minnesota science

volume 31 number 3 fall 1975

Pollutants Damage Plants.

. . . page 8

AGRICULTURAL EXPERIMENT STATION
UNIVERSITY OF MINNESOTA

Research Feeds the State's Economy

Minnesota Science Interviews the Director

Q. *Last issue, you discussed research benefits for food and fiber production. What does the future hold for research in the technology of processing or manufacture of food and fiber products?*

A. We share responsibilities with many commercial organizations, but we limit ourselves to problems affecting the general welfare of Minnesotans. For example, we are investigating strength and durability of particle board. We attempt to develop new board from fibers not now utilized. We are developing new cheese manufacturing processes for farmhouse cheese. We attempt to improve quality of new varieties of fruits and vegetables and of animal products. Improved products for Minnesota consumption or for expanding our export markets are important results.

Q. *What other research—besides that which involves Minnesota's $4.5 billion food and fiber production—is important to the state's economic growth and development?*

A. We have an important stake in the $1.5 billion forest industry. Only a small fraction of our forest lands are handled by commercial forest operators who might undertake their own research. More than half of Minnesota's forest land is owned by government units and 40 percent by farmers and other citizens. These groups must rely on our public research to provide new strains of fast-growing desirable trees, and new or improved cultural, disease-controlling, and harvest practices to upgrade the income from forest lands. Increased income to governmental units lightens the tax burden on individual citizens.

Q. *What about distribution and wholesale and retail marketing of agricultural and forest products?*

A. Our economists are continuously exploring the intricate interrelations involved in marketing major commodities. They are concerned with long range supply and demand and with weaknesses in the marketing system that may be strengthened. For example, in the marketing of milk and dairy products, we are vitally concerned with pricing mechanisms and how they affect our Minnesota dairymen.

Q. *Are there state and policy decisions which affect markets for Minnesota agricultural and forest products?*

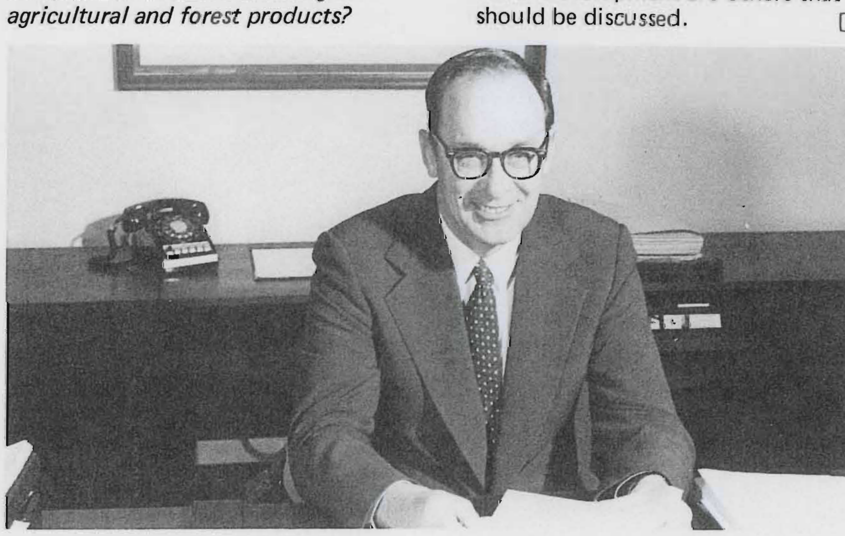
A. Very important ones! The recent intervention of longshoremen in orderly marketing of wheat and the consequent delay of foreign sales of food and feed grains may depress our Minnesota economy. We need to research, develop, and elaborate policy choices so that our commodity groups and political leaders can act effectively and quickly in the interests of the state.

Q. *Why do you constantly emphasize economic concerns in experiment station research?*

A. Food and fiber industries generate 40 percent of the state's wealth, 30 percent of its jobs, and 25 percent of its personal income. No other segment of the economy involves so many jobs for people and, thus, potential for new jobs. No other segment is so vulnerable to unpredictable catastrophes caused by flood, drought, blizzard, pests, or disease. Moreover, no other segment of the economy so profoundly affects the living standards of Minnesotans, particularly those with modest incomes.

Q. *What other important research concerns are there in the experiment station?*

A. Environmental Quality, Human Development and Family Living, and Rural Development are others that should be discussed. ☐



Keith Huston, Director, University of Minnesota Agricultural Experiment Station.

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CONTENTS

COVER: Sulfur dioxide from a paper factory severely injured this hollyhock leaf (story on page 8).

EDITOR'S NOTE: A 1975 Blue Ribbon from the American Association of Agricultural College Editors (AAACE) was won this year for "Benefits from Research." This publication summarizes research applications and accomplishments of the University of Minnesota Agricultural Experiment Station.

AAACE chooses, every 2 years, ". . . output that makes the best use of personnel and financial resources in achieving notable quality . . ." AAACE judged "Benefits from Research" as "superior" among "published special reports, including Annual Experiment Station or Extension Reports prepared to summarize work in one or more specific subject matter areas."

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A Soil Scientist's View of Eating Meat

RUSSELL S. ADAMS, JR.
Department of Soil Science

IN THE PAST DECADE we have been presented with one crisis after another: First, the pollution crisis, then the energy crisis, and close on its heels the food crisis. Some may like to belittle these problems, but none has disappeared as another gained the limelight. All must be considered in decisionmaking today.

One of the interesting things about a crisis is its ability to give birth to "instant experts" who are anxious to promote their own pet solutions to such problems:

In terms of the most recent food crisis, Americans are encouraged to eat less meat or no meat at all. Feeding of grain to animals is regarded as a great luxury, stealing food from starving people.

What is the role of the meat animal in US agriculture?

Sufficient food to maintain a satisfying and healthy human life is not just a matter of getting enough calories. Calories must be accompanied by suitable and balanced protein. Alternate sources of protein must be considered when evaluating the worth of the meat animal. The question then becomes:

How can American agriculture be maintained at a highly productive level and contribute to the alleviation of world food shortages, while also increasing energy efficiency and minimizing environmental pollution?

Many solutions for these problems have been presented. But too often solutions offered are simplistic, with the author failing to recognize that various solutions offered are mutually exclusive. For example, it is not uncommon to read an article that asks Americans to eat less meat in order to release more food for the starving world and at the same time apply more manure to cropland to save energy consumed in fertilizer production. Another article may advocate greater reliance on rotations for soil fertility maintenance so that less-energy-consumptive fertilizer (less energy used in manufacture) is needed, without realizing the loss which would be sustained in food production.

Like it or not, people in agriculture must face the fact that in spite of its rural heritage, urban America has largely lost touch with the land. The complexities of modern agriculture are unknown to the average urbanite and the simplistic solutions which many offer can only lead to more grief for the American farmer, the consuming public, and the starving world.

Numerous misconceptions about modern agriculture have seemingly become entrenched in many urban and even in some rural minds. For example, there are many misconceptions about the role and value of fertilizer in crop production. One most often heard today is as follows:

The use of chemical fertilizers only kills the soil's natural productive capacity and demands the use of even more fertilizer to achieve the same production.

This philosophy seems to suggest that the soil has an endless capacity to supply nutrient elements. Very few people, including many agricultural scientists, recognize the drain on soil elements—such as nitrogen and phosphorus—made by high-yielding crops.

