Plant Growth and Development - Part 1

Objectives

After going through this lesson, the learners will be able to understand the following:

- Important phases of growth?
- Last phase of the development process?
- Log phase in sigmoid growth curve.

Content Outline

- Introduction
- Growth
    - Some Features of Plant Growth
    - Steps in Cell Growth and Development
    - Growth is Measurable
    - Phases of Growth
    - Growth Rates
    - Factors Affecting Growth
- Differentiation, Dedifferentiation and Redifferentiation
- Development

Introduction

Any living organism is not static. Plants are well organised living things, a machine that processes matter and energy in its environment and maintains a relatively low entropy. Plants originate from a diploid single cell zygote, which grows and develops into multicellular organisms. Cell division produces new cells, many of which not only become large but more complex. The cells changed in different ways, producing a mature plant composed of numerous cell types. This process of cellular specialization is called differentiation, and the growth and differentiation of cells into tissues, organs and organisms is often called development. Besides the genetic constitution of a cell there are certain organic compounds called growth substances or growth hormones that often play critical roles in many growth processes. Development can be strongly modified by the environment. Light, which plays an important role in photosynthesis, biological clock, seed germination, flowering and other significant morphogenetic changes. Similarly, changes in temperature and the relative length of day and night often modify or control flower initiation.

Growth

Growth is regarded as one of the most fundamental and vital characteristics of a living being. What is growth? Growth can be defined as an irreversible permanent increase in size, shape, volume and number of an organ or its parts or even of an individual cell. Generally, growth is accompanied by metabolic processes (both anabolic and catabolic), that occur at the expense of energy. Therefore, for example, expansion of a leaf is growth, however the swelling of a piece of wood when placed in water will not be growth. Dry mass of plant/tissue is a more valid estimate of growth than is fresh mass since fresh mass is variable as it depends on the plant's water status. Generally growth is related to cell division and hence increase in cell number but there are certain examples where growth occurs without cell division, such as growth of certain leaves, stems, and fruits after a certain stage of development (fig 15.1).

There are also certain examples of cell division without increase in overall size, as in maturation of embryo sac.

