B1 Water cycle – Evaporation from plant leaves

6 Questions

6.1 General

a) How do plants absorb the water that they then evaporate?

Answer: First, plants absorb the water, primarily through their roots. Because the roots contain more mineral salts and water-soluble organic substances than the water, osmotic pressure develops in the surrounding soil, causing diffusion of the water into the plant's root system. (Salts present in higher concentrations in the soil than in the roots also diffuse into the roots.) Through a combination of osmosis and capillary action, the water is then transported further up to the leaves at the top of the plant. Evaporation then begins at the leaves, which again causes differences in the concentration of the dissolved minerals and in osmotic pressure. In addition, transpiration suction develops, which ensures that water or plant sap constantly flows from the roots to the leaves. Thus, a certain degree of evaporation is vital for plants. You could say that this is a sort of centrifugal pump effect; as long as the liquid column is not broken, the evaporation suction draws in more fluid. The evaporation suction is sufficient for only a 10-m rise, but osmosis and capillary action ensure that the water reaches greater heights (botanists have estimated the maximum to be approximately 130 m, tree height). In short, water and nutrients are transported from a plant's roots to its leaves through the combination of capillary forces (adhesion), osmosis, and transpiration suction.
The plant can control the rate of evaporation, depending on the wind, humidity, and sun exposure: Its leaves are covered on all surfaces by epidermal cells, which are protected by a layer of wax (cuticle) on the outside, making it hard for water vapor (as well as for oxygen and carbon dioxide) to permeate the surfaces. Gas is exchanged with the environment through stomata. These stomata consist of two bean-shaped guard cells, which regulate the gas exchange of the leaf and thus can also control the evaporation rate in the range of two orders of magnitude.

b) Explain why certain plants naturally thrive only in certain geographical regions with particular climatic conditions. As an example, you could use two very different plants, such as cacti and tomatoes to do so.

Answer: In general, the better a plant has adapted to its environment, the more it thrives. The water balance usually plays the key role. Cacti, for example, have the ability to store a lot of water (as compared to other plants), because they have a robust epidermal layer with a very thick cuticle. To prevent excessive heating by the sun, their leaf surface is covered with reflective wax and/or with tiny reflective hairs (spines). In some cases, the stomata are found only on the underside of the leaf and are small and "recessed." As a result, a cactus gives off only approx. 1/10 of the water as evaporation compared to "normal" foliage plants. In extreme cases, a cactus can survive up to two years without water without dying. The situation is exactly the opposite in tomato leaves, and therefore tomato plants need a lot of water. This is a reminder that tomatoes originally came from the South American rainforest. Water is abundant in a rainforest, where a more important factor for a plant's survival is whether it receives more light than its

competitors, or whether it can get by with less light than the competing plants. Today's highly cultivated tomatoes require a lot more light, yet their appetite for water has remained the same. In contrast, cacti need a lot of light, which is sufficiently available in desertlike regions, but they get by with a scarce amount of water.

c) Why does water condense on the surface of the cup, even if the cup is not cooled?

Answer: Because the fresh clippings still have a relatively high water content as compared to the air, the water content of the plant clippings and of the air are not in equilibrium. Due to the influence of solar radiation (or the lamp), the plant clippings heat up and the water in the plant evaporates. At the same time, the ambient air warms up, increasing the air's solubility for water. In contrast, because the cup surface is largely permeable to the radiated light (visible light and heat radiation), the light does not heat it as intensely as the cup's contents. Therefore, the condensation results from the increased humidity and the relatively cool cup surface.

d) Why does the experiment work better if the surface of the cup is cooled?

Answer: If the surface of the cup is cooled, the water vapor saturation concentration of the air inside the cup (higher, because the air is warmer) and on the cup's surface (lower, because the surface is cooler) are not in equilibrium. More water condenses on the surface.

e) On hot summer days, why it is usually cooler in the shade of a tree with a thick canopy of leaves than in the shade of a fabric sun umbrella?

