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Chemical Attack on the Thermometer

Research in Caltech's plant laboratories shows that chemicals can prevent plant damage caused by extreme temperatures

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Recent experiments in Caltech's plant research laboratories indicate that the damage to plants caused by temperature extremes can be prevented – either partially or completely – by spraying the leaves of the plants with solutions of organic nutrients. These results suggest the possibility of new agricultural chemicals to protect crops during periods of adverse climatic conditions.

Environment determines the distribution of plant species as well as their growth and development. Environment, of course, consists of such things as the type of soil, the supply of nutrients and water, rainfall, temperature and daylength. Generally, temperature and water are decisive, because their extremes determine the length of time during which plants can fix light energy to be stored in the form of chemical energy. In an agricultural system, the nutritional status and water supply may be adapted to the crop grown by providing fertilizers and irrigation water. Therefore, temperature is a very important regulating factor of plant growth

A vast amount of effort has gone into the investigation of the temperature requirements and tolerances of plants. Much of this kind of work has been carried out in Caltech's climate-controlled greenhouses, the Earhart Plant Research Laboratory.

The present experiments were also carried out in the Earhart Laboratory, as part of a five-year investigation, supported by the Rockefeller Foundation, of the nature of the responses of plants to climate ("The Chemical Cure of Climatic Lesions," by James Bonner – *E&S*, March 1957).The specific purpose of this investigation was to try to answer the questions: "What goes wrong with the plant when it is grown in unfavorable temperature conditions?" and "How does the plant sense or measure temperatures?"

Plants are affected by temperature in many ways. One relatively complicated way involves rhythmic processes in the plant ("The Biological Clock," by Hendrik J. Ketellapper – *E&S*, November 1960). Another way involves the chemistry of the plant.

The first step in this chemical research consisted in the formulation of a working hypothesis – a hypothesis in two parts.

1. It is assumed that unfavorable temperature conditions affect specific biochemical events and cause a shortage of one, or a few, substances essential for the normal metabolism of plants.

2. Such essential substances can be supplied to the plants from an external source and can be utilized to make up for the shortages caused by unfavorable temperature.

Both parts of this hypothesis can be tested experimentally.

Each plant contains a great variety of compounds, so it is very difficult to find out what goes wrong in extreme temperature conditions. Therefore, as a matter of expediency, a screening technique has been used for testing the second assumption. The approach involves attempts to prevent temperature damage by applying selected chemicals to the plants grown under unfavorable temperature conditions. Positive results prove the correctness of the second assumption, and indicate the probability that temperature acts via biochemical processes, as suggested in the first assumption. Moreover, the nature of the effective chemicals indicates where to start detailed biochemical investigations, which are required for a definite proof of the first assumption.

A number of compounds have been selected for

Research fellow Hendrik Ketellapper examines pea plants, grown in artificial light, that have been damaged by high temperatures. When they are sprayed regularly with sucrose, these plants will flourish like those at the right, which have been grown at the optimal temperature.

the screening process because they are key substances in plant metabolism. In order to speed up the screening process, related compounds are applied to plants in mixtures: a mixture of the members of the vitamin B group; a mixture of the ribosides (the building blocks of ribonucleic acid); and a mixture of amino acids (the building blocks for proteins). Vitamin C has also been used, and in a few experiments the effect of sucrose has been studied.

The substances can be applied to the plants by spraying the leaves. The spray treatment is carried out every other day while the plants are growing under unfavorable temperature conditions. After a few weeks of such treatment the plants are harvested, dried, and weighed. The growth of the plant can be determined by its dry weight.

Plants that prefer warm temperatures

A wide variety of plants have been tested. Some plants prefer warm temperatures, and grow very slowly at low temperatures. Two plants belonging to this group have been selected — a crop plant, eggplant; and an ornamental, Cosmos. Groups of these plants have been grown in temperatures lower than the optimum in air-conditioned greenhouses.

The optimal temperature for Cosmos is approximately 78 degrees Fahrenheit. When Cosmos plants are grown at 55 degrees, their growth rate is only one quarter of the growth rate at the optimal temperature of 78 degrees.

Part of this growth retardation caused by temperature can be overcome by spraying the vitamin B mixture on the leaves of such Cosmos plants. The active component of the mixture is vitamin B-1 (thiamine). Cosmos plants growing at 55 degrees behave as if they are growing at a warmer temperature when they are treated with thiamine. It has been shown by analysis that the thiamine concentration in the tissues of plants grown in low temperatures is lower than that typical for plants grown at the optimal temperature.

Application of thiamine to Cosmos plants grown at 67 degrees also increases their growth rate. But application of thiamine to Cosmos grown at the optimal temperature does not have any effect at all on growth.

The optimal temperature for eggplant is also 78 degrees. At 61 degrees the growth rate of eggplant is only one quarter of that at the optimal temperature. Application of ribosides to eggplant growing at 61 degrees raises the growth rate appreciably.

