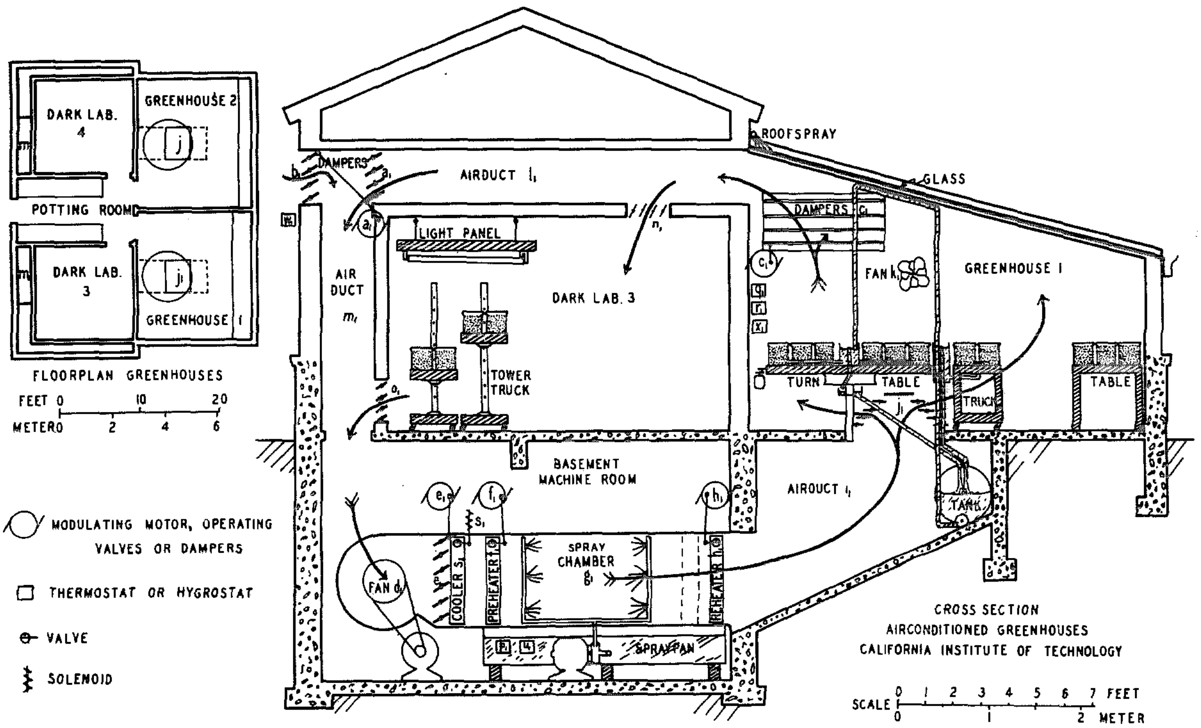


FIG. 1—Floor plan of the greenhouses (left side faces north) and cross median section through house "1" and room "3."

