lists all of the elements

Table 5.1 : Levels of Essential Elements Known to be Critical for Plant Growth (Stout 1961; Price 1970)

Elements	Concentration in dry matter	
	μg/gm or ppm	Percentage (%)
Macronutrients		
Oxygen	450,000	45
Carbon	450,000	45
Hydrogen	60,000	6
Nitrogen	15,000	1.5
Potassium	10,000	1.0
Calcium	5,000	0.5
Magnesium	2,000	0.2
Phosphorus	2,000	0.2
Sulphur	1,000	0.1
Micronutrients		
Molybdenum	0.1	1×10^{-5}
Copper	6	6×10^{-4}
Zinc	20	2×10^{-3}
Manganese	50	5×10^{-3}
Iron	100	1×10^{-2}
Boron	20	2×10^{-3}
Chlorine	100	1×10^{-2}

There are three methods to determine the mineral requirements of plants. These are (i) plant analysis, (ii) solution culture or hydroponics, (iii) solid medium culture.

1. Plant Analysis

The plant material is dried in an oven at a temperature of 70-80° C. At higher temperature some of the sulphur and nitrogen-containing compounds may be converted into gaseous form and may be lost. The dried sample is then powdered with a porcelain mortar and pestle. This powdered plant material is subjected either to wet digestion or to ash analysis.

(a) **Wet Digestion :** In this method, to a small quantity of concentrated sulphuric acid the powdered sample is taken and heated on a low flame. The materials dissolve and a clear solution is obtained.

(b) **Ash Preparation :** Ash is prepared keeping the powdered sample to high temperatures (600° C) in a muffle furnace. All the volatile and non-volatile organic compounds are burnt into gases, leaving a white powder called ash. Carbon, hydrogen and oxygen are given off as CO_2, water and oxygen. Nitrogen cannot be detected with this method since it escapes as ammonia or nitrogen gas. Chemically, ash consists of oxides of metals. The ash content of different plants and tissues varies from 1 per cent to 4 per cent of fresh weight. The ash content is maximum in halophytes and xerophytes and minimum in hydrophytes. Ash is dissolved in warm dilute hydrochloric acid or nitric acid. Detection and quantification of the elements, present in the solution obtained by either of the methods, are done by some chemical, physical and physico-chemical methods. The improved methods are atomic absorption spectrometry, optical emission spectrometry, etc. Atomic absorption spectrophotometers are now used to measure metals and some non-metals. In optical-emission spectrophotometry, the elements are vaporized at temperatures above 5000 K to excite electrons from their ground states to higher-energy excited states. These electrons return to their ground states by emitting the absorbed energy at wavelengths different for each element. Wavelengths are measured and the energy content is quantified by the spectrophotometer.

2. Hydroponics

In 1860 W. Pfeffer, Julius Sachs and W. Knop grew plants in this way and is referred to as ***hydroponics*** or ***solution culture***. This method provides an excellent means for controlling the quantity and relative proportions of mineral salts given to a plant in an experiment.

In this method mineral salts are dissolved in double glass-distilled water. Every time only one element is left out from the solution and the plant is grown on it. If, without that particular element, the plant shows some deficiency symptoms and if those symptoms vanish on supplying the missing element, this element is considered to be essential. There are two advantages for using solution cultures in mineral nutrition studies — (i) water is an excellent solvent for the mineral salts, and (ii) water can be easily freed from contaminations.

In spite of such advantages, the technique has some disadvantage as follows :

(i) There is a need for root aeration that is not sufficient in solution.

(ii) There is a need to replace the solution every day or two for maximum growth because the solution composition changes as certain ions are absorbed more rapidly than others.

(iii) This selective uptake also causes pH changes.

In solution culture, there are many sources of contamination like the reagents, the water, the containers, and the dust in the surrounding atmosphere. It is not possible to eliminate totally these contaminating influences, but they can be kept to a minimum. Most of the difficulties encountered in mineral mutrition studies are associated with trace element contamination.

3. Solid Medium Culture

To avoid some disadvantages of liquid cultures, solid medium cultures are generally used by many physiologists. As a solid medium for roots highly purified silica sand or crushed white quartz sand or gravel is generally easier to work with because those are very low in available trace elements. In this method, the roots can easily anchor the solid substratum and no supporting device needs to be provided to the plant. Nutrient solutions are applied in three different ways : (i) by pouring over the solid medium (called ***slop culture***), (ii) dripping onto the solid medium at suitable intervals (called ***drip culture***) and (iii) by forming solution up from the bottom of the container (called ***subirrigation culture***). In all these techniques, the solutions that are added, drain out through an outlet in the bottom of the container. In the ***subirrigation*** technique recirculating solutions that flow through the solid medium around the roots, are used. The unabsorbed solution flows down into a reservoir in

