Microwave Protection of Plants from Cold*

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ABSTRACT

One per cent reflection and 85% transmission coefficients have been measured for wax bean leaves (Phaseolus vulgaris) *at 915 MHz. Microwave radiation has been successfully used to protect wax bean plants from freezing temperatures over extended periods of time.*

Microwave radiation of intensity 15 mW/cm² at 2450 MHz raised the leaf temperature to 25°C from an environmental cold chamber temperature of —5°C. The plants remained healthy and fresh after removal to normal room temperatures.

We expect that a microwave radiation intensity of a few milliwatts per square centimeter will suffice to protect most vegetation against normal frost. The single largest economic factor to overcome is the capital cost as the percentage operating time is expected to be small. However, the economic aspects are improved if one considers a model farm where microwave energy is also used for drying and curing.

Introduction

The loss of plants, fruits, and crops due to a late spring or an early autumn frost has been a continuous matter of concern for mankind. The increasing world demand for food has instigated studies (1–3) to improve the yield and frequency of harvests. Many protective methods against frost damage are in current use, none of which are truly effective. Orange groves in Florida are protected from cold by burning oil in barrels situated at intervals of several hundred feet. On the Isle d'Orléans, north of Quebec city, strawberry plants are protected by lighting wood fires throughout the month of May. A less picturesque technique consists in sprinkling water during mild frost conditions: the latent heat of fusion of water droplets in contact with the plant leaves can suffice to prevent frost damage. It is obvious that such techniques have serious disadvantages, and better methods must be found in order to improve the rate of food production in temperate and semi-temperate climates significantly.

We have carried out a preliminary investigation on the possibility of using microwave energy as a means of protecting plants from frost damage. Our reasons for trying microwave energy were the following: Microwave energy has the advantage that it is readily controlled and it can thus cope with severe and prolonged frost periods, and save entire crops from damage. In addition, since plant growth rate can be increased by maintaining a higher average plant temperature, during the growing period, than the average environmental temperature, it could also be used to increase the number of yearly harvests. There is a further advantage to microwave energy: it is clean, and does not pollute the air or change the physical state of the soil on which the plants are grown.

Pertinent Microwave Measurements

Choice of parameters. If microwave energy is to be used to irradiate the foliage of an array of plants, as shown in Fig. 1, one must know the reflection (R) and the transmission coefficient (T) of a typical plant leaf (B). Of these two parameters, the reflection coefficient is perhaps the more important because it is directly linked to the problem of microwave power leakage (P_r) into free space. The trans-

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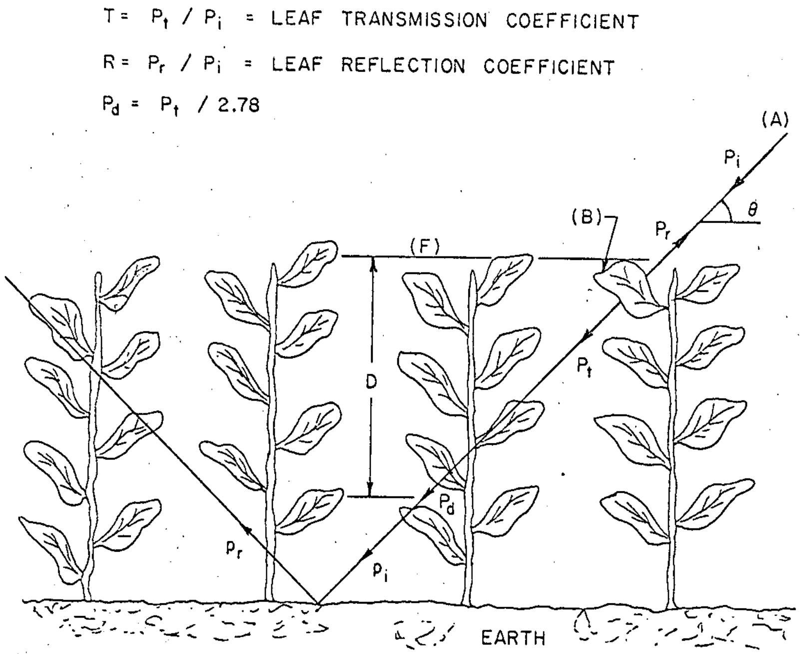