The soil can be regarded as a nutrient element bank. Nearly everyone recognizes that money cannot be withdrawn continually from a bank without replenishing the account. The same is true of elements in the soil. They differ from money in one significant way, in that only a fraction of the nutrient elements can be harvested by plants at any given time. As the available soil elements become depleted the fraction that can be annually withdrawn grows smaller. Eventually, when soils become sufficiently exhausted, deposits of nutrient elements must exceed withdrawals in order to maintain production. Consequently, the misconception stated above can be easily drawn by the observant but uninformed person. The increasing need for fertilizer has resulted from an increasing demand for soil elements and failure to fertilize sufficiently to maintain fertility, rather than from excessive use of soil-degrading chemicals.

The harvest and addition of major plant nutrient elements in the US for the year 1970 is estimated in table one.

The 1970 removal of nitrogen, phosphorus, and potassium from the land by harvesting crops was larger than that returned to the land by applying fertilizer. This means that as late as 1970, US agricultural soils were continuing to be further depleted in spite of large-scale fertilization.

Fertilizer efficiency studies have shown that only about one-third of the nitrogen added will be recovered by the first crop. Another quarter may be recovered by the second crop.

Only about 10 to 15 percent of added phosphorus can be recovered by the crop the first year. In subsequent years only about 4 to 6 percent of the remaining phosphorus will be recovered each year. The remainder will be chemically fixed

Ruminants, such as cattle, can eat forage that is not nutritious for humans.

Figure 1. US 1930-1970 Production of Legumes[1].

[1] USDA data were used for the statistics used to plot this figure.

[2] Since actual figures for leguminous green manure have not been adequately documented by USDA statistics, this acreage was estimated to be one fourth of the oats acreage, a common nurse crop.

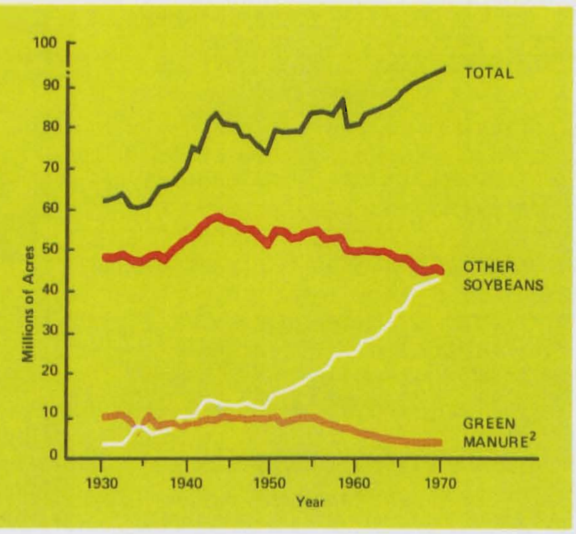


Table 1. US Crop Harvest of Major Nutrient Elements and Fertilizer Returned in 1970[1]

Crop	Crop Production Billions of Pounds	Nitrogen	Phosphorus Billions of Pounds	Potassium
Wheat	82.7	1.74	0.32	0.35
Rye	2.2	0.04	0.01	0.01
Rice	8.3	0.12	0.03	0.04
Corn Grain	230.2	3.20	0.62	0.68
Corn Silage	188.4	0.70	0.08	0.51
Oats	30.9	0.59	0.10	0.13
Barley	19.7	0.41	0.05	0.12
Sorghum Grain	39.0	0.68	0.12	0.14
Sorghum Silage	19.4	0.05	0.01	0.05
Soybeans	68.8	4.17	0.41	1.03
Sugar Beets	52.0	0.14	0.02	0.13
Hay (All)	255.8	5.09	0.51	4.34
Cotton (Seed Only)	8.7	0.32	0.06	0.10
Peanuts	3.0	0.14	0.01	0.02
Vegetables (All)	45.1	0.11	0.02	0.14
Fruit (All)	6.2	0.07	0.01	0.07
Total	1,062.2	17.57	2.37	7.80
Fertilizer Used		14.92	2.00	7.50

[1] Crop production taken from USDA Agriculture Statistics (1972) and crop removal of N, P, K calculated from average values given in Morrison's Feed and Feeding.

Table 2. Estimated Major Nutrient Elements Harvested[1]

Crop	Nitrogen Lbs/Acre	Phosphorus Lbs/Acre	Potassium Lbs/Acre	Calcium Lbs/Acre	Iron Lbs/Acre
Forage					
Alfalfa (Legume)	118	12	103	73.5	3.00
Bromegrass Hay	63	11	94	8.0	0.44
Prairie Hay	12	2	10	5.6	0.20
Grain					
Soybean (Legume)	97	14	24	4.0	0.33
Corn, Yellow Dent	57	11	11	0.8	0.16
Wheat	39	7	8	0.7	0.37
Potato Tubers	69	11	99	2.1	0.68

[1] Nutrient element harvest was estimated from mineral composition of feedstuffs given by Morrison's Feed and Feeding and average US yields in 1971 taken from USDA Agriculture Statistics or estimated as follows: alfalfa hay 2.5 ton per acre; bromegrass hay 2 tons per acre; prairie hay one ton per acre; soybeans 27.3 bushels per acre; corn grain 71.7 bushels per acre; wheat 31.1 bushels per acre; and potatoes 228 hundredweight per acre.

Table 3. Area and Yield of Different Crop Rotations Needed to Equal That of Continuous Corn[1]

Rotation	Digestible Energy (Millions of Kcal)	Relative Area Needed to Produce Equal Energy as Corn Acres
Continuous Corn (Grain)	3.29	100
Continuous Potatoes (Tubers)	4.08	81
Alfalfa Hay	2.85	115
Alfalfa-Wheat (Some Livestock)[2]	1.69	195
Continuous Wheat	1.49	221
Oats-Alfalfa-Corn (No Livestock)[3]	1.48	223
Continuous Soybeans	1.25	263
Continuous Oats	1.15	287
Continuous Prairie Hay (Natural Environment)	0.74	442

[1] These data are based on average yields obtained from 1970 USDA Agriculture Statistics (1972) and data given for digestible energy for ruminants from Morrison's Feed and Feeding.

[2] These data are averages and do not reflect maximum efficiency potentials. Moisture conditions permitting the last cutting of alfalfa will provide enough nitrogen for a subsequent wheat crop. Other cuttings can be fed to livestock. Data assumes 2 cuttings fed.

[3] No alfalfa can be harvested if enough nitrogen is grown for a subsequent corn crop.

by the soil (especially in very acid or alkaline soils). The recovery rates are the same for inorganic fertilizer and manure.

A second misconception commonly held is as follows:

Legumes can supply as many calories and as much good protein as meat. Because they make their own nutrients they can do this without fertilizer.

If this were actually true, then it is difficult to understand how meat could have economically competitive advantage and enjoy the place it holds in our society.

Vegetable proteins are not as effective in the human diet as animal proteins. There seems to be disagreement as to their relative value. One of the more conservative figures suggests 1.6 units of vegetable protein equal 1.0 unit of animal protein.

A related misconception is that:

The American farmer has continued to place less and less reliance on legumes in rotations.

