

HOW PLANTS ACQUIRE NUTRIENTS FOR GROWTH

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The Plumbing Function of Plant Roots

The germinating seed produces an embryonic root (radicle) that grows into the soil, in response to the earth's gravitational field. As new cells are added the root elongates, producing root hairs and lateral roots. The roots remain interconnected, producing a network of living cells throughout the soil. Within the root, the inner cells become specialised to conduct solutes (water plus substances **dissolved** in it) from the root to the shoot (via xylem), and from the shoot to the root (via phloem).

Flow from the shoot to the root is achieved by loading sugars produced in the leaves into the phloem. The sugar-laden solute moves downward, to sites of lower concentration in the root. In contrast, the xylem carrying solute from the roots to the shoot acts more like a plumbing system. The xylem acts like a bundle of capillary tubes, supporting the water in a vertical reservoir. The leaves of the plant actively lose water through pores at the surface (transpiration), drawing the water in the xylem upwards. By this method, essential nutrients extracted from the soil are transported to sites of growth and production in the shoot.

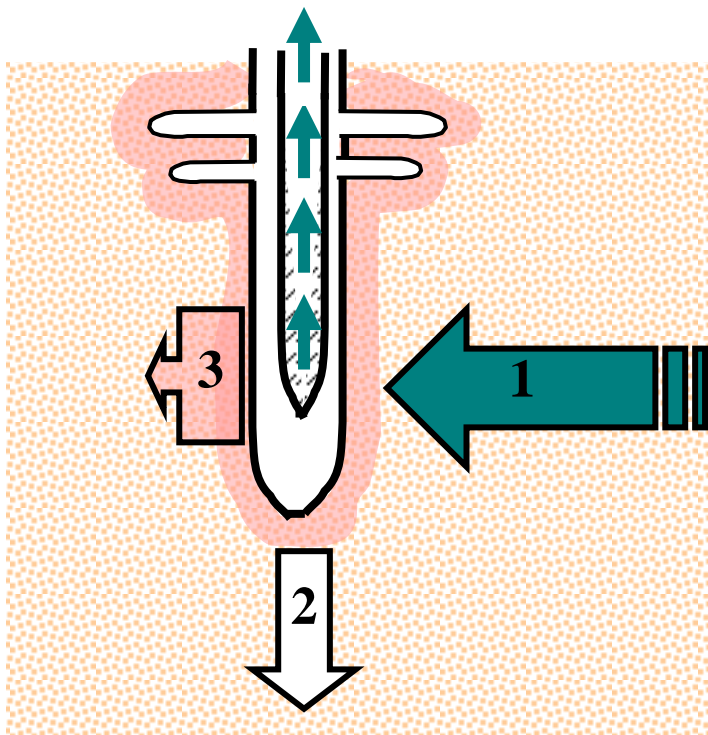


Figure 1:

Nutrient uptake by roots growing in soil.

Arrow 1 indicates the mass flow of nutrients dissolved in the soil water, moving to replace water lost from the surface of the leaves.

Arrow 2 indicates the physical interception of nutrient-rich sites in soil by the growing root tip.

Arrow 3 indicates the potential of organic acids secreted by the living root to chemically alter nutrients on contact, to improve uptake into the root tissues.

Nutrient Extraction from the Soil

Plant roots gain nutrients from the soil using three mechanisms (refer to **Figure 1**). As water is lost from the leaf surface, water in the soil moves via **mass flow** towards the root (arrow 1). As the root tips grow, the living cells of the root **intercept** nutrients that may be bound in the soil (arrow 2). For nutrients to flow in the soil water and to cross the cells of the root, they must be **dissolved**. Accordingly, the major plant nutrients (nitrogen, potassium, phosphorus, sulphur, calcium, magnesium) must be in the **inorganic** state, and must be **soluble** in the soil water. **Organic acids** secreted by root tips into the soil (arrow 3) may change the chemical state of nutrients on contact, improving their uptake into the root tissues.

