ler, and W. A. Mitchell in which changes in root-surface pH were minimized by using fast solution flow. In these studies no root-surface accumulation of phosphorus was found.

Pretreatment of root surface with nitrogen. In addition to the influence of nitrogen on phosphorus uptake through changes in the root-surface pH, evidence is accumulating for a further mechanism within the plant. Investigations by C. V. Cole and coworkers at Colorado and S. J. Thien and W. W. McFee at Purdue have shown that pretreatment of plants with nitrogen, either nitrate or ammonium, results in greater phosphorus uptake. They found no increased uptake of phosphorus when the nitrogen and phosphorus were added together in the uptake solution. They suggest that nitrate or ammonium through themselves are not responsible for this effect but, rather, that a metabolite of nitrogen is connected in some way with the uptake and transport of phosphorus across the root into the xylem.

For background information see PLANT, MINERAL NUTRITON OF in the McGraw-Hill Encyclopedia of Science and Technology.

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Bibliography: G. J. Blair, M. H. Miller, and W. A. Mitchell, *Agron. J.*, vol. 62, no. 4, 1970; M. H. Miller, C. P. Mamaril, and G. J. Blair, *Agron. J.*, vol. 62, no. 4, 1970; D. Riley and S. A. Barber, *Soil Sci. Soc. Amer. Proc.*, 33:905–908, 1969; S. J. Thien and W. W. McFee, *Soil Sci. Soc. Amer. Proc.*, 34:87–90, 1970.

Plant, water relations of

Under field conditions and similar climates, the daily amount of water evaporated by agricultural plants is nearly the same for most agricultural crops at full cover when soil moisture is not limiting. The amount of energy available to evaporate water is the major controlling factor when actively growing, well-watered agricultural plants fully cover the soil. As a result, mean maximum evaporation rates generally vary between 5 and 6 mm per day in humid moderate climates and between 7.5 and 8.5 mm per day in arid irrigated areas. Daily rates of 10–14 mm have been measured on clear, hot, windy days. The total seasonal amount of water evaporated from an annual crop ranges from 50 to 80% of the amount evaporated from a crop such as alfalfa in a given climate. Small plants that do not shade the soil after planting and mature plants near harvest account for most of this difference. Total seasonal evaporation also depends on the length of the growing season.

When a plant is unable to absorb water from the soil as fast as it can be evaporated from the leaves, the plants may wilt and growth is affected. When this occurs, the plant is said to be stressed. Stress may have detrimental effects before visual symptoms develop. Some crops are more sensitive to stress than are others, and every crop is more sensitive at certain stages of growth. Stress during the period of flowering, for example, can greatly reduce the yield of the marketable portion of a plant that depends on flowering. Studies of these factors and their relations to microclimate and soil moisture are being conducted to develop better water management and cultural practices. The results are essential in understanding plant-water relationships and in the future will play a major role in plant breeding for higher-producing crops.

Studies are also being conducted on methods of reducing the amount of water lost by evaporation. Evaporation from the soil surface in row crops can be reduced by using plastic films or similar mulching material. Reduction of evaporation through the leaves has been studied, but no practical control mechanism that does not also adversely affect growth has been developed. Studies of practical methods to reduce the heat energy absorbed by the crop by changing the reflectance of the surface are also under way. Large plastic greenhouses are also being explored as a means of controlling the environment and reducing the evaporation loss.

Energy for water consumption. Evaporation from a field of well-watered, actively growing agricultural plants is controlled principally by the heat energy absorbed from the Sun. Additional heat energy is absorbed from the air by irrigated fields in hot, dry climates. Since agricultural plants generally retain less than 1% of the water absorbed from the soil, water consumption by these plants is approximately equal to the water lost by evaporation.

Measurement of water consumption. Water consumption by crops is being measured throughout the world by using tanks of soil (lysimeters) in which plants are grown. The tanks usually are installed within large fields of the same crop, and similar soil-moisture conditions are maintained to minimize unnatural edge environments. The change in tank weight is usually recorded by modern electronic equipment providing daily and even hourly values of evaporation. Another method is to measure the change in soil moisture over a period of 5–10 days or more. This method has been used for many years. Soil samples are removed and their moisture content determined by measuring the difference in weight before and after drying. Within the past decade, a neutron soil-moisture probe has been used for direct measurements of soil moisture in the field. Other methods of direct and indirect measurements are being refined as new theories and instrumentation are developed. These methods require complex instruments and skilled technicians to make the measurements.

Evaporation rates are related to meteorological conditions, soil moisture levels, growth stage, and leaf area per unit land area. Once these relationships are established, these parameters can be used to estimate evaporation for management purposes. They also can be used directly to determine the efficiency of water use (marketable product per unit of water used) for various management practices, new plant varieties, hybrids, and nutrient levels maintained in the soil.

Estimates of evaporation. C. B. Tanner recently reviewed the numerous general methods of measuring and estimating evaporation from plants and soils. Generally, estimates based on energy-balance approximations are the most conservative and reliable. Modern farm management techniques have increased the need for these estimates. M. E. Jensen used modern computer facilities to combine estimates of daily evaporation from agricultural plants to provide managers of irrigated farms with estimates of the current soil-moisture status of each field as well as the predicted date of the next irrigation. This technique is rapidly being adopted and is expected to be in wide use within a few years. E. A. Fitzpatrick and H. A. Nix developed a similar mathematical model for estimating evaporation to simulate the soil-water regime in alternate fallow-crop systems. An estimate of evaporation from soil and plant surfaces is a basic component of the numerous mathematical models being developed to simulate the other aspects of the crop-soil system. Estimated evaporation is also a component of hydrological models of watersheds and river basins.

