MATHEMATICAL EXPRESSION OF EQUILIBRIUM BETWEEN LIME, MAGNESIA AND POTASH IN PLANTS[1]

THE existence of a relationship between calcium, magnesium and potassium with respect to their absorption by plants has been suggested by many investigators. Loew[2] maintained that plants require a definite CaO/MgO ratio in their medium; Ehrenberg[3] enunciated his so-called "potash-lime law"; and Wiegner and Müller[4] deduced a relationship between calcium and potassium in the soil solution from conditions governing their equilibrium in the exchange complex.

The final truth, however, regarding the nature of the adaptability of the nutritive medium (soil) to the needs of the plant must lie in the mathematical description of the physiological processes within the plant itself. From this point of view, mathematical expression for the physiological relationships between certain elements ("entities") and plant response have been sought, expressible in terms of simple laws.[5,6]

In continuance of our investigations on foliar diagnosis[7] Plot 22, Tier 1, of the Jordan fertility field experiments has received since 1881 manure at the rate of 6 tons per acre applied to corn and wheat in a four-year rotation and has been limed at the rate of 2 tons per acre every four years. This treatment has given the highest yields on this Tier 1. In 1936 the yield of corn was 770.8 pounds per one eighth-acre plot. The plants on this manure plot, therefore, may be considered well nourished and near optimum for the soil and climatic conditions of this region.

In Fig. 1 is plotted in trilinear coordinates a magnitude designated the *CaMgK-unit,* representing the equilibrium between CaO, MgO and K_2O at the moment of sampling. It is derived by converting the percentage composition for CaO, MgO and K_2O of the third leaf into milligram equivalent (m.e.) values, and determining the proportion each of these bears to the milligram equivalent total. To avoid fractions, these values are multiplied by 100. The treatments indicated are of plants growing on the manure plot (Plot No. 22), together with six plots treated as follows: namely, nothing (Plot No. 1); nitrogen (Plot No. 2); superphosphate (Plot No. 3); potash (Plot No. 4); nitrogen + phosphate + potash (Plot No. 9); and lime (Plot No. 23). The numerals 0, 1, 2, 3, 4,

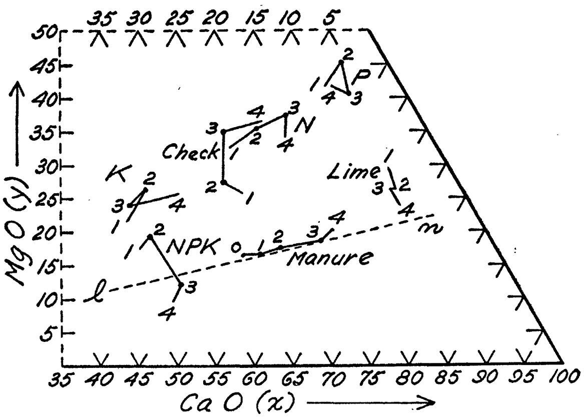

FIG. 1. Showing the deviations from the optimum physiological balance between lime, magnesia and potash in seven differently treated plots.

indicate the coordinate points for the dates of sampling, June 16, July 6, July 21, August 8 and August 25, respectively, in 1936. The straight (broken) line marked *ln* in Fig. 1 has been formed by joining the coordinates (see columns 1 and 2, Table I) for the values obtained at the second and fourth samplings, taken on July 6 and August 8, respectively, of leaves of the same metabolic age from plants growing on the optimum (manure) plot. *The equation of this line is* $y = 0.305\,x + 0.505$. The values from June 16 to August 8 lie sensibly on this line, deviation from which commences only at the last sampling date, August 25, with the incipience of chlorophyll degeneration.

Since, by our procedure[8] the sum of the values of any coordinate point $(x + y + z)$ is equal to 100, and inasmuch as $y = mx + b$, it follows that any two of these variables are related by a linear equation. The deviation of experimental values calculated from the above equation is shown in the last column of Table I.

TABLE I

EXPERIMENTAL VALUES AND VALUES CALCULATED FROM THE EQUATION REPRESENTING THE EQUILIBRIUM BETWEEN CAO – MGO, AT FIVE SUCCESSIVE DATES OF SAMPLING FOR PLANTS GROWING ON THE MANURE PLOT

Dates of sampling	Experimental values		Calculated values	Relative deviation
	MgO (y)	CaO (x)	CaO (x_1)	$\frac{x - x_1}{x}$
June 16 ..	15.600	50.245	49.492	+ 0.015
July 6 ..	16.561	52.632	52.632	0
July 21 ..	17.238	54.463	54.865	– 0.008
Aug. 8 ..	18.634	59.427	59.427	0
Aug. 25 ..	20.105	60.395	64.262	– .063

The yield of grain from the five unlimed plots are: nothing (Plot No. 1), 165.4 pounds; nitrogen (Plot No. 2), 265.5 pounds; phosphate (Plot No. 3), 371.2 pounds; potash (Plot No. 4), 298.3 pounds; nitrogen + phosphate + potash (Plot No. 9), 520.2 pounds;

[1] Authorized for publication as Paper No. 838 in the Journal Series of the Pennsylvania Agricultural Experiment Station.

