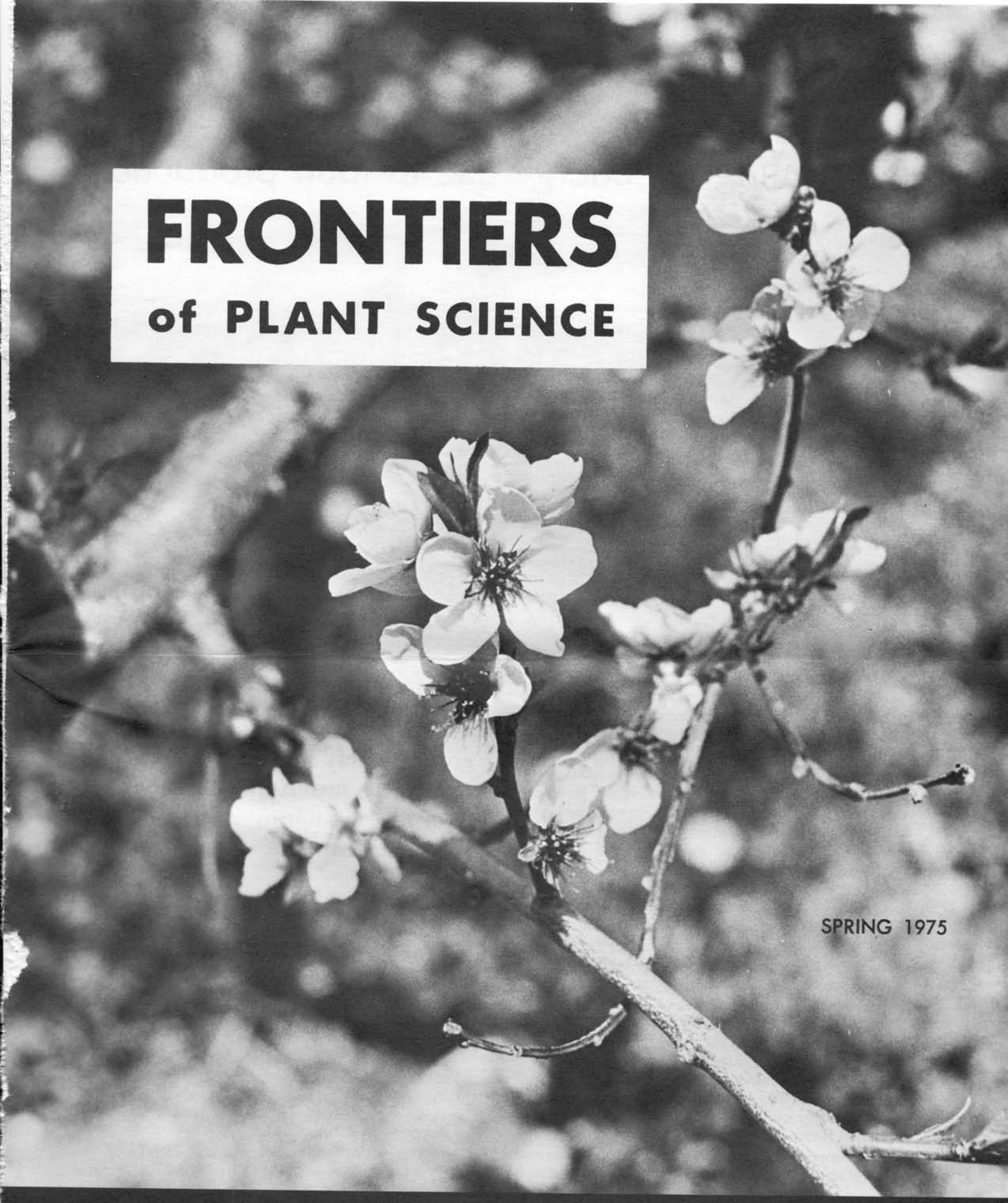
