Morphology and anatomy of the root.

Plan.

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The organs of higher plants are distinguished into vegetative and reproductive. **Vegetative** organs provided up the body of the plant and perform the main functions of its vital activity, including vegetative reproduction. These include the root, stem and leaf. A stem with leaves and buds is called a shoot. **Reproductive** (generative) organs are intended for sexual or asexual reproduction itself. In angiosperms, they include a flower and its derivatives - a seed and a fruit.

Plant organs are characterized by some general patterns.

The symmetry. An organ can have one plane of symmetry (for example, a leaf), or more than one plane of symmetry (for example, a stem, a root).

The polarity. The vegetative organ (or part of it) has two poles: the distal (terminal) and the proximal (basal). Only shoots are formed in the distal part, and only roots are formed in the proximal part.

The geotropism. This is the ability of the plant's organs to orient themselves in a certain way in the space. In whatever position the seed lies in the soil, the root always grows down under the influence of gravity (positive geotropism), and the stem - up (negative geotropism). The axial organs — the stem and root - are located vertically to the surface of the earth (orthotropic organs), and the leaves are at an angle (plagiotropic organs). If an mature plant is removed from its correctly oriented position by some external influence, it bends its young parts so that they take their former position in space. The cereals able to lift their stems after lodging almost entirely due to the fact that their meristem is located at the bases of the internodes.

Metamorphosed (modified) organs are those in which, under the influence of the environment or depending on a certain function, there was a hereditarily fixed strengthening of one function, accompanied by a sharp change in shape, and the loss of others. Metamorphosed organs are the real expression of adaptive evolution. They are distinguished into analogous and homologous ones.

Analogous are called organs that have the same structure and functions, but different origins. For example, a barberry thorn of leaf origin and a hawthorn thorn of shoot origin, a pea tendril of leaf origin and a grape tendril of shoot origin.

Organs that have the same origin are called **homologous**. They may be similar in structure, for example, the thorns of rosehip and gooseberry (both are outgrowths of the surface tissues of the stem), but more often they do not have similarities, for example, an onion bulb and a potato tuber (both are of shoot origin).

The main vegetative organs are already haved in the embryo of the seed.

Root (Latin radix) is an axial, usually underground vegetative organ of higher vascular plants with unlimited growth in length and positive geotropism. The root anchors the plant in the soil and provides absorption and conduction of water with dissolved mineral substances to the stem and leaves.

Root functions.

1. Mineral and water nutrition.
2. Fixing the plant in the soil.
3. Synthesis of organic substances.
4. Synthesis of alkaloids, phytohormones and other active compounds.
5. Accumulation of substances.
6. Vegetative reproduction.
7. Symbiosis with bacteria.
8. Symbiosis with fungi (mycorrhiza)

The root, as well as the stem, arose as a result of plants coming to land and adapting them to new environmental conditions. In the process of evolution, the root appeared later than the shoot. Of the higher plants, mossy and psilotoid roots do not have roots. In addition, there are also secondary rootless plants that have lost their roots due to the aquatic lifestyle (for example, salvinia, pemphigus, hornwort, etc.)

Morphology of the root and root systems.

The root is an axial organ of the plant, it having a cylindrical shape, having radial symmetry, unlimited growth in length and the property of positive geotropism. This is a vegetative organ of leaf - stemmed plants, which serves to attach to the substrate and absorb water and minerals. There are no leaves on it. The apex is covered with a root cap.

Taking into account the anatomical and morphological features, the roots are distinguishing to tap, lateral and adventitious. The embryonal root develops into a tap root that branches endogenously and gives lateral roots, the formation of which begins with cells of pericycle division on the periphery of the central axial cylinder inside the root.

The adventitious roots never arise on the main root. They can be formed on stems, leaves, rhizomes, old lateral and adnexal roots due to the activity of various secondary meristems.

The root system is a set of roots of one plant. The general form and character of which is determined by the ratio of the growth of the tap, lateral and adventitious roots.

With the predominant growth of the tap root, pivotal root system is formed (woody dicotyledonous and gymnosperm plants, etc.).

With weak growth or death of the tap root and the powerful development of adventitious roots, a fibrous root system is formed (buttercup, plantain, cereals, sedges, etc.)

Sometimes mixed root systems are also formed when both the tap and lateral and adventitious roots develop (in strawberries at the end of the first growing season, in tomatoes, etc.)