Rotations have changed, but over the past 40 years croplands devoted to legume production have actually risen from about 17 percent of the cultivated acreage in 1930 to about 32 percent in 1970 (as shown in figure one). This change has been due to increases in soybean and alfalfa production. Over half of the nitrogen returned to US soils in 1970 was fixed by legume bacteria.

The US has fertile soils and extensive marketing facilities which make its legume production very competitive with other parts of the world. Yet, legumes are more depleting of soil nutrient elements than other crops. Although root bacteria of legumes fix nitrogen, the legumes often require greater quantities of calcium, potassium, and some trace elements than do cereal grains (table 2). Severe soil deficiencies of calcium and trace elements are the chief factors limiting the potential of legumes as food producers in third world countries.

Soybeans and beans produce the highest quality of vegetable protein. The quality is close to that of meat. But in rotations, soybeans will not produce enough surplus nitrogen to produce a corn crop for the following year. Soybeans fix 40 to 50 pounds of nitrogen per acre more than they will use. A 100 bushel per acre corn crop requires 140 to 200 pounds of nitrogen. Food beans are even less efficient and in some cases do not fix enough nitrogen to supply their own needs.

Forage legumes in rotation are the most efficient crops for fixing nitrogen. A well established, fairly new, alfalfa stand may fix a few hundred pounds of nitrogen and store enough calories to equal or exceed that of corn. However, man has not learned how to use this protein without expending considerable additional manufacturing energy. Consequently, to be effectively used, alfalfa must be fed to livestock, preferably ruminants.

If alfalfa is grown only for nitrogen fixation, then a year is required to store sufficient nitrogen for a following corn crop; and therefore a year of food production is lost. Even though corn yields may be maintained by such a rotation a given acreage can only produce half as much human food. Table 3 shows several rotations and average digestible energy for ruminants produced with each system. Obviously, farmers of some geographic locations could not grow corn, soybeans, or wheat competitively with farmers of other regions. Corn and potatoes yield large amounts of calories; but they provide a poor quality or very little protein. Under stress of population increases and starvation diets, the natural pressure is to grow high-caloric crops rather than high-protein crops. Wheat, oats, and rice give a higher quality protein but produce lower caloric yields than corn.

Forage legumes such as alfalfa—when used in proper rotation—are at their greatest efficiency when livestock are part of the rotation. Where a productive stand of alfalfa is maintained, fed to livestock, and the manure returned to the land, theoretically no nitrogen fertilizer should be needed, with only modest amounts of lime, potassium, and phosphorus. Two rotations are compared in table 4. Note a substantial loss in energy production of the legume rotation. Certainly, feeding to livestock will further reduce food yields for human consumption. But this forage rotation is designed for soil fertility maintenance and sustained food production over a long period instead of maximum production over a short time. These rotations would require dispersal of livestock enterprises.

An obvious, frequently suggested alternative, is to use sewage sludge and garbage for fertilizing the soil. Western culture's handling of sewage materials for fertilizers poses many environmental and health problems. These arise primarily from the accumulation of poisonous metals and the natural tendency of organic matter to chelate metals already in the soil. Such metals, previously "locked" in the soil, can then be taken in by the plant roots and

Table 4. **Efficiency of a 5-Year Rotation Versus Continuous Corn in Southern Minnesota in 1973**

Year	Crop	Average Crop Yield Per Acre	Optimum Yield Per Acre	Nitrogen Needs Lbs/Acre	Energy Yield Kcal/Acre	Unit Price	Gross Return Per Acre	Cost Per Acre	Net Return Per Acre
1	Wheat	40 Bu	70 Bu	100	3,557,440	$ 4.35	$ 304	$125	$179
2	Alfalfa	2 Tons	5 Tons	0	4,150,000	40.00	240	126	114
3	Corn	94 Bu	130 Bu	50	5,991,440	2.28	296	158	138
4	Corn	94 Bu	130 Bu	150	5,991,440	2.28	296	170	126
5	Soybeans	29 Bu	40 Bu	0	2,032,800	5.22	209	131	78
	Total	---	---	300	21,723,080	---	$1,345	$667	$635
5 Years	Continuous Corn	94 Bu	130 Bu	850	29,957,200	$ 2.28	$1,480	$875	$605

accumulated by the plant. Animals or humans who eat such plants may suffer from health problems caused by the metals.

Farmers, of course, have recycled manure for perhaps as long as the existence of farming. In Minnesota most of the manure is recycled. In recent years some Minnesota farmers could not get all the manure they wanted. Some farmers elsewhere have similar problems.

One study in England—a waste importing nation—showed that if all its garbage and manure were used effectively they could not maintain soil fertility. England could replace only 85 percent of the nitrogen removed by the crop if all garbage wastes and manures were used.

The plant-soil system cannot directly use nutrient elements present in organic fertilizer, especially nitrogen, as efficiently as those from inorganic sources. As a consequence the pollution potential from organic sources of fertilizer also becomes greater. In light of present technology, sewage should not be used for leaf or root crops intended for human consumption.

Here is another popular misconception about the energy efficiency of US agriculture:

So-called 'primitive' cultures obtain 5 to 50 calories of food per calorie invested in agricultural production, while American agriculture barely returns one calorie for each invested.

This sort of statement reflects a lack of understanding of the ecological impact of 'primitive' agriculture. Such complimentary figures are obtained by ignoring the major inputs of energy into the system. Rappaport is the source most often cited.[1] His data considered only human labor and fossil fuels, a shortcoming Rappaport recognized. No credit was given to the consumption of stored environmental energy.

New Guinea's agricultural system involves:

- 15 to 20 years of forest fallow
- slash and burn
- garden for 3 to 5 years
- revert to forest

Tropical montane forests produce about 11,071 pounds of dry matter per acre per year (Dilmy).[2] We can assume 1,820 kilocalories per pound of dry matter (Odum et al).[3] This means from 60 to 135 million kilocalories input of energy per acre per year of actual farming. According to Rappaport[4] about 2 million kilocalories per acre are produced each year in the gardens. Thus, for each unit of energy produced (in the garden) 30 to 63 units of energy are consumed.

Similar comparisons can be drawn relating oriental compost farming to modern agriculture. Technology now exists which can convert this energy into usable forms. The most striking characteristics of the New Guinea system are the low carrying capacity of the system in view of the much idle land and its total dependence on forest fallow with attendent severe soil exploitation by the slash and burn system.

For an account of the consequences of slash and burn agriculture, read Ahn:[5] He describes the progressive decay of ecosystems passing from tropical forest to desert. The severe and irreversible impact of shifting agriculture on natural ecosystems led Ahn to call for a more stable agriculture and an introduction of more livestock into those areas, in spite of West Africa's inability to adequately feed its people.

Evaluation of the role of animals in alleviating world hunger must consider the reduction of pollution, conservation of energy, and maintenance of soil fertility so that future generations may be fed. Simplistic solutions often fail because they do not consider one or more of these concerns. With our present technology there are no efficient rotations which can maintain soil fertility without livestock. Livestock and sewage wastes are alternative fertilizer sources in times of fertilizer scarcity. (A great deal of the manure is already used, though inefficiently.) Livestock reduces the amount of food available for human consumption, at least on a short term basis. Furthermore, these wastes are potentially more polluting than inorganic fertilizer.