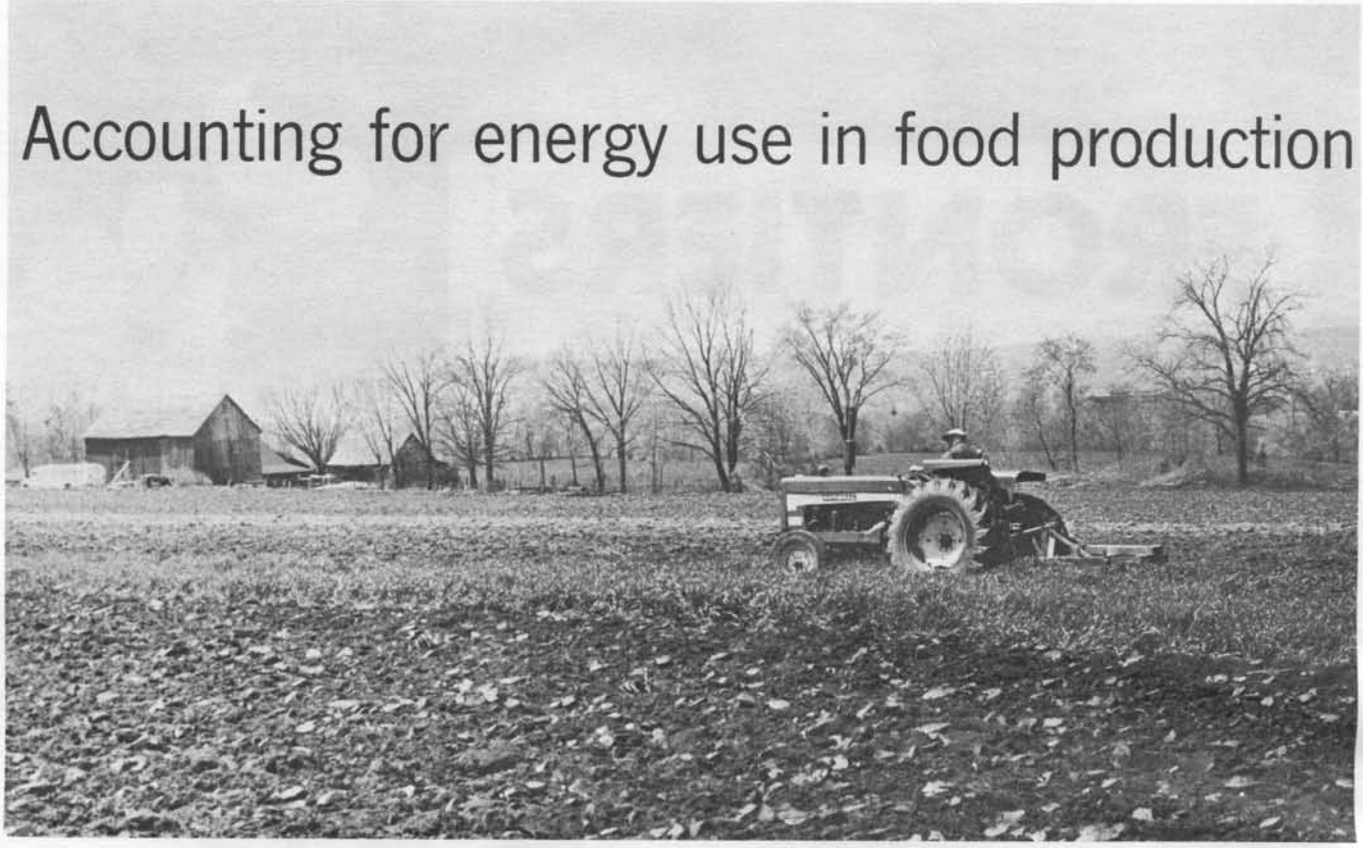
FRONTIERS of PLANT SCIENCE