In root systems, the overgrown tap root forms a root crop, and the overgrown lateral roots from root tubers.

In English botany textbooks, it is common to identify 3 root zones on a longitudinal section. In the Russian botanical school, it is common to identify 4 root zones on a longitudinal section. You and I study botany in Russia and we will follow the traditions of the Russian botanical school. However, some of the figures are taken from English textbooks, so there may be slight discrepancies.

There are 4 distinct zones on the longitudinal section of the root

1. The meristematic zone
2. The elongation zone
3. The maturation zone
4. The conduction zone.

The zone of cell divisions (meristematic zone). 1-2 mm of the tip of the apex of root, consisting of apical meristem, in which intensive mitotic divisions occur. Its cells have thin cell walls, a large nucleus, do not have vacuoles and plastids. As a result of the activity of the apical meristem, all other zones and tissues of the root are formed. The cells of the meristematic zone are covered with a root cap. The apical meristem deposits cells not only inside but also outside. Inside - the cells of the root mass, outside - the root cap. The apical meristem of root does not participate in the formation of lateral organs.

The root cap is a protective formation of the growing tip of the root, it is a cone-shaped cap of living parenchymal cells with sliming walls and starch grains (it is assumed that these grains serve as statolytes, that is, they are able to stream in the cell when the position of the root tip changes in space, so that the root bends and grows in the same direction). The size of the root cap is comparable to the apex of root and only not much smaller than it. The cells of the root cap are differentiated at the early stages of root development from a special meristem (calyptrogen) in cereals and other monocotyledons or from the apical meristem in dicotyledons. The root cap protects the apical meristem of the root and facilitates the growth of the root in the soil, thanks to the deposition of its outer cells. In this case, the peripheral cells peel off or "slide" along the surface of the root cap, sometimes the entire surface layer is separated in the form of a cap. Peeling of the peripheral layers does not lead to thinning of the root cap, since its mass is constantly renewed by the apical meristem. The sliming cells not only attract water, but also provide close contact of the root with the soil. The acids contained in them dissolve soil particles, favoring the movement of the root deep into the soil, and the enzymes that hydrolyze the substances contained in it facilitate their use by the root. The cells separated from the root also contain some substances to be removed from the plant.

Above there is a **zone of elongation** (**growth**) from several mm to several cm. In this zone, the meristem cells stretch out in length and stop dividing

Due to the stretching of the cells in length, the root grows. In this zone, the boundaries between the perible and the pleroma are clearly visible. The pleroma differentiates into an axial cylinder, the periblema into the primary cortex, and the dermatogen into the rhizoderm. While still retaining the character of the meristem, the cells of these divisions already differ in size and relative position. Initials are usually in layers. In the body of the root, the inner tier of the initials gives rise to the pleroma cells, the other tier - the cells of the peribleme and the dermatogen enclosing it. The end of the growth zone is noticeable by the appearance of trichoblast hairs on the epiblem.

Above the growth is **zone maturation (the absorption zone)**, the rhizodermis of which forms root hairs (trichoblasts). It is located at a distance of 0.1-10mm from the root end. Its total length varies from one to several cm. In most higher plants, the rhizoderm consists of two types of cells: hair – forming trichoblasts and atrichoblasts (without hairs). The length of the root hair is 0.15-8mm, in herbaceous plants they are longer than in woody ones. They live for about 10-12 days, after which they die. Sometimes the root hairs are preserved, impregnated with suberin and perform a mechanical function by fixing the root in the soil. Root hairs of the rhizodermis are always in close contact with soil particles and because of their high surface to volume ratio form an absorbing surface which is much larger than the transpiring surfaces of the plant. The number of root hairs per mm2 depends on the individual characteristics of plants and soil moisture. The root hairs greatly increase the adsorbing surface of the roots. Their total length in one plant can be 3-10 km.

The cells of the absorption zone cannot move in the soil because the growth in this zone has already stopped, and the hairs have fused together with the soil, nevertheless, the absorption zone is constantly moving in the soil as the root termination increases.

The maturation zone gradually passes into **the conduction zone**, which makes up most of the length of the root. The role of the dermal tissue in monocotyledones is performed here by the exoderma, and in dicotyledones - by the periderm. In this zone, the root conducting system is fully formed, along which water and mineral substances dissolved in it are moved to the stems and leaves, assimilation products - to the places of storage of these substances and growing root tips.