FIG. 1. Illustration of a microwave beam (A) irradiating a leaf (B) with an incident power P_i. The leaf's reflected (P_r) and transmitted (P_t) powers are also indicated. At a depth D the beam power (P_d) is reduced to 36% of the beam power (P_i) incident at an angle θ with respect to the average foliage level (F). The earth's incident (p_i) and reflected (p_r) powers are also illustrated.

mission coefficient determines the penetration depth (D) for a given average foliage level (F) and a given foliage incidence angle θ. Power may be reflected from the earth's surface (p_r) and allowed back through the foliage, or the earth's surface or incidence angle θ may be made such that this remnant reflected power is neligible.

The wax bean plant was chosen for study because it possesses a good average leaf size and the plant grows readily to maturity.

For the purpose of measuring the reflection and the transmission coefficients the transverse RF electric field in a waveguide was made coplanar with the leaf's surface and normally incident, which corresponds to the case of a plane wave normally incident on a leaf's surface in free space.

Measurements. Both the reflection and transmission coefficients were measured using standard equipment illustrated in the block diagram of Fig. 2. In Fig. 3, we show the results obtained around 915 MHz. Similar results were obtained at 2450 MHz by using a reflectometer technique.

Description of the Cold Tests

Two wax bean plants, grown in separate earth-filled glass containers, were placed at opposite ends of a refrigerated chamber. Copper-constantan thermocouples (No. 36 gauge) were priorily inserted into a leaf of each plant so as to monitor the leaf temperatures. The ambient air temperature in the refrigerated chamber was kept at —5°C, and the temperature of the floor on which the glass containers were situated was then —15°C. Immediately upon inserting the two plants into the refrigerated unit, one plant was protected by irradiating it with a microwave beam at 2450 MHz with a radiation inten-

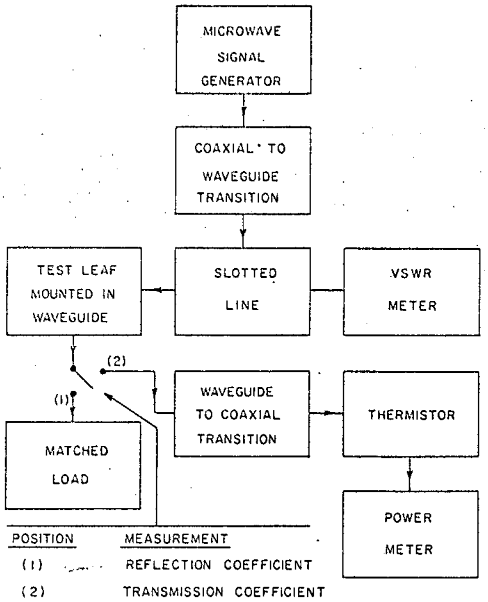

FIG. 2. Block diagram of equipment used to measure the reflection and transmission coefficients.

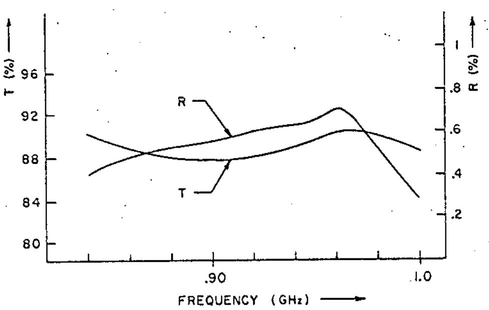

FIG. 3. Reflection (R) and transmission (T) coefficients for a wax bean leaf.

sity of 15 mW/cm². The microwave beam was supplied by a standard diathermy microwave power source (Raytheon CMD7), and the radiation intensity was measured with a Narda radiation monitor (B86B7). The protected wax bean plant maintained a leaf temperature of 25°C, whereas the temperature of the unprotected plant decreased to the ambient temperature (—5°C). The photograph shown in Fig. 4 was taken after 2 hours of cold-testing. It is seen that the protected plant is still fresh whereas the unprotected one has been seriously damaged by the cold environment. After 4 hours of cold-testing the plants were removed to a normal room environment. The microwave-protected plant remained as fresh as before the cold tests and continued to maintain a normal growth, but, as expected, the unprotected plant was completely destroyed by the test.

