Recent developments in plant physiology suggest possible new techniques for rapidly determining how well a crop is growing at various times in the season. Measurements of physiological activities of growing plants such as photosynthetic CO_2 uptake by leaves might be used to detect whether a crop was growing below its maximum potential rate, enabling the farmer to correct an agronomically controllable problem before crop losses were incurred. This report discusses the feasibility of such an approach and presents experimental data on the effects of deficiencies of phosphorus, potassium, magnesium, calcium, and manganese on various physiological attributes of sugar beets.

Instant assessment

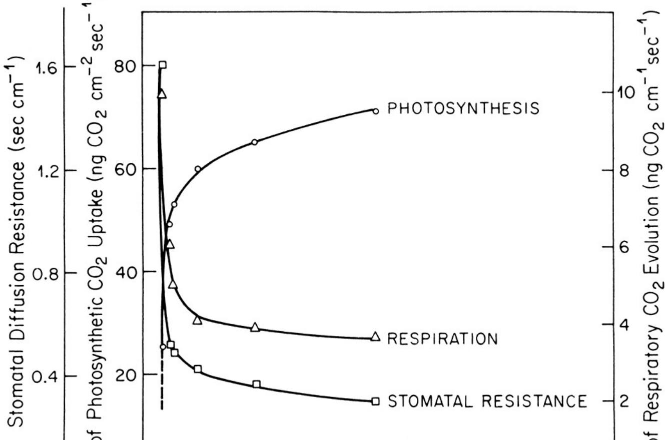
CROP

FARMERS WOULD benefit considerably if they could determine whether a crop was growing below its maximum potential rate at any point during the season. Assuming that a diminished crop performance could be controlled by agronomic means, the farmer would then be able to take remedial action well before actual crop losses were incurred. In the past, it has only been possible to assess how well a crop is growing by taking laborious measurements of some attribute such as plant height, numbers of leaves, or plant weight. These measurements are time-consuming, because they have to be made sequentially over a fairly long interval of days or weeks. A more rapid bioassay is needed which would permit results within minutes or hours.

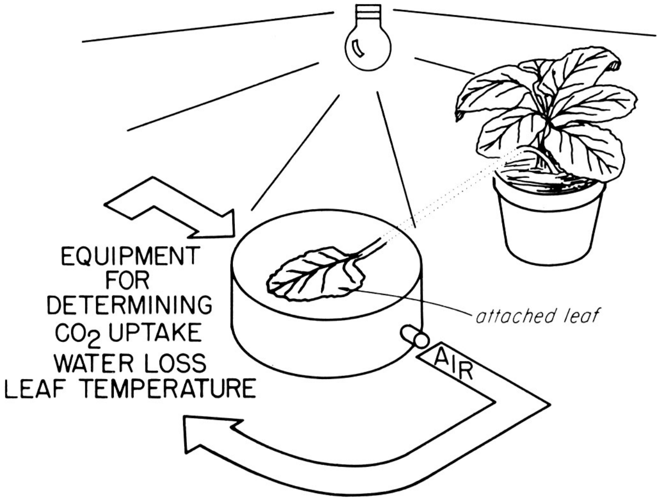
In recent years much progress in the field of photosynthesis has been made. Scientists are now able to remove the tiny organelles which carry out photosynthesis (chloroplasts) from the leaf and get them to function in a test tube. They can also determine accurately the rate at which whole leaves, still attached to the plant, photosynthesize carbon dioxide. Photosynthesis, or some part of the photosynthetic process, might serve therefore as a bioassay of crop condition.

The practical problems of determining the rate of photosynthetic CO_2 uptake for selected leaves of a crop in the field are not great. Portable equipment has already been developed, and, given the present state of technology, such equipment could be produced commercially. In a crop such as sugar beet, photosynthetic CO_2 uptake is remarkably constant from plant to plant for leaves of similar maturity, provided that the leaves are around 20 to 30°C, saturated with light, and well supplied with nutrients and water. A lowering of the photosynthetic rate from the maximum could be reliably detected and would indicate that some environmental factor was having a detrimental effect on plant metabolism.