Answer: Unlike buildings, plants release water, which evaporates from the surface of their leaves. This evaporation generates so-called "evaporative cooling" (see experiment "A4 Evaporation heat – How to cool with heat"). As a result, the air in the immediate vicinity of the plant is cooler than air in shade alone, which illustrates natural air conditioning. This effect was already exploited in earlier times, such as in Bavaria with the planting of chestnut trees in beer gardens to cool the beer cellars underneath. The planting of courtyard gardens of Arabian dwellings and the traditional meeting trees of African villages also serve this purpose.

6.2 Probing question on climate change, based on the example of Paraguay

In the last 30 years, 60 percent of the tropical rain forest in Paraguay has been cleared and the land is now being used to cultivate primarily soy as fodder for animals in Europe. In the past, it rained nearly every day in the rain forest. Today, there are droughts and poor harvests.
Why?

Answer: Rainforests are densely populated with plants. Rainforests have a tremendous capacity to store water thanks to the huge number of massive trees of up to 40 m in height, some of which are over 100 years old, as well as the entire undergrowth, with its mosses, ferns, and lichens. Owing to the relatively warm climate, a large portion of the water constantly evaporates. However, due to the large, thick forest canopies, very little

of the water is transported away by wind. Rather, the moisture is deposited locally, for example, in the form of storms. For most of the year this results in a daily rain storm. This water does not run off for the most part, but instead is absorbed again by the forest. Depending on the geographical location and season, additional rain may fall from clouds that form over oceans and seas.
By comparison, soybean fields have only a low percentage of a rainforest's capacity to store water. The water content of the soil or the water added through irrigation evaporates quickly and is transported away by wind currents. Thus, the land dries out severely within a few years. If heavy rain occasionally falls from clouds that come from the oceans or seas, depending on weather conditions, most of the water drains off very quickly from the surface without being absorbed. In the process, the already thin topsoil is washed away with the rain (soil erosion). As a result, the entire region turns into steppe and becomes desolate within a few decades.

6.3 Probing question on climate change, based on the example of biomass from monocultures

Since fossil fuels (coal, natural gas, oil) are scarce resources, some people are trying to tap into alternative sources of energy by cultivating so-called energy crops. These plants (e.g., soy, sunflowers, corn) are being grown in monocultures.

a) How do people succeed in making solar energy technically available using these plants?

Answer: The plants are cultivated and use solar energy in the process of photosynthesis to thrive. After being harvested, the plants can be used to generate electricity directly by being burned in power plants, or they can be converted into biogas (primarily methane) through fermentation with microorganisms, or fuels such as biodiesel or bioethanol can be produced. The energy use of these plants is seemingly climate-neutral. When they grow, they absorb just as much carbon dioxide as is released later, for example, when they are burned. However, if you factor in the climatic impact and environmental pollution caused by fertilization and spraying of pesticides, in most cases both the climate balance and the ecological balance are also negative.

b) What negative consequences do these monocultures have on the climate?

Answer: A huge problem of monocultures is that they remove certain nutrients from the soil, specifically, the nutrients that the plants of the monoculture need the most. To compensate for this resource deprivation, farmers must use a lot of fertilizer (for example, nitrogen fertilizer, which releases the greenhouse gas N_2O, which is 310 times more harmful to the climate than CO_2). Furthermore, if the same plant is cultivated in the same field for multiple years, the pests, pathogens, and weeds typical for this plant multiply extremely quickly. (Previously, farmers rotated crops for this reason, with a waiting period of up to five years before planting the same crop again.) As a result, farmers must now increasingly rely on the use of insecticides, fungicides, and herbicides.

c) What are the consequences for the people living in these countries where monocultures are cultivated?

Answer: For the people living in these regions, food is becoming more expensive. The farmers who grow the food or the wholesalers now have the choice of selling their products either as raw material to energy producers or as food. The price of corn (main crop for biogas production and bioplastics), for example, has quadrupled since 2005 because corn is increasingly being used for nonfood purposes. Accordingly, the prices for other types of grains are also rising, because they must fill the nutritional gap left by corn. Consequently, malnutrition is again on the rise worldwide.