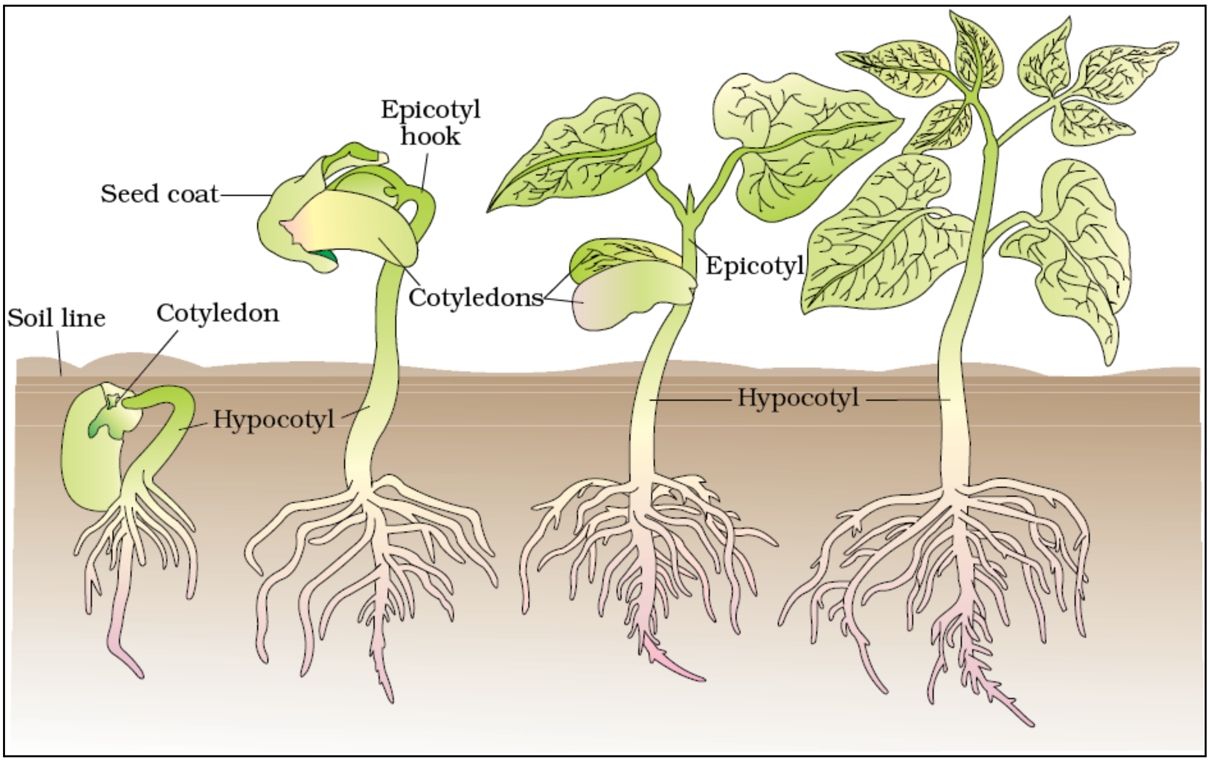

Figure 15.1: Seed germination and seedling growth in bean plant

Some Features of Plant Growth

Plant growth is unique because plants retain the capacity for unlimited growth throughout their life. This ability of the plants is due to the presence of meristems restricted to certain locations in their body. The cells of such meristems have the capacity to divide and self-perpetuate. The product, however, soon loses the capacity to divide and such cells make up the plant body. Root and shoot tips (apices) have meristem. Other meristematic zones are found in the vascular cambium and just above the nodes of monocots or at the bases of their leaves (Fig 15.2). Meristems are of two types, (a) primary meristems: the root and shoot apical meristems are formed during embryo development while the seed being formed, (b) secondary meristem: the vascular cambium and the meristematic zones of monocot nodes and grass leaves which are indistinguishable until germination.

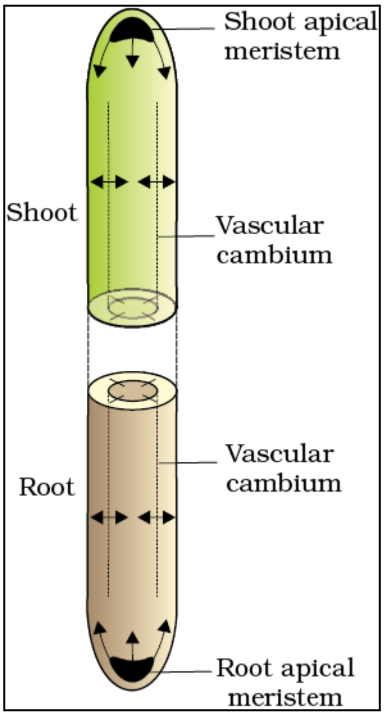

Figure 15.2: Diagrammatic representation of root apical meristem, shoot apical meristem and Vascular cambium. Arrows exhibit direction of growth in cells and organs.

Some plant structures are determinate while others are indeterminate. A determinate structure grows to a certain size and then stops, eventually undergoing senescence and death. Leaves, flowers and fruits are good examples of determinate growth. On the other hand, the vegetative stem and root are indeterminate structures. They grow by meristems that continuously replenish themselves. Although an indeterminate meristem can also become determinate for example when an indeterminate, vegetative meristem becomes reproductive, it becomes determinate.

Plants on the bases of their life cycle are also referred to as monocarpic or polycarpic. Monocarpic species are those which flowers only once and then die eg. Annuals (live only for one year) and biennials which live for two years, spending first year in vegetative state and flower in second year. Polycarpic species are those which flower, return to a vegetative mode of growth, and flower at least once more before dying e.g., Perennials do not convert all their vegetative meristems to determinate reproductive structures, instead they use only some of their axillary buds for the formation of flowers, keeping the terminal buds vegetative or vice versa.

Steps in Cell Growth and Development

All living cells undergo a series of repeating events called the cell cycle. After mitosis there is a period of cell growth (G1), DNA replication (S), then growth after replication (G2) and finally mitosis to complete cell cycle. If any daughter cell produced by mitosis enlarges and differentiate before DNA replication, the differentiated cell will have normal diploid chromosome number but if differentiation occurs after replication then the differentiated cell will have more than diploid chromosome number (fig 15.3). Differentiated cells may sometimes re-enter the cell cycle by a process called dedifferentiation after which they again have the ability to divide.

