supply.

Indications Given by the Graphs Showing the NPK Units in Trilinear Coordinates

The composition of the NPK units at the various sampling dates is given in table 1. The mean intensity of nutrition and the mean

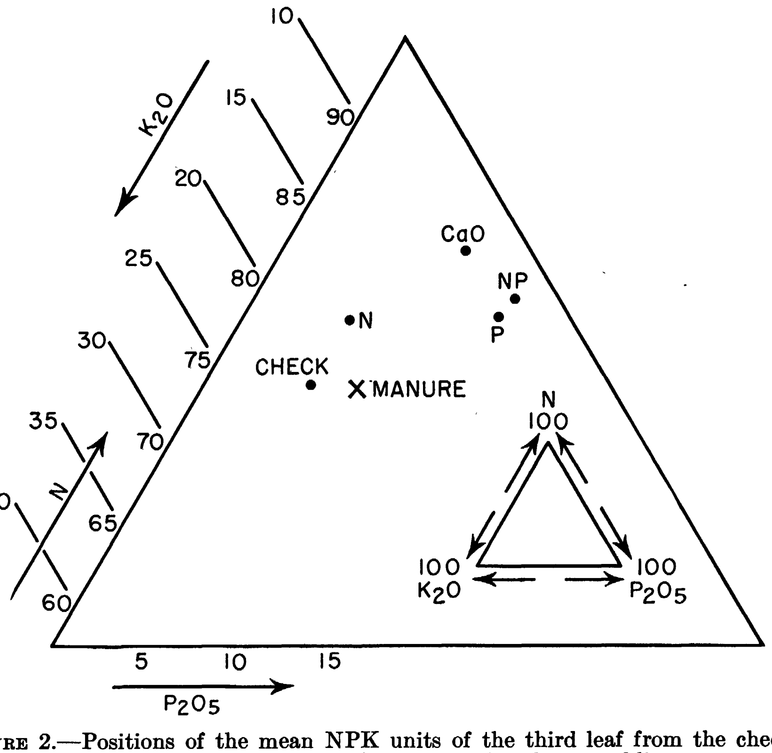

FIGURE 2.—Positions of the mean NPK units of the third leaf from the check plot, and from plots receiving dried blood, superphosphate, and lime, compared with that of the optimum (manure+CaO).

NPK units are given in table 2, and the latter are shown graphically in figure 2.

Liming reduced the intensity of nutrition by its effect in reducing the absorption of potassium. The effect of liming on the N—P_2O_5—K_2O equilibrium was to increase the nitrogen of the NPK unit at the the expense, principally, of the potassium.

In figure 2 the position of the mean NPK unit of the treatment resulting in the highest yields of the plots on tier 1, namely manure+CaO, is marked by a cross (×). Check (No. 1) has a lower intensity than has manure+CaO (No. 22), with insufficient P_2O_5 and a slight excess of K_2O in the NPK unit. Lime alone resulted in reducing the intensity below that of the check (No. 1). The notable effect of liming is on the composition of the NPK unit, the K_2O of which is reduced from a value of 20.595 in the check plot (No. 1) to 8.298 in the lime plot (No. 23), and the P_2O_5 increased by more than 70 percent.

