TRANSPORT OF WATER AND NUTRIENTS IN PLANTS

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Contents

Summary

In plants, the organs that absorb water and inorganic nutrients from the soil (roots) are separated from those that capture energy from the sun (leaves). In order to thrive in a terrestrial habitat, plants must coordinate the physiological processes that occur in the roots with those that occur in the leaves. Uptake of water and soil inorganic nutrients by roots is interdependent with the leaf assimilation activities (release of water, gathering of carbon dioxide and solar energy, and photosynthesis). The transport of materials throughout the plant body provides the physiological basis for this coordinated interdependence. This article contains five sections related to the transport of water and nutrients in plants: Introduction, Source-Sink Relationships, Phloem Loading and Unloading, Driving Gradients and Transport Processes, and Carrier Molecules and Sequestration.

A general description of transport processes in plants is presented in the Introduction. This general description outlines the physiological and structural components of plant transport processes. The section on Source-Sink Relationships discusses the mass-flow hypothesis and the extrapolation of this hypothesis to living plants. Anatomical, physiological, and biochemical characteristics of phloem transport are presented in section 3. The physiological basis of transport and the physical processes of convection and diffusion are discussed in section 4. The biochemistry and physiology of the main types of transporters are discussed in section 5. This section discusses ATPases, channel proteins, carrier proteins, uniporters, antiporters, and symporters.

1. Introduction

As a generalization, mineral nutrients and water are taken up from the soil and transported upward, whereas products of photosynthesis (photosynthate) are produced in green leaves and transported downward. Mineral nutrients and water move in the plant through a series of tissues, beginning at the root hairs, which absorb water from the soil, through the trachieds and vessel elements of the vascular system (collectively called the xylem), and ending in the parenchyma cells which release water to the leaf intercellular spaces.

Tracheids are elongated, non-living cells (at maturity) that have thickened secondary cell walls. Their end walls are tapered but not perforated while their side walls contain many pits. When functional, trachied pits are aligned so that water and solutes flow from tracheid to tracheid. Tracheids also have great tensile strength, and thus play an important role in providing structural support as well as in transport processes. Tracheids are the basic water and solute transport cells in gymnosperms.

Xylem vessel elements are highly modified solute and water transport cells. They are anatomically similar to tracheids, but they also have perforated end walls and pits of greater complexity. Thus vessel elements, when lined up end to end, can form elongated vessels up to several meters long (Figure 1). Vessel elements occur in most angiosperms but not in gymnosperms.

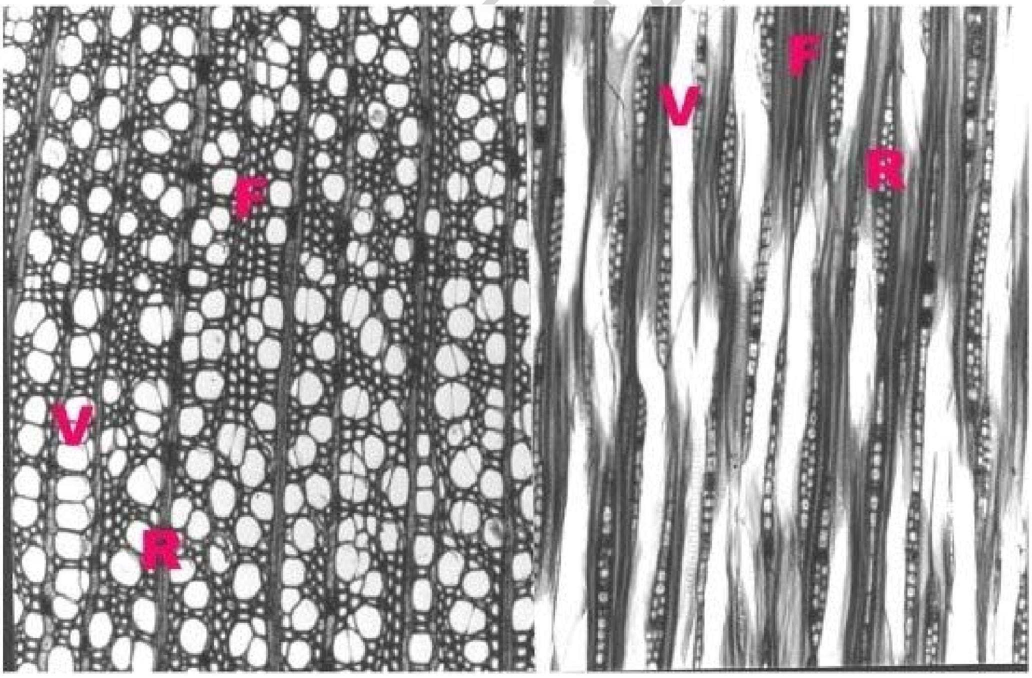

Figure 1. Light micrograph of American sweet gum tree wood showing vessels, fibers and ray cells.

