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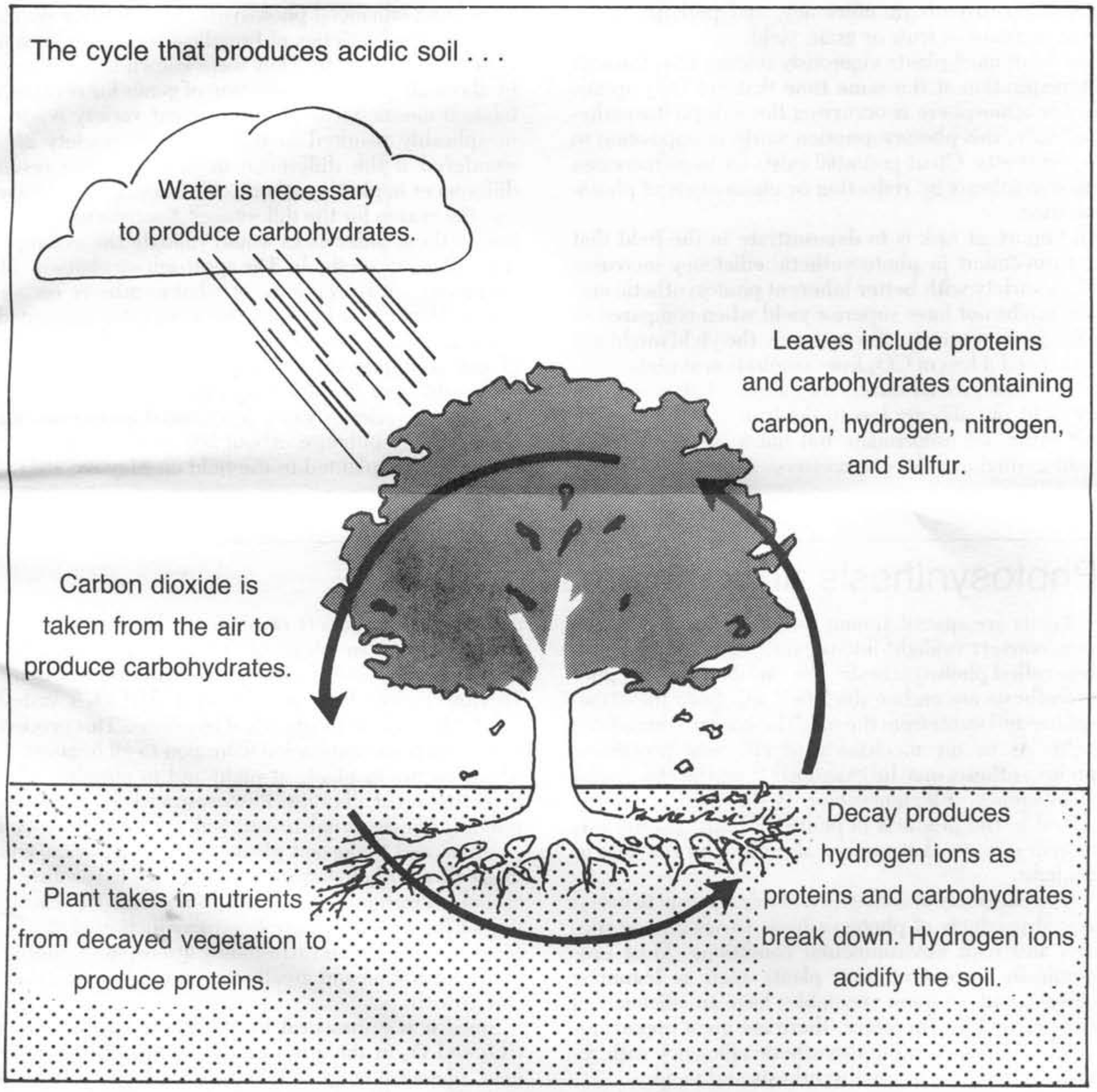

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION NEW HAVEN

Recognizing superior photosynthesis in crops in the field

By Richard B. Peterson and Israel Zelitch

Plant breeders have been successful in improving yields of crop plants by introducing pest and disease resistances and by increasing the proportion of total plant dry weight associated with the fruit or grain portion of the plant. The best evidence available, however, suggests that such improved varieties do not differ greatly in photosynthetic efficiency from their progenitors. At the Experiment Station, we are attempting to modify plants, improve photosynthetic efficiency, and perhaps create a large increase in fruit or grain yield.