SPRING 1975

THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION NEW HAVEN

Accounting for energy use in food production



Gary H. Heichel

Food production in the United States has increased greatly since the days of horse drawn reapers and buck rakes. A lot of this gain is the result of increased use of fossil fuel energy.

Dairymen once laboriously cut silage by hand, cured it in shocks in the field, and chopped it into feed with hand tools. Horses and mules transported milk and cream to market, and eventually to the consumer.

Feed for these animals required about 1/6th the amount of cropland we now use for growing of food. But when the American farmer traded in his 25 million horses and mules for today's five million tractors, he became increasingly dependent on petroleum.

This substitution of motors and machines for animals has greatly changed the pattern of energy consumption on the farm. Agriculture now depends upon plentiful and assured supplies of energy – diesel fuel, gasoline, electricity and LP gas – to produce abundant food.

With concern over this dependence on energy sharpened by the ongoing "energy crisis," we may ask if it foretells a future of scarce and progressively more expensive food. To answer the question, I sought an audit of energy use in food production as a framework for sound future strategies.

My energy accounting has summarized the on-and off-farm energy use. On-farm energy use includes such entries as fuel consumption by machines used in planting, pest protection and harvesting, and electricity needed for pumping irrigation water and warming incubators. Off-farm energy consumption includes such entries as the energy used in making manufactured goods, natural gas for nitrogen fertilizers, coal for steel production, machinery fabrications, and oil for herbicides, fungicides and plastics.

Energy equal to 1.24 barrels of oil is needed to grow one person's yearly food needs. You'd use that much oil to heat an average six-room house for 12 days in January

The bottom line of the hypothetical ledger tells us that food production on U.S. farms requires the equivalent of 340 million barrels of oil per year. This is 2.6% of the nation's energy budget – 1/10 of the energy burned in cars, trucks, trains, and airplanes, and 1/7 of the energy used for heating buildings.

Energy accounts are now available for 24 of the principal U.S. crops. The results enable us to rank cropping systems on a scale of energy intensiveness (Fig. 1).

Field crops like wheat, oats, soybeans, and corn are among the most energy-frugal ones grown. These crops can be grown using 4 barrels of oil per acre per year or less.

Moving up the scale of energy intensiveness, we find that the perennial deciduous fruits, apples, grapes, peaches and pears and the sugar crops that are largely destined for human consumption are of low to moderate energy intensiveness, using 2 to 6 barrels of oil per acre per year.

Citrus fruits requiring about 8 barrels of oil per acre per year use more energy than field crops and deciduous fruits because of their specialized needs for irrigation and frost and pest protection.

The most energy-intensive crops are the annual fruits and vegetables for human consumption (Fig. 1). Thirteen to 20 barrels of oil per acre per year are expended in growing greenbeans, melons, tomatoes, and cauliflower.

The energy accounts also permit evaluation of the total energy needs for producing the ingredients of our diet. The energy equivalent of 14 gallons of oil (0.33 bbl.) is needed to grow the 786 pounds/year of plant products in a person's diet (Table 1). Nearly 60% of this energy is for the production of just three components – vegetable fats and oils, raw vegetables, and pasta products. Converting pounds of food and gallons of oil to an energetic basis we find our daily consumption of 2,010 Kilo-calories (Kcal) of foods from plants requires 1,320 Kcal of cultural energy to produce. Thus the plant products in our diet are grown with a net energy gain, because the solar energy harvested as food exceeds that needed for production.

Fig. 1. Scale of energy expenditure in the production of 24 grain, forage, fruit and vegetable crops.

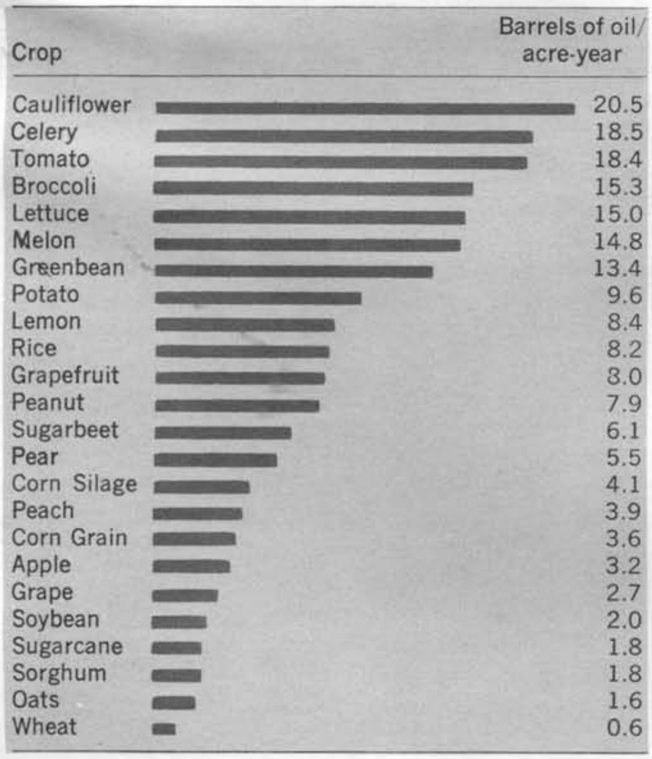


Table 1. The energy required to grow plant products consumed in a year by one person.