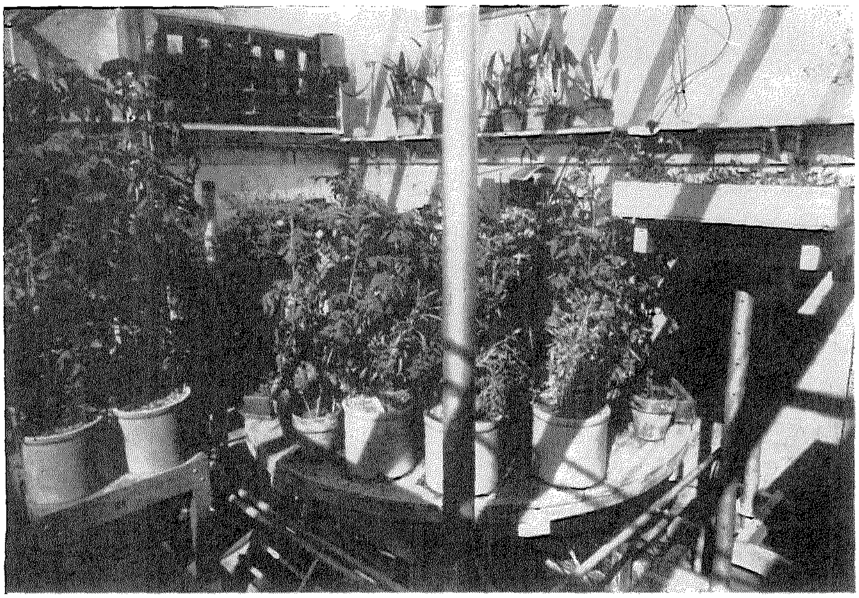
Experiments with Tomato Growing

By FRITS W. WENT

IN THE dim twilight of civilization our ancestors had neither leisure, comforts nor freedom from want; they spent practically all of their time in the procurement of food. Development of the plow, the wagon and draft animals greatly decreased the time required for food production, but even in the colonial period of America a very considerable portion of the energy of the settlers had to be given to the growing of food. During the last century the time required to produce a pound of food has been much reduced, mainly on account of improved agricultural practices, use of fertilizers, control of diseases, development of higher-yielding varieties, and the

AT RIGHT:

FIG. 2—View from southeast on air-conditioned greenhouses. Glass roof of houses "2" (right) and (left) sloping towards left. In east wall of house "2" ventilation opening for air exhaust regulated by dampers "C."



AT LEFT:

FIG. 3.—Interior of greenhouse "I," looking from southeast. Turntable in center. Under it the louvres of the diffuser "j_1." Around it the pipes of the subirrigation system. At right two tower trucks in highest position. At left a small truck with four two-gallon crocks connected with the subirrigation system: behind this truck a tower truck in a lower position. At upper left hand side dampers "c_1" in fully open position, connected with the damper motor. At top center the entrance of airduct "i_1"; below it, just under shelf, thermostat "g_1" with shield.

substitution of labor by mechanical energy. All these improvements were inaugurated during the nineteenth century, and now we are perfecting them. Have we reached already the stage of diminishing returns, where we are approaching asymptotically the state of perfection? Or can our food production horizon still be widened?

Regardless of the enormous progress agriculture has made in the last century, it is a fair statement that the growing of plants still is an art rather than a technology or a science. It is impossible to give such a detailed recipe for the growing of a plant or a crop that everyone can get the same good results when he carefully follows the recipe. This is due both to uncontrollable weather conditions and to a lack of basic information concerning plant growth.

FROM AN ART TO A SCIENCE

In the general endeavor of botonists to raise agriculture from an art to a science, the Plant Physiology Department of the California Institute of Technology started with investigations of the internal factors controlling growth of stems, roots and leaves. To avoid variable effects of climate as much as possible, the work was carried out with seedlings in darkrooms at controlled temperature and humidity. Much was learned about the mechanism of growth control by hormones such as auxin, vitamin B_1, nicotinic acid and traumatic acid. Even though these findings applied to growth in general, it was very desirable to discover to what extent the growth of full grown plants is limited by the same factors as the growth of seedlings.

It became possible to study the growth of mature green plants only after two air-conditioned greenhouses had been constructed, in which temperature and humidity of the air could be controlled within narrow limits. In darkrooms connected with these greenhouses the plants could be subjected to darkness or to artificial light from fluorescent lamps. Figs. No. 1 and 2 give an idea of the construction of these air-conditioned greenhouses. Most plants are placed on small trucks, which can be wheeled from one room to another, making it possible to subject plants to a succession of different conditions. Fig. No. 3.

The tomato was chosen as one of the first experimental plants. This article is concerned with that experiment.

BOTANISTS AND VICTORY GARDENERS

Applying the theoretical knowledge of botany textbooks to growing of tomatoes resulted in fairly sick-looking plants which grew slowly and did not set fruit; or, in other words, we had the same experience that so many new-fledged Victory gardeners had in their first efforts. It became clear that tomato-growing was an art rather than a science. The problem then was to work out step by step the conditions under which tomatoes grew best. Two criteria mainly were used: the stem growth rate gave a good indication of the running condition of the plant; any change in conditions generally was accompanied by a chage in the growth rate. The other criterion was fruit set.

