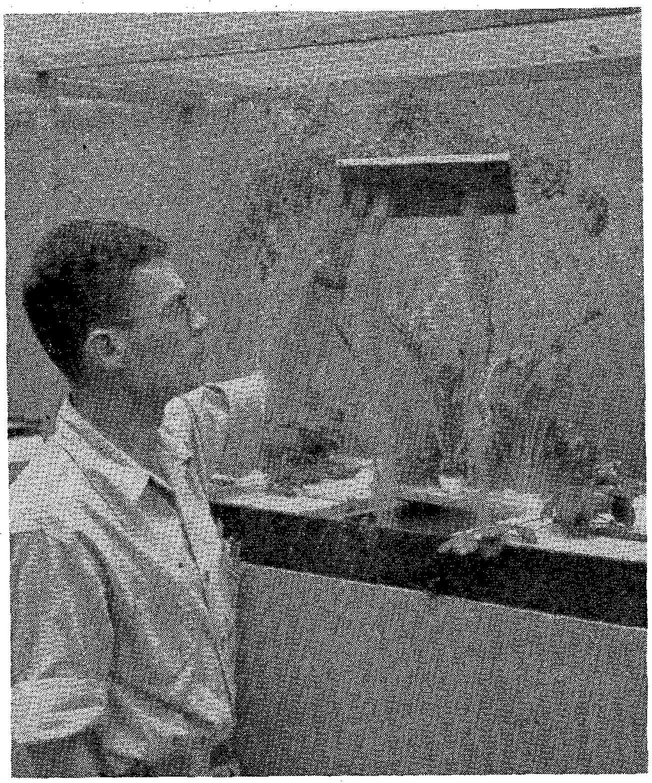


Pret Keyes, Superintendent of the Earhart Lab, checks root development in carrots grown in an atmosphere kept continuously moist with a fog nutrient solution.

THE EARHART PLANT RESEARCH LABORATORY

A Progress Report

by FRITS W. WENT

SCIENTISTS WORKING in Caltech's Earhart Plant Research Laboratory (E&S—June, 1949) are still in an early and very simple part of their investigations on the effects of climate on plant growth. But they have already obtained a number of interesting results from their experiments.

The Earhart Laboratory offers complete weather control. It can simulate sun, rain, shade, heat, cold, humidity, dryness, wind or calm. If each one of these had an important influence on plant growth, it would be exceedingly difficult to come to any general conclusions. Fortunately, most plants are affected more by one of these variables than by the others.

In the Laboratory, for instance, we have studied the effect of day and night temperatures on tuber formation in the potato plant. In different day temperatures, we find that tuber formation does not vary if the plants have the same night temperature. But, if we vary night temperatures, and keep day temperatures constant for a group of plants, then we find that tuber formation is strongly influenced. At a 20 degree Centigrade night temperature, there is no tuber formation at all. At low night temperatures there will be a few tubers, but the total growth of these plants is very small. Optimal tuber formation occurs at about 12 degrees C.

Fruit formation in tomato plants is also dependent on night temperature, and shows an optimum around 17 degrees C. So there are definite differences in requirement from plant to plant, even in plants which react to the same single factor.

Neither light intensity nor photoperiod (the period of daily illumination) is very important in the case of the tomato and the potato. No matter how we vary these other climatic factors we get the same general response.

Another investigation is under way in the Laboratory on *Veratrum* or corn lily. This plant is of special interest because it contains alkaloids which lower hypertension. These alkaloids are extremely complex and, at the moment, cannot be synthesized. Since *Veratrum* is collected in the field only, and is now used in fairly large quantities, the possibility exists that it may some day become extinct.

Before *Veratrum* could be grown commercially, a large number of field plots were laid out to test its growth in different climatic zones. But it doesn't grow easily, and in practically none of the field plots was the growth even remotely normal.

At the same time, we did work on the climatic requirements of the plant in the Earhart Laboratory. We found that *Veratrum* has two or three main conditions which have to be met before it will grow. In the first place it needs a very long rest period—about six months—at approximately 0 degrees C. If the temperature gets higher or lower, this dormancy will not be broken. So far, it has been impossible to break it with any of the chemicals which have been effective on other plants.

In the second place, it needs a cold temperature during its growing period. It must not be *too* cold; 17 degrees C. during the day is about optimum, and the night temperatures should be around 10 degrees C. The third requirement, which is absolutely essential, is that the plant have a good root system. This is a difficulty, because the root system develops very slowly. The plants have to be removed with roots and very carefully transplanted if they are to grow again afterwards.