Leaves of most plants vigorously release CO_2 through photorespiration at the same time that net CO_2 uptake from the atmosphere is occurring through photosynthesis. Clearly, this photorespiration works in opposition to photosynthesis. Great potential exists for large increases in photosynthesis by reduction or elimination of photorespiration.

An important task is to demonstrate in the field that an improvement in photosynthetic efficiency increases yield. A variety with better inherent photosynthetic efficiency might not have superior yield when compared to an unimproved variety. For instance, the yield might not be enhanced if loss of CO_2 from respiration at night were greater. An improved variety may accumulate more total dry weight but allocate less to the fruit or grain. Such a result would be unfortunate but not a failure. Further breeding might reduce necessary nighttime respiration or create optimal allocation of plant dry matter at the various stages of growth. Additional problems concerning the relationship between photosynthetic efficiency and yield arise from the fact that photosynthesis by single leaves in the field varies and depends strongly on such factors as leaf position, leaf angle, plant age, light intensity, and water status.

To develop a method for evaluating in the field varieties possessing enhanced photosynthetic efficiency we chose for study two varieties of broadleaf tobacco with similar genetic backgrounds. They were known to differ in yield by about 20%. The introduction of genes for resistance to tobacco mosaic virus into the parent variety (variety 1) inexplicably resulted in reduced yield (variety 2). We wondered if the difference in yield was the result of differences in photosynthetic efficiency. If not, then what was the reason for the difference? A satisfactory accounting for these differences would validate the assumptions implicit in our methods. The approach we chose involved numerous measurements of photosynthesis on single leaves of both varieties in the field. We attempted to account for accumulation of plant dry weight on the basis of net accumulation of carbon through photosynthesis minus that lost through respiration.

The two varieties were germinated and grown for six weeks in a greenhouse. About 200 seedlings of each variety were transplanted to the field on May 28, 1981. The

Photosynthesis and photorespiration

Plants are special among living organisms because they convert sunlight into organic materials by a process called photosynthesis. The raw materials for photosynthesis are carbon dioxide (CO_2) from the atmosphere and water from the soil. The energy comes from light. As in any mechanical or chemical processes, photosynthesis may be examined from the standpoint of efficiency. Efficiency here is the ratio of energy stored in the products of photosynthesis, mainly carbohydrates, to that energy absorbed by the leaf as sunlight.

The efficiency of conversion of solar energy to useful stored products of photosynthesis varies among species and with environmental conditions. Most economically important crop plants such as legumes, cereals, and common vegetables have an efficiency of only about 1%. Therefore, there are great opportunities for increases in photosynthetic efficiency with resultant increases in photosynthesis and yield.

Photorespiration occurs concurrently with photosynthesis in the leaves of many plants. Some of the early organic products of photosynthesis are broken down, resulting in release of CO_2 at the same time that CO_2 is being fixed by the photosynthetic reactions. This lowers overall efficiency since much CO_2 is wasted in a futile cycle of biochemical reactions. This process is distinct from respiration (common to all organisms) which occurs in plants at night and in nonphotosynthetic tissues at all times. Photorespiration is probably seldom, if ever, vital to survival of a plant. Several common and important plants such as sugarcane and maize do not photorespire and therefore have efficiencies of utilization of sunlight approaching 5%. Elevation of the CO_2 concentration or reduction of the O_2 concentration in the surrounding atmosphere inhibits photorespiration and greatly increases photosynthesis and growth.

Since it is impractical to manipulate the levels of CO_2 and O_2 in the atmosphere around plants in the field, chemical or genetic means are being sought to curb photorespiration and so enhance phototsynthetic efficiency.

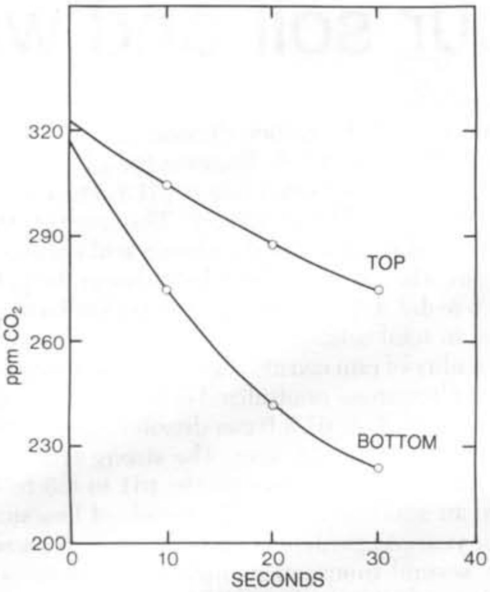

Figure 1. Time course of CO_2 depletion using the technique described for estimation of the rate of photosynthesis by a leaf of field-grown tobacco. The rates of CO_2 uptake by the upper and lower surfaces of the leaf were 8.6 and 14.3 mg $CO_2/dm^2 \cdot h$, respectively.