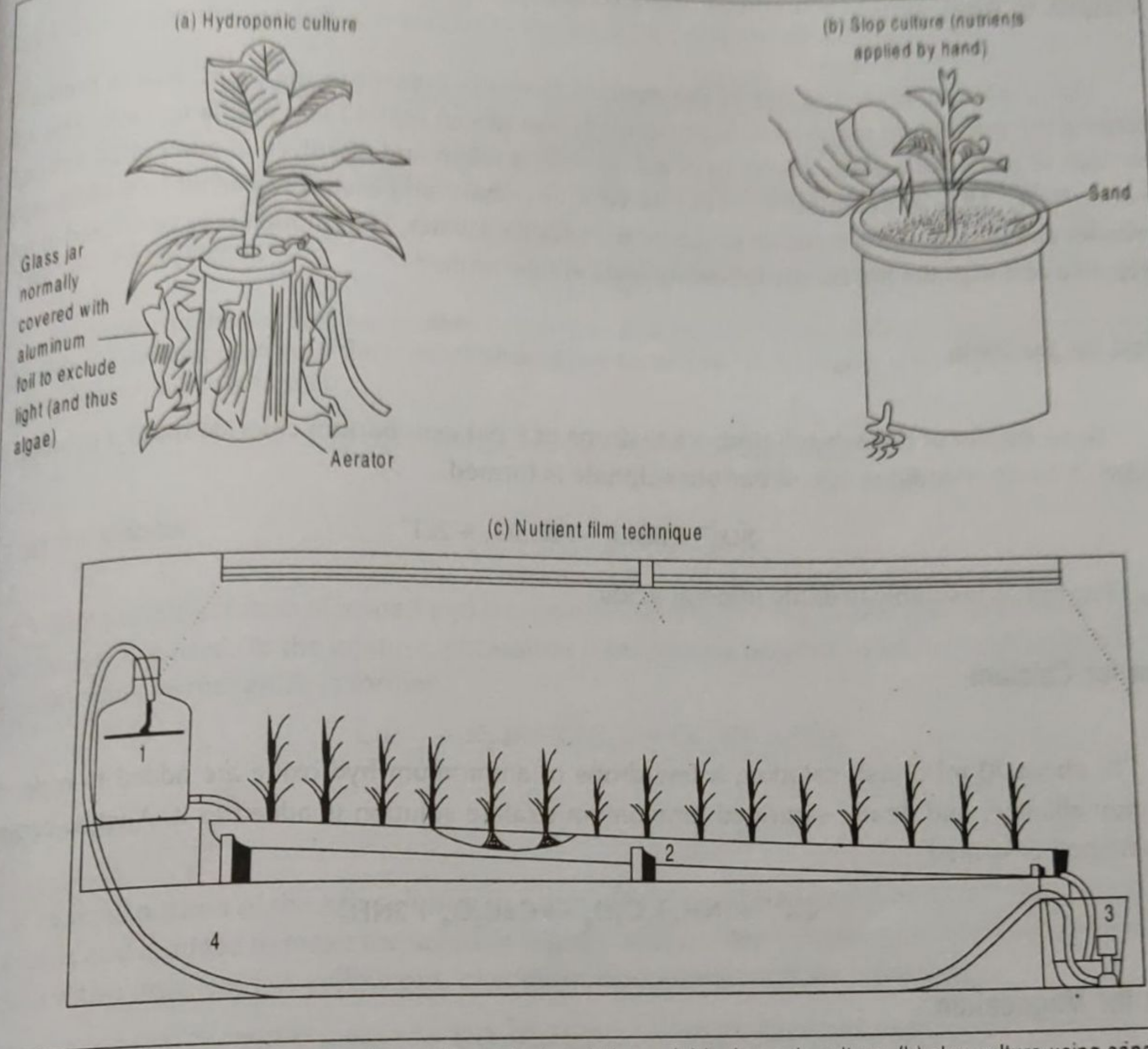

Fig. 5.1 : Three methods for growing plants with nutrients solutions : (a) hydroponic culture, (b) slop culture using sand, and (c) nutrient film technique. Reservoir (1) contains nutrient solution that drains down trough containing plants (2) Unabsorbed solution flows into container (3) that has a pump to force solution through tube (4) back to reservoir.

which the pH and solution composition can be monitored and adjusted automatically and then the solution is pumped up to drain down again bathing the roots. The pumping apparatus is attached to a timing mechanism that gives periodic irrigation to the sand, quartz, or gravel.

The slop culture is the easiest method to operate but exposure of roots to constant amount of essential elements and water cannot be controlled. In drip culture the amount of solution being added should be equal to the amount of solution drained off. So this system allows for a continuous and more or less constant nutrient and water supply. The subirrigation system which operates automatically, is the most desirable of the three systems, but it is most costly and needs sophistication.

Several formulations of nutrient solutions have been developed and named after the workers like Knop, Hoagland, Evans, Shive, Sachs, etc. The most important formulations are Hoagland's solution and Shive's solution (modified by H.A. Evans). The recipes are listed in Table 5.2. These are the general formulations having necessary elements in concentration to allow good growth of many higher plants, but a solution ideal for one species may not be ideal for another species.

CRITERIA OF ESSENTIALITY

An element is considered as essential (a) if without it, the plant cannot complete its life cycle, (b) action of the element must be specific, no element be replaced by other elements, (c) essentiality is confirmed if the element is shown to be directly involved in the nutrition of the plant, i.e., to be a necessary component of an essential metabolite or at least required as an activator of an essential enzyme, of course, there are certain exceptions. An element may be present in insufficient amounts. Its function may be partially replaced by another element. This sparing action may be an essential part of the survival of certain organisms under adverse conditions (Nason and McElory, 1963. Epstein, 1965; Bonds and O'Kelley, 1969).