How Nutrients Cross the Living Barrier of Plant Cells

Just as houses need to be enclosed to control the daily functions that occur within, plant cells also need to be enclosed. Water is the one compound that is small enough to move freely across, moving from zones of low to high concentration (**mass flow**). All other compounds must be in the right form to fit the very specific **carriers**. As with a house, special **channels (carriers)** exist on the outside structure to **selectively** permit the entry of preferred inputs. Copper pipes carry water, insulated wiring carries electricity, and the size of mesh screens, windows and doors determines what and how animals will enter the dwelling. An external signal such as a door-bell will initiate an action from within, to regulate the functions across the threshold. In a similar way, plant cells control the functions within, in response to internal and external signals (refer to **Figure 2**).

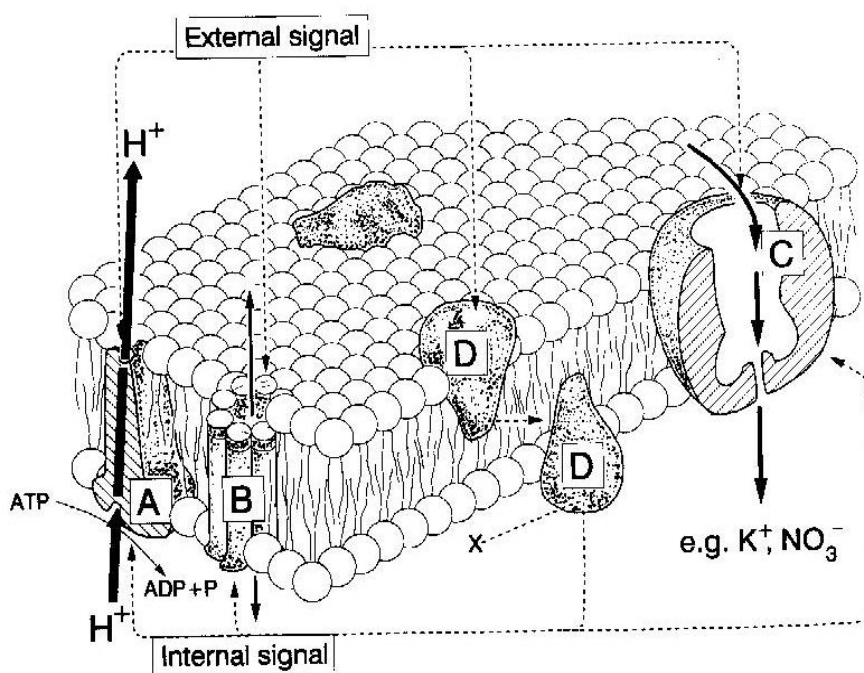


Figure 2:

Selective uptake of specific nutrients across a plant cell membrane. Protons (H^+) are carried across either side of the cell (carrier A) to maintain the pH within. Ion-selective channels and carriers (B and C) ferry ions such as phosphorus or calcium, or potassium and nitrate. Coupling proteins (D) react with specific ions, passing from one to the other. Sugars and amino acids are also selectively transferred using these mechanisms. Source: H Marschner (1995) *Mineral Nutrition of Higher Plants* Academic Press

Salts, Selective Carriers and the Flow of Water

To prove that water does flow freely through plant tissues, try the following practical exercise. Find a plastic container with a lid (eg. take-away food container). Cut a length or two of either celery or carrot to fit into the container. Next, place about a teaspoon of **rock salt** (crystal form of **sodium chloride**) in the container. Replace the lid, and allow it to sit for several hours. Over several hours, water will flow out of the carrot or celery (low concentration of sodium) towards the rock salt (high concentration).

Sodium is required in small amounts for plant growth, but in the undissolved state is not available for uptake. However, the **chemical attraction** of sodium for water is very high. Consider the amount of water absorbed by salt in shakers under humid summer conditions. Rice is often placed with salt in shakers, because the rice seed has a higher affinity for water than the salt – improving the flow of salt from the shaker onto the plate!

In a similar way plants maintain the **water content** of their cells by **selectively transporting** chemically active ions across the cell membrane, to adjust the chemical activity of one side of the membrane relative to the other (**figure 2**). Excessive sodium chloride in the soil (**salinity**) interferes with plant functions by disrupting the water balance across the roots, and within the cells of plants.