[2] Oscar Loew, *Flora*, 75: 368–394, 1892.

[3] Paul Ehrenberg, *Landw. Jahrb.*, 54: 1–159, 1919.

[4] G. Wiegner and K. W. Müller, *Ztschr. Pflanzenernähr. Düngung n. Bodenk.*, (A) 14: 321–347, 1929.

[5] H. Lagatu and L. Maume, *Compt. Rend.*, 179: 782, 1924.

[6] Walter Thomas, SCIENCE, 84: 422–423, 1936.

[7] Walter Thomas, *Plant Physiol.*, 12: 571–600, 1937.

[8] *Ibid.*

and from the limed plot (Plot No. 23), 452.2 pounds.

The deviation from the optimum (broken) line with respect to position, form and length between sampling dates shows in each case the nature of the disequilibrium between CaO-MgO-K_2O resulting from the different treatments.

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SCIENTIFIC APPARATUS AND LABORATORY METHODS

AN INEXPENSIVE SURFACE TENSIOMETER[1]

LLOYD and Scarth (SCIENCE, 64: 253, 1926) devised a simple and cheaply made tensiometer which combined the ring method of measuring surface tension with the essential mechanism of a chainomatic balance.

In our own laboratory we have made a few improvements on their device for measuring surface tension, improvements worth offering to instructors with classes too large for duplication of the excellent but comparatively expensive Du Nouy tensiometer. It is even possible that many research workers may find this apparatus in its improved form adequate for their needs.

The total cost of materials is less than one dollar if a nickel wire ring is made, and not more than three dollars if a standard platinum ring is purchased. Any chemist can build this tensiometer in a few hours.

The accuracy possible is rather astonishing. Readings within 0.1 dyne of the true values for pure liquids have been made by our own students.

The diagram will indicate the general features. Instead of using a single thin strip of bamboo for the balance lever (as advised by Lloyd and Scarth), we now obtain greater stiffness, and a desirable length with light weight, by connecting two bamboo strips, approximately 35 cm long, with two strips 5 cm long placed near the mid-point. The long strips of bamboo are bent sufficiently to permit tying together with strong thread or thin wire at the ends.

Between the two short bracing strips is placed a thin sheet of aluminum, approximately 0.7×3 cm, to serve as a fulcrum rest. The aluminum strip is twisted at the ends to grasp the short bracing strips of bamboo and is smoothly creased in the middle to give a resting place on the razor edge. We have considerably increased the delicacy of beam movement by using a safety razor blade as fulcrum. Of course this blade is firmly attached to the substantial wooden support (at the left). A strip of metal, bent at a right angle and perforated for two screws, makes a good support. Two very light wire hooks are attached to the ends of the beam or balance arm—one as support for the wire ring and the other as point of attachment for one end of the chain.

The ring may be purchased or shaped from platinum or nickel wire (24–28 gauge) by bending around a glass tube of approximately 1.3 cm diameter. Of course, a length of this wire extends almost vertically about 3 cm as a "handle" or arm of the ring. A small loop shaped at the end permits the ring to swing freely from the end of the beam. Platinum rings are best, yet nickel rings are almost as good. It is not difficult to weld two platinum supporting wires to meet above the ring.

In our laboratory we have found the light aluminum chain attached to ten-cent jewelry (Woolworth's and others) to be very suitable for this tensiometer. This chain is extended in length with a piece of strong thread which passes through a small metal ring (or screw-eye) near the top of the vertical board. Near the bottom of the board this thread is wound around a wooden cylinder (half of a common spool or a wooden drawer knob) so attached to the board that it turns stiffly when desired. The smaller the links in the chain the more accurate the readings.

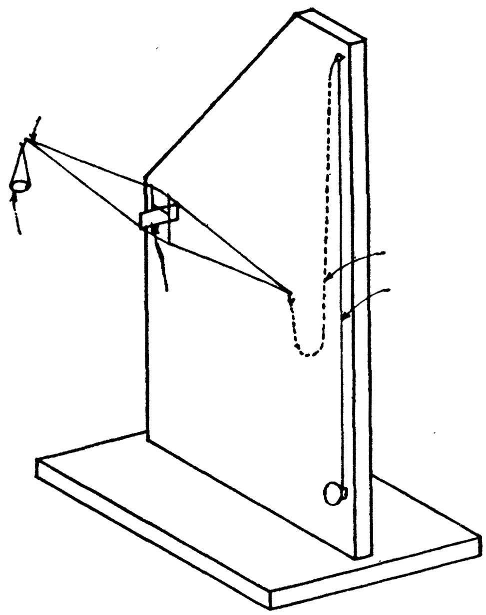

FIG. 1

After trying various lengths of beam to secure the best combination of lightness, stiffness and accuracy, we decided that a length of about 35 cm was most desirable.

The wooden support for the moving parts consists of two common boards nailed together at right angles, as shown in the diagram. A maximum height of 55

[1] Several students have offered useful suggestions, notably Malcolm Keiser and Croom Beatty.