The xylem fluid contains between 1 to 20 mg dry matter per ml, has an acidic pH (range of 5.2 to 6.5), and contains nitrogenous compounds synthesized in the roots as well as mineral nutrients. Xylem fluid also contains sugars, organic acids, and plant hormones.

For the most part, the transport of substances dissolved in the xylem fluid (solutes) is a passive process; the solutes are carried from roots to shoots with the transpiration stream. Thus, the velocity of xylem transport is governed by the rate of transpiration.

Photosynthate produced by leaves is transported downwards in a complex tissue called phloem. Phloem is composed of four cell types: parenchyma cells, fibers, sieve elements, and companion cells that are associated with sieve elements. Sieve elements, the basic transport cells of the phloem, are elongated cells similar to tracheids but are living at maturity (Figure 2). Sieve elements do not have a nucleus or a vacuole while their end walls and frequently their lateral walls have perforated regions called sieve areas. More highly evolved sieve elements have complex sieve regions called sieve plates (Figure 3). Sieve elements lined up end-to-end are called sieve tubes. Sieve elements are always associated with at least one living companion cell. There are many cellular connection tubes (plasmodesmata) between sieve elements and companion cells.

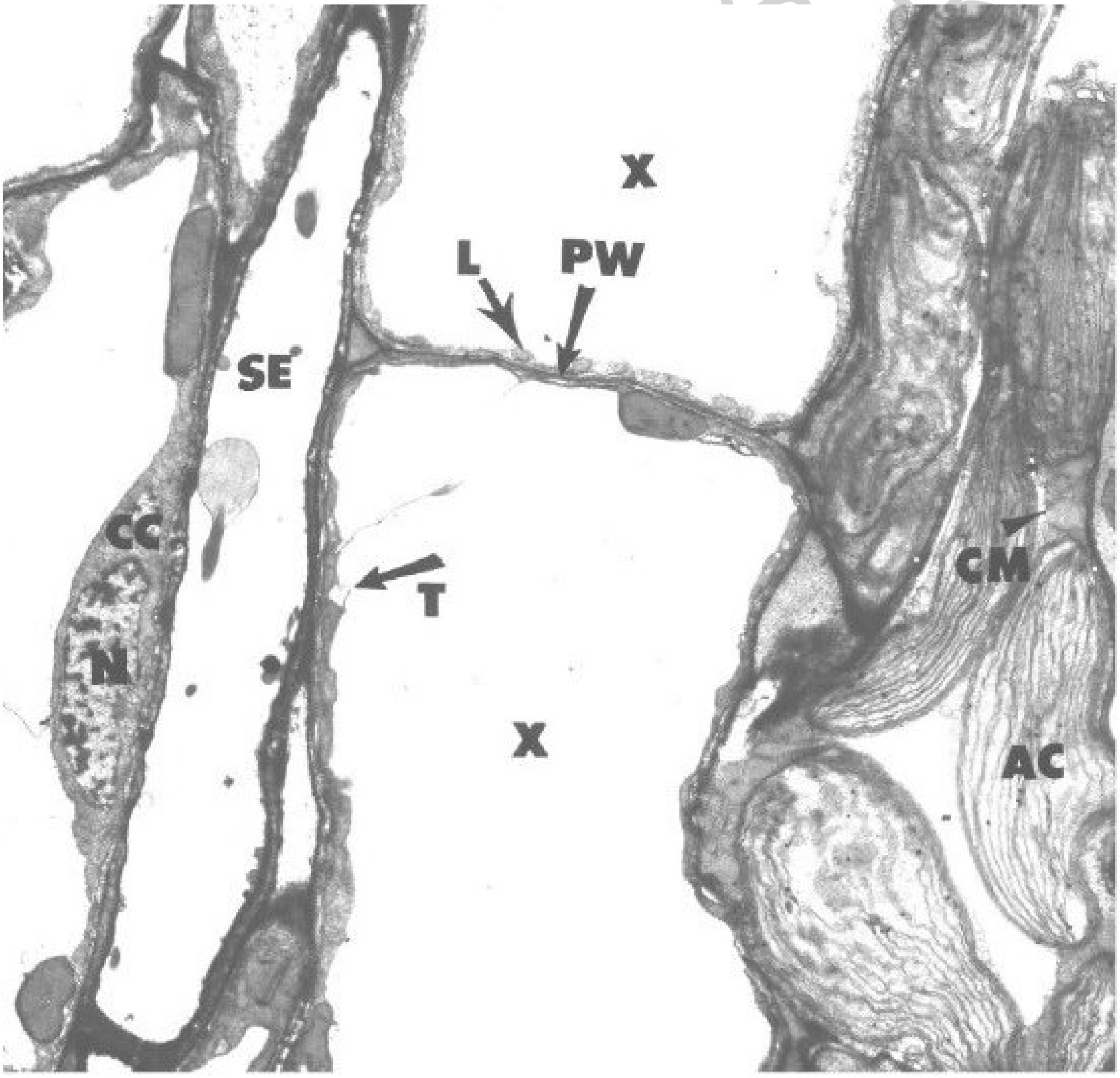

Figure 2. Electron micrograph of young maize leaf showing vascular elements and chloroplasts.

