Adaptations of Plants to Arid Environments

Environmental stresses of low and unpredictable precipitation, low relative humidity with desiccating winds, and high summer temperatures characterize climates of deserts and, coupled with low nutrient availability, produce severe limitations of plant growth. Despite such stresses, desert scrub communities often contain surprisingly large amounts of plant biomass, and possess remarkable diversity of plant growth forms.

The life form of a plant whether annual, perennial, herbaceous, woody, or succulent and the characteristics or its roots, stems, and leaves are presumed to be adaptations to the special conditions within a desert. Diversity of life forms may be considerable (Sonoran Desert) or very low (Atacama Desert).

Life forms may be classified into 4 major categories that represent strategies of adaptation, according to Solbrig and Orians, 1977.

Strategies

1. **Drought-escaping plants** annuals which germinate and grow only when there is sufficient moisture available to complete their life cycle. Only their seeds persist during times of drought. Annuals.
2. **Drought-evading plants** non-succulent perennials which restrict their growth activity to periods when moisture is available. Typically, they are drought-deciduous shrubs which go dormant or die back during dry periods.
3. **Drought-enduring plants** evergreen shrubs. Extensive root systems coupled with various morphological and physiological adaptations of their aerial parts enable these hardy xerophytes to maintain growth even in times of extreme water stress. Creosote bush (*Larrea tridentata*)
4. **Drought-resisting plants** succulent perennials. The water stored in their swollen leaves and stems is usually used very sparingly. Cacti

The major adaptation of both drought-escaping and drought-evading plants is an ability of accurately predict the wet season and to restrict their major growth and reproductive activities to the wet part of the year.

Drought-escaping plants: annuals

1. The proportion of annual species in desert floras is inversely related to the amount and reliability of precipitation in a region.
2. Life cycles of these small, shallow-rooted plants commence when there is water available.
   a. Went noted that no seedlings of any species germinated in the Sonoran Desert following a 10 mm rainfall; extensive germination occurred only after a rainfall of 25 mm.

   b. This was attributed to removal of inhibitors from the seed coats.

4. Winter and summer annuals are distinguished on the basis of optimum temperatures for seed germination. This varies from 15-18 C for winter annuals, and 25-30 C for summer annuals. These refer to temperature conditions prevailing at the time of precipitation.

5. Continued survival of annuals requires that adequate seed reserves be maintained through dry periods until conditions are once again suitable for germination.

6. Few seeds rot in the desert environment, but many are lost to seed predators, particularly rodents. Kangaroo rats (*Dipodomys merriami*) consume as much as 95% of the seed of Erodium cicutarium, an annual of the Mojave Desert.
   a. The highest seed densities are associated with wind shadows where sees are protected from further movement by the wind; lowest values were found in open sites and dry washes.

7. Seeds of most desert annuals have temperature or moisture controlled dormancy which may prevent germination, but seed viability is initially high. Seeds may remain viable for up to 10 years under artificial conditions.

8. Mechanisms which prevent seeds from germinating all at once can increase the chance of survival of annual species. Seed heteroblasty, in which germination requirements differ for seeds produced by the same plant, has been described for some annuals in the Saharo-Arabian Deserts.

9. Since they are not restricted by water they grow only when water is relatively abundant they can exploit the favorable light and temperature conditions of the desert. They require none of the morphological adaptations that other strategists require.

10. Annuals goal is to grow fast (large leaves, maximal photosynthesis, heavy transpiration), flower, set seed, disperse seed, and persist through the dry period as a seed.

Drought-evading plants

1. Drought-deciduous plants; they drop their leaves, and sometimes their stems during periods of drought.

2. Leaf production from mid-Feb. to April, and a leaf canopy persists until drought conditions become extreme in summer.

3. Leaves may be polymorphic.
   a. Leaves developed in early spring when water is available and temperatures moderate, are large and green. High photosynthetic rates.
   b. With the onset of dry period, subsequent leaves produced are smaller, and often with a pubescent covering. Lower photosynthetic rates, but lower heat load and transpiration rates.
   c. Examples*:* Brittlebush *(Encelia farinosa)* white bursage (*Ambrosia dumosa*).