For efficient use of both manure and sewage wastes, livestock and human populations must be dispersed. But such dispersion would reduce both industrial and livestock production efficiency. This, in turn, would lead to higher prices and reduced consumer availability.

Another possible alternative is to retrench and return to older, less efficient and less productive schemes of agriculture. In this case, fossil fuel energy would be conserved, but greater exploitation of the environment would occur and present food production could not be maintained.

All of the alternatives suggested have their shortcomings. As world populations grow, conflicts of interest in terms of food, energy, and pollution will become more intense. Undoubtedly, we must moderate our eating habits. However, as a soil scientist, and in the interest of maintaining soil fertility for generations to come, I cannot view elimination of meat from our diet as either patriotic or resource conserving. □

[1] Rappaport, A. 1967. Pigs for the Ancestors. Yale University Press. New Haven, Conn.

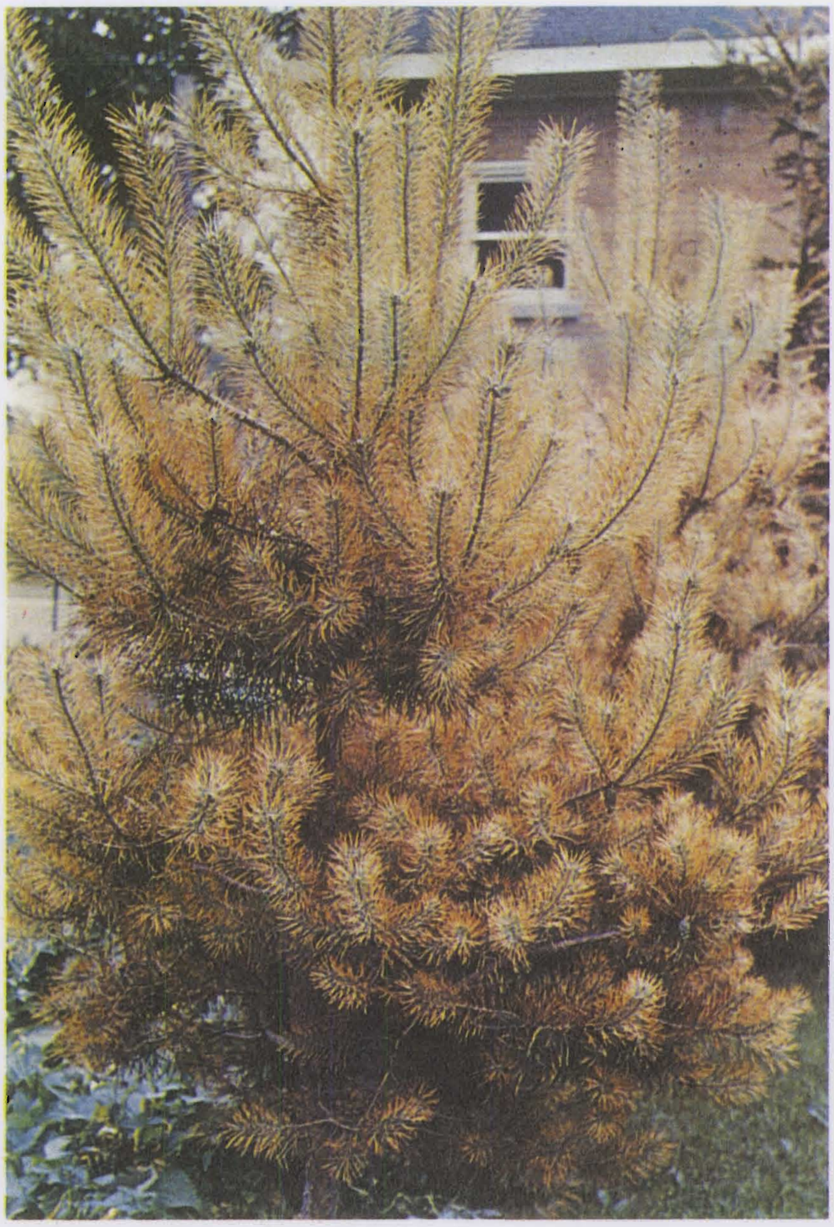
[2] Dilmy, A. 1971. "The primary production of equatorial tropical forests in Indonesia." Productivity of Forest Ecosystems. Unesco and International Biological Program. pp. 33-337.

[3] Odum, H. T., W. Abbot, R. K. Selander, F. B. Golley, and R. F. Wilson. 1970. "Estimates of chlorophyl and biomass of the Tabonuco forest of Puerto Rico." A Tropical Rain Forest, a Study of Irradiation and Ecology at El Verde, Puerto Rico. Ed. H. Odum and R. Pigeon Atomic Energy Corporation, pp. I-1 — I-19.

[4] Rappaport, A. 1971. "The flow of energy in an agricultural society." Energy and Power. Scientific American, Inc. San Francisco, Calif. pp. 69-80.

[5] Ahn, A. P. 1970. "West African Soils." Vol. I. West African Agriculture. Oxford University Press, London.

Plant Attack by Air Pollution:



This Scotch pine was killed by sulfur dioxide pollution from a paper factory in southern Ontario, Canada.

Fly ash from a central Minnesota coal-fired power plant damaged this plant leaf.

Fluoride pollution in northern Minnesota killed much of the tissue of these birch tree leaves.

Minnesota Impacts

See story on page 10.

Tissue of these beet leaves was killed by ammonia pollution from a Minnesota fertilizer factory.

Ethylene damaged this tomato plant. This gas comes from leaky natural gas heaters, from gas- coal-, and oil-fired power plants and home furnaces, from automobiles, and from trash burning.

Secondary pollution severely injured this tomato plant. Fumes from the city of London, Ontario, in Canada interacted with air by using energy from the sun to form PAN, or peroxyacetyl nitrate.

Plant Attack by Air Pollution: Minnesota Impacts

SAGAR V. KRUPA
Department of Plant Pathology

MANY PEOPLE WORRY—justifiably—about health hazards of air pollutants. But there is another aspect of this problem which receives less attention: Air pollutants injure many species of plants. Such injuries are often costly, both economically and aesthetically.

Plants can be damaged by relatively low concentrations of air pollutants. Certain plants can also serve as indicators to warn against a build-up of unwanted chemicals in the air.

Ozone—vegetation's most important pollutant—is mainly generated by reactions involving sunlight and atmospheric chemicals such as nitrogen dioxide and hydrocarbons (emitted by fuel-burning machines, including automobiles). Such contaminants, often components of smog, are known as secondary pollutants.

Other pollutants, such as sulfur dioxide, are called primary pollutants. These are produced directly from such sources as a smoke stack of a coal-fired power plant. Many primary pollutants are harmful to plants.

Air pollutants may be gases, liquids, or solid contaminants of our air (see table one).

Many air pollutants tend to produce their own patterns and records of injury to plants (table one). The extent and nature of such a damage pattern are governed by genetic and environmental factors, as well as by the concentration and duration of exposure to the pollutants. The impact of air pollutants on plants may be noticeable or subtle. Subtle injuries can be detected by comparisons and measurements. Noticeable injury includes distinct patterns of dead areas (orange to dark brown in color) on the leaves, or as a yellowing and premature loss of leaves. Subtle results of air pollution damage also may be detected as reductions in plant growth or yield.

