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Frontiers of Plant Science

Cheshire, exporter and importer of oxygen *See Plants, Oxygen, and People, pages 6 and 7.*

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION NEW HAVEN

Focusing on New Ways to Control Defoliators

John F. Anderson
Department of Entomology

Caterpillars of the gypsy moth and snow-white linden moth cut a wide swath across the Connecticut countryside in 1971, breaking all previous records of defoliation. Some 655,000 acres of woodland or about one-third of the state's total forested land were noticeably consumed. Infestations exceeding 100,000 acres were previously recorded in 1954, 1962, 1964, 1965, and 1970. Gypsy moths, introduced into the United States in 1869 and initially reported in Connecticut in 1905, were primarily responsible for defoliation in the years preceding 1970. The snow-white linden moth, known as the elm spanworm in the caterpillar stage, is a native insect, but has been recorded to have reached outbreak levels only in 1938 when about 250 acres were infested.

The extent and severity of defoliation this past summer varied greatly. Spanworms and gypsy moths teamed together in southwestern and central Connecticut and the gypsy moth alone was responsible for defoliation in eastern Connecticut. More than 10,000 acres were affected in Burlington, Canterbury, Cheshire, Danbury, Hamden, Harwinton, Killingworth, Monroe, New Fairfield, North Stonington, Redding, Shelton, Southbury, Southington, and Voluntown. Almost 8,000 acres were completely stripped in the North Madison area. Several towns initiated municipal spraying programs, of which nine undertook aerial spraying.

With the upsurge of defoliating caterpillars 2 years ago, efforts were initiated to assemble a small group of scientists to work on methods of control that would be least likely to pollute our environment. The team has been mustered and this article reports on their research activities and perhaps provides a glimpse of methods to be used in the future.

Dr. Ronald M. Weseloh examines gypsy moth egg masses for parasites that kill eggs.

Insect parasites would probably be the most acceptable means of managing populations of insects, provided they could be effectively manipulated by man. The major parasites of the gypsy moth are presently under scrutiny by Dr. Ronald Weseloh. His objective is to determine the impact of these parasites on populations of gypsy moth and to ascertain under what conditions the more promising ones can be utilized in suppression programs. There is presently a complex of about a dozen parasites. They come in assorted shapes and sizes, and depending upon the species, attack only one of the juvenile stages of the host. None attacks the adult moth. Initial attention has been focused on a small, hymenopterous egg parasite introduced into this country during the early 1900's from the Orient. The percentage of host eggs destroyed by this insect may be as high as 60, but the overall average is nearer 30 percent. The egg mass of the gypsy moth is comprised of several layers of eggs and this small parasite has only the physical capability of destroying the outermost eggs in a mass.

Other parasites include another small wasp that attacks the egg, four types of flies and a wasp that develop within caterpillars, and five wasps that attack the pupae.

More than 40 parasites have been reported to attack the elm spanworm. Dr. Harry Kaya and I have been investigating an egg parasite which has the capability of destroying most if not all embryos in an egg mass. The spanworm lays its eggs on the branches and trunks of trees, as does the gypsy moth, but the eggs are laid all in one layer and are completely exposed, thereby making them more susceptible to attack by parasites. This parasite has been established in the laboratory and we are deter-

Parasites also attack eggs of the elm spanworm, here examined by Dr. Harry K. Kaya.

mining its impact on eggs in the field.

Use of microscopic organisms for the control of insects has received wide attention because of their host specificity and the commercially available formulations of the bacterium known as *Bacillus thuringiensis*. Presently three products known as Dipel, Biotrol, and Thuricide are available to the consumer. Field tests carried out with ground equipment this past summer by Drs. Dennis Dunbar and Kaya showed that the foliage on trees could be protected from gypsy moth, but that a certain number of caterpillars survived. Spanworms were found to be highly susceptible and excellent control was achieved. So successful were the tests with the spanworm that aerial spray tests are planned for next year.

Natural microbes causing disease in gypsy moths include the polyhedrosis virus and a bacterium called *Streptococcus faecalis*. Dr. Charles C. Doane has cultured the bacterium and has field-tested it. Foliage protection was achieved and further tests are in progress to evaluate its potential. The virus affects both the young and old caterpillars and plays a key role in bringing about a collapse of an outbreak of gypsy moths. The virus is highly specific, apparently affecting only gypsy moths. Laboratory tests have been encouraging and virus preparations will be tested in the field next spring.