With these three requirements established, we know then what sort of locality *Veratrum* will grow in. The right conditions exist in the higher mountains of Northern Washington. Only in the two field plots which were laid out according to the optimal conditions we had established did *Veratrum* grow well.

So here we have the first case in which the climatic region where a plant has to be grown has been selected according to scientific knowledge of its growth requirements.

Another interesting case is the work of Dr. Albert Ulrich with sugar beets. Working in the Earhart Laboratory, he has found that a very important factor for the sugar content of sugar beets is temperature—particularly night temperature. There is a very nice straight-line relationship between sugar percentage and night temperature over the 4 to 30 degree range—the lower the night temperature, the higher the sugar content.

In Holland last year growing conditions were such that the beets were low in sugar content at the time harvesting usually begins. Then for one week the night temperature dropped sharply. At the end of that week the sugar percentage had risen considerably.

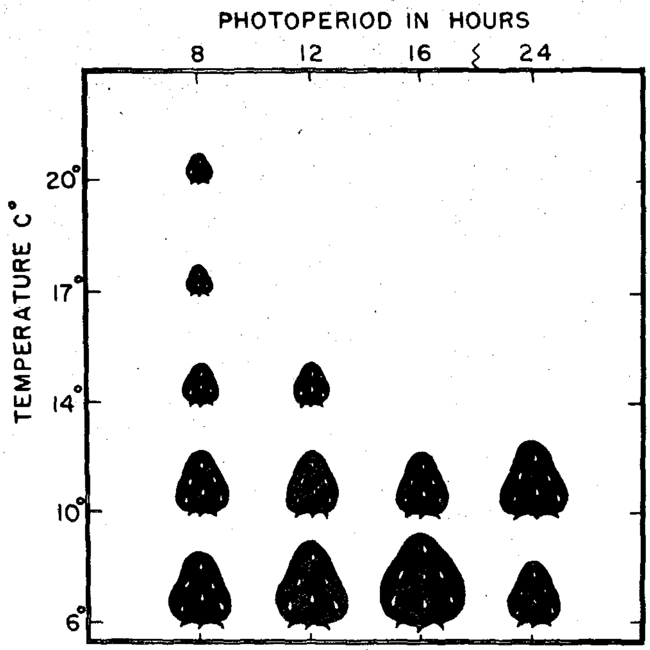
The director of the Sugar Beet Experiment Station in Bergen op Zoom, remembering Ulrich's results, connected the increase in sugar percentage with the cool nights. Therefore he got in touch with the meteorological observatory and asked what the forecast was for the following week. When low temperatures and bright weather were predicted, he phoned all the sugar factories and told them to stop or decrease production as much as they could. One week later the sugar percentage had run up one more percentage unit and thousands and thousands of dollars were saved by getting higher sugar yield through a delay in harvesting.

A number of other plants have been investigated, and in general we find that the optimal day temperature and the optimal night temperature are different in each case. The optimal day temperature usually is higher than the optimal night temperature, which shows that most plants have adapted themselves to this sequence in nature, where the day is warmer than the night.

The only exception that we know of is the African violet (*Saintpaulia*). This plant has a remarkably high night temperature requirement, and unless the night temperatures are in the neighborhood of 20 degrees C. or higher the plants grow relatively poorly. When you give them a lower night temperature—for instance, 10 or 15 degrees—the plants die. However, if you give them the 10 or 15 degrees during the day and 20 degrees

These five potato plants were all grown at the same night temperature (14 degrees C.) but at different day temperatures, rising from 17 degrees (left) to 30 degrees (right). Note how top growth is affected by day temperature, but tuber formation remains the same, due to the same night temperature.

African violets in the Laboratory grow best when night temperature is higher than day temperature. Those shown above were grown at different day temperatures (increasing from left to right) and different night temperatures (increasing from bottom to top).



Effects of temperature and photoperiod on strawberries

during the night, you get very large, deeply colored flowers, with deep green foliage.

There is not a single place in the world where the day temperature is lower than the night temperature, so it may be that the relationship we have found between the optimal day and night temperature in this case is completely fortuitous. Yet in most other cases it agrees with what happens in nature.

At present the effects of photoperiod are very well understood in plants; we know pretty well to what extent most plants respond to it. However, in work which is going on now we find more and more often that temperature and photoperiod are interchangeable in certain plants. By giving the proper temperatures, we can bring a plant to flower without changing the photoperiod; we can also bring the plant to flower with photoperiod, but usually not without the right temperature.