Minnesota is called a clean-air state: Minnesotans are fortunate to be free from frequent stagnant air masses that prevail over the East Coast and the Los Angeles area.

Twin Cities Plants in Danger

The US Environmental Protection Agency's primary and secondary air quality standards relate to average concentrations of a given pollutant throughout a given period of time. The primary standards pertain to human health. The secondary standards pertain to plant health.

For example, for plants, the national secondary standard for ozone in the air is 0.08 parts per million (average) per one hour once a year per locality. During 1973 in the Twin Cities this standard was exceeded 600 times. In other words, some of Twin Cities' plants were in danger of damage or were damaged by the excess of pollutants.

Ozone is generated over urban areas when sunlight feeds energy to certain chemical reactions. Ideal atmospheric concentrations for such photoreactions occur between roughly 2 and 7 p.m. For example, on March 16, 1975 over downtown St. Paul, ozone concentrations ranged between 0.09 to 0.10 parts per million at that time period. In the summer of 1975, significant concentrations of ozone occurred not only over the Twin Cities, but also over Dayton and Becker. Wind was southeast to north-northwest. The ozone pollution recorded at Dayton and Becker seems to be most likely due to ozone-generating substances which were air-carried from the Twin Cities. Fortunately, in the lower atmosphere, ozone does not remain stable for long.

Pollutants Invade Minnesota

UM's Department of Plant Pathology has a monitoring program to evaluate air pollutant concentrations in remote areas which are being increasingly influenced by man, such as Lake Kabetogama in northern Minnesota where summer averages of ozone concentrations per hour have varied between 0.02 and 0.035 parts per million. But these concentrations are generally considered to be background levels. Studies such as this over a few years will help to assess man's influence on air quality and in turn man's impact on natural vegetation.

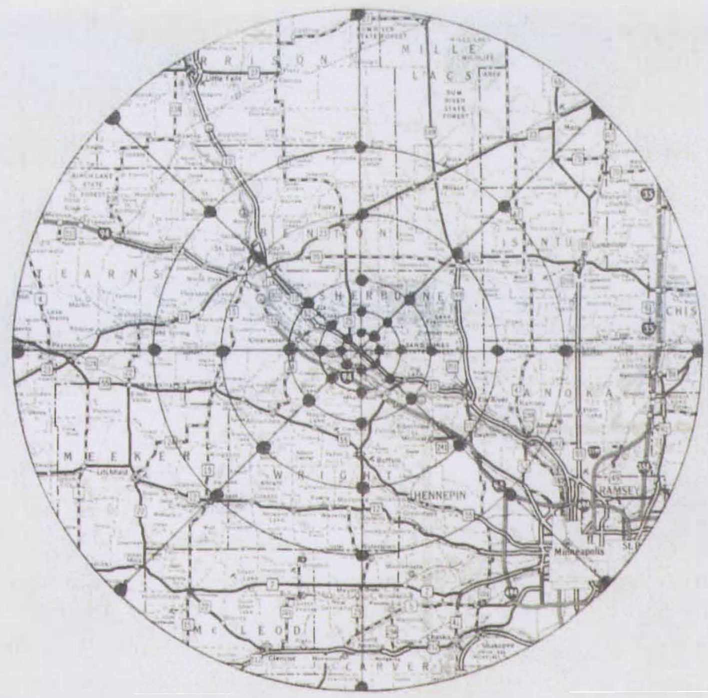
Other surveys by UM plant pathologists during the spring and summer of 1975 pinpointed ozone injury on soybeans in areas north-northwest of the Twin Cities. Symptoms of ozone injury on plants include pigmented dots on the upper leaf surface on broad-leafed plants.

Sulfur dioxide is the second most important atmospheric contaminant of US plants. For example, at certain locations southeast of the Twin Cities, the national secondary standard for sulfur dioxide (0.5 parts per million average over a 3-hour period) was exceeded 100 percent of the monitored time during 1973. There is little, if any, evidence of reduction of such pollution. Usually the impact of sulfur dioxide on vegetation is local compared to ozone. Plant damage is generally restricted to about a 50 mile radius around the source. Sulfur dioxide pollution also occurs in certain parts of northern Minnesota. Typical symptoms of injury include death of the leaf tissue between the veins in plants such as birch and big-leafed aster or a creeping death of the needles in conifers which starts at the tip of needles and spreads downward.

More recently, there has been world concern about acid rain. Acid rain forms when sulfur dioxide in the air is converted to sulfuric acid. The acid falls, dissolved in rain.

Of the new problems originating with the advent of modern pollution-control devices on automobiles, sulfuric acid mist is considered to be a threat to vegetation. University of Minnesota plant pathologists are attacking this pollution problem and its influence on Minnesota vegetation.

Different kinds of plants vary in their response to air pollutants. For example, eastern white pine is more sensitive to ozone than is Scotch pine.



Within a 50-mile radius of the Sherburne County power plant at Becker, Minnesota are study areas—shown plotted here —where UM plant pathologists investigate plants, including farm crops, for possible influences of air pollutants. Already, the Minnesota scientists have found evidence that southeast to north-northwest wind has carried ozone pollution from the Twin Cities to as far as Dayton and Becker, Minnesota.

Table 1. Impacts of Air Pollution on Various Plants in Minnesota

Air Pollutants	Sources	Some Sensitive Plants	General Symptoms of Injury After Acute Fumigation
Ozone	Chemical reactions in the atmosphere involving sunlight, storm centers, and other natural occurrences in the upper atmosphere.	Ash, aspen, bean, carnation, eastern white pine, lilac, petunia, potato, radish, and tobacco.	Pigmented or unpigmented spots, or bleaching, on the upper leaf surface only; browning and death of conifer needles starting at the tip of the needles.
Sulfur Dioxide	Combustion of fuel; petroleum and natural gas industries; and ore smelting and refining processes.	Alfalfa, aster, bean, birch, oats, soybean, sunflower, and wheat.	Death of leaf tissue between the veins; death of conifer needles starting at the tip of the needles.
Fluoride	Brick plants, refineries, industries of aluminum, and manufacturers of steel and phosphate fertilizers.	Blueberry, corn, gladiolus, Scotch pine, and tulip.	Death of leaf tissue at the tip and margins; browning and death of conifer needles.
Peroxyacetyl Nitrate (PAN)	Photochemical reactions in the atmosphere.	Bean, dahlia, oats, petunia, and tomato.	Silvering, glazing, and bronzing of the lower leaf surface only.
Oxides of Nitrogen	Exhaust gases of trucks and autos; combustion of natural gas, fuel oil, and coal; refining of petroleum; and incineration of organic wastes.	For nitrogen dioxide: Bean, lettuce, sunflower, tobacco, and muskmelon.	For nitrogen dioxide: White, tan, or brown dead areas between the veins and waxy coating on the leaf surface.
*Particulates	Cement mills; lime kilns; incinerators; and combustion of coal, gasoline, and fuel oil.	Plants vary in sensitivity.	Visible coating, encrustation, and marginal burn.
*Ethylene	Motor vehicles, refuse burning, combustion of coal and oil, leaky natural gas heaters, and natural occurrences.	Carnation, cucumber, cream pea, Easter lily, orchid, rose, and tomato.	Yellowing and drooping of leaves, premature leaf drop, failure of flower buds to open, and stimulation of lateral growth.
*Ammonia	Leaks or breakdowns in industrial operations and spillage of anhydrous ammonia.	Beet, tomato, and sunflower.	Cooked green appearance, bleaching, dead spots along the margins, and yellowing of leaves.
*Chlorine and Hydrogen Chloride	Refineries, glass industries, scrap burning, and accidental spills.	Coleus, corn, radish, sugar maple, tomato, tulip, and white pine.	Dead spots along the margins of outer leaves; injury may be similar to sulfur dioxide, with bleaching of leaves.