Plant Product	Food Consumption (lbs/person/year)	Energy Requirement (gallons of oil/person/year)
Flour & Cereal	140.0	2.2
Sugar	122.0	1.4
Fats & Oils	41.8	3.7
Fruits	131.5	1.9
Potatoes	104.9	0.6
Beans, Peas & Nuts	16.1	1.8
Green & Yellow Vegetables	215.1	2.3
Miscellaneous	14.8	0.2
	786.2	14.1
		(0.33 bbl oil)

Energy equal to about 38 gallons of oil *(0.91 bbl)* is needed to grow the 666 pounds/year of animal products in a person's diet (Table 2). More than 50% of the energy required for animal products is expended in beef production.

Table 2. The energy required to produce animal products consumed in a year by one person.

Animal Product	Food Consumption (lbs/person/year)	Energy Requirement (gallons of oil/person/year)
Beef	116.0	19.1
Dairy	356.0	4.7
Pork	67.4	4.8
Fats & Oils	14.6	3.5
Poultry	52.4	1.6
Eggs	39.0	1.3
Veal & Lamb	5.5	0.8
Fish	15.2	2.1
	666.1	37.9
		(0.91 bbl oil)

Converting pounds of food from animals and gallons of oil into energy we find that our daily consumption of 1380 Kcal from animals requires 3630 Kcal of cultural energy for production. In contrast with plant products, the animal components of our diet actually incur an energy deficit — less food energy is available from animal foodstuffs than is expended in cultural energy to grow them.

This result may be surprising, but it is a straightforward outcome of animal metabolism. Like plants consumed directly by people, the corn and soybeans that animals eat are produced with a net energy gain. But in animal metabolism, only 1/10 of the energy in the feed is converted into edible meat by broilers and hogs.

On a daily basis, the 3390 food Kcal of plant and animal products consumed required 4950 Kcal of cultural energy for production. This 1 calorie of food energy is obtained from the expenditure of 1.5 calories of fuel energy. Still, this is quite small in terms of energy use. Energy equal to 1.24 barrels of oil is needed to grow one person's yearly food needs. You'd use that much oil to heat an average six-room house for 12 days in January.

The food yields of the modern farming systems in Fig. 1 are usually in familiar measures like pounds or bushels. But the food energy in these yields can be expressed as its equivalent in oil, and related to the cultural energy input to provide a measure of the energy efficiency of modern farming. We found that the output-input ratio for modern farming ranges from a low of 1:4 to 1:2 for energy intensive crops like cauliflower, broccoli and lettuce for man to a high of 4:1 to 5:1 for production of corn and sorghum for animals (Table 3).

The result that some food plants grown by modern farming methods seemingly incur an energy deficit in production has led to questionable proposals for growing plants in confinement rather than in open fields. Unfortunately, a preliminary energy account for a modern, sunlit greenhouse continuously producing lettuce revealed that a cultural energy input of 1000 barrels of oil per acre per year, 70 times that of lettuce on farms, would be expended (Table 3).

Another accounting for a large growth chamber, an artificially illuminated, climate controlled, lettuce-growing facility revealed that a cultural energy input of 4400 barrels of oil per acre per year, nearly 800 times that of farm lettuce production, would be needed. Analysis suggested that the artificial light for lettuce growth might cost 33 cents/head at current electrical prices of 4 cents/kwh. The output-input ratio for greenhouse and growth chamber lettuce is 1:100 less than 1/25 the efficiency of lettuce production on farms (Table 3).

These studies provide new insights into the energy needs of food production. Crops vary strikingly in energy intensiveness, which reveals that food can be produced more efficiently by certain plants than by others. It takes as much energy to build the family car as is needed to grow cauliflower on an acre of land in a favorable climate that permits five crops in a year. By comparison, about five acres of energy-frugal corn and 20 of wheat can be grown on the same amount of energy. These are potentially significant findings in an era of increasing scarce and expensive fossil fuel. Lastly, it seems that growing food plants on farmland with free and plentiful sunlight is a great energy bargain.

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Table 3. A comparison of energy consumption of modern farming, and two alternate methods.

FOOD PRODUCTION SYSTEM	Cultural Energy Input	Food Energy Output	Output / Input
	(barrels of oil/acre/year)		
MODERN FARMING	1 - 20	1 - 20	1:4 to 5:1
GREENHOUSE (climate controlled, natural sunlight)	1000	12	1:100
GROWTH CHAMBER (climate controlled, artificial light)	4400	65	1:100

Injections control peach diseases

David C. Sands and Gerald S. Walton

In Connecticut, the acreage in peach orchards has decreased 80% in the last 40 years. Although Connecticut is at the northern limit of the hardiness zone, where cold sometimes causes peach crops to fail, decrease in peach acreage has also been hastened by diseases for which there are no commercially available cures. We have made advances on two of these: X disease and bacterial leaf spot.