plants were spaced at six foot intervals, which is much wider than usual, to facilitate access to individual plants. The soil was well fertilized with commercial fertilizer. Moisture was provided mainly by rainfall but water was provided by irrigation during a drought in July. Measurements of photosynthesis started 22 days after planting in the field. Analyses ended after 35 days when the plants showed the first signs of senescence.

The estimates of the rates of CO_2 uptake by leaves were made by the CO_2-depletion technique. This method employs a small, hand-held, transparent chamber which clamps around a portion of a leaf enclosing about 100 square centimeters of leaf surface. The air trapped within the chamber is mixed by small battery-operated fans mounted in the chamber walls. Samples of the enclosed air are withdrawn at timed intervals using hypodermic syringes inserted through rubber septa in the walls. The decrease in the CO_2 content of the air inside the chamber yields an estimate of the photosynthetic rate of the leaf under ambient field conditions. A typical measurement is illustrated in Figure 1. Usually tobacco leaves are sufficiently large to completely separate the top half from the bottom half of the chamber, hence the CO_2 uptake rates of the bottom and top sides of the leaf are determined independently. Normally, the bottom of the leaf exhibits a higher photosynthetic rate than the top due to a greater number of stomata on the lower side. Stomata are small pores which allow gases like CO_2 and oxygen to pass into and out of the leaf. Also, stomata on the upper surface tend to close more readily at high temperatures and light intensities to minimize water loss.

The air samples withdrawn from the chamber were quickly analyzed with an infrared gas analyzer located in a nearby barn. The samples were injected into the analyzer which measures CO_2 by detecting absorbed infrared radiation. Up to 80 measurements of leaf photosynthesis were conducted in a day.

Table 1 shows the photosynthetic rate versus even numbered leaf positions for variety 2 on a typical overcast day (day 7) and a sunny day (day 20). Leaves were numbered on the plants from the bottom up. Axillary buds (suckers) were removed by hand as they appeared. The average photosynthetic rate at specific leaf positions is the average of several measurements made on five plants during the day. The rates are less at the lower leaf positions due to their greater age and because of shading by other leaves. The lowest leaves were sometimes respiring because of heavy shading. The photosynthetic rate for the entire leaf was estimated by multiplying the measured rate of CO_2 uptake per unit of leaf area times the leaf area. These two quantities clearly vary independently during the season and knowledge of both are necessary to assess the contribution of any given leaf to photosynthetic carbon accumulation. Much of the variability in CO_2 uptake per unit of leaf area in Table 1 arose from fluctuations in environmental conditions, particularly light intensity.

Since it was impossible to sample 24 hours each day during the growing season, a mathematical model was devised to permit estimation of net photosynthetic carbon input on any given day. The model was based on the assumptions that the daily total solar energy input and the age of the plant were the two most important factors determining carbon accumulation. As plants mature they have greater total leaf area, are able to intercept more sunlight, and hence carry out more photosynthesis. Solar energy was continuously monitored by a recording pyrheliometer near the field.

Measurements of CO_2 uptake were made on 18 of the 35 days during which about 90% of the final yield was accumulated. The individual estimates of CO_2 input into the various leaf positions on a given day were combined to produce an estimate of CO_2 input into a typical entire plant for each variety. Incorporation of these estimates of whole plant CO_2 input into the model enabled prediction of CO_2 inputs on any day simply by substitution of solar

Continued on Page 7

Table 1. Net photosynthetic CO_2 fixation rates at different leaf positions in a stand of field-grown tobacco on an overcast and on a sunny day.

	Rate of photosynthesis	
Leaf position	Day 7	Day 20
No.	mg $CO_2/dm^2 \cdot h$	
4	2	−3
6	8	10
8	6	20
10	3	28
12		22
14		32
16		28
18		17
20		20

Is acid rain harming our soil and water?