Little is known about the microbial parasites of elm spanworms and such other defoliators as the orange-striped oakworm, forest tent caterpillar, etc. Dr. Kaya has initiated an exploratory study to determine the types killing these insects. Three previously undescribed protozoa called microsporidia have been isolated this summer and an evaluation of their potential as living insecticides is in progress.

One of the more novel possibilities of controlling insects, and surely one that intrigues the mind, is the use of sex attractants. The sex attractant of the gypsy moth, known as disparlure, has been isolated and synthesized by Dr. Beroza of the U.S. Department of Agriculture. This is a highly potent substance, as we soon learned here at the Station. A sample was shipped to Dr. Jeffrey Granett last June and before he was able to unwrap the package and open the bottle in his office, 75 to 100 or more male moths were flying frantically just outside his window screen. Tests conducted in three areas of the state this summer showed that the material did indeed attract large numbers of moths, but virgin females placed near the traps likewise attracted males. Extensive tests are planned for next summer. The use of hormones is a relatively new idea in insect control and Dr. Granett is in the process of testing various materials.

What effect is this extensive defoliation having on Connecticut forests? This is a question that Drs. Dunbar and George Stephens intend to have the answers to in the next few years. A plot of land has been set aside in Haddam to evaluate the impact of various types and numbers of caterpillars on different species of trees growing under a variety of conditions. Each tree in the plot will be studied annually during the coming years to ascertain the interactions between caterpillars and the forest.

An extensive effort is being placed on biological methods of suppressing defoliating insects. None can yet be relied upon. Consequently we will continue to depend upon the use of chemicals for their suppression. For this reason we are evaluating moderately toxic and non-persistent insecticides. Results of three new formulations tested aerially by Dr. Doane may be found in Bulletin 724 published earlier this year.

Our objective is the development of methods of controlling defoliating caterpillars by means that are least likely to pollute and are least likely to damage the landscape. This is a long and difficult road to travel, but we intend to follow this route.

New Publications

Station research is reported in technical journals and in Station publications. The following have been published since you last received FRONTIERS. Address requests to Publications, Box 1106, New Haven, Connecticut 06504.

Entomology

B 724 *Aerial application of insecticides for control of the gypsy moth.* C. C. Doane and P. W. Schaefer.

B 725 *Insecticidal mycotoxins produced by* Aspergillus flavus var. columnaris. R. L. Beard and G. S. Walton.

C 243 *The holly berry midge.* J. C. Schread.

Forest Ecology

B 718 *Drainage, drought, defoliation, and death in unmanaged Connecticut forests.* G. R. Stephens and D. E. Hill.

B 723 *The relation of insect defoliation to mortality in Connecticut forests.* G. R. Stephens.

B 726 *Transpiration and its control by stomata in a pine forest.* P. E. Waggoner and N. C. Turner.

The Purifying Power of Soil

David E. Hill

Department of Soil and Water

IN CONNECTICUT'S CITIES and densely populated towns, man's strategy of domestic sewage treatment includes transportation via the sewer network to the treatment plant, removal of solids, chlorination of the liquid effluent for disease protection, and finally disposal of the effluent into the nearest river where hopefully it is diluted. The river is tolerant when the volume of effluent is small in comparison to the river's volume. As the volume of nutrient-laden effluent increases or the flow decreases during summer months, dilution, which we have relied on in the past, becomes less effective and the greater quantities of nutrients begin to exert their influence.

Water green with algae and occasional fish kills due to competition between the fish and decaying algae for dissolved oxygen are no longer rare occurrences. Today, efforts in Connecticut are marshaled to obtain at least secondary treatment and chlorination to keep raw disease-bearing sewage from Connecticut's waters. But the burgeoning nutrient problem remains until satisfactory tertiary treatment methods are available for nutrient removal.