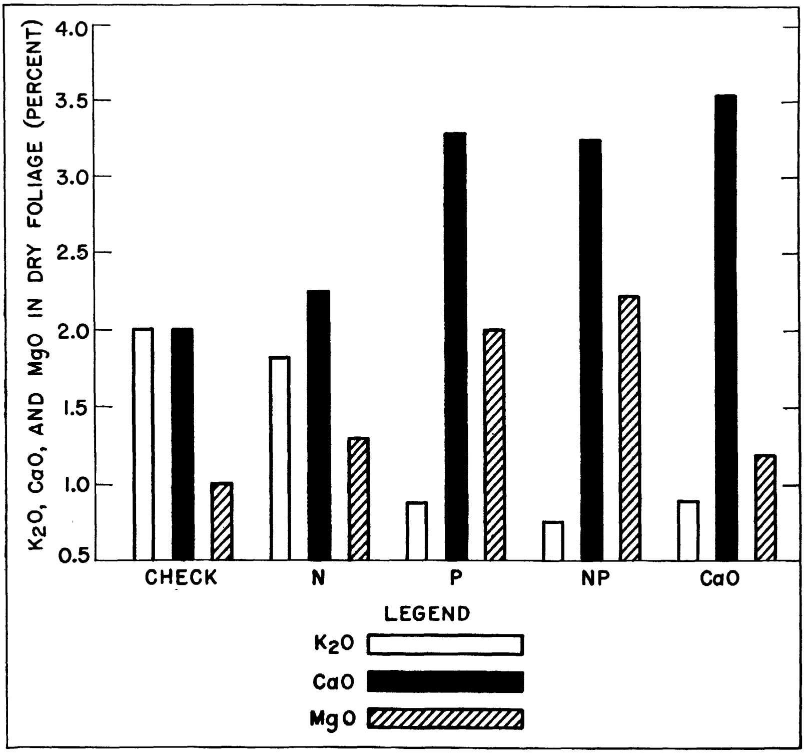

FIGURE 3.—The mean content of potash, lime, and magnesia, respectively, of the third leaf of plants from the check plot, and from the plots receiving dried blood, superphosphate, and lime.

TABLE 2.—*The mean intensity of nutrition, the mean NPK unit and yield of plot No. 1 (check) and plot No. 23 (lime), and plot No. 22 (manure)*

Plot No.	Treatment	Intensity of nutrition	Composition of the mean NPK unit [1]			Yield of grain per plot
			N	P_2O_5	K_2O	
			Percent	*Percent*	*Percent*	*Pounds*
1	Nothing	4.62	73.668	5.737	20.595	165.4
23	Lime	4.11	81.905	9.797	8.298	452.2
22	Manure	5.88	73.376	8.234	18.390	770.8

[1] The values of the mean intensity of nutrition and of the mean NPK unit for the respective treatments are the mean of the values for the intensities and NPK units, respectively, at the four dates of sampling recorded in column 5 and in columns 8, 9, and 10 of table 1.

COMPARISON OF THE FOLIAR DIAGNOSIS OF PLANTS GROWING ON PLOTS P (NO. 3), NP (NO. 5) AND LIME (NO. 23) WITH THAT OF CHECK PLOTS (NO. 1) AND N (NO. 2)

INDICATIONS GIVEN BY THE GRAPHS SHOWING THE PERCENTAGE OF N, P_2O_5, K_2O, CAO, AND MGO AS ORDINATES AND DATES OF SAMPLING AS ABSCISSAE

The K_2O graphs of P (No. 3), NP (No. 5), and lime (No. 23) are characterized by relatively small changes with advancing age of the leaf. The K_2O graph for lime (No. 23) differs but little either in form or position from the graphs for K_2O of P (No. 3) and of NP (No. 5), which are the lowest of any treatments in tier 1.[6] The comparisons are brought out better in table 3 and figure 3, which show the mean percentage composition with respect to K_2O, CaO, and MgO, respectively, at the four sampling dates.

TABLE 3.—*Comparison of the foliar diagnosis and yield of plants on the P plot (No. 3), NP plot (No. 5), and lime plot (No. 23) with check plot (No. 1) and N plot (No. 2)*

Plot No.	Treatment	K_2O	CaO	MgO	Yield of grain per plot
		Percent	*Percent*	*Percent*	*Pounds*
3	P	0.87	3.29	2.00	371.2
5	NP	.75	3.26	2.23	376.7
1	Nothing	2.09	2.00	1.03	165.4
2	N	1.82	2.26	1.29	265.6
23	CaO	.89	3.55	1.18	452.2

The addition of phosphate only and also of phosphate combined with nitrogen (NP) has resulted in a reduction of the potash content of the leaf by one-third of the values found in the check (No. 1) and also in N (No. 2). Liming has produced effects quantitatively similar. The conclusion is that the element common to both treatments—calcium—is the causal factor.