*Minor pollutants

Sulfur dioxide from a power plant caused this severe birch leaf damage.

UM plant pathologists test important Minnesota plants including soybean, potato, white pine, red pine, spruce, and poplar to see how air pollutants such as ozone injure the plants. The UM researchers built special laboratory fumigation facilities to assess the plants' sensitivity and tolerance to air pollutants. Such information coupled with available plant-breeding programs will help toward the selection of proper varieties of plants for Minnesota crop improvement and forest management in a future of varying degrees of air pollution.

Other air pollutants injurious to important Minnesota plants include hydrogen fluoride, ammonia, ethylene, lead, fly ash, and other particulates.

While it is possible to study the influences of a single pollutant or a mixture of 2 or 3 pollutants on plants under controlled conditions in the laboratory, studies should also be performed under field conditions, since the surrounding air is always a complex mixture of interacting components. To this end, the UM air pollution research group uses what are known as "open-top chambers."

An open-top chamber consists of a cylindrical column, 8 feet tall, 10 feet in diameter, with an open top covered by a nylon fish net. A blower feeds air into the sides of the bottom of the column. Air at the bottom rises and helps to prevent air from entering the open top. Two such chambers are set up in the field to cover a previously existing crop.

Alternatively, a special crop can be planted inside the chambers. Air entering one of the chambers is filtered to reduce the air pollutants, while air entering the other chamber is not filtered. A comparison of growth and yield of the 2 groups of plants in the chambers gives the UM scientists an estimate of impacts of air pollutants on plants in the field. From such data the scientists can make estimates of crop yield loss due to air pollution injury.

Plant diseases, of course, are also caused by parasites such as fungi, bacteria, viruses, and nematodes. But air pollutants can alter the course of such diseases. For example, pine bark beetles are attracted to trees that have had ozone stress. Similarly, tobacco mosaic virus disease is stimulated in bean plants that have had ozone stress. In contrast, crown rust disease is inhibited on oat plants that have had ozone stress.

Recent studies at UM's plant pathology department indicate that a disease-causing agent such as alfalfa mosaic virus, when inoculated on bean, can either be stimulated or inhibited depending upon whether the plants were first exposed to the virus or to the ozone. Such findings can have an important bearing on future crop health and preservation of forest lands.

The air pollution-vegetation research at UM is a fledgling 3-year-old program consisting of 4 staff members and 2 students. But as studies continue, more and more information is coming forth on Minnesota air pollution problems.

UM's Department of Plant Pathology, the Minnesota Pollution Control Agency, and several other groups, are now learning more about air pollution problems in Minnesota. However, in view of the existing technological limitations, alternative solutions to air pollution problems must be sought. Identification, evaluation, and prevention of plant injury by such methods as selection and use of tolerant varieties of important crop and tree species must be sought until more effective measures are developed.[1] ☐

[1] Sagar V. Krupa thanks scientists in the US and Canada from whose slide collections some of the photographs accompanying this article were taken.

A big leaved aster injured by sulfur dioxide pollution from a coal-fired power plant in Minnesota near Lake Michigan.

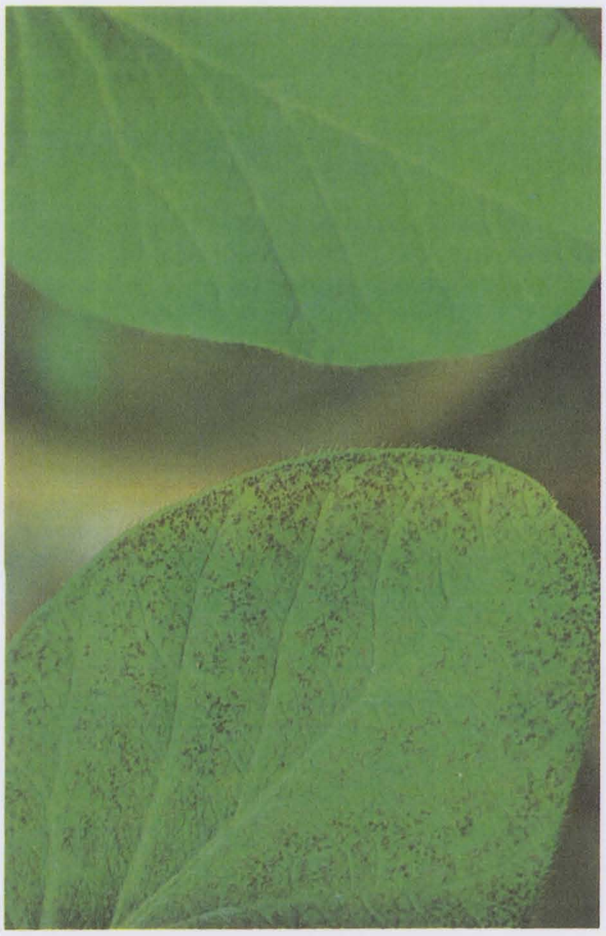
Air Pollutants Damage Plants

DAVID A. ZARKIN
Department of Information and Agricultural Journalism

AIR POLLUTION PROBLEMS in the Upper Midwest escape the public eye while concerns such as the national economy and world food situation take top priority.

It is particularly difficult to get Minnesotans aroused about air pollution. The Gopher State's sky seems relatively clear compared to the daily blanket of thick gray haze which engulfs Los Angeles and some of the Eastern Seaboard cities. Yet, air pollution in the Twin Cities is similar to that in Los Angeles but less severe because of differences in urbanization, topography, and weather. Air pollution in other regions of Minnesota can be attributed to well defined sources such as power plants, taconite industries, and smelter plants.

Noticeable drought and early freeze frustrate Minnesota farmers. But less-noticeable air pollution can also lower



Ozone damage to broad-leaved plants has occurred in the Sand Plains region of Minnesota. Such ozone damage is demonstrated here: The bottom leaf was exposed to 0.2 ppm of ozone, and the top leaf, none. The ozone exposure lasted only 4 hours.

crop yields. Air pollution can lower yields of soybeans and other field crops, and it can reduce the growth of white pine and other trees, according to Minnesota researchers. Sulfur dioxide from some Minnesota coal-fueled power plants damages field crops. Fluoride and sulfur dioxide pollution has also damaged some northern Minnesota aspen and birch trees, according to Sagar V. Krupa, of University of Minnesota's Department of Plant Pathology.

Some indication of the current situation for research on pollution is given by Francis A. (Al) Wood, head of the UM Department of Plant Pathology. He says there were more air pollution research funds available in 1967 than are available now.