Plant stress. The degree of plant stress caused by the difficulty the plant has in absorbing water from soil as rapidly as it is evaporated from the leaves influences plant growth and evaporation. When a crop is severely stressed, evaporation decreases because the plants lose turgor and the stomates close. Numerous studies are being conducted to determine the optimum environmental conditions for maximum plant growth and minimum plant stress. The evaporative demand in agricultural fields can be reduced by using modern, automatic sprinkler systems to reduce temperatures and increase humidity. Such cooling may slightly increase the total amount of water evaporated from the field. Plastic field-size greenhouses enable even greater control of the environment.

Some agricultural plants such as alfalfa must be stressed to a certain degree to achieve optimum seed production. A higher plant stress is usually maintained by not irrigating until the soil becomes very dry and then applying only small amounts of water. As a result, alfalfa grown for seed requires less water than alfalfa grown for hay.

The degree of plant stress varies diurnally. Generally stress is lowest during early morning hours and greatest in midafternoon. Techniques for measuring and describing plant stress under field conditions are still being studied. The chemical potential of water may be directly related to the stress to which a plant is subjected. J. W. Cary and H. D. Fisher recently developed a simple, economical freezing-point device that permits rapid measurement of the chemical potential of plant water in the field. Other studies are determining the effects of plant stress on the various biochemical reactions in the plant that are essential to plant growth.

Plant stress generally can be minimized by maintaining high soil-moisture content. However, under field conditions, keeping the soil very wet may produce counteracting adverse effects on plant growth because of lower soil temperatures in the spring or low oxygen levels in the soil. Also, more water may be required to maintain high soil-moisture levels because of increased drainage from a wet soil. The total evaporation from irrigated fields is usually not increased significantly by maintaining very high soil moisture after the plants fully shade the soil.

For background information *see* PLANT, WATER RELATIONS OF in the McGraw-Hill Encyclopedia of Science and Technology.

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Bibliography: J. W. Cary and H. D. Fisher, *Agron. J.*, 61(2):302–305, 1969; E. A. Fitzpatrick and H. A. Nix, *Agr. Meteorol.*, 6(5):303–319, 1969; M. E. Jensen, *J. Soil Water Conserv.*, 24(5): 193–195, 1969; T. T. Kozlowski (ed.), *Water Deficits and Plant Growth*, vols. 1 and 2, 1968.

Plant anatomy

The use of the scanning electron microscope (SEM) by botanists has been rather limited to date, and its potential is only just being realized. Most botanical studies using the SEM have revealed that the value of the instrument lies not so much in providing information otherwise unobtainable but in providing information with ease and in a form readily understood; that is, the specimen preparation is simple and rapid, and the image obtained is of high resolution and has a distinct three-dimensional quality.

In scanning electron microscopy, which differs considerably from more conventional transmission electron microscopy, a primary beam of electrons is finely focused and made to scan repeatedly in a regular pattern on a specimen surface by deflection coils. Primary electron beam–specimen interaction causes, among other things, the release of lower-energy (secondary) electrons, the number of which varies as the beam sweeps across the specimen surface. The generated secondary electrons are collected by a scintillator-photomultiplier system. The resulting electric signal is then amplified and used to modulate the brightness of a cathode-ray tube which is being scanned in synchrony with the specimen. An image is formed on the face of the cathode-ray tube and it may then be photographed. Figure 1 illustrates these principles schematically.

Palynology. To date the SEM has probably affected the study of pollen structure and taxonomy more than any other area of plant science. Palynologists are continually confronted with the task of examining pollen grains which range from 5 to 250 microns (μ) in diameter. The sculpturing or wall ornamentation of a pollen grain is heavily relied upon for identification purposes. The details of these minute and often extremely complex surface patterns frequently lie beyond the resolution and

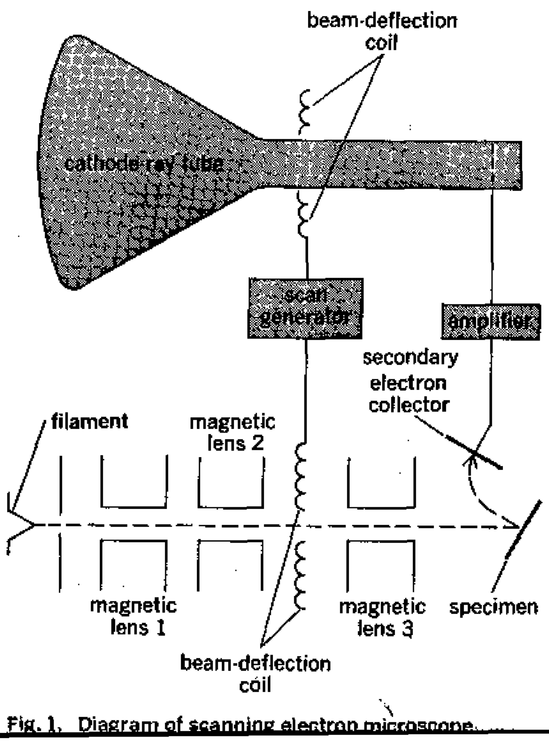

Fig. 1. Diagram of scanning electron microscope.