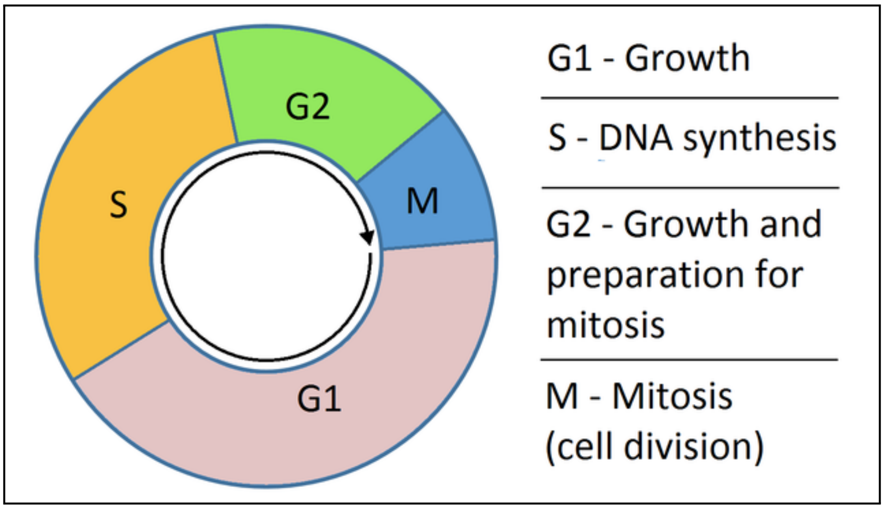

Figure 15.3: Phases of cell cycle

There are three simple steps in the growth and development process, the first is cell division, in which a mature cell divides into two daughter cells. The second event is cell enlargement, in which one or both daughter cells increases in size and volume and followed by third event cellular differentiation, in which a cell, perhaps having achieved its final volume, becomes specialized. Cell division is not only concerned with formation of various structures, but also direction in which they are formed therefore it can occur in different planes. Cell enlargement in organs like stem and root occurs mostly in one dimension, and therefore called elongation. Newly formed meristematic cells however can enlarge in all three dimensions.

Growth is Measurable

Growth, at a cellular level, is principally a consequence of increase in the amount of protoplasm. Since increase in protoplasm is difficult to measure directly, one generally measures some quantity which is more or less proportional to it. Growth is, therefore, measured by a variety of parameters some of which are: increase in fresh weight, dry weight, length, area, volume and cell number. You may find it amazing to know that one single maize root apical meristem can give rise to more than 17,500 new cells per hour, whereas cells in a watermelon may increase in size by upto 3,50,000 times. In the former, growth is expressed as increase in cell number; the latter expresses growth as increase in size of the cell. While the growth of a pollen tube is measured in terms of its length, an increase in surface area denotes the growth in a dorsiventral leaf.

Phases of Growth

The period of growth is generally divided into three phases, namely, meristematic, elongation and maturation. Let us understand this by looking at the root tips. The constantly dividing cells, both at the root apex and the shoot apex, represent the meristematic phase of growth. The cells in this region are rich in protoplasm, possess large conspicuous nuclei. Their cell walls are primary in nature, thin and cellulosic with abundant plasmodesmatal connections. The cells proximal (just next, away from the tip) to the meristematic zone represent the phase of elongation. Increased vacuolation, cell enlargement and new cell wall deposition are the characteristics of the cells in this phase. Further away from the apex, i.e., more proximal to the phase of elongation, lies the portion of the axis which is undergoing the phase of maturation. The cells of this zone attain their maximal size in terms of wall thickening and protoplasmic modifications.

Growth Rates

The increased growth per unit time is termed as growth rate. Thus, the rate of growth can be expressed mathematically. An organism, or a part of the organism can produce more cells in a variety of ways. The growth rate shows an increase that may be arithmetic or geometric and arithmetic growth, following mitotic cell division, only one daughter cell continues to divide while the other differentiates and matures. The simplest expression of arithmetic growth is exemplified by a root elongating at a constant rate. On plotting the length of the organ against time, a linear curve is obtained (fig 15.4).

Mathematically, it is expressed as –

$L_t = L_0 + rt$

L_t = length at time 't'

L_0 = length at time 'zero'

r = growth rate / elongation per unit time.