Nutrition is one such factor that can be controlled agronomically. The experiments reported here studied the way in which plant nutrients influence photosynthesis and other physiological activities such as respiration and stomatal opening. The plants were cultured hydroponically in growth chambers under constant conditions of light intensity, temperature, and day-length. About four weeks after germination the plants were subjected to nutrient cut-off—the nutrient element un-



CHANGES IN PHOTOSYNTHESIS, RESPIRATION AND STOMATAL DIFFUSION RESISTANCE WHICH OCCUR WITH INCREASING POTASSIUM DEFICIENCY
(Decreasing leaf blade potassium concentration indicates that leaves are becoming more potassium deficient)



Leaf, still attached to the plant, is enclosed in a chamber and maintained in a constant environment of 25° C, 10,000 ft. c. illumination, and 85% relative humidity. Air is passed through the chamber over the leaf, and the rate of CO_2 taken up by the leaf (photosynthesis), the rate of water vapor evaporated from the leaf (transpiration) and leaf temperature are continuously monitored. From these measurements stomatal diffusion resistance may be computed and a measure thus obtained of the degree of opening of the pores (stomata) in the leaf surface.

techniques for
PERFORMANCE

NORMAN TERRY

DEFICIENCY EFFECTS ON THREE PHYSIOLOGICAL ATTRIBUTES OF SUGAR BEET LEAVES

Nutrient element	Blade concentration[1] (ppm)		% Change in physiological attributes with decrease in blade nutrient concentration to the critical level[2]		
	Visible symptoms	Critical level	Photosynthetic[3] CO_2 uptake	Respiratory[4] CO_2 output	Stomatal[5] resistance
K (> 1.5% Na)	3000–6000	10,000	–21	+ 28	+ 80
K (< 1.5% Na)	4000–5000	10,000	–44	+ 77	+240
P	500–1000	2,000	–34	—	+ 72
Mn	4–20	10	–48	0	0
Mg	250–500	1,000	–25	+105	0
Ca	1000–4000	5,000	+15	0	0

[1] Data obtained from Ulrich, A. and F. J. Hills (**Sugar beet nutrient deficiency symptoms. A color atlas and chemical guide.** Berkeley: University of California, Division of Agricultural Science, 1969).

[2] Percentage change as compared to values obtained for standard-grown control leaves.

[3] Rate of photosynthetic CO_2 uptake per unit area of leaf surface.

[4] Rate of respiratory CO_2 output per unit area of leaf surface in darkness.

[5] Resistance (mainly stomatal) to the diffusion of CO_2 from the external leaf surface to the surfaces of the mesophyll cell walls.

der study was withheld from the culture solution so that the plant became deficient in that element. The changes in dry weight, photosynthesis, respiration, leaf area, leaf minerals, chlorophyll content and the enzyme activities of chloroplasts isolated from leaves were followed with time after cut-off. The leaf chosen for study is usually about 150 to 300 cm^2 and is the largest of the rapidly-growing young leaves.

The measurement of CO_2 uptake or output and of transpirational water loss was conducted in a specially-constructed leaf chamber apparatus (see sketch), so that the leaf remained attached to the plant. At the end of the 24-hr experiment, the leaf was picked, to obtain the concentrations of the main elements within the leaf. The enzyme systems were studied by isolating the chloroplasts from a similar leaf taken from a plant cultured in the same environment.

The kinds of changes which occur with increasing deficiency are shown in the graph. As the potassium concentration in the leaf blade decreased from 6% to 1% dry weight, the photosynthetic rate per unit area diminished slowly. The level of 1% of potassium in the blade is known as the critical level, the concentration of nutrient element at which there is a 10% reduction in plant growth rate from the optimum. At this level photosynthesis had decreased by about 21%; below it, photosynthetic rates decreased much more precipitously. The rate of CO_2 output per unit leaf area in the dark, which is a measure of "dark" respiration, increased by 28% as leaf potassium decreased to the critical level. Stomatal diffusion resistance, an indication of the degree of stomatal opening, also increased as the leaf potassium decreased (i.e., the stomata tended to close). Stomatal resistance increased by 80% as the leaf potassium declined to the critical level.