We now seek alternatives to the practice of dilution of sewage treatment plant effluent in our rivers and lakes by using soil and the plants that grow on them to filter the effluent and remove its nutrients. The purifying power of soils and plants have been known to soil scientists for some time. Nutrient-rich effluent applied to the land by irrigation undergoes a variety of physical, chemical, and biological changes in the soil. Some nutrients become fixed in the soil, others are held on the exchange complex where plants can utilize them, while others may leach to the water table below.

Our task, then, is to determine which soils are the best purifiers of waste water. The waste water contains the negatively charged anions phosphate, sulfate, nitrate, and chloride and the positively charged cations potassium, calcium, magnesium, and sodium. We are concerned with these particular anions and cations for several reasons. Nitrate and phosphate are plant nutrients that nourish algae in lakes and streams. In addition, high nitrate content in water supplies is a potential health hazard. Calcium and magnesium contribute hardness to water supplies and sodium, potassium, chloride, and sulfate add saltiness.

From our soil surveys we selected six soils that are divergent in their physical and chemical

Undisturbed columns of soil, left, were encased in plastic, hoisted out, and taken to the Soils laboratory in New Haven.

characteristics and represent thousands of Connecticut's acres. The pictures show how we sculptured soil columns, measuring 12 inches in diameter and 36 inches high, encased them with plastic, and brought them to the laboratory. Each week for 2 years we leached 2 inches of a synthetic effluent through the cores. This rate would be equivalent to applying nearly 3 million gallons of effluent to one acre of soil each year. The effluent, after leaching through the soil column, was periodically analyzed to determine how much of each nutrient was absorbed by the soil. There were obvious differences among the soils in their capacity to remove nutrients and we compare the performance of the loamy Paxton soil formed on compact glacial till and the sandy Merrimac soil formed on sandy and gravelly terraces.

Phosphate Removed in Topsoil

First, let us look at the anionic nutrients whose chemical charge is similar to the predominant chemical charge in the soil. In both acid soils all phosphate added to them for 2 years was removed in the topsoil layer. Phosphate is most likely removed by formation of a complex gel with iron, aluminum, and silica which abound in Connecticut soils. In fact, some of the calcium and magnesium in the effluent may also be tied up in this complex gel. Phosphate was also removed in the alkaline Stockbridge soil. After 2 years some phosphate leached below the topsoil, but the subsoil was capable of removing the phosphate that had leached from above. It appears that soils derived from limestone may have a shorter life span of phosphorus removal.

After 6 months, Paxton removed 90 percent of the sulfate added but soon began to fail. After one year less than 40 percent was removed and after 2 years all sulfate added passed through the column. In the coarse-textured Merrimac soil, all sulfate passed through from the start. The highly mobile nitrate and chloride ions leached through both columns from the beginning. In fact, nitrate recovered in the leachate during the first year was 125 to 150 percent greater than the concentrations added. The excess nitrogen was probably released as the organic matter in the soil decomposed. Thus, the anionic nutrients, except phosphate, are ineffectively removed from all soils tested. This is not difficult to understand because of the similarity in chemical charge, which inhibits ion exchange. The phosphorus is removed because it is capable of forming a complex gel as the chemically unstable effluent reacts with the complex chemical system of the soil.

The cationic nutrients, which have a positive chemical charge, are removed in unequal amounts. Large amounts of potassium are removed by the loamy Paxton soil and its efficiency remains high after 2 years. The sandy Merrimac soil removes little potassium because it contains little clay and organic matter which provide chemically active surfaces. More than two-thirds of the calcium and magnesium are removed by both soils after 2 years. Little sodium is removed by both soils but Paxton is clearly more efficient than Merrimac. We have estimated that the Paxton soil will still adsorb some cations after 13 years while the Merrimac soil will lose its adsorptive capacity after 10 years.

The Paxton soil is a more efficient purifier of waste water than Merrimac soil but it is obvious that soil alone will not provide the renovation we seek for some nutrients, notably nitrate. Other scientists in the Northeast have shown, however, that removal of nitrates may be assisted by a cropping system in which the nitrate is utilized by growing plants, harvested, removed from the site, and recycled elsewhere. In this manner, nitrate, a potential pollutor of ground water, can be reduced by as much as two-thirds by a corn crop or three-quarters by forest trees.