Ignorance of these inter-relationships can lead to international misunderstandings. In the U.S.A. the chrysanthemum is considered to be a short-day plant, because it flowers only when the days are shorter than 12 hours. The English are convinced that temperature is the most important factor, because they get chrysanthemums in flower even on long days in summer.

This turns out to be a simple matter of the difference in summer temperatures of the two countries. At high temperatures chrysanthemums are strictly short-day plants. At the lower temperatures of the English summer they are more or less indeterminate. So the English can think that the Americans are rather short-sighted in laying so much stress on photoperiodism, and we can think that the English are not too bright in ignoring it so. Actually, both of us are right.

This shows how careful we must be in thinking that our scientific results are independent of geographic location. Not until we have laboratories like Earhart everywhere in the world will botanists be independent of geography.

Work on strawberries has produced some interesting results on the inter-relation between photoperiodism and temperature. Strawberries were generally considered to be short-day plants; that is to say, they need a short-day period before they actually come into flower and bear fruit.

In this case the day temperature is the all-important factor; the night temperature has very little to do with their development. At 20 degrees and 17 degrees (see chart at left) flowering and fruiting occur only in an 8-hour photoperiod. At 14 degrees they occur in both 8 and 12-hour photoperiods, and at 10 degrees and 6 degrees we get flowering and fruiting even at 24 hours of light. Also, the lower the day temperature is, the larger the fruits are.

The same thing is true for tomatoes, but here it is a low night temperature that causes large fruits. So here again photoperiod and temperature seem to be more or less comparable; both of them can do the same thing.

In the Earhart Laboratory we can also study a particular process in detail, and under controlled conditions find out how this process works. The biochemical aspects of photosynthesis (the CO_2-reduction process occurring in green leaves in light) have been thoroughly studied, but practically no effort has been made to find out under which environmental conditions CO_2-reduction occurs most efficiently.

Theoretically, 30 percent of the light energy from the sun can be transformed into chemical energy by a plant, and laid down as carbohydrate material. In reality, only 1 percent, or at the most, 2 percent of the light energy falling on, say, a cornfield can be harvested as plant material.

In recent work, it was found that this low efficiency in field-grown plants is largely due to unfavorable en-

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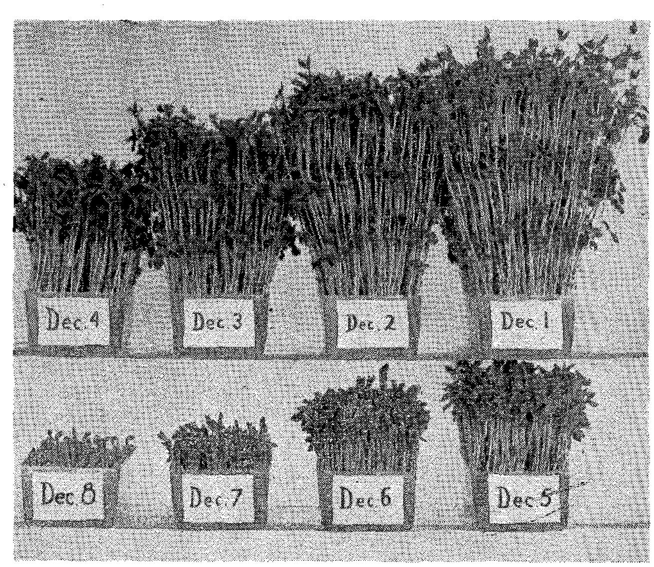
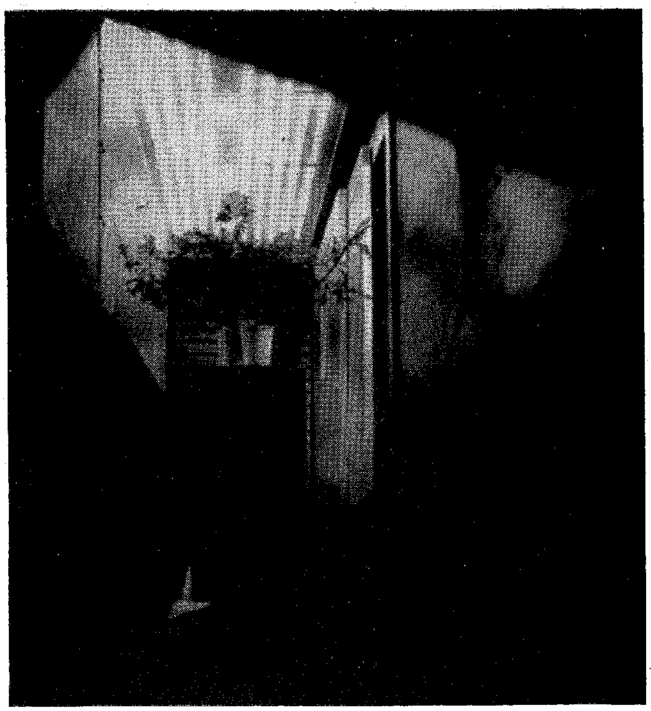


