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Plants and mineral nutrients

Right: *Tomato plants growing hydroponically in a glasshouse*

If a plant or tree were to be burned, most of it would go up in smoke, but part of it would be left behind as ash. This article looks at the chemicals that make up the ash and the role they play in the life of the plant, as well as at some novel ways they can be supplied to plants.

GCSE key words
Plant nutrition
Photosynthesis
Mineral ions
Deficiency symptoms
Nutrient cycling

Photosynthesis is an amazing process. Plants use carbon dioxide (CO_2) from the air and water (H_2O) from the soil to synthesise a wide range of carbohydrates and lipids. With the addition of the element nitrogen (N), taken up via the roots in nitrate ions (NO_3^-), plants can also make amino acids (to be joined together into proteins) and nucleic acids. Two other important mineral ions that plants take up via their roots are phosphorus (P), as phosphate ions, and potassium (K).

• Nutrients such as nitrogen (N) are cycled. Check your understanding of the nitrogen cycle. What happens to P and K?

NPK

These three elements are all essential for plant growth. Compared with the mass of the plant to whose structure they contribute, the amount needed is small. Nevertheless, sufficient quantities are needed for them to be called **macronutrients**. Other macronutrients are:

- magnesium (Mg) — a component of chlorophyll molecules
- calcium (Ca) — a component of plant cell walls (see Box 1)
- sulphur (S) (see Box 2)

More details about macronutrients are given in Table 1, including brief descriptions of what happens when plants are short of particular macronutrients. **Micronutrients**, which are needed in very small quantities, include iron (Fe) — this is important in enzymes involved in respiration.

Why are fertilisers needed?

When a crop is harvested many nutrients are removed from the soil. Sugar beet, for example, is grown for its root, which can contain 16% or more sugar. When it is harvested the leafy top of the plant, together with the point of attachment to the root, called the crown, is cut off the root. After the root has been lifted these waste parts may be used as animal feed or may be ploughed in to the soil to decompose.

Table 1 Macronutrients

Mineral elements and ions	Needed for	Symptoms if not enough is available
Nitrogen (as nitrate, NO_3^-)	It is a constituent of DNA, RNA and the amino acids which are used to build protein molecules	Pale, lower leaves which are yellow or dying; light green to yellow appearance of leaves, especially older leaves; stunted growth; poor fruit development
Phosphorus (as phosphate, PO_4^{3-})	It is a component of cell membranes and ATP. It is essential for reproduction and photosynthesis and is involved in energy transfer and the formation of oils, sugars and starches. It also helps maturation, blooming and root growth	Slow development; poor growth, flowering and fruiting; leaves may appear purple
Potassium (as K^+)	It activates many enzymes, encourages flowering and is important in osmosis. It also builds disease-resistance and improves fruit quality	Older leaves yellowing around edges and then dying; poor growth; vulnerable to disease

Approximately 90% of all cut fresh flowers purchased in the UK are grown hydroponically. An estimated 65% of all fruit and vegetables purchased from supermarkets are also grown in hydroponic systems.

Box 1 Calcium: a useful chemical for improving soils

Calcium is an important mineral in the life of plants. It is a component of the calcium pectate that helps glue cell walls together in young plant tissues. Although there are few soils where the availability of calcium ions to plants is so low that it causes any problem, calcium, in the form of lime, is often applied to soils. This is because it has another important use. Lime is used to help adjust the pH of agricultural soils when they are too acidic for successful crop growth.

Lime used to be made by heating limestone (calcium carbonate) to more than 825°C, which produced calcium oxide (quick lime), or, once water was added, calcium hydroxide (slaked lime). Nowadays most 'lime' applied to fields is limestone or chalk that has been crushed.

Box 2 Sulphur: an overlooked mineral nutrient

Sulphur is an important element in small quantities in the structure of certain amino acids (and hence proteins). Deficiency in soils leads to a decrease in productivity, poor crop quality and higher susceptibility of plants to certain diseases.

Until quite recently sulphur deficiency was not a significant problem in the UK. For much of the time since modern agriculture systems started and yields were recorded, people burnt sulphur-rich coals in their houses, factories and power stations. The sulphur dioxide produced ended up back in soils as sulphate ions. However, the use of low-sulphur fuels has resulted in a reduction in sulphur emissions to the environment and sulphur deficiency is now an important and increasing problem not only in the UK, but worldwide.

In common with all living cells, the cells of roots need oxygen for respiration. Root cells do a lot of work because mineral ions are taken up by active transport. This requires energy from respiration and hence a good supply of oxygen.

Table 2 shows just how much of a number of nutrients is removed when a crop of sugar beet giving a good yield of 50 tonnes per hectare is harvested. These nutrients must be replaced by using fertilisers — either natural ones, such as farmyard manure, or artificial, inorganic fertilisers.

Table 2 Amount of nutrients removed from the soil by a crop of sugar beet

Element	Tops and crowns ploughed in (kg/hectare)	Tops and crowns used as animal feed (kg/hectare)
N	65	170
P	30	65
K	90	235
Na	10	90
Mg	10	20
Ca	60	85

Below: Two bags of fertiliser. The bag on the left has a mixture of nitrogen, phosphorus and potassium, but the one on the right does not contain any nitrogen

Martyn F. Chillmaid/SPL

Any system to grow plants in outer space is based on hydroponics.