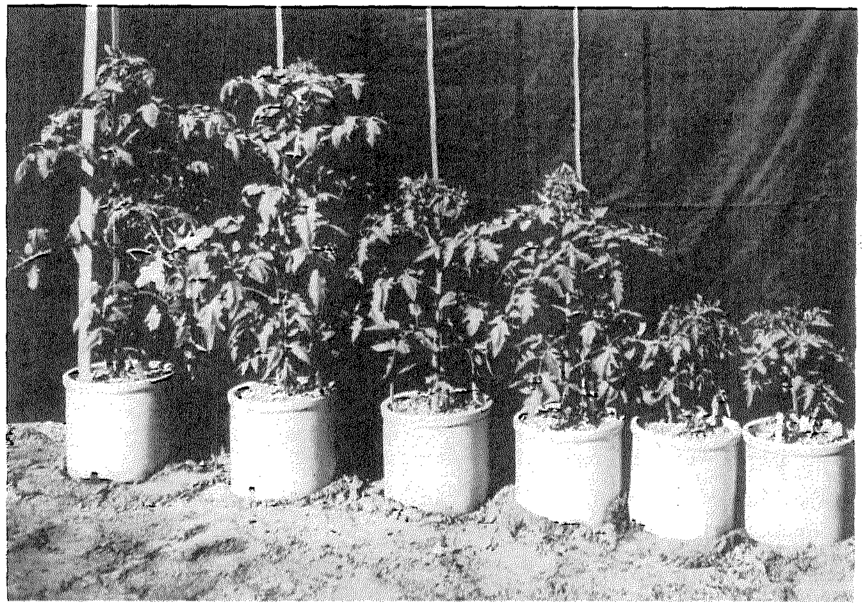
The plants were not grown in soil, since it is practically impossible to duplicate soils in different experiments. Soil is a little understood medium for the roots of plants. It was known, however, that it supplies minerals and water to the roots growing in it. For this purpose, soil is well suited: its colloidal system holds a fairly large amount of minerals loosely bound, which are slowly given off into the water phase, and thus the soil acts as an ideal buffer system. This can be duplicated by growing the plants in some medium like sand or gravel, which is watered daily with a dilute solution of minerals required by plants. This nutrient solution contains $CA(NO_3)_2$, KNO_3, NH_4NO_3, $MgSO_4$, K_2HPO_4 and traces of iron, manganese, copper, zinc, molybdenum and boron. Tomatoes grown with this nutrient solution in sand or gravel grow as well as in the best soil, and this method has the advantage of being completely reproducible.

FRUITLESS RESULTS

To make the results of the investigations still more comparable, all plants were automatically subirrigated with the same nutrient solution. This was pumped from a storage tank into the two-gallon crocks in which the plants were growing. The pump was started three times daily by a time clock, so that all plants received exactly the same amount of the same nutrient at the same time. After the proper adjustment of the nutrient salts and the

AT RIGHT:

FIG. 4—Tomato plants, all grown at a day temperature of 80° F. The night temperatures were: for two plants at left 80°, two in middle 50°, two at right 40°. All plants were eight inches high when treatment was started (height of crocks eight inches).



frequency of feeding, the tomato plants came into their stride and grew vigorously and fast, at the rate of 22-23 mm. per day, when kept at 80 degrees F. both day and night. They kept that rate of growth up for months in succession, until they were too tall to keep in the greenhouses. In a score of experiments in the last three years all plants kept at 80 degrees F. day and night grew at that same rate of almost an inch per day. This means that length of day and intensity of light did not have much influence on the growth rate of tomatoes, provided temperature and nutrition were properly controlled.

Although in general the tomatoes looked healthy, grew fast and were sturdy, there was one thing radically wrong with them: they did not set fruit. In a number of experiments extending over one year, half a dozen fruits were obtained. It was tried to make them more fruitful by increasing or decreasing the nitrate in the nutrient solution, by changing the concentration of the other nutrients, by varying the humidity of the air, the frequency of feeding, the light intensity, the daily duration of illumination, or by artificial pollination, or treatment with hormones. Nothing helped.