"Too often plant damage is attributed to air pollution on a wholesale basis lacking the facts to back up that judgment, or else pollution is overlooked as a possibility because the observer may be attuned to more classic causes," says Wood. "Uneducated guesses about air pollution set back efforts to come to grips with the problem."

Wood says that definitions of air pollution change as technology and attitudes change. A generalized definition is:

An air pollutant is any air constituent which causes an unwanted effect.

Ozone is an area-wide pollutant in such places as the Eastern Seaboard—from Boston, Massachusetts to Richmond, Virginia—or in the almost equally populous Los Angeles southland of California. Ozone, one of the most dangerous pollutants to plants, is known to cause what has been called "weather fleck" in tobacco. Ozone-induced diseases have been associated with atmospheric disturbances for many years.

Ozone may play an important part in damage to vegetables, ornamentals, and fruit trees in the Twin Cities metropolitan area, says the UM researcher. Photochemical pollution is common over urban areas and has important implications regarding its influence on shade trees, says Wood. Ozone is also in remote areas, such as Kabetogama Lake near International Falls, where it is generated over forests.

"We know very little about influences of photochemical air pollution on woody plants," says Wood; "and consequently it is imperative that research programs be instituted to provide information in this important area."

Sulfur Dioxide to Increase

Shade-tree damage caused by sulfur dioxide, hydrogen fluoride, and other pollutants is expected along with the continued importance of photochemical air pollutants, says the Minnesota scientist. As a result, resistance and tolerance—considerations in the selection of shade trees for the future—will be important.

Plant breeders probably will have to select trees that tolerate pollution or those that absorb pollution, says Wood. Seedlings that readily remove pollutants from the air often become severely damaged when sufficiently exposed to pollutants.

Wood predicts that sulfur dioxide as a serious pollution problem will get worse but should be reduced by the year 2000:

"Between now and then the situation will definitely get worse," warns Wood. "This is especially true of sources related to the generation of electricity."

Major sources of sulfur dioxide are power plants and industrial plants. These will continue to be major pollution sources in the future, says Wood.

Another pollutant, hydrogen fluoride, is accumulated by plants. Some plants, such as dogwood and tea, are better accumulators than others, said plant scientist Leonard H. Weinstein of the Boyce Thompson Institute for Plant Research, Yonkers, N.Y., at a recent Minnesota conference on air pollution: Most industries with fluoride problems have vegetation-sampling programs, said Weinstein. During the growing season they periodically analyze the plants. Plants which accumulate fluoride can become hazardous without any obvious visible symptoms.

"Then, just the accumulation of fluoride in alfalfa beyond a standard has damaged that alfalfa, because it cannot be used as forage," said Weinstein. "The reason it cannot be used as forage is because fluoride beyond a concentration of approximately 35 parts per million fed to cattle and to other foraging animals can cause a disease called fluorosis."

Fluorosis is primarily a disease of bones and teeth: The animal's teeth can wear away. The animal can become crippled and weakened and the disease can affect milk production and cattle reproduction. Deer which browse on trees that have been fumigated with fluoride can get the disease. Squirrels that eat contaminated seeds can also get fluorosis.

Annual tonnages of fluorides do not compare with pollutants such as sulfur dioxide, but they still present a major problem because fluorides are poisonous at much lower concentrations than some other air pollutants which damage plants. □

Science Notes

WASTE HEAT TO BE USED

A practical way to conserve energy, recycle resources and produce food more efficiently soon will be demonstrated in Minnesota's Sherburne County.

Warm water, a potential threat to fish if dumped in Minnesota lakes and streams, will be recycled from the condensers of Northern States Power Company's Sherburne County (Sherco) generating plant at Becker to a nearby half-acre greenhouse.

The University of Minnesota's Agricultural Experiment Station and NSP with a $250,000 grant from the Environmental Protection Agency (EPA) are cooperating on a half-acre greenhouse demonstration project west of Becker that will use warm waste water from the electric generating plant.

The project could serve as a sign post for the future, by saving significant amounts of oil and natural gas and providing a year-round growing season in Minnesota.

Construction started on the 96- x 238-foot greenhouse in July and is expected to be operating soon this fall with a standby electric boiler system (until warm waste water is available when the first unit of the Sherburne plant is completed in 1976). Heat energy from the water used to cool the condensers of electric generating plants will be captured in the greenhouse to grow tomatoes, lettuce, radishes, chrysanthemums, geraniums, and roses.

Evergreen seedlings may be grown in part of the greenhouse by 1976, according to Landis L. Boyd, project director and assistant director of the UM Agricultural Experiment Station. "Starting evergreens in the warm water heated greenhouse would allow larger than normal seedlings for replanting in the forest," says Boyd. "The total time in which the trees could be grown for harvest might be reduced with the greater growth stimulation received in the warm water greenhouse."

Boyd envisions clusters of greenhouses, organized much like industrial parks, and warm waste water from adjacent power plants in Minnesota and other states.

"In addition to saving fuel," says Boyd, "the Sherco project will provide a local supply of salad vegetables, such as tomatoes, during the non-growing seasons in Minnesota. The quality of these vine ripened, locally-produced tomatoes would be far superior to those picked green and shipped in from out of the region. The increased growing season also could mean more income for growers and more jobs in an expanded agribusiness industry."

Initially demonstrating recovery of otherwise wasted energy, the project later will provide UM Agricultural Experiment Station researchers with opportunities to do heat transfer studies and determine what vegetable and flower varieties are best suited to such environments.

Boyd looks beyond vegetables and flowers to growing evergreens in the greenhouse next year to allow larger than normal seedlings for replanting in the forest. The total time in which the trees could be grown for harvest might be reduced with the greater early growth stimulation received in the warm water greenhouse.

As much as a 100-acre greenhouse complex could be operating by 1985, contingent upon the success of the half-acre experiment and economic considerations. Pilot work on the project has been underway in a small commercial greenhouse near Forest Lake, where, growing geraniums and poinsettias, the concept of the Becker project was tested successfully for a year.

Standard unit heaters will be modified for a greater airflow rate to allow more heat transfer in the greenhouse, Boyd says. In addition, as a result of favorable cooperative federal and state demonstrations in Oregon, the warm waste water will be used to heat the soil.

NSP officials say heating and cooling a half-acre greenhouse for a year with fuel oil or natural gas would require 25,000 gallons of oil or 3,500,000 cubic feet of gas. A 100-acre greenhouse would require 5,000,000 gallons of oil or 700,000,000 cubic feet of natural gas.

"These potential energy savings are extremely significant in light of the growing scarcity of oil and gas," says David F. McElroy, NSP board chairman.

In converting fuel to electricity, power plants produce waste heat, most of which ends up as warm water that is dissipated to the atmosphere by cooling towers or natural means. In the Sherco experiment, a small portion of the plant's warm water (approximately 350 gallons per minute) will be piped to the greenhouse at 85 degrees. It will be circulated through a series of tubes in the unit heater at one end of the greenhouse, where a fan will draw air over the tubes and through a large plastic duct which runs the length of the building.

Here is one way to conserve heat energy from water used to cool condensers of fuel combustion plants that generate electricity: The method is to pipe warm water to greenhouses, as demonstrated above, and then use the heat energy—otherwise wasted—to grow living plants such as tomatoes, lettuce, radishes, chrysanthemums, geraniums, and roses.