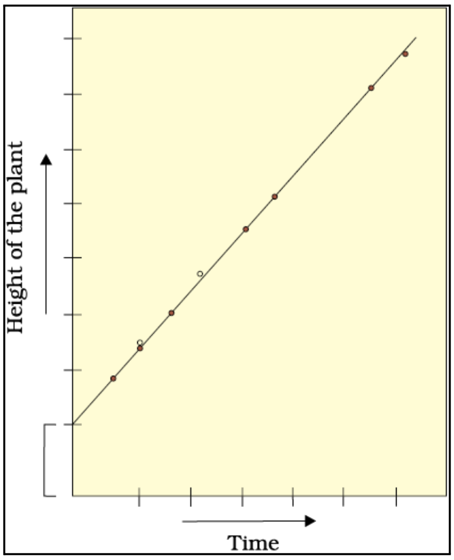

Figure 15.4: Constant linear growth, a plot of length L against time t

Let us now see what happens in geometrical growth. In most systems, the initial growth is slow (lag phase), and it increases rapidly thereafter – at an exponential rate (log or exponential phase). Here, both the progeny cells following mitotic cell division retain the ability to divide and continue to do so. However, with limited nutrient supply, the growth slows down leading to a stationary phase. Final stage in the growth curve is the senescence phase which is characterized by a decreasing growth rate. If we plot the parameter of growth against time, we get a typical sigmoid or S-curve (fig 15.5). A sigmoid curve is a characteristic of living organisms growing in a natural environment. It is typical for all cells, tissues and organs of a plant.

The exponential growth can be expressed as –

$W_1 = W_0$ ert

W_1 = final size (weight, height, number etc.)

W_0 = initial size at the beginning of the period

r = growth rate

t = time of growth

e = base of natural logarithms

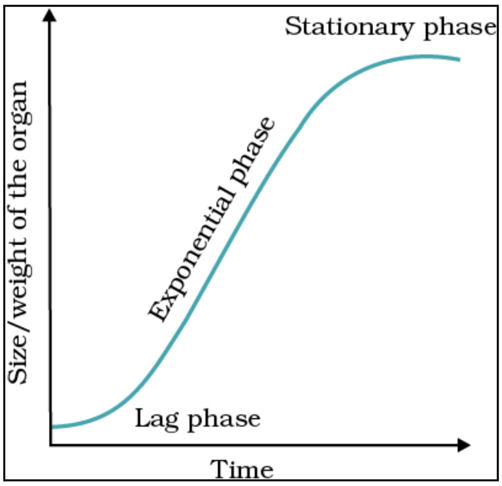

Figure 15.5: An idealised sigmoid growth curve typical of cells in culture, and many higher plants and plant organs

Here, r is the relative growth rate and is also the measure of the ability of the plant to produce new plant material, referred to as efficiency index. Hence, the final size of W1 depends on the initial size, W0. Quantitative comparisons between the growth of the living system can also be made in two ways: (i) measurement and the comparison of total growth per unit time is called the absolute growth rate. (ii) The growth of the given system per unit time expressed on a common basis, e.g., per unit initial parameter is called the relative growth rate.

Factors Affecting Growth

What are necessary factors which affect growth? The list may include Light, water, oxygen and nutrients as very essential elements for growth. The effect of light on growth can be studied under three headings (a) light intensities (b) light quality, and (c) duration of light. Growth is generally favoured by darkness, nonetheless, light is indispensable because of its role in photosynthesis to prepare food for plants. Young plants growing in absence of light develop elongated but thin stems with narrow leaves and poorly developed root system. Such plants are called etiolated plants. The plant cells grow in size by cell enlargement which in turn requires water. Turgidity of cells helps in extension growth. Thus, plant growth and further development is intimately linked to the water status of the plant. Water also provides the medium for enzymatic activities needed for growth. Oxygen helps in releasing metabolic energy essential for growth activities. Nutrients (macro and micro essential elements) are required by plants for the synthesis of protoplasm and act as a source of energy. In addition, every plant organism has an optimum temperature range best suited for its growth. Any deviation from this range could be detrimental to its survival. Environmental signals such as light and gravity also affect certain phases/stages of growth.