By Edward C. Krug and Charles R. Frink

Acid rain is not new. Microbial decomposition of plant residues and other organic materials produces oxides of carbon, nitrogen and sulfur that can then react with rain to produce carbonic, nitric and sulfuric acids. Indeed, the first chemical analyses of rain were begun about 1850 by botanists and agriculturists seeking the sources of nutrients used by plants. These studies were continued at a number of Experiment Stations and include detailed analyses of rain at our Valley Laboratory in Windsor during 1929-1948. These analyses showed that the nitrate resulting from reactions of nitrogen oxides with rain is a significant proportion of the total nitrogen available to crops, particularly range and forest lands that are not regularly fertilized. Sulfate produced by sulfur oxides in rain often exceeds the requirements of crops, except in a few areas of the world where soils are extremely deficient in sulfur.

Burning fossil fuels such as coal or petroleum that contain sulfur also produces sulfur oxides and acids, while high temperature combustion causes the nitrogen in air to react with oxygen to produce nitrogen oxides and acids. When wood and coal were major fuels, much of the acidity was apparently neutralized by soot and smoke. The soot and smoke, however, also caused local air pollution that became severe about 1950. Then, particle precipitators were installed in tall smoke stacks and, coupled with increased burning of petroleum, converted local smog into regional acid rain.

While there is little doubt that man has increased the acidity of rain in the Northeast to pH 4.3 to 4.4, there is doubt about its effects on soil and water. Many believe that an increase in acid rain is acidifying our lakes and streams, killing fish and gradually sterilizing our environment. From its inception the formation of soil is an acidifying process (cover). If undisturbed, the chemical and biological weathering of the granitic bedrock typical of much of the Northeast can produce some of the most acid soils in the world, namely podzols and their associated peats. In the Adirondacks and northern New England, the climax forests on such soils are generally conifers or mixed hardwoods and conifers which have always produced an extremely acid humus of about pH 3.5 on the forest floor. In Connecticut, however, our forests are mostly hardwoods, and their litter decomposes more readily. Thus, our soils here do not develop the classic podzol profile, although the humus layer is still acid with a pH of 4.0 or less. If these forested soils of the Adirondacks and New England, including Connecticut, are disturbed by lumbering, grazing, or burning, the acid humus layer disappears. Reforestation after such disturbances allows the natural processes of soil formation and acidification to begin anew.

To assess the impact of acid rain on soils, we look briefly at the chemistry of rain. Presently, rain in Connecticut has an average pH of about 4.3 to 4.4. Unpolluted rain in equilibrium with the carbon dioxide naturally present in air has a pH of about 5.6. Because the pH scale is logarithmic, it is often said that rain at pH 4.3 to 4.4 has been acidified twenty-fold from pH 5.6. This neglects the acidity of the weakly-dissociated carbonic acid normally present in rain. The strong acid needed to lower the pH of rain from 5.6 to 4.3-4.4 actually represents about a three-fold increase in total acidity.

The acidity of rain can also be expressed in terms of the amount of limestone neutralized or leached from the soil. A year of rainfall at pH 5.6 can dissolve about 400 to 500 pounds of limestone per acre. The strong acids added to rain by man that have lowered the pH to 4.3 to 4.4 can dissolve an additional 20 to 25 pounds of limestone per acre per year. As gardeners and farmers well know, soils require several thousand pounds of limestone per acre annually to counteract the acidification caused by biological oxidation of nitrogen fertilizers and decaying plant residues. Hence, damage to agricultural soils in Connecticut or elsewhere in the Northeast from acid rain seems highly unlikely.

Is acid rain damaging our

By Thomas M. Rathier

Does acid rain damage crops? If so, what does the damage look like and can it affect the appearance or yield of crops? Although popular reports on acid rain often mention damage to plants, there is little experimental evidence to confirm or deny such reports. Therefore, I performed an experiment using tobacco as the test crop.

I chose tobacco for two reasons. First, its leaves are sensitive to damage by ozone and other air pollutants. Second, much of the tobacco grown in Connecticut depends on the appearance of its leaves for its value: a single blemish can render a normally valuable leaf nearly worthless.

Acid rain was simulated by adding nitric and sulfuric acids to tap water to produce six treatments with "rain" at pHs of 2.0, 2.5, 3.0, 3.5, 4.0, and 5.6. Since the accompanying article shows that unpolluted rain has a pH of 5.6, and rain in Connecticut has an average pH of about 4.3 to 4.4., these treatments are drastic.

Each treatment was applied to the leaves of tobacco twice a week for one to five weeks. The plants were grown in containers with trickle irrigation to prevent irrigation water from washing the leaves, and the soil in the pots was covered to prevent the simulated acid rain from reaching the roots. The experiment was located outdoors at the Valley Laboratory in Windsor but in a plastic house to prevent natural rainfall from washing the treatments off the leaves.