The results of our studies also tell us about the fate of nitrate and phosphate from septic tank systems which utilize only the subsoil to purify effluent. Phosphate, passing through the septic system, is effectively removed as the complex gel forms in contact with soil. But nitrate is not removed and its discharge in the soil is generally below the depth of feeding root systems. Some may be converted to harmless nitrogen gas by anaerobic bacteria in waterlogged soil but much of the nitrate leaches to ground water supplies. Usually it is dilute enough to be harmless but great numbers of septic systems in sandy areas may create intolerable concentrations of nitrate in ground water.

We have also compared the nutrient levels in the leachate escaping our soil columns with the concentrations naturally occurring in our ground water supplies. Most soils reduced the concentrations of phosphate, potassium, calcium, and magnesium in the effluent below natural levels in the ground water. The coarse-textured soils, exemplified by the sandy Merrimac soil, reduce only phosphorus and calcium to acceptable levels.

With vast differences in permeability and capacity to remove and store nutrients in Connecticut soils, each one must be examined and safe loading rates established. Others have estimated that a soil capable of accepting 2 inches of effluent each week will serve a community of 10,000 people on 130 acres of farm or forest land.

Sound Strategy

The strategy, then, of using soil and plants to reduce the nutrient load in waste water is sound from a chemical point of view. Also, economists have determined that the costs of treating effluent in this manner are lower than other methods of tertiary treatment by chemical and biological means. It appears, then, that land application, using soils and plants to absorb nutrients, provides an effective and economical means to reduce the nutrient load in waste water from our municipal secondary treatment plants.

Plants, Oxygen, and People

Gary H. Heichel

Department of Ecology and Climatology

OXYGEN is the second most numerous constituent of air. Man and other animals inhale air containing 20.946 percent and expire air containing 16 to 18 percent oxygen to support essential life processes. Oxygen is also vital to our economy. The machines of our industrial society consume large quantities of oxygen during the combustion of fossil fuels. Indeed, the hourly oxygen consumption of an adult is miniscule compared with that of machines (Table 1). I explain here how plants maintain the oxygen balance of our atmosphere by producing more oxygen than man and machines consume.

Terrestrial plants and the plankton of the oceans produce most of the earth's oxygen supply by photosynthesis; one volume of oxygen is released to the atmosphere for every volume of carbon dioxide synthesized into carbohydrate during photosynthesis. Plants exchange 12 million billion moles (1 mole equals 0.8 cubic foot) of oxygen for an equal quantity of carbon dioxide each year. This mammoth feat emphasizes that photosynthesis is the world's most essential biochemical process!

Unlike man and machines, plants are both producers and consumers of oxygen. Oxygen production by photosynthesis proceeds during the day, and oxygen consumption by respiration occurs at night. Years of research at this Station and others have shown that plants vary greatly in their capacity to produce oxygen (Table 2).

If the average consumption of an adult is known, the capacity of vegetation to produce oxygen for human use can be assessed. We learned earlier that human oxygen consumption varies with activity (Table 1), but a logical balance of activity and caloric intake for an office worker or housewife yields an estimated oxygen consumption of 30 moles per day. Assuming that day and night are of equal length, estimates of vegetation required to supply the daily oxygen requirements of an adult are easily computed (Table 3). Clearly, kinds of vegetation differ greatly in their oxygen productivity.

Dense cornfields, leafy suburban forests, and populous fields of small grains are highly efficient oxygen factories; only a few square meters of these crops will balance the oxygen requirements of a person. Lush lawns produce little oxygen and parched lawns even less because they have very little leaf area. The flora of the oceans produce oxygen very slowly because the vegetation is dispersed throughout vast and dimly-lit volumes of water. Nevertheless, oceans cover 70 percent of the earth's surface and produce 33 to 75 percent of its oxygen supply. The seriousness of decreasing oxygen production by poisoning oceans with toxic effluents is difficult to assess. Better estimates of the ocean's role in oxygen production are needed. Decreasing oxygen production by replacing forests and farms with concrete and asphalt will become important