Differentiation, Dedifferentiation and Redifferentiation

Differentiation is the process by which cells acquire metabolic, structural, and functional properties distinct from those of their progenitors. The cells derived from root apical and shoot-apical meristems and cambium differentiate and mature to perform specific functions. This act leading to maturation is termed as differentiation. During differentiation, cells undergo few to major structural changes both in their cell walls and protoplasm. For example, to form a tracheary element, the cells would lose their protoplasm. Microtubules participate in determining the pattern in which the cellulose microfibrils are deposited in the secondary walls of tracheary elements. They develop very strong, elastic, lignocellulosic secondary cell walls, to carry water to long distances even under extreme tension. Try to correlate the various anatomical features you encounter in plants to the functions they perform. Plants show another interesting phenomenon. The living differentiated cells, that by now have lost the capacity to divide can regain the capacity of division under certain conditions. This phenomenon is termed as dedifferentiation. For example, formation of meristems – interfascicular cambium and cork cambium from fully differentiated parenchyma cells. While doing so, such meristems/tissues are able to divide and produce cells that once again lose the capacity to divide but mature to perform specific functions, i.e., get re-differentiated. List some of the tissues in a woody dicotyledonous plant that are the products of redifferentiation.
Recall, in Section 15.1.1, we have mentioned that the growth in plants is open, i.e., it can be indeterminate or determinate. Now, we may say that even differentiation in plants is open, because cells/tissues arising out of the same meristem have different structures at maturity.

The final structure at maturity of a cell/tissue is also determined by the location of the cell within. For example, cells positioned away from root apical meristems differentiate as root-cap cells, while those pushed to the periphery mature as epidermis.

Development

Development is a term that includes all changes that an organism goes through during its life cycle from germination of the seed to senescence (fig 15.6).

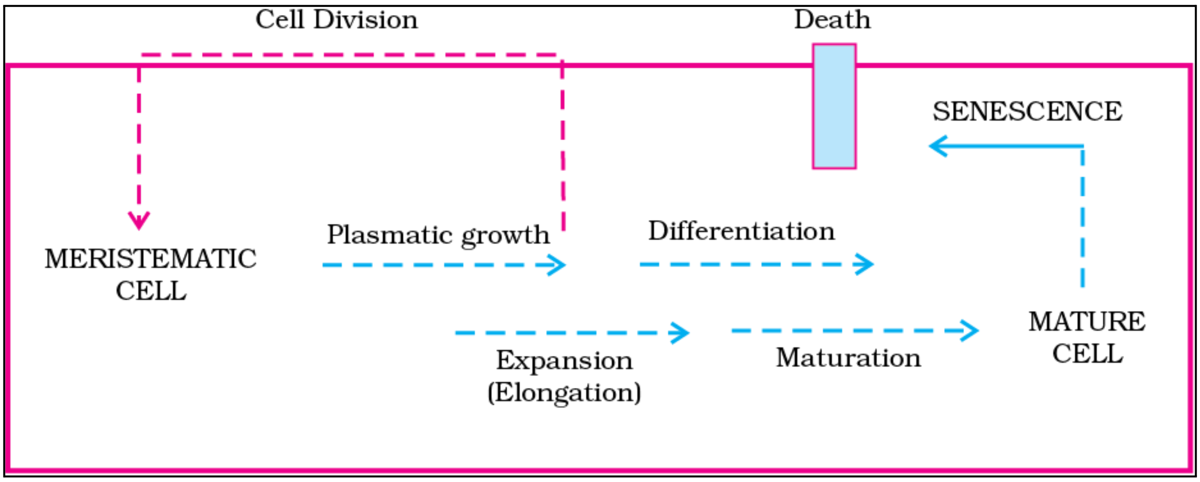

Figure 15.6: Diagrammatic representation of the sequence of processes which constitute the development of a cell of a higher plant is given in

It is also applicable to tissues/organs. Plants follow different pathways in response to the environment or phases of life to form different kinds of structures. This ability is called plasticity, e.g., heterophylly in cotton, coriander and larkspur. In such plants, the leaves of the juvenile plant are different in shape from those in mature plants. On the other hand, the difference in shapes of leaves produced in air and those produced in water in buttercup also represents heterophyllous development due to the environment (Figure 15.7). This phenomenon of heterophylly is an example of plasticity.