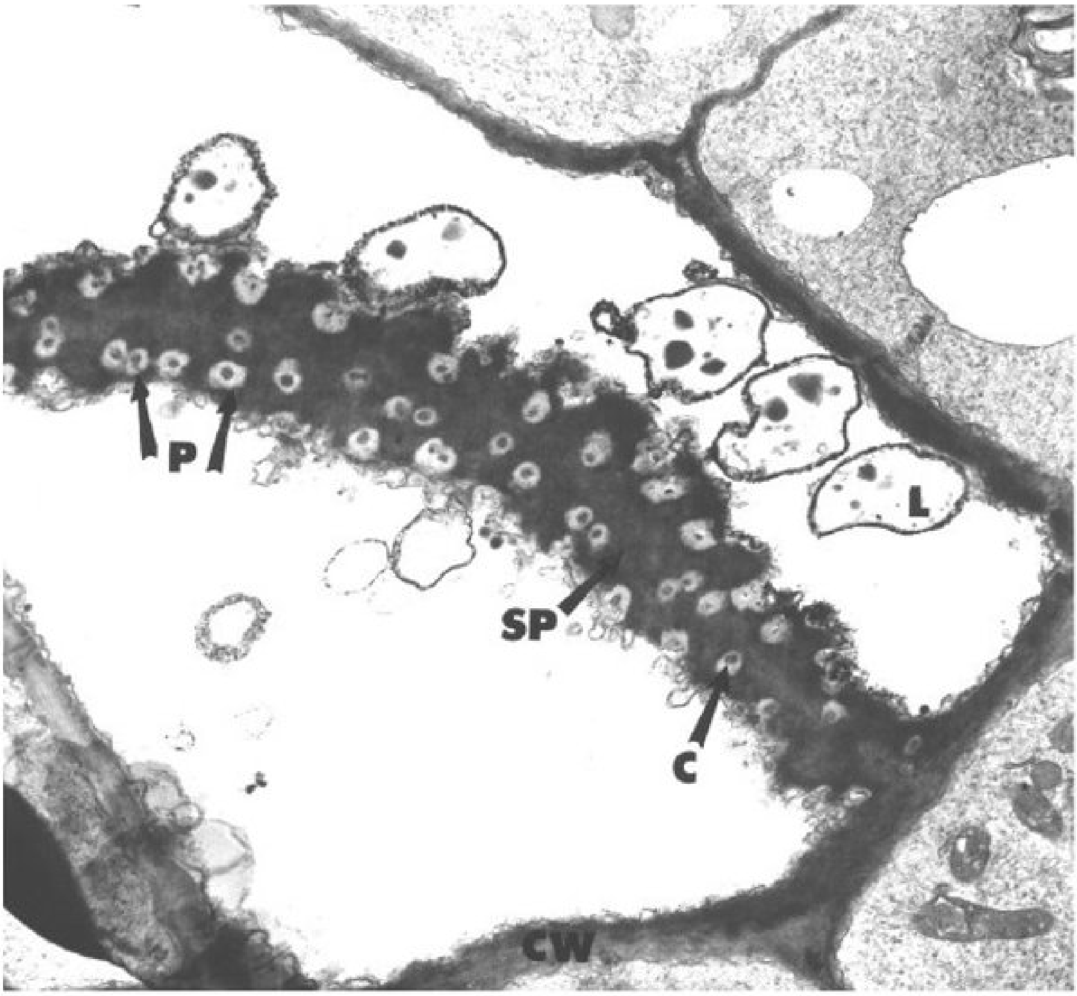

Figure 3. Electron micrograph of onion root tip showing phloem sieve element and sieve plate.

Fluid contained in the phloem has a solute concentration of 50 to 300 mg dry matter per ml and has an alkaline pH (8.0 to 8.4). About 80 to 90% of the total dry matter in phloem fluid is sugar. Nitrogenous compounds, amino acids, organic acids, inorganic nutrients, and plant hormones are also transported by the phloem. The velocity of phloem transport is about 5 times slower than that of xylem transport.

From both a physiological and a structural point of view, transport activities in the plant may be divided into two parts.