LIME AND MAGNESIA

In a preceding paper,[6] it was shown that the CaO graphs of P (No. 3) and also of NP (No. 5) were much higher than that of any of the other treatments without lime, viz. (check, N, K, NK, PK, NPK), and that throughout the whole period, the CaO content of the leaf from plots receiving superphosphate without potash (P, NP), were only slightly lower than the CaO content of the leaf from the limed plot, whereas the MgO content was actually greater. McIntire [7] stated many years ago that—

> the application of phosphorus in the form of dissolved bone black (used as the carrier of phosphorus prior to 1890) carries at least one-half as much $CaSO_4$ as is applied on plat 33 (gypsum only), and it is possible that part of the increase upon the phosphorus treated plats is due to the lime or sulphur in the gypsum contained in the dissolved bone material * * *.

But the element sulphur is not present in the lime added to plot No. 23, which fact eliminates this factor from consideration here.

[6] THOMAS, WALTER, and MACK, WARREN B. See footnote 2.
[7] MCINTIRE, W. H. RESULTS OF THIRTY YEARS OF LIMING. Pa. Agr. Expt. Sta. Ann. Rept. 1911-12: 64-75. 1913. See p. 71.

The writers indicated in the previous paper[8] that the CaO and MgO graphs of plots PK (No. 7) and NPK (No. 9) which received both superphosphate and potash were below those of plots P (No. 3) and NP (No. 5) which received superphosphate without potash. Their findings give additional confirmation of the reciprocal effects of potassium and calcium and of the fact that the seat of this influence is located in the soil and not in the plant.

Indications Given by the Graphs Showing the NPK Units Plotted in Trilinear Coordinates

The mean intensities and the mean NPK units of the third leaf are shown in table 4 and graphically in figure 2. The calcium of superphosphate has had a depressing effect on the intensity of nutrition (table 4, column 3) just as lime has had.

The mean NPK units (fig. 2) of plots P (No. 3), NP (No. 5), and lime (No. 23) are displaced relatively higher up and farther toward the apex of the triangle representing $P_2O_5=100$ percent than the others, indicating a low K_2O and a high P_2O_5 in the NPK unit.

The relative positions of the check plot (No. 1) and of the plot receiving manure + CaO (No. 22), the lowest and highest yielding plots, are interesting. The composition of the NPK units with respect to N is nearly identical in both; with respect to K_2O the difference is not very great. The great differences in the yields of these two treatments are associable with relatively large differences in the intensity of nutrition and in the composition of the NPK unit with respect to P_2O_5 which is nearly 50 percent higher in plot receiving manure (No. 22).

Table 4.—*Comparison of the mean intensities of nutrition, mean NPK-units, and yield of P (plot No. 3), NP (plot No. 5), and lime (plot No. 23), with nothing (plot No. 1) and N (plot No. 2)*

Class order	Plot No.	Treatment	Intensity of nutrition	Composition of the NPK units			Yield
				N	P_2O_5	K_2O	
				Percent	*Percent*	*Percent*	*Pounds*
3	3	P	3.97	77.84	13.64	8.52	371.2
	5	NP	4.13	78.84	13.92	7.24	376.7
4	1	Nothing	4.62	73.67	5.74	20.59	165.4
	2	N	4.67	77.62	5.77	16.61	265.6
2	23	Lime	4.11	81.90	9.79	8.29	452.2
1	22	Manure	5.88	73.38	8.23	18.39	770.8

The importance of P_2O_5 is shown by the P plot (No. 3) as compared with the check plot (No. 1). A reduction of P_2O_5 in the NPK unit from 13.64 to 5.737, or approximately 58 percent, brought about a reduction in yield of grain, regardless of the simultaneous increase of K_2O in the NPK unit from 8.52 to 20.595, or approximately 142 percent, which occurred principally at the expense of the P_2O_5, though to a lesser extent at the expense also of the N in the NPK unit.