Table 1. Oxygen consumption of man compared with machines

	Oxygen Consumption *Moles per Hour*
Man (resting)	0.8
(average daily activity)	3
(extreme physical activity)	16
Automobile (30 mph, 15 mpg)	47
(60 mph, 15 mpg)	94
Oil-fired home furnace (winter)	137
Jet airplane (4 turbojets, Mach 0.9 at 35,000 feet)	450,000
Open-hearth blast furnace (6400 tons pig iron/day)	9,700,000
Steam-turbine driven electrical generator (500 Megawatt)	10,800,000

Table 2. Oxygen production and consumption by vegetation

Vegetation	Photosynthetic O_2 production	Respiratory O_2 consumption
	Moles per hour per square meter of soil or water	
Corn	0.20	0.05
Oak-Pine Forest	0.13	0.02
Wheat	0.10	0.03
Lawn Turf	0.01	0.003
Ocean	0.007	—

Table 3. Estimated vegetation required to supply the daily oxygen requirements of an adult

Vegetation	Area *Square meters*
Corn	17
Oak-Pine Forest	22
Wheat	36
Lawn Turf	350
Ocean	400

if oceanic oxygen production is curtailed.

Choosing a familiar frame of reference, like a suburb, helps us appreciate the relation between oxygen supply and demand. Suburban Cheshire contains about 29 square miles of forests, farmlands, and lawns. Production of oxygen by that vegetation is so large that during a sunny summer day Cheshire's inhabitants consume only 0.7 percent, industries only 1 percent, and vehicular traffic only 1.5 percent of the daily oxygen production. No more than 3 to 4 percent of the oxygen production of the town is used internally. The balance is released to the surrounding air, where mixing and turbulent transport in the atmosphere distributes the excess oxygen and prevents localized depletion of oxygen in areas of low production like large cities, deserts, or regions experiencing winter. During the winter, oxygen production by Cheshire's vegetation practically ceases and the town, like the entire Northeast, consumes oxygen generated elsewhere on the globe.

World-wide Supplies are Abundant

Comparing the oxygen production and consumption of the earth reveals that world consumption of fossil fuel from all sources requires only 4 percent of the yearly oxygen production. The 3.5 billion inhabitants of the earth consume only 0.3 percent of the yearly oxygen production. These calculations are brief but they confirm that oceans and vegetation produce each year about 25 times the consumption of oxygen by man and machines powered by fossil fuel. Oxygen does not accumulate in the atmosphere because volcanic activity and oxidation of minerals in the soil balance oxygen consumption with photosynthetic oxygen production. Maintaining the quantity of oxygen in air will not be a problem in the foreseeable future because plants buffer the atmospheric oxygen at a constant value and atmospheric turbulence distributes oxygen rapidly and uniformly.

Waggoner Named Director, Dimond Vice Director

Paul E. Waggoner

Albert E. Dimond

The Station Board of Control has announced the appointment of Dr. Paul E. Waggoner as director of this Station and Dr. Albert E. Dimond as vice director, effective January 1, 1972.

Dr. James G. Horsfall, director since 1948, will concern himself with research as Samuel W. Johnson Distinguished Scientist.

Dr. Waggoner is now vice director and head of the Department of Ecology and Climatology. He came to the Station in 1951 and became a department head in 1956 and vice director in 1969. His research includes the climate of shade, water conservation through stomatal closure, natural changes in Connecticut woodlands, and simulation of plant disease epidemics.

Dr. Waggoner is a Fellow of the American Phytopathological Society, (as are Drs. Horsfall and Dimond) and of the American Society of Agronomy. A native of Appanoose County, Iowa, he is a graduate of the University of Chicago with advanced degrees from Iowa State University.

Dr. Dimond became head of the department of Plant Pathology in 1950 after 6 years on the Station staff. Best known for his work on how wilt diseases damage plants, his research deals with Dutch elm disease. In 1969 he was designated a Samuel W. Johnson Distinguished Scientist. He is a past president of the American Phytopathological Society and was a consultant on the Regulatory Biology Panel of the National Science Foundation from 1961 to 1965. He earned his doctorate at the University of Wisconsin.

Cover Photo

The town of Cheshire, located about 15 miles from the center of Connecticut, has a population of about 19,000, compared with the average 17,700 of the 169 towns in the state. Like Connecticut as a whole, it is both manufacturer and exporter of oxygen during the growing season, and an importer the rest of the year. Photo shows the center of Cheshire.