4. Stem photosynthesis
   a. Stems lose less water than leaves (reduced transpiration).

b. During period of low water stress, leaves are more productive than stems, but under periods of water stress, the superiority of leaves is lost.
c. Example cheeseweed (*Hymenoclea salsola*).
d. A number of plants are essentially aphyllous (without leaves), relying on stem photosynthesis: Mormon tea (*Ephedra spp*.), spiny menodora (*Menodora spinescens*), turpentine bush (*Thamnosmamontana*).

Drought-enduring plants

1. True xerophytes, maintaining a canopy and positive net carbon gain (photosynthesis) throughout the year.

2. Example: creosote bush (*Larrea tridentata*)
   a. Compound leaves (2 leaflets) commonly live for 8-14 months, but a canopy of photosynthetically active leaves is present throughout the year.
   b. Leaves of creosote are oriented more or less vertically, parallel to the sun.
   c. Glandular trichomes secrete a resin that covers the leaf surface. The resin limits photosynthesis, but also drastically reduces transpiration.

3. Phreatophytes: These plants usually have extensive root systems which either spread through the surface soils or penetrate several meters below the surface Example mesquite (*Prosopis*).
   a. Branching usually occurs in the capillary fringe above the water table in deep-rooted plants (phreatophytes) that are able to tap permanent ground water; while short-lived rain roots develop on woody surface roots in response to soil moistening.

Drought-resisting plants – succulents

1. Succulence is the most obvious characteristic of drought-resisting plants.

2. Desert succulents are generally shallow-rooted, allowing them to respond quickly to light rainfalls.

3. Stems are often heavily waxed to reduced cuticular water loss.

4. Leaves are often reduced to spines, and this increases the volume to surface ratio. In barrel cactus the ratio is 2.5, compared with 0.92 for a succulent leaf of an agave, and 0.01 for many non-succulent leaves. The maximum ratio is achieved by the spherical form of many cacti.

5. Spines also help to reduce heat load, and dissipate heat. Tissue temperatures below spines of the cholla cactus (*Opuntia bigelovii*) can be reduced by as much as 11 C.

6. Desert succulent are rarely killed by high temperatures, and several species of cacti and agave can withstand temperatures over 60C (140F) for short periods. However, their seedlings are especially sensitive to high-temperature injury, and establishment is often prevented in open areas where soil temperatures can rise to 80 C (176F).

7. Seedlings of saguaro and other cacti require the shade of a nurse plant, like palo verde, to survive.

8. CAM plants stomata of succulents open in the cool of the night. Transpirational water loss is reduced, restricting CO_2 uptake to the dark hours. Assimilation products are stored at night, before being converted to photosynthates during the daylight period.

9. Water loss is very limited in desert succulents, but photosynthetic rates and, consequently, growth rates are low also. Annual growth rates in barrel cactus (*Ferocactus acanthodes*) is less than 2 cm.

Other adaptations

1. **Microphylly** typical leaves of warm desert plants are small and narrow, a design that enables leaf temperature to be near ambient temperature even when stomata are closed, so leaves can avoid lethal summertime temperatures during summer drought.
    a. Broad leaves are characteristic of plants in mesic environments or, if in the desert, in microclimatically mesic environments, like in a riparian zone, by a wash, or perched on top of a shallow water table, like the California palm (*Washingtonia filifera*).

2. **Solar angles** Steeper leaf angles (parallel to solar radiation) reduces solar interception at midday during summer months, when air temperature and water loss may be most severe.

3. **Solar tracking**

4. **Leaf reflectance / leaf absorptance**
    a. Leaf absorptance in mesic communities is generally 85%.
    b. Leaf absorptance in desert communities range from 60-85%, but are as low as 29% in brittle bush (*Encelia farinosa*).
    c. Trichomes reduce heat load, reduce leaf temperature, reduce transpiration rates, reduces photosynthetically active radiation (negative effect), by absorbing and reflecting infra-red radiation.

5. **Leaf type** Finely divided compound leaves, like those of Acacia, decrease the rate of water loss during periods of water stress, and reduce head load when stomata are closed.

.