Soil Type and Nutrient Uptake by Plants

Different plant species and varieties require **different amounts** of nutrients (refer **Table 1**). This is reflected in the different types and density of selective ion carriers located on the surface of cells, and in the amounts of nutrients locked up in plant tissues **harvested** for sale and consumption. Nutritionists use this information when recommending healthy, balanced diets! Ion carriers are most numerous on the surface of root hairs and root tips, demonstrating that roots are the main conduit for nutrient uptake in plants.

	Quantity of nutrients exported in produce kg per ha					
	Nitrogen	phosphorus	potassium	calcium	magnesium	sulphur
Wheat grain 4 t/ha crop	76	16	24			
Soybean 2.5 t/ha crop	188	18	55			
Capsicum fruit	98	8	128	72	32	19
Lettuce 50 t/ha crop	100	18	180	33	15	
Onions 30 t/ha crop	80	18	100			
Potato tubers 25 t/ha	90	15	134	6	6	
Bananas 50 t/ha crop	189	29	778	101	49	23

Table 1: Quantity of nutrients exported from the soil in different crops (kg per hectare). Values are from Qld DPI Agrilink publications and NSW Agriculture Nutrient Management Guide.

However soil types differ in the total amount of nutrients present. Soil pH, the chemistry of clay particles and the amount of organic matter present determine the **form** in which the nutrients occur, and therefore their **availability** for plant uptake. Outside the pH range of 5 to 9, the **solubility** of some essential plant nutrients in soil water changes. For example in alkaline soils (>9) calcium becomes insoluble, and in acidic soils (<5) phosphorus becomes insoluble. Similarly, commercial fertilisers must be **soluble** in the soil water (refer to **Figure 1**) for immediate plant uptake. Ask vendors how **water soluble** their **rock fertiliser** is (many are insoluble), before purchasing. Fertilisers sold as organic (nutrients locked in the **organic form**) are also unavailable for immediate plant uptake, requiring the activity of microbes to **mineralise** them over time (**slow-release**).

Nutrient Ratios and Plant Uptake

Nitrogen, phosphorus and potassium (NPK) are the nutrients required in the greatest amounts for plant growth, with sulphur, calcium and magnesium required the next (Ca, Mg), and manganese, zinc, iron, boron, copper and molybdenum needed only in trace amounts (Mn, Zn, Fe, B, Cu, Mo). Many fertiliser companies provide inorganic fertiliser mixtures that reflect the needs of specific crop varieties across most agricultural soils. As the technology for assessing nutrient deficiencies across a paddock improves, more sophisticated techniques for applying custom blends across variable soil types will become available.

Yet despite our advance in the knowledge of crop varietal requirements for nutrients and the capacity of different soils to supply them, some myths about nutrients persist. One such myth is the **Calcium to Magnesium ratio**. Why should there be one optimal ratio for all crops across all soil types, when the nutritional needs of crops vary (ratio varies from 1 to 2.3 in **Table 1**), as does the capacity of soil types to supply them? **Calcium** may be limiting in **acidic soil**, and **liming** will reduce the acidity rendering more trace elements – including phosphorus, plant-available. **Calcium** may also need to be added to a **sodic soil**, to replace the sodium ions that cause dispersion (see ‘can do’ sheet 11 on Sodic Soils). But if your soil is **neither acidic nor sodic**, soil tests and local experience are the best indicator as to whether additional calcium or magnesium is required,- **not** a ‘one size fits all’ ratio.

Foliar Feeding and the Nutrition of Plants

The surface of the leaf is specialised for trapping energy from light (photosynthesis) and storing it as sugars and starch. Therefore the upper leaf surface must be angled to face the sun, reaching surface temperatures of more than 10⁰C above ambient air temperature. To control water loss under such conditions, most leaves have a thick, **water resilient** waxy layer (the cuticle: refer to **Figure 3**). The specialised openings that control the rate of water loss (**stomates**) tend to be more numerous on the under side of the leaf.