The primary anatomical structure of the root.

The primary structure of the root is formed in the maturation zone and is similar in all plants. In monocotyledons, the primary structure is preserved throughout the life of the plant. In dicotyledons, it is subsequently replaced by a secondary one.

In the primary structure of the root, 3 zones are distinguished on the cross-section.

1. The dermal tissue (Rhizoderma)
2. The primary cortex
3. The central axial cylinder.

1. The epiblema (rhizodermis)

The epiblema performs a protective function, the function of absorbing water and minerals dissolved in it. This is a tissue consisting of cells with thin cellulose cell wall, the cells of which have outgrowths - trichoblasts (root hairs). In the conduction zone epiblema dies off and quickly peels off.

2. The primary cortex - a set of tissues and tissue complexes of the root of the primary type of structure located between the central cylinder (pericycle) and the rhizoderm. Includes the outer layer of cells - exoderma, the core parenchyma of the primary cortex (the mesoderma) and the layer of endoderm cells.

At the roots, the thickness of the primary cortex exceeds the volume of the central axial cylinder.

Exoderma cells are polygonal, tightly closed, with thickened cell walls impregnated with suberin and lignin. The exoderm is multilayered in monocotyledonous plants and one-two-layered in dicotyledons. The cells impregnated with suberin are impervious to gases and water, lignification determines their strength. Opposite the root hairs in the exoderm there are pass-through cells not impregnated with lignin and suberin, through which the metabolism is carried out. The exoderm performs the function of protecting the root from the loss of water and substances dissolved in it, as well as from the penetration of pathogenic microorganisms into the root.

The mesoderma consists of living parenchymal cells. It may contain mechanical elements - sclereids and cavities: schizogenous and lysigenous cavities, idioblasts, and laticifers (latex tubes cells). Spare nutrients are accumulated in the mesoderm. This is the abundance part of the primary cortex.

The endoderm is the inner single-row layer of cells of the primary cortex. The main purpose of endoderma is the flow of water currents in a horizontal direction from the cortex to the central axial cylinder, where the vascular elements are located.

In the roots, the radial and transverse walls of endoderm cells have thickenings in the form of strips containing suberin and lignin (these strips are called **Caspari strips**), the passage cells of this layer remain thin-walled . Thus, the endoderm is a physiological barrier that regulates the flow of water and ions from the primary cortex into the central cylinder of the root.

Caspari strips are rarely visible on cross sections, but usually the sections of these strips on adjacent radial walls are clearly visible. They are called Caspari spots. Kaspari strips are impregnated with suberin. Since the suberin is impermeable to water, the Caspari strips prevent the free diffusion of ions along the shell, and the tight fit of the plasmalemma to the cell wall excludes the transfer of substances between them. Therefore, the movement of ions is carried out only under the control of the cytoplasm of the endoderm cell.

The endoderm can go through three stages in its development. The first stage is characterized by the presence of Kaspari strips.

At the second stage of development, suberin is deposited along the entire inner surface of the walls of the endoderm. However, the endoderm remains permeable to solutions, since some cells retain their primary structure. They are called access points.

In plants that do not have a secondary thickening of the roots, the endoderm can get a tertiary structure. It is characterized by a strong thickening and lignification of the side and inner walls, the walls facing outward remain relatively thin. On the cross-section, such cells have horseshoe-shaped thickenings. The protoplasts of the cells die off.

In dicotyledones and gymnosperms, the endoderm passes through stages 1 and 2 of development, in monocotyledons, the root does not undergo secondary changes and the endoderm passes through all 3 stages of development. In old roots of monocotyledonous plants, the endoderm consists of two types of cells: living thin-walled passageways and cells with U-shaped thickening of the membranes.

3. Central axial cylinder.

It begins with a pericycle, which in young roots consists of living thin-walled parenchymal cells arranged in a single row. Lateral roots are formed from the pericycle and therefore it is called the root layer.

The conducting system of the root is represented by primary xylem and phloem. The xylem is located in the center of the root in the form of a star, and the phloem is located between the rays of the primary xylem. The rays of the primary xylem are located opposite the passage cells of the endoderm. Dicotyledones have from 1 to 5 rays of the primary xylem, monocotyledons have 6 or more rays of the primary xylem. There is no pith at the root, but sometimes there are parenchymal elements of the xylem in the center, outwardly resembling the pith.