TEMPERATURE CYCLE

The solution of the riddle of the unfruitfulness of the tomatoes came unexpectedly, when the temperature in one of the air-conditioned greenhouses was lowered. All plants kept during night in darkness at a temperature of around 68 degrees F. set fruit abundantly. Also growth was improved: by keeping the plants during day in the 80-degree greenhouse, and during night in the 68-degree house the growth rate was between 25 and 30 mm. per day. This was more than when the plants were kept constantly at 80 degrees F. (22-23 mm. per day) or constantly at 68 degrees F. (18-19 mm. per day). The temperature conditions were varied in many ways to discover how the temperature effect came about. Keeping the plants during day at 68 degrees and during night at 80 degrees did not do any good: no fruits were set and the growth rate was 18-19 mm. per day. This indicated that the tomato plant does not need a lower temperature at any time during the day, but that it must be kept cool during the night. This was also proved by experiments in which the plants were kept under optimal temperature conditions (80 degrees during day and 68 degrees during night), but where the plants were illuminated during the night period. This decreased the growth rate and no fruits developed. This proves that the lower temperature must prevail during night: when the plants are kept in light 24 hours per day they are unable to recognize the night period.

Further experiments were carried out at many different temperatures, combined with further variations in growing conditions. It was possible to narrow the effective temperature range during night to the following rule (which of course only holds for the variety of tomato used in these experiments: the San Jose Canner, which is a large-fruited variety grown commercially in the San Joaquin Valley): between 60 degrees and 70 degrees night temperature fruit set is very good, but below 50 degrees and above 80 degrees practically no fruits are formed, and also growth is slowed down. But fruit set is much more sensitive to night temperature than vegetative growth, so that with night temperatures of 50 degrees a fairly good-looking plant can be grown, which is completely unfruitful. (Fig. No. 4).

TRANSLOCATION OF SUGAR

The experiments have shown that while during day a process prevails in the tomato plant which has an optimal temperature around 80 degrees, during night a process with an optimal temperature of 65 degrees limits development. The process during the day undoubtedly is photosynthesis, which at high light intensities has a fairly high optimal temperature, as had been found by many other scientists. But what is the process which occurs during night? The experiments on this question have not been concluded as yet, but all evidence points in one direction: the process limiting growth during night is the transport of the assimilates from the leaves to the growing stem tip, to the fruits and to the roots. The sugar formed in the leaves during the day serves as food for the rest of the plant, and in some plants the translocation of sugar occurs mainly during the night. The tomato seems to belong to this group of

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Wage Incentives

(*Continued from Page* 12)

gencies of combat require frequent and drastic revisions of design. There is not time to standardize on methods, equipment, or work place layout. The flow of materials is uncertain, and substitutes must often be used. The work force consists of anyone who can be induced to work, ranging from highly skilled and experienced hands to complete newcomers and to incompetents. Supervision is inexperienced and badly overloaded. Under these circumstances, can any fair standard of output be set? The average war-production job simply will not hold still long enough to be carefully studied.

Industry has used two compromises to avoid the difficulty of inaccurate standards:

1. A very mild incentive prevents earnings from getting far out of line, even with defective standards. This is generally unsatisfactory because the incentive exerts little beneficial effect.
2. Individual standards are avoided by hanging the incentive on total output of the plant rather than on individual achievement. The incentive effect is doubtful because reward does not necessarily follow effort; the lazy workman is rewarded equally with the energetic and capable man.

LABOR BOARD ATTITUDE

The National War Labor Board, in a recent decision, granted the Grumman Aircraft Engineering Corporation permission to use a plant-wide incentive plan, but included reservations as to the general adoption of such a plan. The Board recognized the underlying principles as untested but stated, "This is no reason for denying a trial of the plan. There is a possibility that in certain situations it may, without an increase in costs, result in an expanded production of urgently needed war materials from present facilities and presently employed manpower. It seems clear, however, that only under an unusual set of circumstances do the plant-wide or company-wide wage-incentive plans offer sufficient promise to invite experimentation with them. The Grumman plan cannot be used as a readymade model for extensive application. On the contrary, it has a highly limited application.".