To assess the potential damage to forest soils from acid rain, we first examine the history of the forests in the Northeast. The early settlers treated the seemingly endless forest in New England as an enemy and cleared much of it for crops. By 1790, less than 40% of Connecticut was forested, and by 1820, the virgin forests had virtually disappeared. The landscape in Connecticut must have been particularly dreary, causing the Secretary of the Connecticut Board of Agriculture to note that, in 1850, "even the hillsides have been rendered bleak by the removal of trees which formerly grew upon them."

Following the decline of logging of hardwoods, technology gave forestry in New England a new industry—paper. Although the virgin spruce and fir forests of the Adirondacks and northern New England were not particularly desirable for fuel or lumber, they were ideal for making paper. Initially, individual spruce trees were culled from the more accessible mixed forest of the valleys and lower slopes. As demand increased, the nearly pure stands of spruce and fir on the steep slopes were clear-cut. This cutting was often followed by fire, which largely destroyed the original thick layer of humus.

Fortunately, the forests were sufficiently resilient that the trees began to return to logged-over land. Also, trees invaded old fields as farmers migrated to the new lands to the west.

By 1900, changes in land use in Connecticut were so dramatic that Station scientists established plots to determine the effects of planting red pine on abandoned corn and tobacco fields. In 1929, Lunt of this Station found that an organic horizon had developed under the pine, and its pH was about 4.4. By 1944, the forest floor had thickened and its pH had decreased to about 3.8. Thus, in less than 50 years, the normal process of soil formation had acidified the surface of the soil well below the pH of today's acid rain.

Other plots were established in 1926-1927 by Hicock and colleagues to study changes in Connecticut's then young hardwood forest. While protected from cutting and burning, these forest plots have suffered varying degrees of mortality from disease, drought, and defoliation. Consequently, the forest on specific plots is now older, of

ops?

Damage was visible only on the plants receiving the most acidic rain at pH 2.0. Lesions began as small yellow or light green spots and progressed to bleached dead spots that enlarged with repeated applications. Continued application of the "rain" at pH 2.0 completely destroyed the tissue and caused a shot-hole appearance (Figure 1). Those receiving two applications per week for five weeks were the most dramatically affected, whereas those receiving only two applications for one week showed no additional damage after applications ceased. Damage increased from about 30% of the leaves after two applications of pH 2.0 rain to 97% after ten applications. No treatments at any pH affected the total dry weight of the plants at the end of the experiment.

Although the lesions produced by treatment with acid rain at pH 2.0 can be confused with those produced by ozone, ozone damages regions of the leaf where stomata have recently become functional, and symptoms appear first on the interior leaf tissue and progress outward. Damage from acid rain occurs only where water gathers for extended periods, and the damage progresses from the exterior to the interior tissues. It has been suggested that acidic water droplets remaining on leaves might evaporate and thereby concentrate their acidity. In my experiment, all treatments had a similar opportunity to evaporate on the leaves, but again, damage occurred only with rain at pH 2.0.

Since rain in Connecticut has an average pH of 4.3 to 4.4, the likelihood of damage to crops is remote.

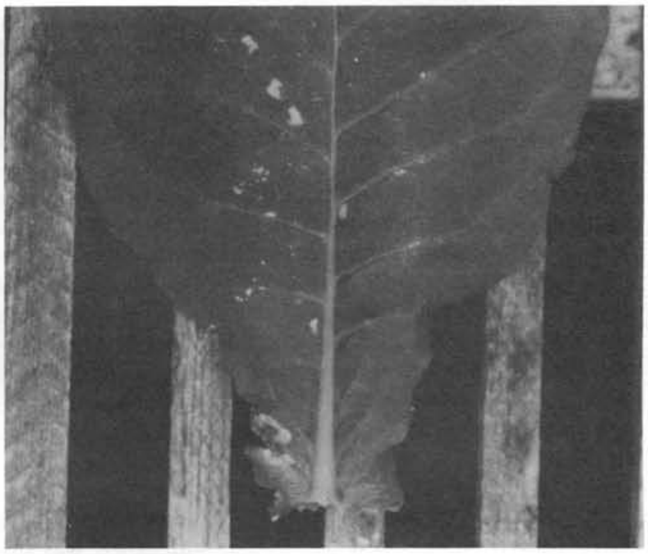

Figure 1. Damage to tobacco leaf after 10 applications of pH 2.0 rain.

approximately the same age, or younger than when the plots were established over 50 years ago. When the plots were begun, Lunt carefully recorded a description of the soil profile at each site, including the depth and pH of the humus layer. In 1981 and 1982 we revisited these sites and compared our measurements with Lunt's. We found that where the hardwood forest had remained undisturbed, weathering had acidified the forest floor from about pH 5.5 to pH 3.9 and the underlying mineral soil from pH 5.1 to pH 4.6. At another site, where drought and defoliation during 1957 to 1977 had killed nearly all of the trees, the pH of the floor of the relatively young forest had actually increased from pH 3.8 to 4.2.