Pea plants show remarkable uniformity when grown in uniform conditions of the Earhart Lab. Picture was taken Dec. 14. Dates show when seeds were planted.



Wind is one of the special problems now under investigation in the Lab. Plants above were photographed through blades of fan in Lab wind tunnel.

vironmental conditions. Under ideal conditions, a tomato plant can transform 20 percent of the light energy that it has received into chemical energy. This fact was determined by measuring the increase in dry weight of sets of plants, which gives an incontrovertible indication of the photosynthesis which has occurred.

We have concluded that the growing and physiological conditions of plants have a great deal to do with the efficiency of their photosynthesis, and that the history of a plant must be considered before we can measure photosynthesis in higher plants accurately.

Ecology in Earhart

We are also working on a large number of ecological problems in Earhart. Ecology is not an experimental science as yet. It is largely descriptive, concerning the relationship of organisms to one another. The reasons for these relationships are seldom investigated. In the Earhart Laboratory it is possible to study the inter-relationship of organisms in great detail.

Our ecological studies were started with desert plants. These make excellent experimental material. In the first place, because they are placed far apart we don't get strong interactions between neighboring plants. In the second place, it is easier in such a violent climate to assign a particular phenomenon to a particular rain or high temperature which has occurred. So it becomes possible to find out the relationship between particular climatic conditions in the desert and the occurrence of certain plants in particular locations.

This was first done by observation in the desert, and then by experiments in the laboratory. It turns out that unless there has been a sufficient amount of rain, no germination occurs at all. Therefore, seeds which are present in desert soil do not germinate unless there has been a sufficient amount of rain and leaching of the soil.

The effect of rain has been studied in the laboratory recently by Alberto Soriano. He has found a relationship between the amount of rain and the degree of germination. Comparing precipitation of 5, 10, 25, 50 and 75 mm., he found that optimal germination occurred at 10-25 mm.

He found that the degree of germination also depended on the intensity of rain, so that 25 mm. given in one hour's time is far less effective than when it is spread over 10 or 24 hours. Apparently, this phenomenon is due to the presence of germination inhibitors in the seeds which can be leached out by the rain. Over short periods they don't have enough time to diffuse out, while prolonged rain leaches them thoroughly. This explains why there is such poor germination after a cloudburst.

It is curious that when you grow tomato plants with and without rain, but otherwise in exactly the same conditions, the plants with rain are about half as big as those without it. Apparently, there is a leaching out of either sugar or growth factors from the tomato plant, which is caused by raindrops running off the leaves. Just as we know that substances can be absorbed by the leaves (a tomato plant will grow faster when you spray it with sugar), it is also logical to assume that we can leach substances out of the leaves. This, of course, would have much to do with the irrigation of plants—whether you use overhead sprinklers or irrigate from ditches.

Special problems

There are several other special problems under investigation in the Laboratory now, such as smog (E&S—December, 1950) and wind. But the potentialities of the Laboratory are far from being fully utilized. We don't yet know all the things which *can* be done. We are constantly finding more things which can be investigated under the conditions we have there.

If we want to use the Laboratory to the fullest advantage, we must remember that there are two completely different types of problems which should be investigated there. We know practically nothing about the relationship between climate and plant growth as yet. We need to collect a lot of data before we can actually start to theorize about it. Large theoretical structures have often been built on just a single phenomenon or just a single organism. I think this is dangerous.

In this laboratory it is possible to get a large variety of conditions and organisms on which to base theoretical conclusions; we need this development in breadth. And yet, on the other hand, we must go into detail with specific problems. We should go deeper and deeper into particular problems until we are also able to go into their theoretical ramifications.

But first we have to lay a sound foundation. That is what we have been trying to do in the survey work which has occupied us in the Laboratory to date.