The data presented in the graph are for plants well supplied with sodium. If sodium was also withheld, the effects of potassium deficiency on the plant were more severe. Photosynthesis, for example, was diminished by 44% as leaf potassium decreased to the critical level, while respiration and stomatal diffusion resistance were increased by 77 and 240%, respectively. These physiological attributes were more sensitive indicators of potassium deficiency than were visible symptoms, which are not exhibited until leaf blade potassium reaches as low as about 0.3 to 0.5%.

In the case of phosphorus deficiency, visible symptoms were obtained at leaf phosphorus levels of 0.05% to 0.1%. Photosynthetic CO_2 uptake, however, was decreased by one-third, with decrease in leaf blade phosphorus to the critical level of 0.2%. Respiration rates were not affected in a systematic way by phosphorus deficiency, while stomatal resistance had increased by 72% at the critical level. It might be concluded that if the sugar beet crop were suffering from phosphorus deficiency, it might well be possible to detect this from the rates of photosynthesis or from effects on stomata.

Visible symptoms of magnesium deficiency are not obtained until the magnesium concentration in the leaf blade decreases to 250 to 500 ppm. Photosynthesis decreased by 25% at the critical level, and was therefore quite sensitive to magnesium deficiency. Respiration increased with decrease in leaf magnesium, while stomata were scarcely affected.

The data for manganese deficiency show that there was no change in either respiration or stomatal resistance with decrease in blade manganese from 275 to 5 ppm. The critical concentration for manganese in the blade is about 10 ppm and deficiency symptoms are exhibited from 4 to 20 ppm. Photosynthetic CO_2 uptake decreased markedly below 100 ppm and at the critical level (10 ppm) it had decreased by about 48% from the control rate. Photosynthesis could therefore be used as a sensitive assay of manganese deficiency.

In the case of calcium deficiency, however, photosynthetic activity increased by 15% when leaf calcium decreased from 1.5 to 0.3%. The increase was almost certainly due to an increase in the concentration of chlorophyll per unit area of leaf surface. Leaves below 0.3% leaf calcium were too distorted to measure CO_2 uptake in the leaf chamber, so the photosynthetic activities of the chloroplasts were examined. This was done by following the rates of activity of cyclic and non-cyclic ATP production, and the photo-reduction of an artificial electron acceptor, potassium ferricyanide, as well as the rate of CO_2 assimilation of the CO_2-fixing enzyme, ribulose-1,5-diphosphate carboxylase. However, even though the leaves were reduced in size by calcium deficiency to 12 cm^2, compared to 200 to 600 cm^2 for control leaves, the photosynthetic activity of the calcium-deficient chloroplasts was unchanged.

Dark respiration in calcium-deficient plants increased sharply when the blade calcium had decreased to about 0.4%. However, dark respiration is somewhat erratic in its behavior, and from the studies of elements so far conducted, it is unlikely to be of much use as a physiological assay. Stomatal diffusion resistance was unchanged by calcium deficiency, and it was concluded that visual symptoms coupled with tissue analysis probably was the most sensitive and reliable indicator of deficiency for calcium.

It is likely that photosynthetic CO_2 uptake is considerably reduced by potassium/sodium, phosphorus and manganese deficiencies; less by magnesium and potassium deficiencies; and not affected (on a per unit chlorophyll basis) by calcium deficiency. To determine phosphate deficiencies in crops, growers could, for example (through a technical service agency), sample leaves at random in a crop to determine whether photosynthetic rates were significantly below their maximum potential. If the rates were not low, there would be no need to apply phosphate fertilizer. If the rates *were* low, a determination would have to be made as to whether phosphate deficiency, or some other environmental factor, was causing the problem. At this point, other types of analysis would be needed—such as tissue and soil analysis—to complement the photosynthesis study.