Portents . . . and Aloha

(continued from page 8)

fitted by computer and not by guess.

What does this curve portend? Presumably it means that for many crops the yield is not being significantly increased by fertilizers. And this has been a mainstay for increasing yields to match the growth of population.

It means to me as an administrator of science that we must dig deeper into the principles of how crops grow if we are to be able to capture in the future enough of the kinetic energy of the sun and convert it to food energy for man.

But, on New Year's Eve this year, I depart from the administration of science. The oil runs low in my lantern to peer into the night to see "what its signs of promise are" and so I hang up my lantern and take down again the shovel and the hoe of science itself and do my bit to help with the digging.

May I express here in the last of my 40 essays in FRONTIERS my thanks and my gratitude to my colleagues at the Station who have made my administrative life so pleasant. I wish them continued success in their own digging, and say with my Hawaiian friends,

"Aloha."

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Portents . . . and Aloha

James G. Horsfall

Director

A GRAND old Welsh hymn admonishes us — "Watchman, tell us of the night — what its signs of promise are." Administrators of the science that serves the public must be watchmen. They must hold up their lanterns, and peer into the future to try to see in the night "what its signs of promise are." And they must not fail to ask as well what its signs of "unpromise" are.

And being an administrator of science myself in an institution dedicated to the public weal, I am a watchman, too. Our business here is plants, all plants from corn to tomatoes and from asters to zinnias. I must shine my lantern on the plants that grow in the fields and gardens. I must ask the farmers and gardeners how grow their crops.

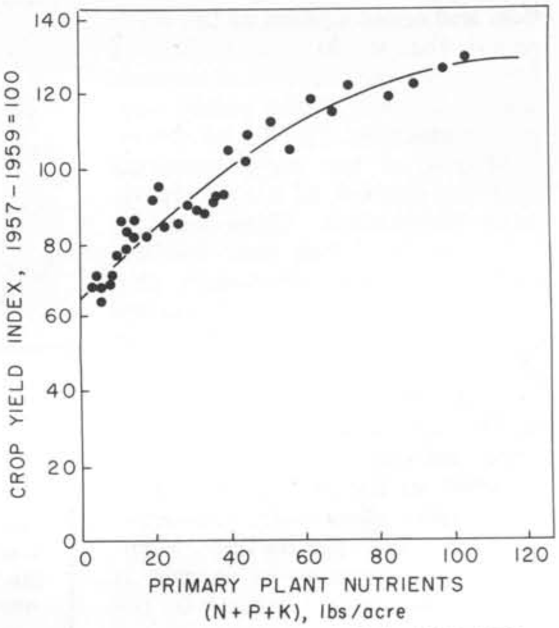
How do American crops grow? Are they in a high state of health? Will technology continue to make them grow bigger and bigger to match the population as it grows bigger and bigger? Prophets guess the future from the past, and the past two decades tell us clearly that technology is making crops grow bigger and bigger and that the food supply is ahead of the population. This pleases us. We all prefer to live in a Nation that can produce more food than it can eat, rather than in one of the Hungry Nations that cannot.

But, what do the trends look like? Is there evidence that any production curves are "topping out?" Is there any feature of technology that is losing strength? A couple of years ago, I examined some crop production curves for a lecture at Yale on the "Green Revolution." One of these curves seems worth presenting here even though only once before have I used a curve in one of my essays for FRONTIERS.

A basic feature of agricultural technology is to increase yields with fertilizer. Even the most amateurish of gardeners realizes that he can increase the growth of the plants in his field or garden with fertilizers. And so the use of fertilizers has been rising if for no other reason than that fertilizers are getting cheaper as the technology of squeezing nitrogen out of the air improves. Is the increasing use of fertilizer nationwide increasing yields and is the curve still rising or topping out?

Even a glance at the accompanying curve shows that on the average American crops are "using more fertilizer and enjoying it less," to paraphrase a current idiom. This is not true for all crops, of course. The curve for corn yields still reaches for the sky and shows no general signs of topping out. The overall curve for all crops seems to be plateauing, however. If any of my mathematically minded brethren happen to read this, I may say that the curve was

(continued on page 7)



Fertilizer used and U.S. crop yields, 1910-1969.

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