Pertinent to the issue are the 800 applications for approval of various types of wage-incentive plans received by the National War Labor Board and the Regional Boards since the issuance of Executive Order No. 9328 on April 8, 1943. Many of these applications have been only a means to provide "hidden wage increases" contrary to the national wage stabilization program; many of them have been based on a desire to attract additional manpower rather than to stabilize the existing facilities and manpower; and others have been honest attempts prescribed without fundamental knowledge of wage-incentive plans or have been haphazardly constructed. The Board, which must approve each new wage-incentive installation, is moving with caution in granting permission because it fears that great damage can be done with poorly conceived incentive plans.

Wage-incentive measures, in the contention of the Board, will not automatically result in a startling increase in production. The Board strongly urges management and unions not to approach the incentive wage question as a cure-all for the solution of production problems. The Grumman decision states, "Actually, the fashioning of a wage-incentive plan adapted to the particular needs of any company is a major and a complex problem which requires the combined best efforts of specialists and of top executives. Its adoption is a major policy decision. It is not a casual undertaking. Even a properly designed plan may be likened to a highly specialized tool with a sharp cutting edge. Wielded by experts, it can be highly productive. On the other hand, it can cut off the fingers of the inexpert who attempts to use it. There is also a question of adopting any program to significant changes in operating conditions if the plan is to have a continuing influence on production. This must be anticipated at the time a plan is being developed. The determination to install an incentive wage-payment plan is not a light matter; it is a policy decision of the first magnitude."

WAR PRODUCTION

What, then, is the place of wage incentives in the war production picture? There is real need for development of the incentive principle in industry, but not at the cost of disrupting the wage structure and jeopardizing good industrial relations. Incentives can be developed through a well-administered hourly wage structure, or through the proper use of non-financial incentives. Wage incentive plans are only to be used safely under conditions of careful standardization of the work, and when proper and fair standards of performance have been set. Installation of wage incentives in the absence of these conditions is likely to bring about serious trouble, interfere with production, and result in ultimate abandonment of the plan.

The use of wage incentives in many war plants will only increase the burden on supervision already overtaxed to the breaking point. The manager who adopts wage incentives in the hope that they will substitute for good supervision is likely to find that he has started more than he has finished. Wage incentives cannot succeed unless management has mastered its job.

Let us, then, put first things first. Improve methods, standardize designs and equipment, train employees, develop supervision, and master techniques of control. The possibilities for increasing production in these ways are enormous. After that, incentives can be profitably employed. The wise driver of the donkey mends the broken wheel of his cart before he uses the carrot incentive to produce action.

Tomato Growing

(*Continued from Page* 15)

plants, and it is this process of translocation which has an optimal temperature of 65 degrees F.

Some further experiments clearly showed the essentiality of both sugar and darkness for growth. Tomato plants were placed in a dark-room. Thirty hours later they had stopped growing, but when their leaves were submerged in a 10 per cent sucrose solution, growth was resumed in about 24 hours, and they reached a growth rate about twice that of plants grown normally in daylight.

LETTUCE AND ORCHIDS

Not only tomatoes show the phenomenon of different optimal temperatures during day and night. Thus far most plants tried in the air-conditioned greenhouses need a fairly high day temperature and a cool night. Very remarkable differences are shown, for instance, by lettuce. Most varieties start to bolt soon after they are transferred to 80-degree night temperatures. In a 70-degree night temperature the plants also do not head properly, but very fine heads are obtained with lettuce kept during night at 45 and 55 degrees. The optimal day temperature for lettuce lies around 65 degrees. Even in tropical orchids the night temperature must be kept well below the day temperature, and most remarkable of all, the optimal temperatures for such orchids very closely approach the mean temperatures prevailing during day and during night in their natural surroundings.