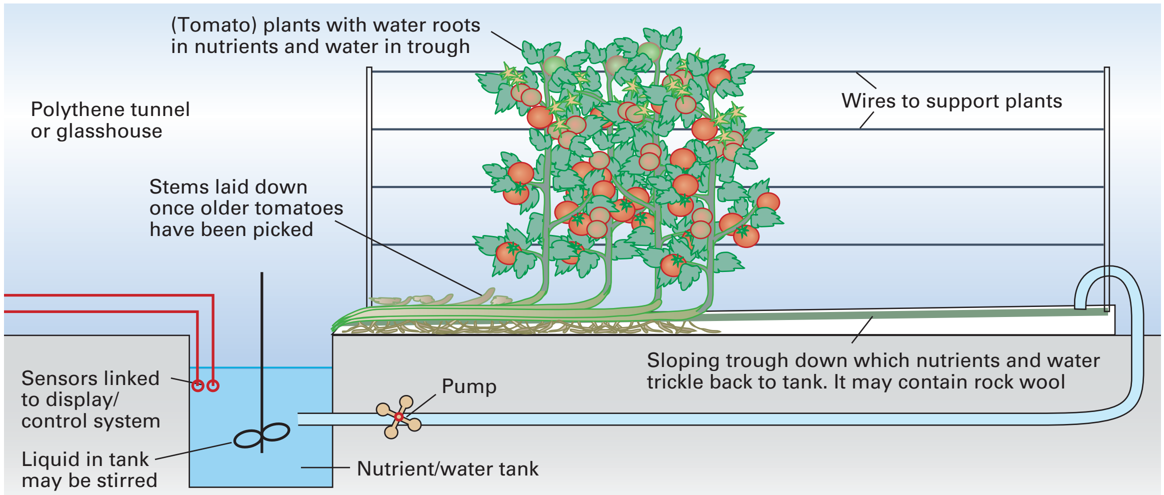

Figure 1 *Tomato plants being grown hydroponically*

Hydroponics

Although most plants grow in soil, soil is not essential. Plants can be grown with their roots in water to which the necessary minerals have been added. However, without soil to anchor their roots, plants grown in such a system require artificial supports.

In fact, plants grown in this way develop what are known as 'water roots' – these form a very fine mesh, directed at absorption rather than anchorage. Such rooting systems are on nowhere near the scale of those found in soil, which develop to anchor the plant and grow into fresh patches of soil all the time, where there will be untapped sources of minerals and water.

One downside to hydroponic systems is that where one reservoir serves a lot of plants, any disease can spread very quickly among them.

Salad crops

Many salad crops are grown hydroponically (Figure 1). They are grown in gently sloping shallow troughs which have a thin film of water and nutrients, 1–3 mm deep, trickling down them to a tank. A pump is used to return the water to the top end of the trough. This Nutrient Film Technique was the first system devised.

- **Why is the film of water so shallow in the Nutrient Film Technique of hydroponics? (Answer below.)**

Tomato plants are often grown in this way, supported on wires as they grow, flower and fruit. As soon as the ripe tomatoes have been harvested the plants can have their stems lowered to the ground. The younger parts are left upright and go on to flower and fruit themselves. By the end of the season the plants can be many metres long, linked through a long horizontal stem to roots far back in the nutrient film. Sometimes the plants are rooted in an inert supportive material through which the nutrients trickle. An example of this is rock wool.

- **Find out more about cutting edge hydroponics at www.1-hydroponics.co.uk/main.htm**

Office plants

You may see plants in public buildings and offices growing out of a pot full of brown granules. This is another system of hydroponics. In this system the roots are provided with support by an inert material, such as baked clay granules which are porous.

In the simplest of such systems there is a pot within a pot. The inner pot contains the plant's water roots among the granules and has slits to allow free flow of water and minerals. The outer pot contains water and minerals. Capillary action keeps the granules moist.

A water level indicator is built into the outer pot, showing maximum/optimum/minimum levels. The water level is allowed to fall as transpiration and evaporation occur. This drop also ensures that the roots receive enough oxygen.

Mineral nutrients are added as slow release cartridges or tablets. The precise type used depends on the hardness of the water. This system does not have a pump.

Figure 2
A hydropod

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Optimising plant growth

Much more sophisticated systems have been developed to optimise plant growth, such as the hydropod shown in Figure 2. Water and nutrients are pumped from the reservoir up into the inert growth medium to flood it for a few minutes. Stale air is pushed up and away from the roots. The water and nutrients then fall back into the reservoir, leaving the roots and the granules covered in a film. Fresh air flows in around the roots, bringing in more oxygen for respiration. Under these conditions plants can grow much more quickly than in soil.

The film is shallow so that the roots are not deprived of oxygen for respiration.

Nigel Collins teaches biology and is an editor of CATALYST.