Phosphate deficiency is a particularly good example of the usefulness of this approach, because visible symptoms of phosphorus deficiency in sugar beets do not become apparent until the blade phosphorus has decreased to 0.05 to 0.1%, whereas photosynthesis is reduced by a third by the time the blade phosphorus level has decreased to 0.2%. Thus phosphorus deficiency in sugar beets shows up first in photosynthesis, then growth, and lastly as visible symptoms. Also the advantage of measuring photosynthesis as compared with blade or petiole phosphate analysis is that it is a direct measure of plant metabolic activity. Even though tissue analysis may show the nutrient element concentration to be below the critical level, plant metabolism is not necessarily affected. Lower rates of photosynthesis would tend to confirm that the low level of phosphate was really damaging the plant.

There is another aspect of this problem which remains to be resolved. To what extent is photosynthesis actually related to crop yield? Even if it is determined that photosynthesis is below par for a crop in a particular environment, it is still unknown if the crop's productivity is actually limited by photosynthesis. Other factors may also be limiting: for example, the partitioning of photosynthate between the harvestable portion and other parts of the plant, or the expansion of the leaf surface.

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'CALIFORNIA'— a new fresh market

BEAUTY, TANTALIZING AROMA, and delicious flavor are combined in 'California,' a new pear soon to be available to California growers. The new cultivar, the result of an extensive and continuous pear-breeding program in the Department of Pomology at U.C. Davis, is expected to be used primarily as a fresh fruit dessert. In form, flavor, soluble solids content, season, and storage life, the fruit resembles Comice, but is distinguished by its more poignant aroma, freedom from russeting, and its color. The bright red on the side exposed to the sun harmonizes with the glistening yellows on the shaded areas, giving the fruit a strikingly attractive appearance. The originators feel that California will fill a need of the west coast pear industry for an excellent, productive, early- and annual-bearing fall and winter dessert pear.

The state of California produces about half of the nation's commercial crop of pears from 42,269 acres. The Bartlett cultivar occupies 95% of this acreage and produces 97% of the California crop. Bartlett bears early, heavily, and annually, and is generally well suited for fresh, canned, and dried fruit outlets. Bartlett has a short storage life, however, and must be canned or otherwise utilized during the summer or early fall months. Also, under certain cultural and climatic conditions, Bartlett develops only fair quality as a fresh dessert fruit.

In the other important pear-producing states, Oregon and Washington, Bartlett accounts for 42 and 65%, respectively, of the total pear crop. The remaining production in these states comes mainly from Comice, Anjou, and Bosc cultivars, all of which have relatively long storage lives, and are consumed as fresh fruits in late fall and winter. These cultivars have been tried in California, but their undesirable characteristics have resulted in constantly diminishing acreages. Anjou and Bosc attain only fair quality under California conditions, and both have a biennial bearing pattern. Comice is slow to come into bearing, and is also a biennial bearer. Its fruits have excellent quality, but are relatively unattractive because of their dull yellow skin, which is often partly covered with various amounts of russeting.

One of the objectives of the university's pear-breeding program was to develop an early, annual-bearing Comice-type pear with an attractive skin. This objective seems to have been attained with the introduction of California.

Development

The new cultivar resulted from pollinating the flowers on a Max-Red Bartlett pear tree (Plant Patent No. 741 of July 1, 1947) with pollen from a Comice (unpatented) tree on April 3, 1959. The seeds obtained from the resulting fruits were stratified during the winter of 1959–60 and planted in April 1960. When the seedlings bore fruits, one had commercially desirable characteristics. It was therefore selected for asexual reproduction and testing preparatory to patenting and introduction to the trade. California has been asexually reproduced by top-grafting on *Pyrus communis* pear seedling trees, and by budding into *P. communis* seedlings in the U.C. Davis orchards and nursery.