METEOROLOGICAL DATA REQUIRED

If we ask now what these results mean for agriculture in general, there are several answers. In the first place, we gained a better insight into the conditions which determine growth and fruitfulness, so that we can give more precise directions for growing of tomatoes. These directions should include day and more particularly night temperatures. This leads to the second general conclusion: meteorological data, as usually presented to indicate the climate of a region, prominently display the *mean* temperature. This means very little from a tomato's viewpoint. The experiments described above indicate that the most important meteorological value for tomato growing would be the mean night temperature for each month. Extension of this line of research probably would lead to the most practical way of presenting meteorological data for agricultural use in general. In the third place, it becomes highly advisable to select better varieties of agricultural crops not in field trials, but in the synthetic climate of air-conditioned greenhouses. This conclusion is based on the observation that from year to year and from season to season tomato plants perform uniformly in air-conditioned greenhouses. Various synthetic climates, exemplifying main growing centers, could be created, and the best performers could be selected for each climate. Nowadays selection is made under natural conditions, which may mean a warm summer or a cool summer. The plants doing best one year in a warm summer probably will not do so well a subsequent year in a cool summer, so that selection under natural conditions becomes highly complex. By creating special Los Angeles area hot and cool weather varieties, and by utilizing future long-range weather forecasting, many of the hazards of agriculture could be eliminated, through use of the proper variety as indicated by the long-range weather forecast in spring. This would bring agriculture another step from the realm of art into the folds of engineering.

Wood- and Paper-Base Plastics

(Continued from Page 9)

Table No. II gives the readily obtainable properties of parallel-laminated papreg (machine direction of sheets all in same direction). Cross-banded papreg will have properties about two-thirds to three-fourths those of Table No. II.

Papreg has strength properties adequate for a large number of semistructural uses and some structural uses. As a structural material, its brittleness seems to be its most serious handicap. Compared to ordinary plastics, it has quite good Izod values, but it is definitely inferior in this respect to fabric and glass fabric laminates. It is, however, superior to fabric laminates in practically all other strength properties.

TABLE II—APPROXIMATE PROPERTIES OF PARALLEL-LAMINATED PAPREG

Property	Value
Specific gravity	1.38
	Lb. per sq. in.
Tension:	
Maximum strength	36,000
Modulus of elasticity	3,000,000
Flexure:	
Modulus of rupture	30,000
Modulus of elasticity	3,000,000
Compression:	
Parallel to grain	17,000
Flatwise perpendicular to grain	40,000
Edgewise perpendicular to grain	15,000
Johnson double shear, parallel to grain, perpendicular to laminations	13,000
	Ft.-Lb. per in.
Izod impact:	
Face-notched	5.0
Edge-notched	0.8
Hardness (Rockwell)	M 100
Water absorption (24 hours)	6 per cent

Because of its low elongation, papreg is not as easily molded to double curvatures as are fabric laminates. It has been successfully used, however, in molding of quite intricate objects with but a limited amount of goring and tailoring.

Work is now underway on incorporating other resins, both natural and synthetic, in paper-base plastics primarily from the standpoint of cheapening the product and also with the objective of building up the toughness without too great a sacrifice in water resistance and other mechanical properties. Details on this phase of the work cannot be given at present.

CONCLUSIONS

It is obvious from this array of products that wood is making an important place for itself in the plastics field. Although wood and its constituents serve mostly as the structural or filler part of these plastics, wood and wood products show promise of invading the resin field. Lignin and Vinsol (a rosin-purification residue) show promise as resin diluents. It is also of interest that phenols, furfural, and other resin-forming constituents are obtainable from wood by destructive distillation and hydrogenation processes. It does not require great imagination to visualize a self-contained wood industry that uses wood almost exclusively in the manufacture of wood plastics.

SOCIETY HONORS DR. MICHAL

The American Mathematical Society, at its 50th Annual Meeting in Chicago last week, elected Aristotle D. Michal a vice-president. The society is a national organization devoted in peacetime to mathematical research and during wartime to mathematical problems connected with the design of military equipment. Dr. Michal, a member of the society for 20 years, has been at the Institute since 1928 as a professor of mathematics.