Many reactions involved in the growth process will proceed more slowly at lower temperatures. However, in the case of Cosmos, the production of thiamine is more retarded than any of the other reactions. Therefore, Cosmos plants growing at lower than the optimal temperature suffer from lack of thiamine, and their growth rate may be increased by application of thiamine. In the case of eggplant, a reaction involving the metabolism of ribosides is most sensitive to temperature.

Plants that prefer moderate temperatures

Some plants prefer moderate or low temperatures for best growth, and are injured by warm temperatures. Again, two plants from this group have been selected for tests — a crop plant, peas; and a California wildflower, lupin. (This particular lupin is a species which occurs along the California coast between Santa Barbara and Santa Cruz.) These plants were subjected to warmer than optimal temperatures in the laboratory.

The pea experiments were carried out in artificial light. Peas respond very markedly to the temperature during the day. The optimal temperature for peas grown in artificial light is 62 degrees. When the day temperature is raised to 73 degrees pea plants grow more slowly; the growth rate is three quarters of that at 62 degrees. However, when a 10 percent solution of sucrose is sprayed on the leaves of pea plants growing at 73 degrees, they grow at the same rate as plants growing at 62 degrees. Sucrose has no effect on growth at the optimal temperature. Apparently the high temperature interferes with photosynthesis, and so causes a shortage of sucrose in the plants. Direct measurements have shown that the rate of photosynthesis of pea plants growing at high temperatures is lower than that characteristic for peas growing at the optimal temperature.

When the peas are grown in warmer than optimal temperatures in a greenhouse, using sunlight instead of artificial light, the application of sucrose does not stimulate growth Some pea varieties respond to vitamin C under these conditions.

The lupins grow best at 67 degrees in the greenhouse. Application of the vitamin B mixture to lupin plants grown at 78 degrees can completely prevent the high temperature damage. The treated plants behave as if they were growing in optimal temperature conditions.

Apparently high temperature inhibits growth because one particular reaction is more sensitive to high temperature than the general average. In two cases, then, it has been possible to prevent high temperature damage completely by the application of substances which are apparently in short supply.

Preventing damage

These examples (in addition to a number not yet published) show conclusively that damage caused by temperatures above or below the optimum can be partially or wholly prevented by the application of chemically well-defined substances. These compounds are composed of relatively large molecules and apparently plants can absorb such molecules when they are applied to the leaves. All of the evidence derived from this chemical research indicates that indeed the chemical cure of climatic lesions is a proven fact.

At least part of the growth reduction caused by temperature extremes seems to be the result of the interference of temperature with the biochemical processes of the plant. This interference causes a shortage in one or a few key substances.

It may be that an undesirable temperature decreases the rate of synthesis of certain compounds. The concentration of such substances in the plant will then be too low for good growth. This is probably the case in moderately low temperatures.

Extreme temperatures may even cause the destruction of the compounds. High temperature combined with a shortage of water causes the breakdown of macromolecules forming part of the plant cell. For example, proteins and starch are hydrolyzed as soon as plants are subjected to a slight shortage of water. The rate of breakdown of ribonucleic acid is also increased in young tomato plants as a result of moisture stress.

In the supra-optimal temperature range dramatic effects can be observed as a result of very small changes in temperature — changes as small as one half to one degree. Such large effects of small temperature changes suggest sudden, profound changes in plant metabolism, probably caused by the destruction of key substances or the inactivation of enzymes.

Such destructive processes involving complex cell components raise the possibility that the relationship between "curing" substance and injury is indirect. So far it has been suggested that substances active in preventing temperature damage work because their application makes up for the deficiency of that particular substance in the plant. For example, the application of thiamine to Cosmos plants grown in low temperatures prevents part of the growth retardation, because Cosmos plants growing in low temperatures do not have enough thiamine. This is a direct relationship between "curing" substance and temperature damage.

Other chemical applications

Leaf sprays are not the only method of application of chemicals. In a few cases good results have been obtained by applying substances to the roots of plants grown in sand culture or in aseptic culture in agar. Furthermore, it has been possible to overcome a large part of the retardation of early growth of tomato plants, caused by low temperature, by soaking the seeds in nicotinic acid before planting.

The major climatic "lesion" studied in this program has been the reduction in dry weight of the plant. Measuring the weight of a dried plant is one of the best ways to determine growth. Often morphological abnormalities occur as the result of extreme temperature. Such abnormalities may also be reversed by chemicals. For example, in high temperature conditions leaves are often small and withered looking. Sometimes there are dead spots or areas in the leaf. In soybeans such morphological symptoms can be prevented by the application of the amino acid mixture. In addition, growth is increased by 50 percent. In some strains of *Arabidopsis thaliana*, a European weed, leaves will be normal when biotin or cytidine are applied.

Continued research will undoubtedly provide much more detailed information on how various types of temperature injury in plants can be prevented by applying chemicals. Then it may be possible to put this information to more practical use — in terms of the protection of cash crops against sudden short periods of unfavorable conditions.