X disease is spread by leafhoppers which inject the mycoplasma into the leaves. The infection results in a buildup of nutrients in the sugar-conducting tissues. Infected leaves often turn red and fall off in midsummer and fruit from infected trees is small and has a bitter taste. Young trees are killed outright by the disease.

Station research on X disease started when it was described and named by E. M. Stoddard in 1933. "X" denoted the unknown cause of the disease, which was presumed to be a virus. But in 1967, Japanese workers found a similar "virus" disease to be caused by a bacterium called mycoplasma. Peach X disease mycoplasma can be seen in Fig. 1.

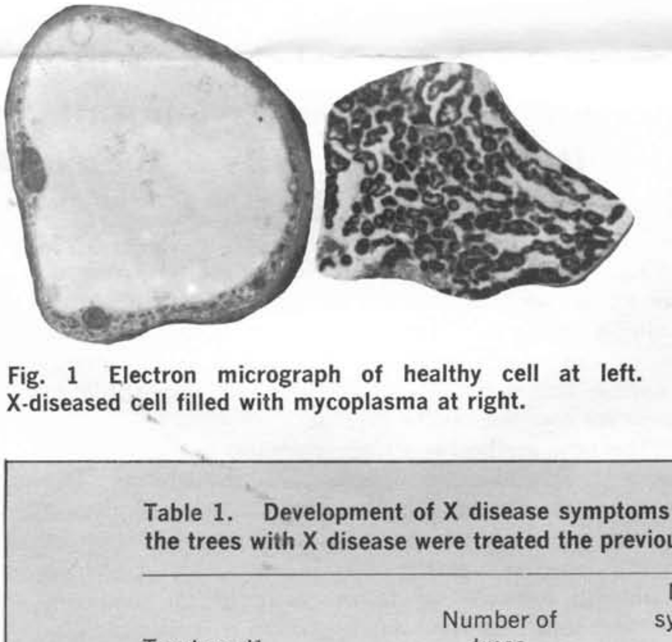

Fig. 1 Electron micrograph of healthy cell at left. X-diseased cell filled with mycoplasma at right.

We have found that the antibiotic moves through the leaves, stem and roots of the tree within a day.

As with many other bacteria, but not with viruses, mycoplasma can be controlled with antibiotics such as the tetracyclines. These findings altered the course of X disease research.

In 1970, we started treating trees with dilute solutions of tetracycline. The solutions were fed into holes drilled into the basal trunk area of the tree through a system of plastic tubing, similar to a blood-transfusion apparatus. This transfusion technique had been used in California for treating peaches infected with western X disease, a related disease.

Unfortunately, the system did not work well for us. Some trees did not receive sufficient antibiotic and during the 1 to 7 days it took the solution to be taken in, most of the antibioic was degraded, principally by sunlight and heat. Also, the system is cumbersome and difficult to use.

But after four years of research, we have developed an easier injection method that appears to be effective against both X disease and bacterial leaf spot. First, using an alcohol-sterilized drill bit, we drill a downward slanting hole 7/32 inch in diameter and 1½ inch deep beneath each scaffold limb. Immediately we fill the hole with a 2.7% citric acid solution containing a high concentration of oxytetracycline hydrochloride (10% w/v). The citric acid helps to solubilize and stabilize the antibiotic. The solution is taken up by the tree in minutes. We have found that the antibiotic moves throughout the leaves, stem and roots of the tree within a day.

Table 1. Development of X disease symptoms in August on limbs that were symptomless when the trees with X disease were treated the previous year.

Treatment[1]	Number of trees	Number of symptomless limbs	Number of limbs with symptoms	Protection %
Oxytetracycline HCl	9	21	1	95
Citric acid alone	6	6	17	26
Untreated	7	2	25	7

[1] Antibiotics made in 2.7% citric acid solution.

Injecting trees with antibiotic causes a slight and temporary yellowing of leaves the following spring. But most important, X disease symptoms do not appear in early summer on the antibiotic-treated trees as they do on trees not treated with antibiotic.