Discussion

In order to maintain a temperature differential of 30°C between the plant leaf and its environment it was necessary to irradiate 15 mW/cm² onto the plant leaves. From the reflection and transmission results reported in Fig. 3 we calculate that about 2 mW/cm² of this is absorbed by the leaves to maintain this temperature difference. Assuming the leaf's heat loss is mostly due to radiation, it is calculated that about 1 mW/cm² of leaf surface represents the threshold leaf protection for 5 degrees Celsius of frost. Thus the threshold protection power required for the same amount of frost is 36 kW per acre of foliage.

Let us consider a power radiation of 50 kW per acre of land as being an average figure for a given season. Then the average operating cost for frost protection per acre of land comes out to one dollar per hour if we use information supplied by Goerz and Jolly (4). However, the microwave equipment capital costs (4, p. 91) for the same acre of land are $25,000, which would seem to limit the suggested microwave protection method to agricultural products commanding a premium market value. The economic aspects would be less prohibitive on a model farm basis where large quantities of microwave power are used and the duty cycle of the equipment is increased, for perhaps such operations as agricultural microwave drying and curing, which have already been suggested and investigated (5–7).

Biological Hazards

To provide threshold protection at —5°C it was found that the plant leaf must ab-

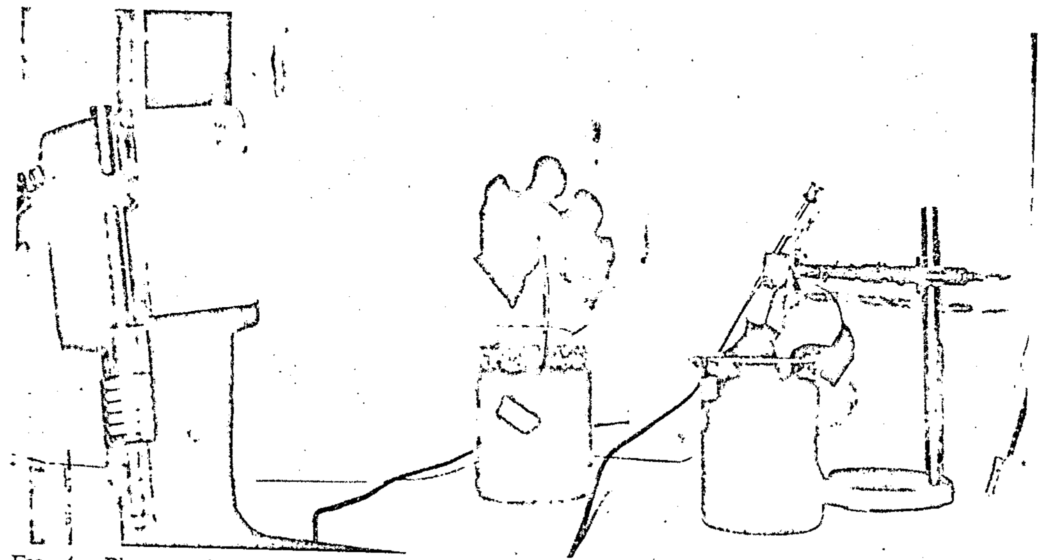

FIG. 4. Photograph showing a microwave-protected wax bean plant and an unprotected plant inside the cold test chamber after 2 hours at an ambient air temperature of −5°C.

sorb about 1 mW/cm^2 of microwave energy. This requires an incident free-space radiation intensity of about 7.5 mW/cm^2, a level which is just below the currently accepted hazard limit of 10 mW/cm^2. In other words, we can conclude that microwave protection of plants from frost conditions at temperatures below −5°C must be safeguarded against biological hazards. However, such safeguards would not be necessary for many regions, such as the rich farm lands surrounding the Great Lakes and the St. Lawrence River, which encounter a temperature of −5°C only late in the autumn when most of the crops have been harvested, and those where more temperate climates prevail (e.g., the Florida peninsula) and a temperature of −5°C is rarely reached.

In situations where it is necessary to irradiate above the accepted radiation level men and farm animals must be kept away from the field during the radiation period. This may be done without too great an inconvenience. Severe frost conditions are usually forecast ahead of time so that sufficient warning may be given to evacuate a forbidden zone where excessive microwave radiation will be expected, and since killing frosts usually occur during the night, this "forbidden zone" approach may be easily enforced.

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