In dicotyledons, as they grow, a secondary thickening of the root is observed and the radial structure of the conducting tissues is replaced by a collateral or annular one.

The transformation to the secondary structure and the secondary structure of the root.

Initiation of secondary growth takes place in the zone of maturation soon after the cells stop elongating there. The vascular cambium differentiates between the primary xylem and phloem in this zone and pericycle cells divide simultaneously with the procambium initials. The result is a cylinder of cambium encircling the primary xylem.

The formation of cambium is associated with the division of thin-walled cells located on the inner side of each phloem strand. The cambium develops as a single-layer meristem, which is located on the cross sections at first in separate, inward-concave arcs. Their number corresponds to the number of rays of the primary phloem and xylem. The length of the cambial arches increases due to the formation of new cells at their tips. When the cambium arcs reach the pericycle, its cells also begin to divide, connecting the cambial arcs. There is obtained a series of cells that are continuously dividing and forming a continuous ring. The vascular cambium almost immediately begins producing xylem cells inward and phloem cells toward the outside of the root, in the process flattening the primary phloem against the more resistant endodermis. The primary xylem remains in the center, and the primary phloem is pushed to the periphery and flattened. The cambial cells formed from the pericycle give beginning to the parenchyma of the pith rays. If the rays are thin, an annular structure is formed, if they are wide, then open collateral bundles are formed at the root according to the number of rays of the primary xylem. In the old roots, in addition to the primary ones, secondary pith rays are formed, which are given the origin of the cambium. These rays, as well as the primary ones, carry out the radial transport of substances. The overgrowth of the central axial cylinder caused by the presence of secondary growth causes ruptures and peeling of the primary cortex. By this time, the pericycle cells begin to divide intensively, forming a wide zone of the parenchyma of the secondary cortex in which the cork cambium (phellogen) occurs, forming the periderm. Sometimes it occurs directly from the cells of the pericycle. The fellogen is forming of phellem in outside and pheloderm inward. The phellem isolates the primary cortex from the vascular tissues. The primary cortex completely dies off and is peeling. Thus, in the root of the secondary structure, the dermal tissue is the periderm, and the primary cortex is absent. In the secondary structure of the root, it is possible to distinguish the secondary integumentary tissue of the periderm, the secondary cortex (from the pericyclic parenchyma and phloem) and the xylem (wood and the star of the primary xylem).

By the end of the first year, secondary growth has obliterated all but the central core of primary xylem cells and a few fibers of primary xylem pushed against the periderm. The zones at this time, therefore, from outside to inside are: periderm, pericycle, primary phloem, secondary phloem, vascular cambium, secondary xylem, and primary xylem.

The long-term roots of woody plants often thicken greatly as a result of prolonged cambial activity. In this case, the secondary xylem united into a solid cylinder surrounded on the outside by a cambium ring and a solid ring of the secondary phloem. The xylem layer formed during one growing season is called the annual ring. The annual growth in the root is less than the annual growth in the stem, the boundaries between them are not clearly expressed. In the roots, the vessels of the tracheid are more thin-walled, there are more of them and they are distributed more evenly. The parenchyma of the pith rays is larger, and the wood fibers (libriform) are larger than in the stems. There are relatively many storage parenchyma in the phloem and xylem.

Secondary tissues comprise the greatest volume of the root mass of woody perennial plants. Primary tissues continue to form in the feeder roots, but the supporting root structure consists of secondary tissues produced by the lateral meristems, the vascular cambium, and one or more cork cambia. The usually unobserved underground root systems of most trees are as massive as the huge aerial bodies and counterbalance the aboveground weight thus keeping the tree upright and stable.

In perennial herbaceous plants, due to the annual death and renewal of shoots, a large amount of reserve nutrient substances is deposited in the roots. They accumulate either in the parenchyma of the cortex part of the root (carrots and parsley), or in the xylem (radish), and then these parts grow expended and contain a large amount of storage parenchyma. Sometimes reserve nutrient substances are deposited in the parenchyma formed by additional cambium rings (beetroot). Such modified roots with a large amount of storage parenchyma are called root crops.

Roots of many herbaceous plants form fleshy swellings. The upper part of the main root and together with it (in beetroot, carrot, radish) the subseed is usually growing in thickness. Fleshy roots have the function of storing reserves in the form of starch, sugars, mucilage, inulin, hemicelluloses, etc. The roots of beetroot, for example, are rich in sucrose, the root cones of dahlia are rich in inulin; the roots of althea contain large amounts of starch and slugs.