Trees treated with antibiotic, although still weak from X disease of the previous year, produce more foliage and fruit. The data in Table 1 show the protection given by the antibiotic injection. Only 5% of the limbs of antibiotic-treated trees showed symptoms of X disease. On the trees not treated with antibiotic, up to 95% of the limbs showed symptoms. The average fruit size of the antibiotic-treated trees was 36% greater than the fruit size of X diseased trees not treated with antibiotics but somewhat smaller than fruits from trees without X disease.

Results with tetracyclines on the bacterial spot disease were similar to the control of X disease. The treated trees showed 75% less leaf spot than did the untreated trees.

We found that injecting for both diseases in October worked best because the antibiotic disappears from the tree before the fruit is harvested the following year. We also found that treating for bacterial spot as the organism overwinters in stem cankers reduces the chances that this disease will cause a problem the following spring.

Our continuing research will tell us how long we can safely stretch the interval between injections. Samples from our treatments are also being used to learn the safety of tetracyclines for the control of these peach diseases. Until safety is determined and registration is obtained, of course, the only available control for X disease is the elimination of chokecherry, the principal wild host of the disease.

Food additives are elusive

Paul Gough

Many of the additives that Station chemists test for in the analytical laboratory were unknown when Samuel W. Johnson initiated public food testing at the Experiment Station in 1895.

But today, food is replete with additives and exotic chemicals; some make it look or taste better, some protect it from spoilage, and some make it more nutritious. Many of these substances are present in such minute amounts that they are not easily detected by existing methods.

This is where the researcher takes over from the analyst and attempts to find unseen contaminants or to measure additives to make sure that they are not present in excessive quantities.

One such food additive is glycine. This primary amino acid is often added to diet beverages to cover the bitter aftertaste of the saccharin used as an artificial sweetner.

When research was initiated there was no limit on the amount of glycine allowed in diet beverages, but if used, it had to be listed on the label.

Researcher Elia D. Coppola, with the help of others, began to develop an infrared qualitative test to detect glycine because inspectors suspected that glycine was an undeclared additive in some diet beverages being sold in Connecticut.

While he was working on the problem, a limit (0.20%) to the amount of glycine in beverages was imposed.

Many of these substances are present in such minute amounts that they are not easily detected by existing methods.

The previous analytical method involved potentiometric titration of a dried sample of the diet drink, using a strong acid. But with this test, other additives such as sodium benzoate, sodium citrate, and saccharin confuse the determination, making it impossible to measure less than 0.2% glycine.

The new method is a fluororometric test in which a reagent, fluorescamine, reacts with the glycine. The resulting fluorescence indicates the amount of glycine in the beverage. A comparison of the intensity of fluorescence of a group of known amounts of glycine with the intensity of fluorescence of an unknown amount indicates how much glycine is in the sample. The test can detect as little as 0.02% glycine which is one tenth of the amount allowed in diet beverages.

Another additive found in food is monosodium glutamate (MSG), which is used to enhance flavor. But excessive amounts of MSG have been blamed for the burning sensation and headache that is known as the Chinese Restaurant Syndrome.

Formerly, ion-exchange column separation of MSG took more than 9 hours, but a procedure developed at the Experiment Station has shortened this separation to about 4 hours. The test, which also uses fluorescamine, is sensitive enough to measure 0.05% monosodium glutamate in a variety of prepared foods.

Coppola actually tests for glutamatic acid, which is formed by acidifying MSG. To convert to MSG the following formula is used:

$$\% \text{ MSG} = \% \text{glutamatic acid} \times 1.15$$

The intensity of the outcome varies with acidity, and the optimum pH of the test solution is 9.8 as shown in Fig. 1.

Table 1 shows the results of analyses of various consumer products for MSG. After the MSG level in the sample was found, a known amount of MSG was added to test the accuracy of the test. The new procedure was within acceptable tolerances.

Station analysts often must test for sodium nitrite, which is added to processed meats to retard spoilage, but is dangerous if used in excess. Thus, no more than 200 ppm is allowed in bologna, frankfurters, and similar cured meats.

The pink color of the meat, some of which comes from the sodium nitrite, could interfere with the test, but Coppola has overcome this using fluorescamine.

To obtain a measurement, a known amount of sulfanilic acid is added to the unknown sample and allowed to react with sodium nitrite. Then fluorescamine is reacted with the sulfanilic acid that has not reacted with sodium nitrite. The amount of sodium nitrite in the unknown sample is then calculated by subtracting the amount of sulfanilic acid present after the reaction from the amount added before the reaction.