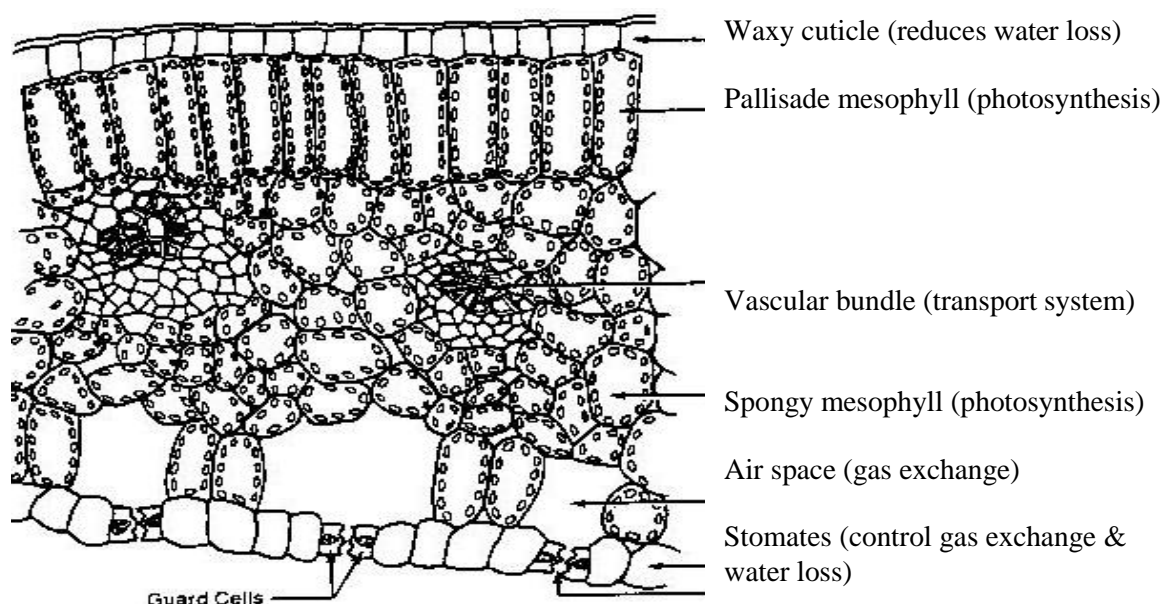


Figure 3: Cross section of the structure of a leaf. From Hartman et al (1998) Plant Science, Growth, Development and Utilisation of Cultivated Plants.

Accordingly, leaves **are not adapted** for taking up nutrients. The specialised ion carriers within the walls of the leaf cells (refer to **Figure 2**) are not as numerous as on root hairs and root tips, and water is less likely to be in contact with leaf cells due to the presence of the protective waxy cuticle at the surface. Comparatively, **mass flow** of solutes from the soil to the roots provides the greatest amount of nutrients for plants. Moreover, root tips branch prolifically when they intercept concentrated pockets of nutrients in the soil. However plants only need **micronutrients** such as manganese, zinc, iron, boron, copper and molybdenum in trace amounts, which can be applied successfully as a **foliar spray** to leaves.

Implications for Organic Agriculture

Foliar applications of **water-soluble** nutrients are highly **unlikely** to supply the macronutrient needs (N, P, K, Ca, Mg, S) of plants. Nutrients locked up in the **organic form** are not readily soluble in the soil solution, and are also highly **unlikely** to be carried into the cells of the root. Over time, these organic nutrients become **mineralised (inorganic)** as microbes and soil animals degrade them. However whilst plants may not utilise organic nutrients directly, indirectly **organic matter** is essential for maintaining a healthy soil (refer to 'can do' sheet 4: What is a Healthy Soil).

Soil tests based on chemical methods that reproduce the chemistry of the soil water, provide the best indication of the quantity of nutrients that are **available** for plant uptake (available P, available K, nitrate N & ammonia N, available S, exchangeable Ca & Mg). Balancing nutrients exported in the produce with fertiliser inputs, enhances the quality and sustainability of crop production.