Strong development of fleshy roots in thickness is usually due to the abundance of parenchyma, in the cells of which are mainly deposited reserve substances.

Fleshy roots with secondary growth are characterized by strong development of juicy, thin-walled, non-woody parenchyma in them. The origin of this parenchyma may be different.

There are three main types of fleshy roots.

Some are characterized by the formation of abundant storage parenchyma in the xylem of the root (turnip, radish, radish).

Others are characterized by the growth of root cortex (phloem) (carrot, parsley). In the wood of such root crops, vessels are present in the form of scattered groups. Mechanical elements - libriform fibers in the wood and bast fibers in the husk - are absent or few in number, and their sheaths thicken little and become weakly woody. The above applies fully to the first-year growth of fleshy roots, which usually live for two years: in the first year they accumulate reserves, and in the second year these reserves are spent mainly on the formation of shoots with inflorescences and fruits with seeds. The secondary growth of the second year is of a different character; thus, for example, the wood formed in the root of carrots before the flowering of the plant and later has vessels with strongly woody walls and well-developed fibres. Growth of fleshy roots in thickness occurs in many plants not only directly due to the work of cambium; in carrots, for example, part of woody and part of bast parenchyma, differentiating, take the character of meristem and, vigorously dividing, produce new parenchyma cells.

In the third group of ‘root crops’ secondary growth is generated by several additional meristems - cambium, forming additional vascular bundles and storing parenchyma, in which reserve nutrients are deposited.

In beet root and other representatives of the Chenopodiaceae family, additive cambium appear one after another in the form of closed rings. In its primary structure, the beet root has an axial cylinder with a diarchic radial bundle, with a continuous pericycle. On the tenth day or so of the seedling's life, the first (‘normal’) cambium is formed, producing the bast (floem) and wood (xylem). Soon afterwards, successively new, additional concentric cambia arise. The cells of the first of the additive cambia are separated by tangential septa from the cells of the pericycle. More precisely, cells of the first additive cambium are appear of the forming cambial ring from cells of the primary phloem parenchyma, and partly from procambium cells remaining in undifferentiated state between pericycle and primary phloem. In sectors of the same cambial ring, located against the apices of the primary xylem strands, the cells of the first additive cambium are isolated from the cells of the pericycle.

After the appearance of the first additive cambium, its cells divide tangentially. The inner layer of daughter cells begins to produce new permanent tissues, and the outer layer of daughter cells becomes the second additive cambium. This cambium functions similarly to the first additive cambium, i.e. it detaches by tangential cell division a new (third) additive cambium and then produces a ring of permanent tissues.

A whole series of cambia is formed; each of them continues to function even after the commencement of cell division of each subsequent cambium. A pencil-thick root contains almost all the cambia already in working order, but the rings of new growths near the periphery are still very narrow. Each of the accessory cambia produces a ring of growth consisting of collateral conductive bundles and parenchyma.

Sectors of the accessory cambium, forming conducting bundles, give parenchyma-rich phloem to the root periphery, and inside - first only parenchyma and then xylem, containing, besides parenchyma, porous vessels. Almost concentric cycles are formed, consisting of conductive, parenchyma-rich collateral bundles with radial layers of parenchyma between bundles in the cycle and annular layers of parenchyma between cycles.

Usually, only 4-5 cycles reach full development, and peripheral cycles remain at the stage of narrow rings of poorly differentiated tissues. The structure of the beetroot is further complicated by the formation of anastomoses between bundles of the same cycle and between bundles of neighbouring cycles, by the departure of bundles into leaves, by the change in the number of cycles as a result of their fusion towards the upper and lower ends of the root, etc.; in general, the system of its bundles represents a very complex three-dimensional grid.

The storage tissue in roots may also be of primary origin. In the roots of Filago, Ficaria, in the lateral roots of the *Apocynaceae*, the storage parenchyma is powerful in the area of the primary cortex, in *Asphodelus* - in the primary cortex and in the medulla. In some orchids, fleshy roots consist mainly of parenchyma, in which diarch steles, each with its own endoderm, are scattered near the periphery; the root is as if a product of fusion of several roots.

Zemlyanskaya I.V.