Because forest soils are acid, with large reserves of acidity in their partially decomposed organic layers, runoff from such soils will also be acid, regardless of the pH of the rain. Indeed, experiments in our laboratories show that large amounts of distilled water can be acidified to about pH 3.6 by simply passing the water through samples of Connecticut forest soil rich in organic matter. Because the solubility of aluminum increases with increasing acidity, these extracts also contain substantial amounts of dissolved aluminum. In agricultural soils in New England, the potential toxicity of aluminum to plants is averted by regular and liberal applications of limestone. In forests, however, soil can become sufficiently acid through natural processes of soil formation that aluminum may become toxic to trees.

If runoff can be acidified by contact with acid soils, what is the impact of rain—acid or not—on lakes with heavily forested watersheds? In Station Bulletin 811, we have reviewed much of the literature on acidification of lakes and conclude that the mountains of the Northeast are not pristine environments that are acted on only by acid rain. Nearly the entire region has undergone extreme changes in land use, with the areas that were ruthlessly cut and burned now reverting to a former state. Thus, the landscapes thought to be most severely affected by acid rain are precisely those that are undergoing the greatest soil acidification following disturbance. From these observations we conclude that natural soil formation is often more important than acid rain in determining acidity of lakes and streams.

In Connecticut, where the soils are less acid, we have studied the nutrient enrichment of about 70 lakes, and we have also analyzed their waters for bicarbonate alkalinity. In 35 lakes analyzed in 1937-1939 by the then Board of Fisheries and Game, we found no significant changes in alkalinity (Figure 1). However, most of the lakes have become enriched in phosphorus with a consequent increase in algae whose biological activity adds to the water bicarbonate ions that offset acidification of lakes to some extent.

The impact of forested land on the alkalinity of Connecticut's lakes can also be tested for 63 of the lakes we have studied where land use in the watershed was obtained from aerial surveys. Our data show that the acidity of the lakes tends to increase as the proportion of forest land increases, but the correlation between the two only accounts for 15 to 20% of the variability.

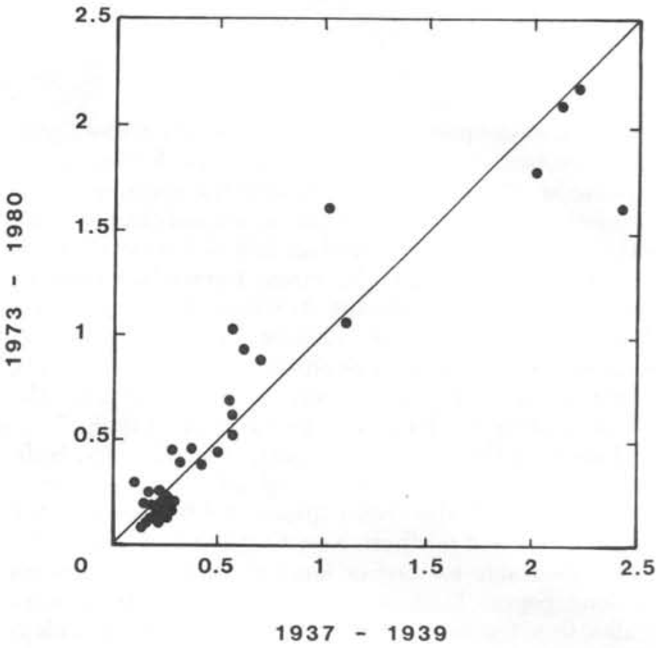

Figure 1. Comparison of alkalinity in meq/l for 35 Connecticut lakes.