[8] See footnote 2, p. 685.

(C) THE RECIPROCAL EFFECTS OF CALCIUM AND POTASSIUM

The absorption of an element does not depend only upon the quantity of that element in the fertilizer, but on its quantitative relations to the other elements, even if there is not an absolute deficiency of them. Conclusions cannot, therefore, be drawn with respect to the nutrition of a plant from experiments in which the quantity of a single fertilizer element applied to the soil is the variable.

The addition of calcium in the form of superphosphate or in the form of lime lowers the level of nutrition with respect to potassium, producing very low values for K_2O in the NPK units. The causes lie in the changes in the equilibrium between K and Ca in the medium (soil), which result in a lower concentration of potassium in the soil.[9] This condition is reflected by the leaf with great sensitivity. Hence, in passing from a plot in which calcium dominates over potassium to a plot in which potassium dominates over calcium, the leaf faithfully reflects this inversion.

The effect on yields depends upon the level to which K or Ca has been reduced in the leaf. The mean K_2O content of the leaf in the optimum treatment—manure+CaO (No. 23)—is 2.44 percent, and the addition of calcium to the fertilizers on other plots, whether as superphosphate or as lime without potash additions, has reduced the level of K_2O in the leaf considerably below this optimum level. This reduction is a causal factor contributing to the reduced yields.

Thus through a deficiency of the medium (soil) in a certain element, the plant reacts by increasing the absorption of another element—an indication of the great changes possible (plasticity) in the composition of the plant.

SUMMARY

The nutrition of *Zea mays* growing on long-continued fertility plots receiving calcium from two sources, lime and superphosphate, is compared with that of plants on (1) a check plot receiving no fertilizer and no lime, (2) an unlimed plot receiving nitrogen only without superphosphate or potash, and (3) unlimed plots receiving superphosphate and potash with and without nitrogen (NPK, PK).

The results are recorded by means of graphs showing (1) the percentages of N, P_2O_5, K_2O, CaO, and MgO (as ordinates) and dates of sampling (as abscissae), and (2) the equilibrium between N, P_2O_5, and K_2O and the intensities of nutrition at the moment of sampling.

The effects of calcium from the two sources, lime and superphosphate, were similar, resulting in increased absorption of native soil nitrogen and depressed absorption of native soil potassium as well as of added potassium, with concomitant increases in the absorption of calcium and magnesium.

Calcium from both sources reduced the intensity of nutrition with respect to nitrogen, phosphoric acid, and potash ($N+P_2O_5+K_2O$) and also lowered the K_2O in the NPK unit from 20 to 8 (in round numbers).

Liming resulted in an increase in the nitrogen of the NPK unit and in a relatively great increase in the P_2O_5 made at the expense, principally, of the potash.

[9] THOMAS WALTER. THE DISTRIBUTION AND CONDITION OF THE POTASSIUM IN A DIFFERENTIALLY FERTILIZED HAGERSTOWN CLAY LOAM SOIL PLANTED TO APPLE TREES IN CYLINDERS. Jour. Agr. Research 53: 533–546. 1936.

The yields of grain from the different treatments are classed in relation to the intensities of nutrition and the composition of the mean NPK units.

The lowest yields of grain are associated not with treatments (check, dried blood) having the lowest intensity of nutrition, but with the lowest P_2O_5 in the NPK unit. A reduction of 58 percent in P_2O_5 in the NPK unit of the check as compared with P brought about a reduction in yield of grain not offset by the accompanying increase of 142 percent in K_2O in the NPK unit which occurred at the expense, principally, of P_2O_5.