Experiments showed that the interference caused by the color, proteins and amino acids in the meat could be minimized by running the test at a light wavelength of 435 nm, and at a pH of 3.3.

Development of these new tests show the potential for new ways to measure food additives. The increased speed and sensitivity of analysis both help the Station continue to protect the consumer by testing food in the analytical laboratory.

Fig. 1. Relative Intensity at various pH levels.

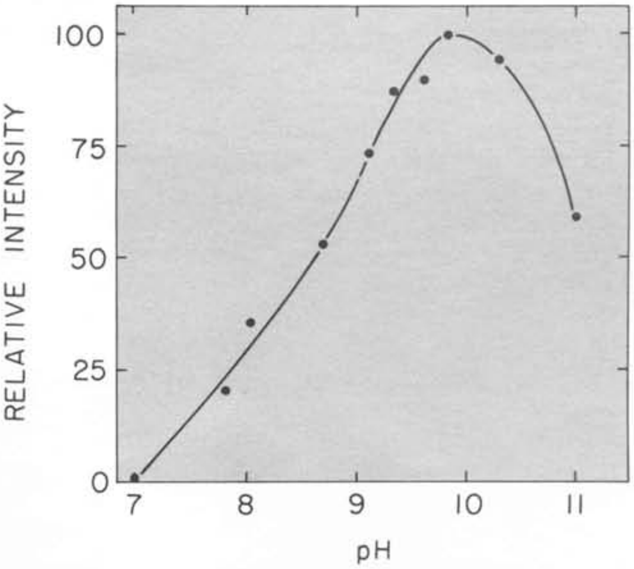

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Table 1. Recovery of monosodium glutamate from food products.

Product	Monosodium glutamate, g/100 g Found	Added	Total found	Rec., %
Shrimp egg rolls	0.587	1.020	1.480	87.5
Chicken chow mein	0.759	0.0805	0.829	87.0
Chicken rice soup (liquid)	0.0603	0.805	0.835	96.2
Frankfurter	0.423	0.805	1.110	85.3
Bologna	0.302	0.402	0.694	97.5
Chicken bouillon soup (cubes)	4.350	3.260	7.350	92.0
Chicken noodle soup (dry mix)	8.350	2.410	10.76	100.0
New England chowder (dry mix)	4.390	1.610	5.695	81.0

Av. rec., % 90.8
Std. dev., % 6.67

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Beetles are on the rise again

The Japanese beetle (*Popillia japonica* Newman) and the Oriental beetle (*Anomala orientalis* Waterhouse), which were serious problems in turf during the 1940s, have been on the increase in lawns and gardens in Connecticut during the past few years.

Experiments by Entomologists Dennis Dunbar and Raimon Beard (retired), indicate that the increase in beetle problems is due in part to a breakdown of natural control by the milky disease, *Bacillus popilliae* Dutky.

Milky disease spores were spread at 2996 sites in Connecticut during 1939-51. The disease became established at many of these sites and spread to other areas. The incidence of milky disease was found to be high enough in 1962 to support a conclusion that Japanese and Oriental beetles would become a problem only in infested areas where the disease or other natural controls were absent.

But in 1974, Dunbar and Beard collected beetle grubs at 53 sites in the spring and 62 sites in the fall and found that the incidence of milky disease was low among both beetle species.

Included in the fall survey were 16 sites where the spore dust was distributed in the past; but at the seven places for which data was available, much lower rates of infection were found in 1974 than 30 years before. At six locations no infected grubs were found although the number of grubs ranged from 46 to 341 per square meter.

Laboratory investigations indicate that the milky disease has become less infective, apparently because fewer spores are now produced in infected grubs. In addition, the rate of infection is much lower than the rate expected from previous experience. Thus, it appears that the grubs have developed some resistance to the bacterium.

The increase in beetle problems is due in part to a breakdown of natural control by the milky disease.

Further investigations by Dunbar and Harry Kaya indicate that the commercially available milky spore dust is ineffective against large grubs in the spring. Using up to 10 pounds of the dust per 100 square foot plot, Dunbar and Kaya found that the rate of infection wasn't significantly higher in treated plots than in plots that received no treatment. Ten pounds per 100 square feet is about 44 times the recommended dose of the spore dust.

Dunbar and Kaya are now seeking a more virulent strain of the milky disease that will be effective in controlling grubs in Connecticut.

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