Some important exceptions to these lakes are several small ponds in Connecticut that have recently been found to be acid. The most acidic is Emmons Pond in Hartland, where the lowest pH we observed was 4.3 in the late fall of 1982. At the turn of the century, the pond itself was a swamp, but in the early 1900's it was impounded and now covers 7.5 acres to an estimated average depth of 4 to 5 feet. Although the watershed was farmed earlier, it is now entirely forested with numerous hemlock and other conifers mixed with hardwoods. Beds of acid sphagnum peat surround the inlet streams. The pH of the humus layer under the hemlocks is about 3.6, typical of forests north of Connecticut. In addition to acid runoff from the humus, studies begun this spring show that the inlet water is acidified to about pH 4.2 by the beds of sphagnum moss. Although further work is needed to quantify the various sources of acidity in the watershed, we believe that Emmons Pond is a striking example of the acidification produced by soil formation and vegetational succession. Since acid rain is superimposed on these much larger natural sources of acidity, acid rain is not likely to harm our soil and water in Connecticut. Indeed, in areas such as the watershed of Emmons Pond, rain at pH 4.2 would be expected to make soil at pH 3.5 more alkaline—but not by much.

Additional Reading:

Krug, E. C. and C. R. Frink. 1983. Effects of acid rain on soil and water. Conn. Agr. Exp. Sta. Bull. 811.

Acid Rain Task Force. 1983. Report to the Governor and to the General Assembly. Acid Rain: Sources and Effects in Connecticut. Conn. Agr. Exp. Sta. Bull. 809.

PHOTOSYNTHESIS—Continued from Page 3
energy input and the number of days elapsed since the beginning of the experiment.

The CO_2 release rate of leaves during the first few hours after sunset on three days and the CO_2 release rate of stem segments were measured using the chamber. Root respiration, however, is more difficult to measure. Since CO_2 released by roots in the soil must eventually escape to the atmosphere, root respiration was estimated from the rate of release of CO_2 from the soil around an individual plant. Metal cylinders open at one end were forced open-end first a few centimeters into the soil, thus capturing the CO_2 released from the enclosed area of soil. Samples of the air enclosed within the cylinder were withdrawn at timed intervals and analyzed for CO_2. As expected, CO_2 release was usually greatest near the base of the plant where the root density was greatest. Several feet away the rate was much lower and probably reflected respiration by non-plant sources such as soil bacteria and invertebrates. Measurements of CO_2 release near the plant were corrected for this latter contribution to the total CO_2 release rate. Knowledge of the rate of CO_2 release from roots versus distance from the plant enables calculation of respiration by an entire root system using simple geometry.

The estimates of total daily CO_2 input were adjusted for losses occurring in stems, roots, and leaves at night. The predicted course of accumulation of total dry weight per plant based on these measurements is shown in Figure 2 in comparison to independent determinations of actual total dry weight performed at intervals throughout the season. Variety 1 yielded about 15% more than variety 2 at the end of the season. The close agreement between actual total dry weight accumulation and that predicted for both varieties on the basis of our photosynthesis and respiration measurements graphically demonstrates that greater net carbon accumulation is associated with higher yield.

Table 2 shows the cumulative inputs and outputs of CO_2 for the two varieties over the 35-day experiment. Significantly, 41 to 47% of the carbon fixed over the season was lost by respiration, mostly via the roots and leaves. Again, the net CO_2 input after correction for respiratory losses agrees with the measured increases in dry weight.

The lower yielding variety respired less, so differences in total CO_2 loss from respiration cannot account for the difference in yield for the two varieties. Statistical analyses showed that the two varieties did not differ significantly in photosynthetic efficiency, i.e., rate of CO_2 input per unit area of leaf surface. Nor did they differ greatly in the relative allocation of biomass to leaves or other plant parts. Then how could these two varieties yield differently?

The answer probably lies in events which occurred before our measurements began. Variety 2 germinated slightly later, grew less vigorously as a seedling prior to transplantation to the field, or adapted less readily to the field environment following transplantation. Consequently, although it was growing at a similar rate, variety 2 was simply unable to catch up to variety 1. This experiment pointed out that critical determinants that influence final yield need not be expressed at all times during the season. Further experiments should more precisely identify important differences between these varieties which determine yield.

Table 2. Carbon budget of field-grown tobacco during a 35-day experiment. Values in parentheses are percent of total CO_2 input.