During the summer, the air will be drawn through water-soaked pads made of wood fiber in order to cool the greenhouse by evaporation, much the same way perspiration cools the human body.

Plans call for the warm water to maintain greenhouse temperatures at a minimum of 65°F. degrees during the winter and not greater than 95°F. degrees during the summer.

—David Zarkin

UM RESEARCHERS CHECK POWER PLANT IMPACTS

Northern States Power is funding a 4-year, $250,000 study of environmental impacts and effectiveness of pollution control devices being installed on a NSP power plant at Becker, Minn.

Sagar Krupa, who heads a team of UM plant pathologists in charge of the study, says they will monitor living plants, including farm crops.

The Environmental Quality Council of the State of Minnesota has also funded the UM plant pathologists for related studies of air pollution impacts on living plants.

MOTHER NATURE POLLUTES SAYS UM PLANT SCIENTIST

The National Park Service of the US Department of Interior has funded UM plant pathologists for studies on how air pollutant levels in remote areas, such as national parks, affect plant life.

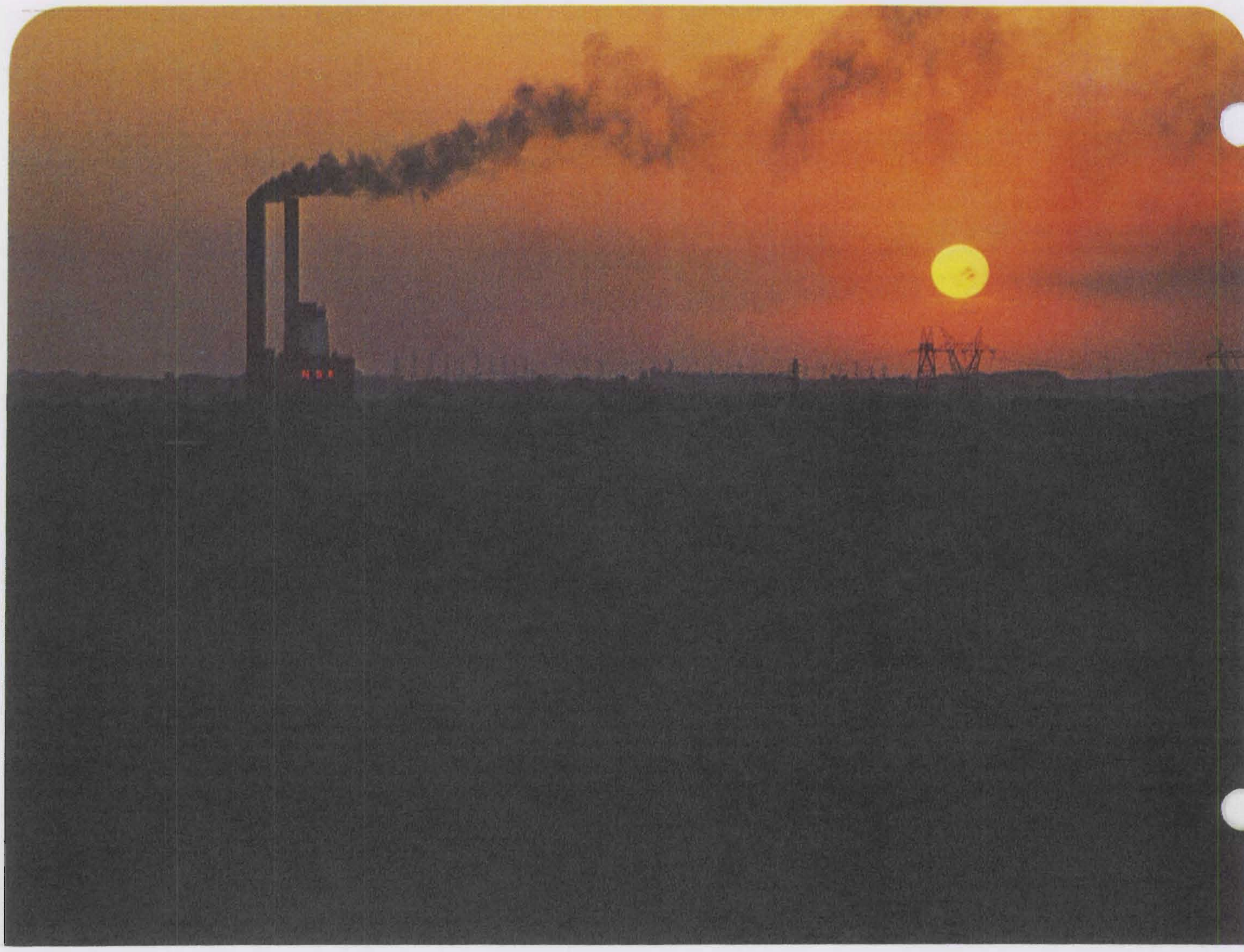
UM plant pathologist Sagar Krupa reports that at times, the ozone levels in wilderness areas such as Voyageur National Park, are as high as those reached in the Twin Cities. He calls such air pollution a product of nature: Ozone forms when terpenes of evergreens are exposed to sunlight in the presence of nitrogen dioxide, a natural product of nature's nitrification process.

NEW SPRING WHEAT RELEASED BY AGRICULTURAL WORKERS

Kitt, a semidwarf hard red spring wheat, was developed, named, and released jointly by the University of Minnesota Agricultural Experiment Station and ARS, USDA, in 1975. Kitt has been tested in Minnesota yield trials since 1969.

Kitt is yellow chaffed with good lodging resistance. Its kernels are red, hard, and short to medium in length. Kitt is resistant to the prevalent races of stem rust and to most other virulent isolates found in low frequency in recent stem rust surveys. Kitt has a broader spectrum of resistance to leaf rust than Chris or Era. It is also tolerant of black chaff, ergot, and mildew. The bushel weight for Kitt is lower than those of Polk, Chris, Era, and Waldron, but similar to Bounty 208, Manitou, and Selkirk. Kitt is high-yielding. It produces 15 to 30 percent more grain than Chris, Waldron, Justin, and Selkirk. Regional and Minnesota performance trials show that Kitt and Era are very similar in yield in Minnesota, South Dakota, and North Dakota. Milling performance, mixing characteristics, and general bread-making quality are satisfactory. Kitt is significantly higher than Era in protein content, bake absorption, and loaf volume, but is lower than Chris in these quality traits under conditions of high grain yield.

Breeder seed will be maintained by the UM Agricultural Experiment Station. □



This sunset near a Minnesota power plant would be called ugly by some and beautiful by others. Environmental and social impacts must be weighed against dollar and energy costs: "We can't just close down industries and go back to pioneer living," says UM researcher Sagar V. Krupa (for related story see page 8).

Pollutants from the combustion of fuel include nitric oxide, nitrogen dioxide, particulates, ethylene, and sulfur dioxide.

Sulfur dioxide pollution will be on the increase for most of the rest of this century, according to one Minnesota scientist (see story page 13). Sulfur dioxide damage includes the death of leaf tissue between the veins, and death of conifer needles starting at the tip of the needles. Sulfur dioxide damages plants including alfalfa, aster, bean, birch, oats, soybean, sunflower, and wheat (see story page 8).

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