1) Transport of water and nutrients through cells. Examples of this include the movement of water from the soil solution through root cells to the vascular system and the movement of water from the vascular system through leaf cells to the intercellular spaces. Water moves for only short distances through cells. Short-distance transport, which is important in cell to cell interactions, probably takes place mostly by diffusion through plasmodesmata. In some cases, short-distance transport is an active process requiring energy expenditure by the cells. An example of active short-distance transport is phloem loading and unloading during sugar transport (see sections 3 and 4). The

living portions of plant cells (components within the cellular membrane e.g. cytoplasm and the sieve element conducting cells of the phloem) are considered to represent the symplasm.

2) Transport between roots and leaves. Long-distance movement of water and nutrients is mainly through the xylem tracheids and vessels and the phloem sieve elements of the vascular system (Figure 4). The xylem tracheids and vessels, which are dead cells, can be envisioned as a series of water-filled tubes. In herbaceous plants the distance of water movement through the xylem may be only centimeters while in trees the water may move through this system over 110 meters. The aqueous phase that lies outside of the cellular membrane (e.g. cell walls and the conducting cells of the xylem) are considered to represent the apoplast.

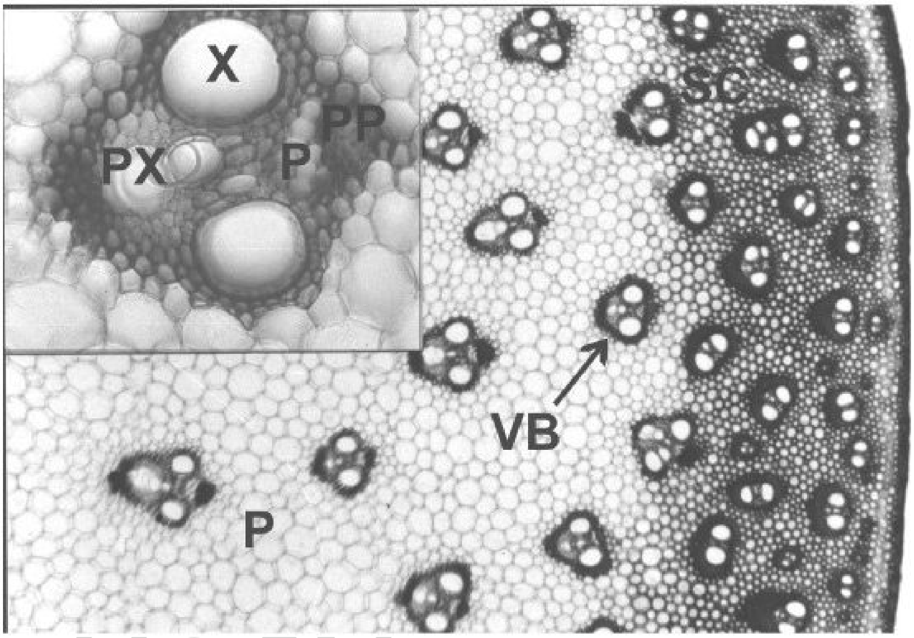

Figure 4. Light micrograph of maize stem showing vascular bundles, sclerenchyma cells, and parenchyma cells.

Transport processes in plants include water and inorganic nutrient uptake, the short-distance transport of inorganic and organic nutrients from cell to cell, and the long-distance transport of water and nutrients throughout the plant by the vascular system. Water and inorganic nutrient uptake are covered in sections 2 and 3.

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Biographical Sketches

W.E. Riedell is a Plant Physiologist with the U.S. Department of Agriculture, Agricultural Research Service in Brookings, South Dakota. Dr. Riedell has research experience in plant cell biology, ultrastructure, mineral nutrient relationships, and plant/insect interactions. Dr. Riedell's research activities are focused on two major areas. First, to investigate the effects of biotic and abiotic stresses on crop plant physiology and to develop integrated crop management systems that help reduce yield losses under stress conditions. Second, to develop a comprehensive understanding of crop response to rotation, tillage/residue management practices, and cover crops and to develop sustainable crop production systems.

T.E. Schumacher is a Professor of Soil Biophysics at South Dakota State University. Dr. Schumacher has research experience in soil biophysics, soil management, and plant physiology. Research activities are broken down into three areas: 1. The application of soil physics and plant physiology to agro-ecological problems; 2. The development of management practices that protect soil and water resources; and 3. Working with plant breeders to develop crops adapted to abiotic stresses. Of special interest is the interaction of plant root systems with the soil environment. These include studies of changes in root systems in response to physical alterations within the root environment. A second related area of interest is the change in soil physical environments caused by root systems. He is actively involved in the application of research results to soil and water conservation efforts.