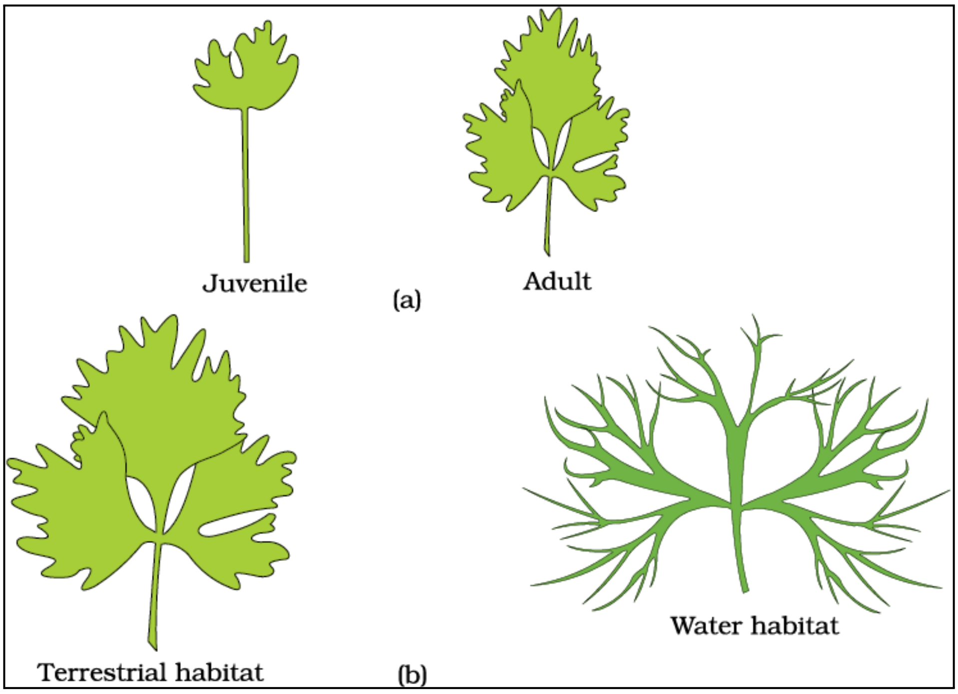

Figure 15.7: Heterophylly in (a) larkspur and (b) buttercup

Genes play critical roles in regulating growth, cell differentiation, and pattern formation. Genes important for development were revealed by carrying out mutational studies in the simplest plant genome like that of *Arabidopsis* and then analysing mutants with altered phenotypes. These studies have given the following insights.

- The expression of genes that encodes transcription factors determine cell, tissue, and organ identity
- The fate of a cell is determined by its position and not by its clonal history (its site of origin)
- Developmental pathways are controlled by networks of interacting genes.
- Development is regulated by cell to cell signalling.

MADS box genes are key regulators of important biological functions in plants, animals and fungi. Homeobox genes encode transcription factor proteins which regulate expression of other genes whose products transform and characterize the differentiated cell. Cell's position is more important than its lineage in deciding its fate. Maize genes KNOTTED 1 and SHOOT MERISTEMLESS are important maize genes necessary for continued indeterminate growth of shoot apical meristem and WUSCHEL gene determine stem cell identity. Loss of expression of KNOX gene in the leaf primordia is important in the shift to determinate growth in these structures. Cell position is communicated via cell-cell signalling, which may involve ligand – induced signalling, hormone signalling or trafficking of regulatory proteins through plasmodesmata.

Plant growth can be described in both spatial and material terms. Spatial description focuses on the patterns generated by all the cells located at different positions in the growth zone. Material description focus on the fate of the individual cells or tissue at various stages of development

Senescence and programmed cell death (PCD) are essential aspects of plant development. Plants show different senescence phenomena. Senescence is an active developmental process that is genetically controlled and initiated by specific environmental factors. Senescence involves a series of cytological and biochemical events. The expression of most genes is reduced during senescence except for SAG (senescence associated genes). These genes encode several hydrolytic enzymes like, proteases, ribonucleases, lipases, and ethylene bio-synthesizing enzymes, which carry out degradation processes in tissue. PCD is a specialised type of senescence. Its importance in plants is in protection against pathogens.

Thus, we can say that growth, differentiation and development are very closely related events in the life span of a plant. Broadly, development is considered as the sum of growth and differentiation. Development in plants (i.e., both growth and differentiation) is under the control of intrinsic and extrinsic factors. The former includes both intracellular (genetic) or intercellular factors (chemicals such as plant growth regulators) while the latter includes light, temperature, water, oxygen, nutrition, etc.