	Variety 1, CO_2 Equivalents	Variety 2, CO_2 Equivalents
	g	
Total CO_2 input	749.1 (100)	645.9 (100)
Respiration losses		
Leaves (night)	−102.3 (13.7)	−98.2 (15.2)
Roots	−186.7 (24.9)	−103.1 (16.0)
Stems	−65.0 (8.5)	−63.0 (9.8)
Total	−353.0 (47.1)	−265.3 (40.9)
Net input from CO_2 exchange measurements	396.1 (52.9)	381.6 (59.1)
Observed dry wt increase (CO_2 equivalents)	409.5	357.5

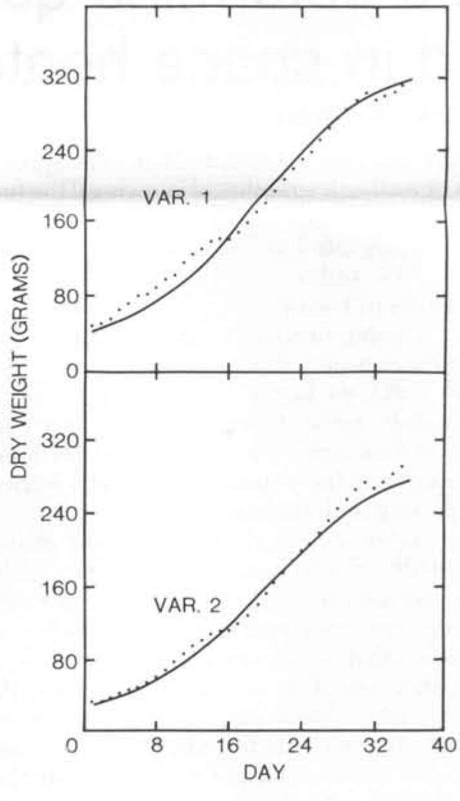

Figure 2. Measured growth (dry weight, solid lines) and predicted cumulative CO_2 assimilation (broken lines) by stands of field-grown tobacco (varieties 1 and 2) over a 35-day period. The carbon of the bulked plant dry matter was assumed to be at the oxidation level of carbohydrate, so the values of net CO_2 incorporation were multiplied by 0.68 for comparison with dry weight increases.

THE CONNECTICUT
AGRICULTURAL EXPERIMENT STATION
P.O. BOX 1106
NEW HAVEN, CONNECTICUT 06504-1106

Paul E. Waggoner
Director

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Tests determine quality of kerosene used in space heaters

By Sherman R. Squires

With increased use of unvented kerosene space heaters in homes came the desirability of knowing if the fuel being burned met present standards. The appropriate grade of kerosene is designated as "No. 1-K" and may contain no more than .04% sulfur.

Combustion of kerosene results in the transformation of its sulfur to sulfur dioxide, which is a respiratory irritant that contributes to air pollution in the home. Consequently, in early 1982, we began examining kerosene samples for the Product Safety Division of the Connecticut Department of Consumer Protection to determine if the sulfur content met the requirement of the American Society For Testing and Materials (ASTM).

The apparatus used to determine sulfur content consists essentially of a glass lamp and chimney with appropriate connections for admitting air for combustion and for drawing the combustion product, sulfur dioxide, through a solution of hydrogen peroxide, which, in turn, causes further oxidation to sulfuric acid. Reaction with barium chloride solution converts the sulfuric acid to a white solid, barium sulfate, which can be isolated by filtration, dried and weighed. From this weight the equivalent amount of sulfur in the kerosene is calculated.

Thirty-three samples of kerosene were obtained during 1982 and early 1983 from consumers and from suppliers in 21 different towns. The 23 samples from consumers were not necessarily purchased as 1-K grade. Five of them had a sulfur content in excess of .04%. The range for the 33 samples was from .010% to .066%.

Ten samples were obtained as official samples by state inspectors and are the brands being sold as 1-K kerosene in Connecticut. All met the sulfur specification; therefore, a purchaser of 1-K kerosene can be reasonably confident of a proper sulfur content.

Later, the Product Safety Division requested that we test kerosenes collected in a study of air quality in homes where unvented kerosene heaters were being used. Determinations of sulfur, flash point and lead were made. Twenty-one of 49 samples exceeded the recommended sulfur figure and the range of sulfur content was .020% to .084%.

The flash point and lead determinations were included to detect possible contamination of the kerosene by gasoline, which could cause an explosion or fire. The ASTM specification requires a minimum flash point of 100° F; a lower flash point would indicate too volatile a fuel. Detection of appreciable lead would suggest the presence of leaded gasoline. The results from the 49 samples did not indicate contamination by gasoline.

As a result of these tests it is apparent that not all users have been using 1-K kerosene in unvented space heaters but the 1-K grade that we tested met present standards.

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Vol. 36 No. 1 Fall, 1983 ISSN 0016-2167 Paul Gough, *Editor*